**European Journal of Research Development and Sustainability (EJRDS)**
Available Online at: https://www.scholarzest.com
Vol. 6 No 02 February 2025
ISSN: 2660-5570

# DYNAMIC EFFECTS OF CENTRAL X STEEL BRACES AT THE SPECIFIED NODE POINT IN THE STEEL STRUCTURE MODEL

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**Article history:**
**Received:** 14th January 2025
**Accepted:** 10th February 2025

**Abstract:**
This study aims to examine the effects of strengthening steel structures with steel cross elements on the dynamic behavior of the structure, and if we expand the subject, it addresses the behavior of steel structures under dynamic effects and the behavior of steel structures after strengthening with steel crosses. The concept of rigidity is particularly emphasized. While conducting this research, data were obtained and interpreted by using the SAP2000 package program with the comparison method. For comparison, the frame system model with moment transfer and the new model strengthened with X-type central steel crosses of this model were used. The materials were assumed to be linear elastic and time domain calculation methods were used. In both different models, the node number 24, which is in the most adverse situation, i.e. has the maximum displacement and acceleration, was taken as basis. The dynamic behaviors of the structure were compared by applying the acceleration values of the El centro earthquake in the U1 direction to the systems. As a result of these examinations, it was observed that the strengthening of steel structures with steel crosses increased the rigidity of the structure.

**Keywords:** Steel structures; steel braces; strengthening; dynamic effects

## 1.INTRODUCTION

Nowadays, it is possible to analyze and design reinforced concrete, steel or steel-reinforced concrete composite building load-bearing systems resistant to earthquakes by using advanced calculation methods. On the other hand, it may be necessary to strengthen existing structures that are not designed and/or constructed according to engineering methods and regulations in order to increase their earthquake performance.

The main elements that constitute steel framed structures are columns, beams, cross members, connections and floors. Steel structures that need to be strengthened or improved can be examined in two main groups. In the steel structures in the first group, the load-bearing elements are mostly formed by using plates, angle irons and/or U profiles and especially by riveting. In this group of steel structures, which are older in terms of their construction dates, widespread corrosion effects are generally observed. The structures in the second group are structures constructed using today's technology (welded and/or bolted connections of rolled profiles). The common feature of the two groups is that their earthquake performances are insufficient at the system level. This insufficiency can be understood by examining and evaluating the current status of the structure at the on-site material, element and system level (Kıymaz, 2010).

Some methods that can be applied in strengthening rigid frames are given below. The target in these methods is to raise the structure, and therefore the frames that form it, to a certain performance level. The point to be considered here is the harmony between the elements to be added for the purpose of strengthening and the existing system elements. The strengthened system should provide the displacements foreseen for the targeted performance level in sufficient harmony. Strengthening methods can be listed as follows:

a) Adding central or eccentric crosses
b) Adding ductile reinforced concrete or masonry shear walls
c) Strengthening moment-transmitting connections
d) Ensuring the strong column-weak beam rule in the frame
e) Mounting additional steel frames on the existing frames on the building facade

