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# Determination of the Seismic Performance of Concentrically Braced Steel Structures

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**Abstract**: Steel building systems are preferred lateral force resisting system in regions with high seismic risk due to their ductility capacity. Concentrically Braced Frames (CBF) are commonly used in steel structures provide one of the most economical solutions. Concentrically braced frames are widely used in steel structures as lateral load bearing system in the high level seismic zones.

In this study, it is aimed to perform a performance analysis according to the Turkish Building Earthquake Code 2018 in a five-story reinforced concrete shear wall-framed structure in Izmir where active fault lines are located. Steel structure was designed and also, the performance analysis of this structure was performed by using SAP 2000 computer software which has advanced analytical techniques. In the earthquake engineering, performance-based design method is used to determine the level of expected performance of the structures under the earthquake effect. Level of performance is related to the damage situation that could be occurred in the structure after the earthquake.

The selected structure has 6 storey and CBF's designed with respect to Turkish Building Earthquake Code-2018(TBEC-2018) and Steel Structure Code 2018 (SSC-2018). In addition, the structure is consisted of 4 bays in X direction and 3 bays in Y direction. Results show that for CBF steel structures expected performance level which is life safety has been provided.

**Keywords:** Concentrically braced steel structure; performance based design; TBEC-2018; Steel Structures Design Code 2018.

## 1. INTRODUCTION

It is important to design an economical and safe structure in earthquake zones. As a result of many earthquake, Turkey has been damaged as a result of many earthquakes. For this reason, it is closely related to the nonlinear behaviour and ductility of the structures that will be designed in earthquake zones under the effects of the earthquake. These steel structures increase their importance. Erdem (2015) [1] investigated non-linear performance analysis of existing and strengthened steel structures by X shaped bracing members with 3, 5 and 7 stories which have soft story irregularity is performed according to FEMA-356 and Turkish Earthquake Code-2007. Damage ratios of the structural members and global performance levels are determined as well as modal properties and story drift ratios after non-linear finite elements analysis for each structure. Speicher et al., (2016) [2] presented the results of a seismic performance assessment using ASCE 41-06 for six special concentrically braced frames (SCBFs) designed in accordance with the 2012 International Building Code. The correlation between ASCE 7-10 and ASCE 41-06 is investigated to compare the seismic performance anticipated by the two standards. Three archetype buildings (4-, 8-, and 16-story) with SCBFs along one principal direction are designed for seismic effects. Wijesundura et al., (2018) [3] evaluated the seismic performance of suspended zipper concentric braced frames designed according to Eurocode 8 and to compare their performance with conventional concentric braced configurations. In this studies, introduces a novel design methodology to size braces, zipper columns, beams and columns in suspended zipper frames. it can be concluded that the performance of suspended zipper frame is better than that of conventional concentrically braced frames in medium-rise buildings, but not in low-rise buildings.

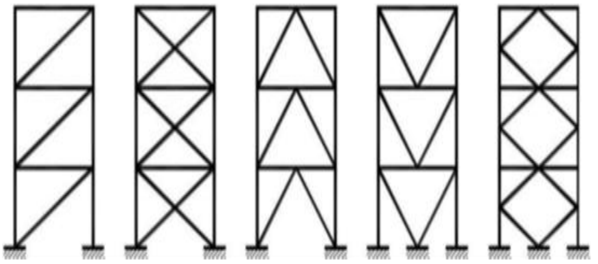
Diagonal steel frames are horizontal load bearing systems consisting of frames using moment-transfer or moment-free beam-column connections, and diameters connected centrally and eccentrically. The horizontal load bearing capacities of such system are provided by the axial force of the elements, in addition to their bending strength. 4]Crossed steel frames are divided into two depending on the arrangement of the diagonal [4].

a) Concentric Steel Bracing (Figure 1)
b) Eccentric Steel Bracing (Figure 2)

Concentric steel bracings are designed as a system of high ductility level or a system of nominal ductility level. However, eccentric steel bracing should be designed as a system of high ductility level.

In the analysis of structural systems under earthquake effects, linear and nonlinear calculation methods can be used. According to the linear theory it is assumed that the materials is linear-elastic and the displacements are very small. In the nonlinear calculus, the behaviour of materials beyond the linear-elastic boundary is taken into account and the displacements are not very small.

Construction systems usually show linear behaviour under operating loads. Calculated displacements, deformations and stresses are accepted for linear theory. With external influences, the deformation and linear-elastic limit is exceeded when the operating load limit is exceeded and the



Diagonal Bracing X Bracing Reverse V Bracing V Bracing K Bracing

**Figure 1.** Concentric Steel Bracings

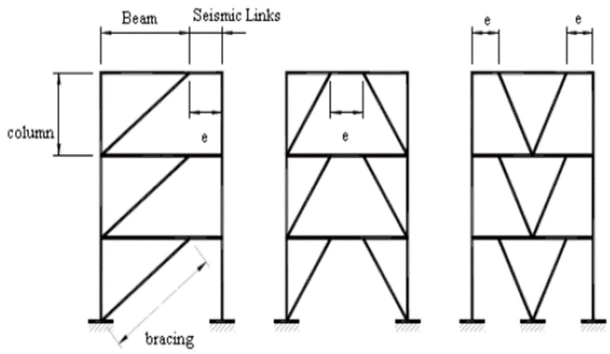



**Figure 2**. Eccentric steel bracing

carrying power is approached. In this case, displacements taken are not too small. In this case the linear theory is not valid. The non-linear theory will apply considering the behavior beyond the linear elastic boundary.

Non-linear pushover analysis is a special analysis method used in the performance-based design of structures under seismic effect. In the pushover analysis method, the capacity curve showing the relationship between the base shear force of the structure and the top displacement volition is obtained. This curve expresses the behaviour of the structure under the influence of increased base shear force. In order to achieve the projected performance target, the capacity must meet the required volition. Under the effect of the increased base shear force, changes in the slope of the force-displacement curve are absorbed with the starting capacity elements of the horizontal carrier system exceeding the yield limit values of these elements.

In this study, horizontal load bearing system is examined by using linear and nonlinear calculation methods which are determined in the earthquake regulations of the system chosen as the central Concentric Bracing with high ductility level. For this purpose, the building's design Steel Structures Code-2018 (SSC-2018) [4] and restored Turkish Earthquake Code-2018 (TEC-2018) [5] were used.

The aim of this study is to show linear and non-linear behaviors under the effect of horizontal load of steel structures using different stiffness element. In this study, using the SAP 2000 program [6], 3 different models with 4 storeys with 5 spans in X direction and 3 spans in Y direction were modeled in SAP 2000 program. Equivalent Seismic Load Method and Pushover Analysis were applied. As a result of these analyses, the mode shapes, period and displacement values of the obtained structures and the cross-sectional effects of each analysis were examined and the comparisons were made. Based on these results it is compared models and decided on the ideal bracing-sections model.

## 2. METHODS

In this study, steel structures consisting of 6-storeys with 4 spans in X directions and 3 span in Y directions were performed according to the equivalent earthquake load method and static pushover analysis. Moment Resisting Frame (Model 1) is added to this building model in the X direction by rigid bracing members and X bracing (Model 2) and Reverse V bracing (Model 3) building models are taken into consideration. SAP 2000 package program was used for modelling steel structure types. Equivalent Earthquake Load method and Single Mode Pushover analysis were used in earthquake analysis of three different steel structure models. Periods, displacements and internal forces are obtained as a result of the analyses are compared with each other for three different models with the help of tables and figures. The structure is in İzmir province Bayraklı district Latitude: 38.4813360, Longitude: 27.1259430. Spectral acceleration coefficients are Ss=1.088, S1=0.266. Ground class is ZC and building coefficients of importance at the level of DD-2 earthquake ground motion is selected as I=1. Ground floor is 3.50 m in height and normal floors are 3.0 m in height. In the moment resisting frame, the columns are selected as HE450B, X directions beams are IPE270, Y directions beams are IPE400/IPE360, secondary beams are selected as IPE 270 profile in X directions. X bracing structure, the columns are selected as HE450B, X directions beams are IPE240, Y directions beams are IPE300, secondary beams are selected as IPE 270 profile in X directions, bracing-members are box 120/120/10 profile. In reverse V bracing structure, the columns HE450B, X directions beams are IPE240, Y directions beams are IPE300, secondary beams are IPE270 in the X directions, bracing-members are box 100/100/10 profile directions.

In Figure 3 the floor plan of the steel Moment Resisting Frame model (Model 1) examined is given.