Industrial steel structures are mostly constructed with systems whose carrier system is centrally braced steel frames (CBRs). CBRs are the easiest carrier systems to design among steel carrier systems, all calculations can be done very easily by hand. Although CBRs have high ductility, they have low ductility, high cohesion and energy dissipation capacity when compared to moment resisting frames and eccentrically braced steel frames. Early fractures and brittle fractures in cross connections seen in crosses during design earthquake ground motions are the biggest problems related to CBRs. CBRs need a carrier system ductility between 3-5 under design earthquake ground motions. In order for the carrier system to behave ductilely, the cross element and cross connections must be perfectly detailed. Failure in cross connections is a brittle failure mode and cross connections should be designed by considering the maximum force that can be transferred from the connection cross element in accordance with capacity design principles. In order to prevent global buckling in diagonal members, the slenderness ratio and in order to prevent local buckling, the width/thickness (b/t) ratios should be limited. These limitations will prevent fractures that may occur in diagonals due to excessive buckling deformation. The ends of the gusset plate should be allowed to rotate freely plastically. For this purpose, a 2t fold line should be created between the gusset plate and the diagonal end. In the design of diagonal beams in V and inverted V shaped diagonal arrangements, the unbalanced force arising from the buckling of the diagonal member under the effect of compressive load should be taken into account (Akbaş, 2011). Celep and Kumbasar (2004), in their book Introduction to Earthquake Engineering and Earthquake Resistant Structural Design, provide us with valuable information about the design and behavior of central steel braces and eccentric steel braces in the section on the design of steel structures, and this has shed light on our work. Since central braces are quite stiff compared to moment resisting frames, they can also behave brittle if they are not well detailed, and the changes made in earthquake codes (ANSI/AISC 341-10, 2005; TDY, 2007) over time have been mostly about increasing brace strength and stiffness. In X type diagonals, horizontal loads are only resisted by the diagonal members working in tension. Diagonals working in compression are not taken into account here. In Eurocode 8, it is aimed to design the diagonal members in tension in shear walls with central steel braces in such a way that they yield before the connections fail and the beams and columns yield or buckling. Because diagonals in compression cannot make a significant contribution to the stiffness and strength due to compression buckling. In the first stage, the compression effect in the diagonals may increase and reach the buckling strength, but in the next cycle, i.e. when the load changes direction, the compression force carrying capacity decreases due to the permanent deformation caused by buckling and never reaches the plastic compression force carrying capacity $N_{Pl,Rd}$ in the following cycles. The decrease in strength is rapid and is not easy to predict under cyclic loading. The problem is to predict a structural behavior that remains on the safe side. This reality forms the design philosophy of the articles on compression braces in EC8 (Fardis, Carvalho et al., 2005). Under vertical weight loads, only beams and columns should be considered to carry the loads, steel braces should not be taken into account. For seismic load, braces should be considered as follows in elastic analysis; In steel braced shear walls, only tension rods should be taken into account. The structural analysis is performed as if there were only one brace for each central steel braced shear wall, the other brace is considered to have buckled before and contribute to the strength. This corresponds to neglecting the stiffness and strength contribution to the structural system at the beginning, and ensures that it remains in a safe direction for the situation after buckling. Each diagonal member of the reinforced frame should have similar deformation properties under changing loads at each floor and in each diagonal direction. For this purpose, it should be shown that the following rules are met from floor to floor;

$$\frac{A^{+}-A^{-}}{A^{+}-A^{-}} \leq 0,05 \qquad (1)$$

Here A+, A-: Horizontal projection areas of tension crosses when acting from (+) and (-) directions in case of horizontal earthquake forces, cross elements used must meet the condition of $\lambda \leq 1,5$ as dimensionless slenderness to prevent elastic buckling.

The tensile force N must be limited by the gross cross-section yield strength $N_{Pl,Rd}$. In the connection of diagonals with any element, all strength conditions must be provided as follows;

$$R_d \geq 1,2 N_{PlRd} \ (2)$$

Here, $N_{Pl,\,Rd}$: Axial strength of the cross member in tension and compression

In X braced walls, the dimensionless slenderness ratio is limited to $1.3 < l \leq 2$. Thus, the slender diagonals are prevented from being subjected to shock effects in case the axial load changes direction.

Also, (Aslanbay et al. 2023), (Düğenci et al. 2023), (Sancioğlu and Carbas, 2021), (Sancioğlu et al. 2019), (Yanik, 2019) have done current studies on central X type steel braces.

The purpose of this study is to expand the boundaries of steel structures and to examine the principles of strengthening these structures in more depth. It is a fact that interest in steel structures has increased in our country especially after the 1999 Marmara earthquake and this has been reflected in practice. This increased interest after the earthquake means that expectations regarding the seismic performance of steel structures have also increased. Therefore, it is concluded that the principles of strengthening steel structures should be examined more deeply. Based on this result, the effect of strengthening steel structures with steel cross elements on the dynamic behavior of the structure is examined.

## 2. MATERIALS AND METHODS

As a numerical example; It is aimed to determine the dynamic behavior of the model obtained with a steel structure model with a frame system transferring moment with the SAP2000 package program by strengthening it with central steel braces and examining the analysis results of these 2 separate models. Thus, it is thought that the subject of strengthening explained in the previous sections will be understood more concretely on the numerical example. As a method, the finite element method, which is a globally accepted method, was used in all stages.

### 2.1 The steel structure model

The steel structure model consists of 2 openings in the X and Y directions. The opening distances were selected as 6 m for all directions. The model was designed symmetrically. The aim of the symmetric design is to ensure that the behavior of the structure changes only depending on a single variable under the effect of dynamic forces to be applied in the subsequent stages. In this way, it is thought that the results obtained will be more consistent and reliable. The floor height of the model is 3 meters. The number of floors was selected as 7, ensuring that the total building height was 21 meters. The support conditions of the structure were determined as built-in support. The material class of steel profiles is accepted as A992Fy50 in ASTM A992 standards. The flooring thickness is 1 mm steel. Columns and beams were selected as I profile. Dimensioning of columns and beams is given in Table 1.