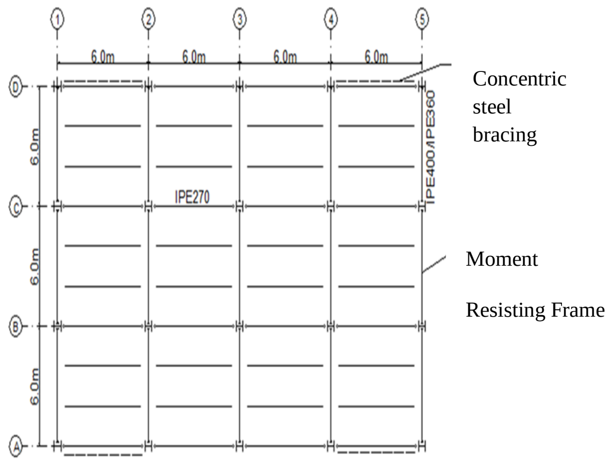



Figure 3. Typical floor plan of the steel structures

Figure 4-6 shows the 3D finite element model prepared in SAP 2000 of the building models taken into account in the study.

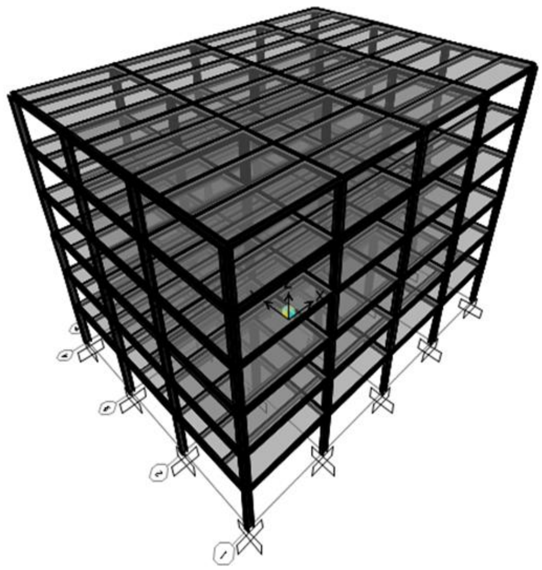


**Figure 4**. Model 1 3D Finite Element Model

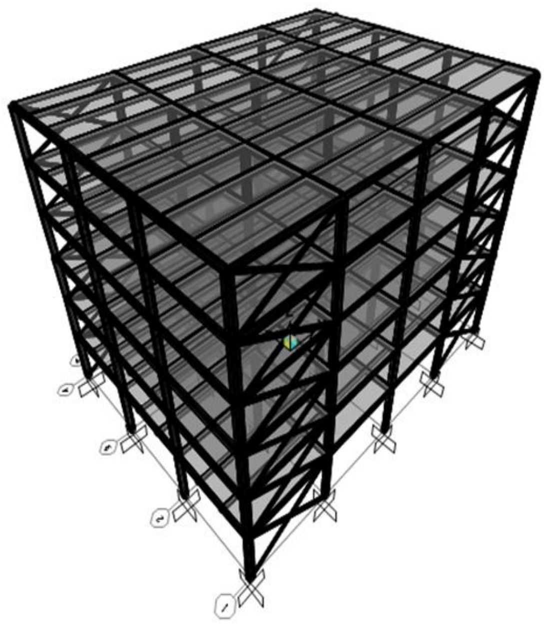


**Figure 5**. Model 2 3D Finite Element Model

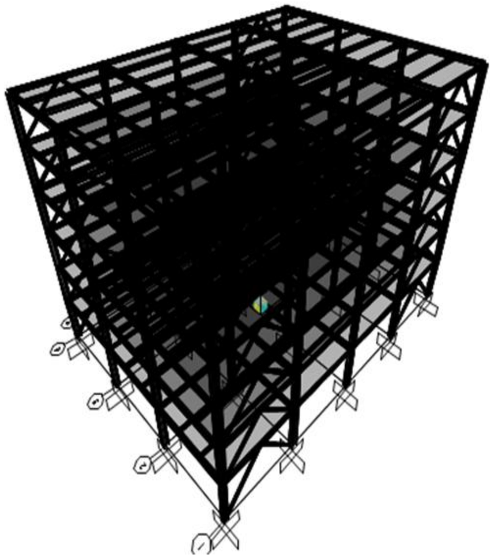


**Figure 6**. Model 3 3D Finite Element Model

## *2.1. The Equivalent Earthquake Load Method*

According to TEC-2018, for each structure linear analysis were performed under earthquake force by using equivalent earthquake load.

The vertical loads used in the structural calculations are accepted as follows (TS 498) [7]

a) Roofing: Total dead load 4.8 kN /$m^2$

Live load 1.5 kN/$m^2$

Parapet wall load 1.0 kN/m

b) Normal Floor upholstery: Total dead load 4.8 kN /m$^2$

Live load 2.0 kN /m$^2$

Stair load 3.5 kN /m$^2$

External wall load 3.0 kN/m$^2$

Snow load value is taken from TS 498 load standard. TBDY (2019), 30% of the snow loads will be taken into account in the calculation of the weight of the roof. Snow load value is calculated as 0.6kN/m2.

Equivalent Seismic Load Analysis and Static Pushover Analysis were designed in SAP 2000 program and analysis are done according to AISC360-10 [8] and result were obtained.

Static analysis results are given under the effect of earthquake, model of Moment Resisting Frame (Model 1), X bracing (Model 2) and reverse V bracing (Model 3) which ae formed with SAP 2000 program. As a result of the analysis, the period, displacement values 1.2G+Q+Qr+0.2S+EY12+0.3EZ and 1.2G+Q+Qr+0.2S+EY12+0.3EZ_NL loadings of the bracing –sectional impact values of the tables and figures with the help of three different models are given for each other. In the these combinations, G1,G2 is the dead loads consisting of the constant load floor and wall respectively,

Q, Qr is the live loads consisting of normal story and roof story moving loads, respectively S is the snow load, Ex, Ey, Ez is the earthquake loads in the X, Y and Z directions respectively. Ez_NL is the influence of design basis earthquake in the direction of the non-linear effect of earthquakes.

The period and displacement values of the Moment Resisting Frame (Model 1), X Bracing (Model 2) and Reverse V Bracing (Model 3) models for the node indicated in Figure 7 are given in Figure 8-9. The displacement in the effect of earthquake loads according to the section given in Figure 7 are given in the graphs. As can be seen in the graphs, in Model 1 the largest period and displacement values were obtained.

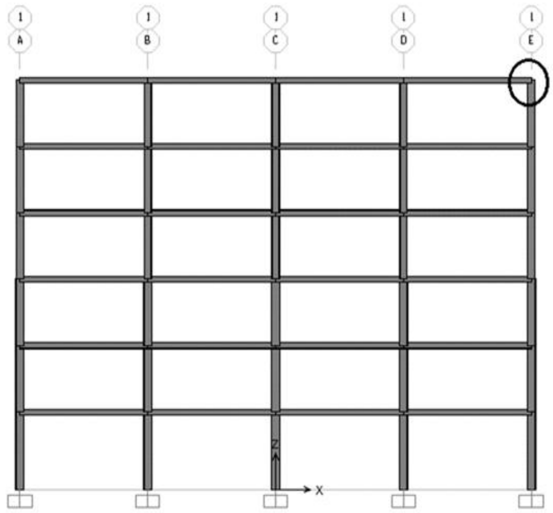


**Figure 7**. The joint nodes at which the displacement values are examined

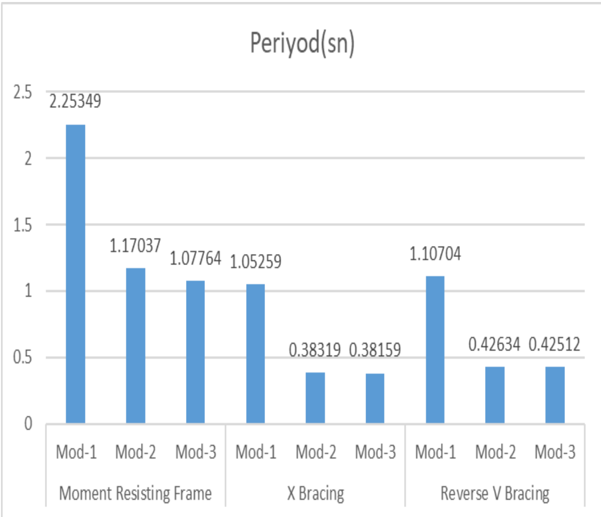



**Figure 8**. Period values of the examined building models

Figure 8 shows the values of the models analysis results and periods of the Moment Resisting Frame (Model 1) X Bracing (Model 2) and Reverse V Bracing (Model 3) models. As can be seen from the table, the largest period values are obtained in Model 1. It was found that there was a 46.7 % decrease in period values with the use of rigid elements in the structure. Figure 9 shows the values of the displacements. In this figure, Ex and Ey are earthquake effects X and Y directions, respectively.

As seen in Figure 9, the largest displacement value was obtained in Model 1 under earthquake effect in the X direction.