Table 1. Dimensions of columns and beams

| Dimensions | Columns | Beams |
|---|---|---|
| Outside height | 0.3 m | 0.15 m |
| Top flange width | 0.12 m | 0.08 m |
| Top flange thickness | 0.01 m | 0.01 m |
| Web thickness | 0.01 m | 0.01 m |
| Bottom flange width | 0.12 m | 0.08 m |
| Bottom flange thickness | 0.01 m | 0.01 m |

### 2.2 The steel structure with central X braces model

For the purpose of future comparison, a new model example was created by reinforcing the system we created with X-type central steel braces. The purpose of this reinforcement is to increase the rigidity of the system and to observe its effects on dynamic behavior. The reason for choosing the X-type central steel brace is that it is the central steel brace type with the highest rigidity and the nodal points remain the same. Thus, more reliable results were obtained in future system comparisons.

Before dimensioning the X-type central steel braces, we determined the frames we would apply. We found it appropriate to apply X-type central steel braces in the XZ and YZ planes. With this application, we ensured that the system was reinforced in 2 directions and for better visibility, all frames on the A-A axis in the XZ plane and on the 1-1 axis in the YZ plane were reinforced. The material class of steel central x braces is accepted as A992Fy50 in ASTM A992 standards. Braces were selected as UPN80 profile. Dimensioning of braces is given in Table 2.

Table 2. Dimensions of central X braces

| Dimensions | Central X Braces |
|---|---|
| Outside depth | 0.08 m |
| Outside flange width | 0.045 m |
| Flange thickness | 0.008 m |
| Web thickness | 0.006 m |

### 2.3 Dynamic effects applied to the models

The El Centro north-south components of the earthquake accelerations were applied to both model systems as 1 to 1. Since the models were selected as symmetric, only the El Centro earthquake acceleration in the U1 direction was applied to the system. The analysis type was selected as linear analysis. The output time step number was taken as 150 and the output time step size as 0.02. Modal damping was accepted as 0.05. The acceleration-time graph of the El Centro earthquake used in the study is given in Figure 1.

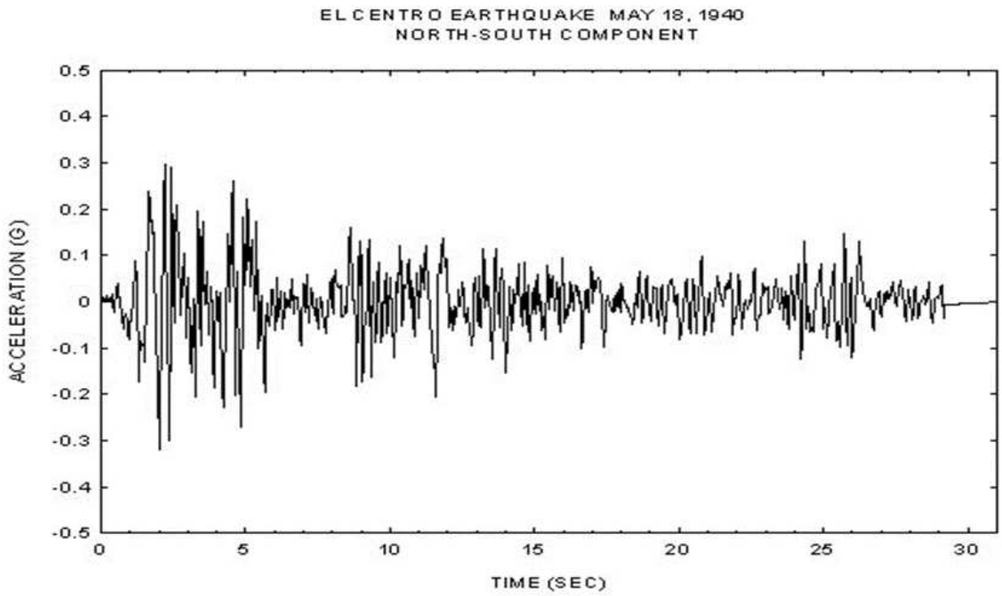


Figure 1. El centro earthquake acceleration record

## 3. RESULT AND DISCUSSION

The existing steel structure model and the model with the determined frames reinforced with central X type steel braces were analyzed using the finite element method. The obtained data will be compared by giving them under separate titles for each model.

### 3.1 The steel structure model results

Since each floor is considered as a rigid diaphragm, all the nodes on the same floors act as a single point. Therefore, it will be sufficient to take one node point on each floor. In order to see the highest displacement and acceleration, node number 24 is taken as the basis, as seen in Figure 2.

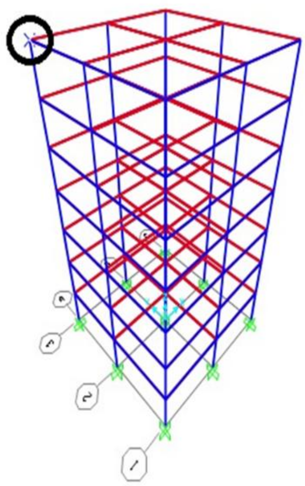

Figure 2. The steel structure finite element model and specified node point

As a result of time history analysis, the displacement values of the 24th node are given in Table 3.

Table 3. The displacement values of the 24th node

| Case | Value | U1 (m) | U2 (m) | U3 (m) |
|---|---|---|---|---|
| EARTHQUAKE | Max | 0,007123 | 8,954E-08 | 0,000017 |
| EARTHQUAKE | Min | -0,01117 | -8,67E-08 | -0,000024 |

As a result of the time history analysis, the displacement UX values of the 24th node point obtained depending on time are given in Figure 3.

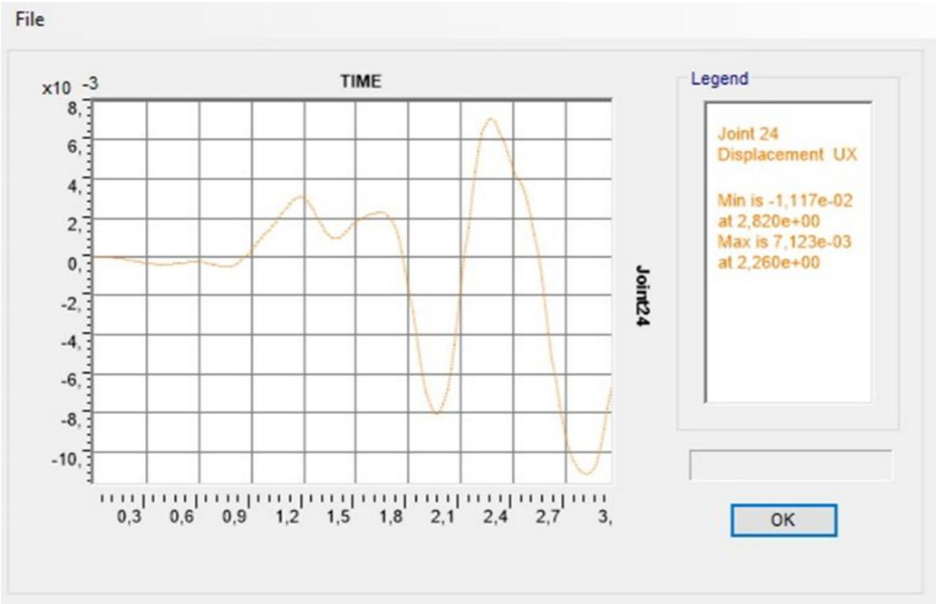


Figure 3. The displacement UX values of the 24th node point with time

As a result of time history analysis, the rotation values of the 24th node are given in Table 4.

Table 4. The rotation values of the 24th node

| Case | Value | R1 (Radian) | R2 (Radian) | R3 (Radian) |
|---|---|---|---|---|
| EARTHQUAKE | Max | 2,25E-08 | 0,000238 | 5,622E-08 |
| EARTHQUAKE | Min | -2E-08 | -0,00032 | -6,012E-08 |

As a result of time history analysis, the acceleration values of the 24th node are given in Table 5.

Table 5. The acceleration values of the 24th node

| Case | Value | U1 ($m/sn^2$) | U2 ($m/sn^2$) | U3 ($m/sn^2$) |
|---|---|---|---|---|
| EARTHQUAKE | Max | 0,76998 | 7,34E-05 | 0,00263 |
| EARTHQUAKE | Min | -0,77338 | -0,00016 | -0,0028 |

As a result of the time history analysis, the acceleration UX values of the 24th node point obtained depending on time are given in Figure 4.