The axial forces, shear forces and bending moments values of the Moment Resisting Frame (Model 1), X Bracing (Model 2) and Reverse V Bracing (Model 3) models for the beam and column indicated in Figure 10 are given in Table 1-2. The internal forces in the effect of earthquake load combinations,

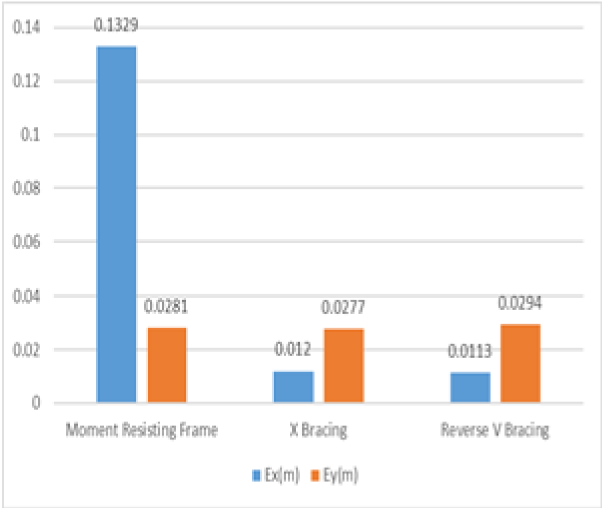



**Figure 9**. Displacement values of examined building models

(1.2G + Q + Qr + 0.2S + EY12 + 0.3EZ and 1.2G + Q + Qr + 0.2S + EY12 + 0.3EZ) according to the sections given in Figure 10 are given in the Tables 1-2. As can be seen in the tables, it is seen that the bending moment values in the Model 1 are higher than the models using rigid element.

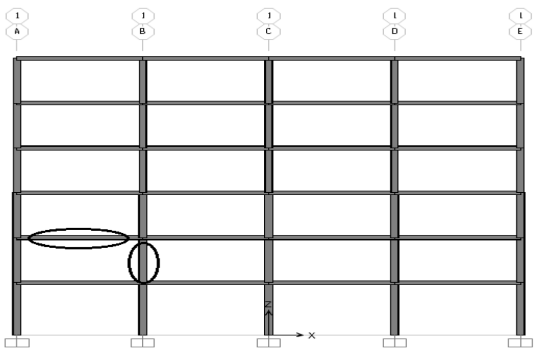


**Figure 10.** The beam and column at which the internal forces are examined

When the internal forces given are examined, it is seen that the bending moment values in the Moment Resisting Frame (Model 1) model are higher than the models using rigid element. The bracing members types used in this study increase the axial forces from load combination and decrease the bending moment of the steel structures.

### *2.2. The Pushover Analysis Method*

Pushover analysis method is applied to determine the strength and deformation capacity of a structure under earthquake effects. The plastic hinge places are assumed and defined on the two ends of the column and beams elements constituting the bearing system. Nonlinear static analysis was performed for Model 1-3 in the X and Y directions. It is seen from Figures 11,12,13 that static pushover curvatures are obtained by analysing bearing system under the vertical loads and proportional incremental interval seismic loads for Model 1-3.