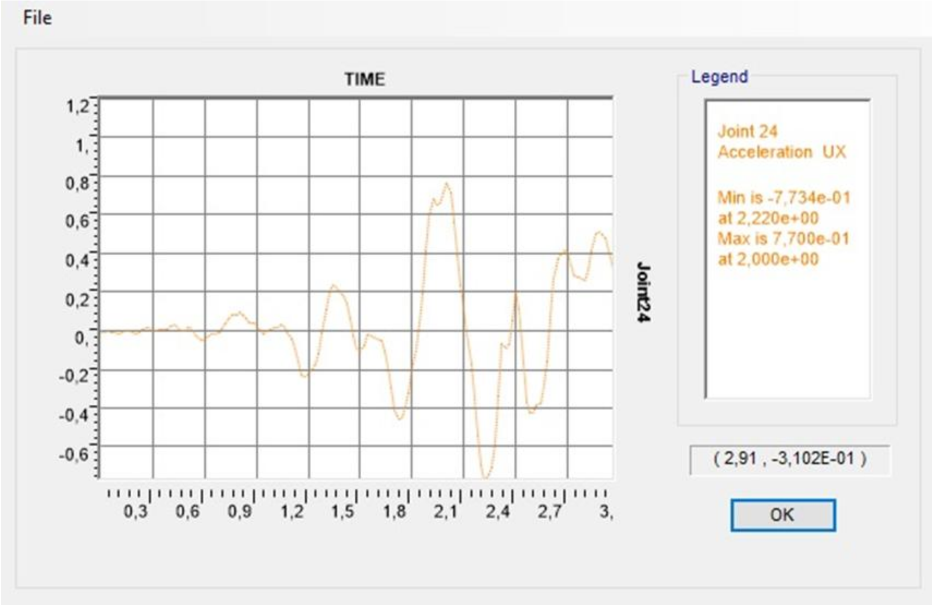


Figure 4. The acceleration UX values of the 24th node point with time

### 3.2 The steel structure with central X braces model results

Since each floor is considered as a rigid diaphragm, all the nodes on the same floors act as a single point. Therefore, it will be sufficient to take one node point on each floor. In order to see the highest displacement and acceleration, node number 24 is taken as the basis, as seen in Figure 5.

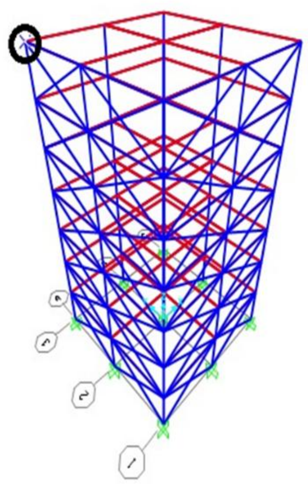

Figure 5. The steel structure with central X braces finite element model and specified node point

As a result of time history analysis, the displacement values of the 24th node are given in Table 6.

Table 6. The displacement values of the 24th node

| Case | Value | U1 (m) | U2 (m) | U3 (m) |
|---|---|---|---|---|
| EARTHQUAKE | Max | 0,002808 | 0,00066 | 0,000087 |
| EARTHQUAKE | Min | -0,007303 | -0,000619 | -0,000097 |

As a result of the time history analysis, the displacement UX values of the 24th node point obtained depending on time are given in Figure 6.

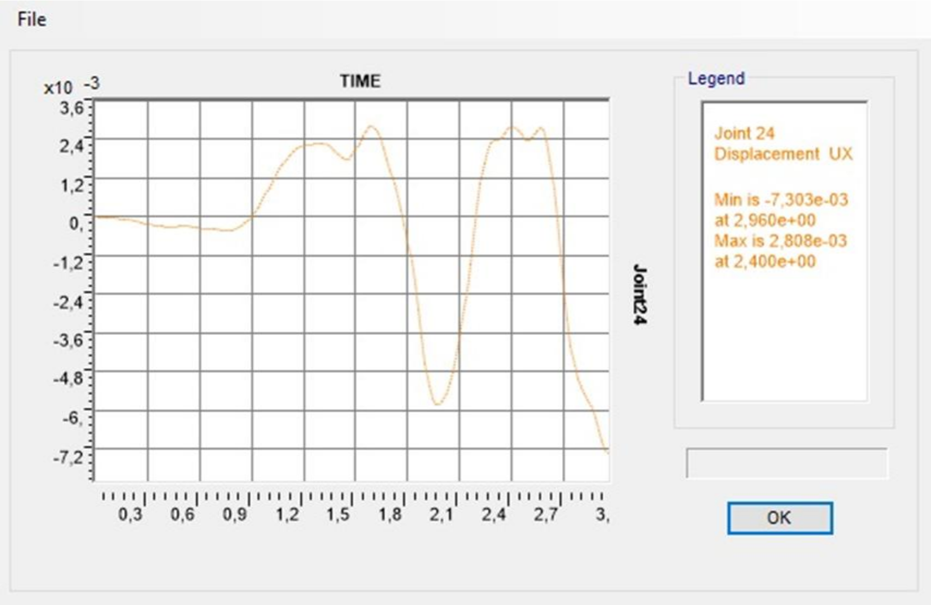


Figure 6. The displacement UX values of the 24th node point with time

As a result of time history analysis, the rotation values of the 24th node are given in Table 7.

Table 7. The rotation values of the 24th node

| Case | Value | R1 (Radian) | R2 (Radian) | R3 (Radian) |
|---|---|---|---|---|
| EARTHQUAKE | Max | 0,000019 | 0,000191 | 0,000571 |
| EARTHQUAKE | Min | -0,00002 | -0,000199 | -0,000257 |

As a result of time history analysis, the acceleration values of the 24th node are given in Table 8.

Table 8. The acceleration values of the 24th node

| Case | Value | U1 ($m/sn^2$) | U2 ($m/sn^2$) | U3 ($m/sn^2$) |
|---|---|---|---|---|
| EARTHQUAKE | Max | 0,61306 | 0,4772 | 0,06345 |
| EARTHQUAKE | Min | -0,73714 | -0,46545 | -0,08107 |

As a result of the time history analysis, the acceleration UX values of the 24th node point obtained depending on time are given in Figure 7.

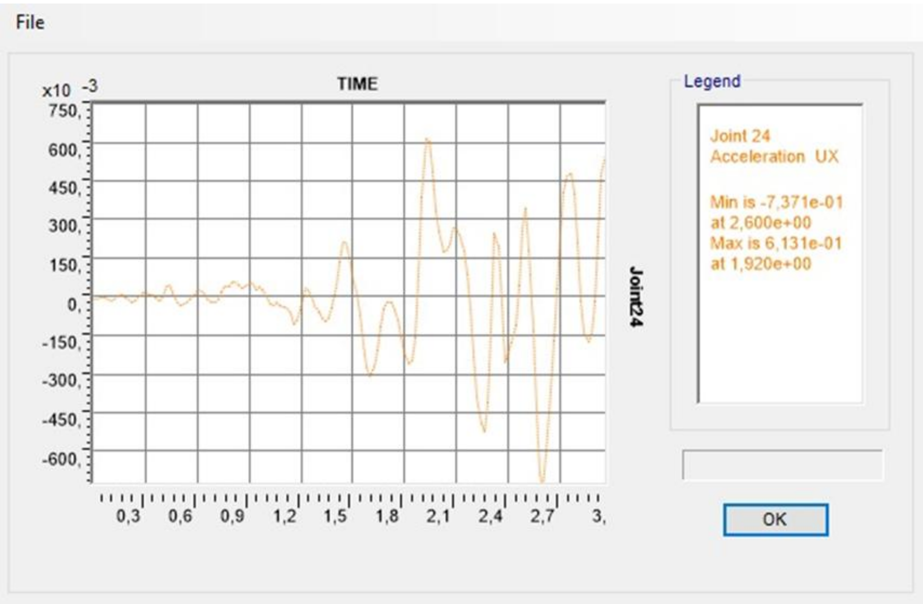


Figure 7. The acceleration UX values of the 24th node point with time

### 3.3 Comparison of results

The displacement differences and percentage changes at the 24th node point of the system reinforced with moment-transmitting frame system and central X braces are given in Table 9.

Table 9. Displacement differences and percentage changes

| | U1 (m) | U2 (m) | U3 (m) |
|---|---|---|---|
| Moment-transmitting frame | 0,011167 | 8,669E-08 | 0,000024 |
| Central X braces frame | 0,007303 | 0,000619 | 0,000097 |
| Difference (m) | 0,003864 | -0,0006189 | -0,000073 |
| Difference (%) | 34,601952 | 99,9859952 | 75,25773196 |

When the displacement results are compared, a displacement reduction of approximately 35% is observed in the U1 direction. A displacement reduction of 0.003864 m was achieved. This is seen as evidence that reinforcement with steel braces increases the system rigidity.

When we look at the percentage in the U2 and U3 directions, a very high increase is seen. Although it seems negative, when we look at the displacement increases, it is seen that there are very small increases such as 0.000619 m in the U2 direction and 0.000097 m in the U3 direction. It was realized that the reason for these increases was the torsion in the structure. However, since the values were small, they were ignored. However, this seemingly negative result leads to the following. Steel braces play a role in distributing the earthquake load on the structure in a balanced way.

In addition, when we take the maximum value as a basis, this is 0.011167 m, and thanks to the reinforcement with steel crosses, this value decreases to 0.007303 m. This is an indication that the reinforced system is on the safer side.

The rotation differences and percentage changes at the 24th node point of the system reinforced with moment-transmitting frame system and central X braces are given in Table 10.