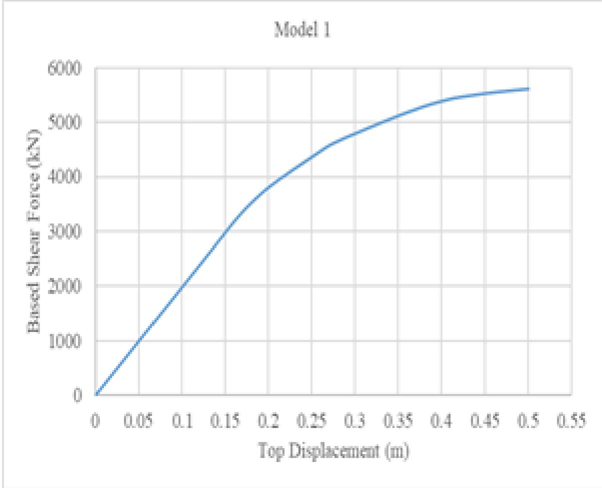



**Figure 11.** Capacity curves for Y direction by pushover analysis for Model 1.

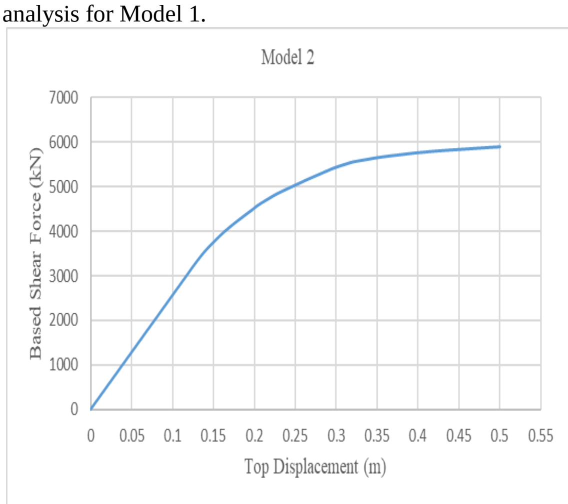



**Figure 12.** Capacity curves for Y direction by pushover analysis for Model 2.

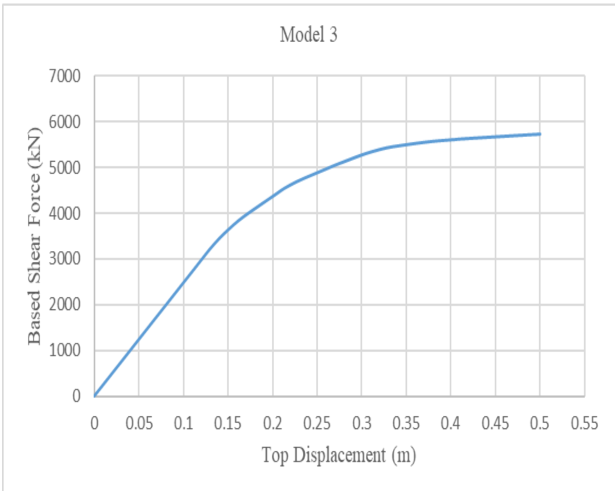



**Figure 13.** Capacity curves for Y direction by pushover analysis for Model 3.

The base shear forces and top displacements at the performance paint by the static pushover analysis are show in Table 1-2.

**Table 1.** X Base shear force and top displacement values

| **Models** | **Base shear force (kN)** | **Top displacement (m)** |
|---|---|---|
| Model 1 | 2154.61 | 0.512 |
| Model 2 | 8709.67 | 0.182 |
| Model 3 | 2577.59 | 0.098 |

**Table 2.** +Y Base shear force and top displacement values

| **Models** | **Base shear force (kN)** | **Top displacement (m)** |
|---|---|---|
| Model 1 | 5605.87 | 0.52 |
| Model 2 | 5901.18 | 0.51 |
| Model 3 | 5746.14 | 0.51 |

As can be seen from Table 1-2, the peak displacement in the three different models were observed close to each other. On the other hand, the base shear force values at the performance point are the largest in the X- bracing system and the smallest value in the Moment Resisting Frames. This exhibit shows that more rigid behavior of the X-bracing system.

## 3. CONCLUSIONS

In this study, analysis was performed according to the Equivalent Seismic Load method and nonlinear static analysis (pushover analyses) of a steel structure consisting of 6-storey X directions 4 spans, Y directions 3 spans. Then, the rigid elements were added to the Moment Resisting Frame (Model 1) building model in the X direction differently. X Bracing (Model 2) and Reverse V Bracing (Model 3) building models were considered. As a result of the analyzes, the period, displacement, internal forces and plastic hinge points were compared with each other for three different models with the help of figures and tables. After examining the data obtained in the study, the following conclusions are reached.

As can be seen in the steel structures examined, it has been observed that there has been a significant decrease in the period, displacement and bracing-section effects of the models using the X bracing members in steel structures. It has been observed that the bracing members against horizontal loads increase the strength and stiffness. Model 2 showed a more rigid behavior compared to the other models. The rigid bracing members used in the elements provide this.

In the Y direction, the pushover analysis results close to the peak displacement values. However, the base shear force is the highest in Model 2. It shows that Model 2 will be more rigid against horizontal force. When looking at the number of plastic hinges, it is possible to obtain similar values in crossed systems, whereas in the system consisting of frames more plastic sections are obtained. This difference can be explained by the high degree of hyper statics in the system consisting of frames.

As a result of the + X direction pushover analysis, the base shear force value is the largest of the Model 2 system. This shows that the Model 2 system behaves rigidly. Model 1 has the largest displacement value in the system. This shows that the Model 1 system behaves ductile.

The bracing members types used in this study increase the axial forces from load combination and decrease the bending moment of the steel structures. In this case, it results with the yielding of columns under compression if not carefully designed.

On the other hand, the base shear force values at the performance point are the largest in the X- bracing system and the smallest value in the Moment Resisting Frames. This exhibit shows that more rigid behavior of the X-bracing system.

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