Table 10. Rotation differences and percentage changes

| | R1 (Radian) | R2 (Radian) | R3 (Radian) |
|---|---|---|---|
| Moment-transmitting frame | 2,254E-08 | 0,00032 | 6,012E-08 |
| Central X braces frame | 0,000019 | 0,000199 | 0,000571 |
| Difference (m) | -1,9E-05 | 0,000121 | -0,00057094 |
| Difference (%) | 99,88137 | 60,8040201 | 99,9894711 |

As can be seen, the percentage change in rotation values is very high, but since the increase amount is low as in displacements, it is ignored. The reason for rotation in the system is that when the system is strengthened, its symmetrical structure is disrupted and torsion occurs. Steel crosses reduce the incoming load by distributing it to other axes. As it is known, balanced shape changes and displacements in 3 directions are desired for structural safety rather than high shape changes and displacements in a single direction. The success of steel crosses is seen in this comparison.

The acceleration differences and percentage changes at the 24th node point of the system reinforced with moment-transmitting frame system and central X braces are given in Table 11.

Table 11. Acceleration differences and percentage changes

| | U1 (m/sn2) | U2 (m/sn2) | U3 (m/sn2) |
|---|---|---|---|
| Moment-transmitting frame | 0,77338 | 0,00016 | 0,0028 |
| Central X braces frame | 0,73714 | 0,4772 | 0,08107 |
| Difference (m) | 0,03624 | -0,47704 | -0,07827 |
| Difference (%) | 4,685924 | -99,9665 | -96,5461946 |

As a result of the comparison, it is seen that the maximum acceleration decreases by approximately 5% with the reinforcement with steel braces. There is an increase in acceleration in the U2 and U3 directions. However, when the maximum acceleration is taken as a basis and the results obtained, it is seen once again that the reinforcement with steel braces increases the rigidity.

## 4. CONCLUSIONS

The effect of central steel braces on the rigidity of the structure is also seen numerically in the comparisons made. It is seen that the maximum displacement at the 24th node point decreases by approximately 35%. However, an increase is seen in the displacements in the U2 and U3 directions. From here, it is also understood how steel braces work under dynamic effects. Steel braces distribute the incoming effect to other axes, reducing the maximum effect and ensuring that the system operates as rigid. Again, the effect of the acceleration, which is effective in the formation of plastic jointing and displacement, on the joint points is compared and it is seen that it decreases by approximately 5%. This decrease also sheds light on the benefit of strengthening with central steel braces on rigidity and the solution of joint point problems in all steel structures. It is seen that the most important problem of frame systems transferring moment is that they cannot distribute the incoming dynamic effects and loads evenly and move in one direction. This situation is proven once again when the deformation patterns are examined. However, torsion effects are also observed in the system strengthened with steel braces. It can be said that another effect on rigidity is the symmetry of the structure. Especially when reinforcing with central steel braces, we ensured that the frame in the 1-1 axis in the X axis direction and the frame in the A-A axis in the Y axis direction were strengthened, and by leaving the frames in the 2-2 and 3-3 axes in the X axis direction empty and again by leaving the frames in the B-B and C-C axes in the Y axis direction empty, the initial symmetrical state of the structure in the X and Y axes was changed. As a result of this, torsion was observed.

In light of all these findings, it has been observed that reinforcing steel structures with steel braces increases rigidity in steel structures that are rebuilt or need to be strengthened, and is effective in distributing earthquake loads evenly in the structure. Using central X type steel braces in steel structures can improve the behavior under earthquake loads to the desired level with a good design that paying attention to torsional effects.

## ACKNOWLEDGMENT

This study is derived from Furkan Günday's master's thesis titled "Investigation of The Effects of Steel by Structural Cross Elements on Structural Dynamics Behavior"

## REFERENCES

1. AISC Seismic Provisions for Structural Steel Buildings, (2005), Standard No. ANSI/AISC 341-05.
2. Akbaş B., "Endüstriyel çelik yapıların sismik detaylandırılması", 1. Türkiye Deprem Mühendisliği ve Sismoloji Konferansı, (2011)
3. Ar E., "Çelik Yapıların Tasarım Metodları ve Bunların Karşılaştırılması" Yüksek lisans tezi, Dokuz Eylül Üniversitesi, (2009)
4. Aslanbay, H. H., Düğenci, O., & Serpil, S. S. (2023). Merkezi ters V ve X çaprazlı çerçeveli yüksek katlı çelik yapıların mod birleştirme yöntemi ile yapısal analiz sonuçlarının karşılaştırılması. Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, 12(3), 844-852.
5. Bayındırlık ve İskân Bakanlığı (2007). Deprem Bölgelerinde Yapılacak Binalar Hakkında Yönetmelik. 26454 Sayılı Resmî Gazete, Ankara.
6. Bulut M., "Merkezi çaprazlı ve dış merkez çaprazlı çok katlı çelik yapıların doğrusal olmayan davranışında sünekli düzeylerinin karşılaştırılması", Yüksek lisans tezi, Sakarya Üniversitesi (2008)
7. Celep Z. ve Kumbasar, N. (2004). Deprem Mühendisliğine Giriş ve Depreme Dayanıklı Yapı Tasarımı (Üçüncü Baskı). İstanbul: Beta Dağıtım.
8. Darılmaz K., SAP 2000 ile Yapı Sistemlerinin Analizi, TMMOB İnşaat Mühendisleri Odası İzmir Şubesi Seminer Notları, Şubat 2007
9. Deren H., Uzgider E., Piroğlu F. (2003). Çelik Yapılar. (Birinci Baskı). İstanbul: Çağlayan Kitabevi.
10. Dönmez B."Çubuk elemanlı çerçevelerin plak elemanlar ile analizi", 3estructure.blogcu.com,(2010)
11. Düzel E, "Düşeyde rijitlik düzensizliği bulunan çerçevelerin sönüm elemanları ve çelik çaprazlar ile rehabilitasyonu" Yüksek lisans tezi, Niğde Üniversitesi, (2010)
12. Düğenci, O., Aslanbay, H. H., & Serpil, S. S. (2023). Merkezi ters V ve X çaprazlı çerçeveli yüksek katlı çelik yapıların mod birleştirme yöntemi ile yapısal analiz sonuçlarının karşılaştırılması. Nigde Omer Halisdemir University Journal of Engineering Sciences/Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, 12(3).
13. European Convention for Constructional Steelwork. (1993). Examplesto EC3. (First Edition). Brussel.
14. Eurocode 8, EVN 1998 Dizayn of Structures for Earthquake Resistance, (1998)
15. Eurocode 8, EVN 1998 Dizayn of Structures for Earthquake Resistance, CEN Ders Notları, Prof. Salih Zeki Bulut
16. Fardis, M., Carvalho, E., Elnashai, A., Faccioli, E., Pinto, P. ve Plumier., A. (2005). Designers' Guide to EN 1998-1 and EN 1998-5 Eurocode 8: Design of Structures for Earthquake Resistance London: Thomas Telford Ltd.

17. Günday, F. (2017). Investigation of The Effects of Steel by Structural Cross Elements on Structural Dynamics Behavior, Yüksek Lisans Tezi, Ondokuz Mayıs Üniversitesi, Fen Bilimleri Enstitüsü, Samsun.
18. Kıymaz, G., "Çelik Yapıların Depreme Karşı Güçlendirilmesi", Dünya İnşaat Dergisi,(2010)
19. Özmen, G., İnşaat Mühendisleri İçin Excel Uygulamaları Birsen Yayınevi, (2005)
20. SAP2000, Integrated Finite Element Analysis and Design of Structures, Computers and Structures Inc, Berkeley, California, USA, 1997.
21. Sancioğlu, S., & Çarbaş, S. (2021, December). Merkezi çelik çaprazların bir çelik yapı üzerinde incelenmesi. 1st International Conference on Applied Engineering and Natural Sciences.
22. Sancioğlu, S., Aribaş, S., Bayram, B., Şimşek, M., & Çarbaş, S. (2019). Çelik Bir Binada Kullanılan Çapraz Tiplerinin Deprem Etkisi Altında Analizi.
23. Tama,Y., "Çelik Yapılarda Bayrak Levhalarının Sismik Davranışlarının Araştırılması", Osmangazi Üniversitesi Müh.Mim.Fak. Dergisi. (2010)
24. TS498, Yapı Elemanlarının Boyutlandırılmasında Alınacak Yüklerin Hesap Değerleri, Kasım 1997
25. TS648, Çelik Yapıların Hesap ve Yapım Kuralları, Aralık 1980
26. TS4561, Çelik Yapıların Plastik Teoriye Göre Hesap Kuralları, TSE, Ankara 1985
27. Uzgider E., Piroğlu F., Çağlayan Ö. (2007). Sünek Tasıyıcı Sistemlerin Tasarımı Seminer Notları İnşaat Mühendisleri Odası İzmir şubesi.
28. Yanik, E. (2019). Çelik taşıyıcı sistemlerde kullanılan çaprazların yapı davranışı üzerine etkilerinin araştırılması (Master's thesis, Fen Bilimleri Enstitüsü).