

Düzce University Journal of Science & Technology

Research Article

Numerical Investigation of the Behavior of Crusher Buildings Under Earthquake Effect

Batuhan AYKANAT [a,*]

[a] *Department of Civil Engineering, Faculty of Engineering, Düzce University, Düzce, TÜRKİYE*
* *Corresponding author's e-mail address: batuhanaykanat@duzce.edu.tr*
DOI: 10.29130/dubited.1657397

ABSTRACT

Steel structures are frequently used especially in industry and construction of the buildings. Due to its widespread use, many researchers have been studying to investigate the behavior of steel structures. Steel structures used in mining areas are generally used to keep transmission lines and crushers safe. Crushers are vital equipment for mines to continue operating. For this reason, crusher buildings are constructed using steel profiles to protect the crushers. The aim of this study is to investigate the behavior of crusher buildings constructed to protect the crusher under earthquake effects. For this purpose, a sample crusher building was designed and its structural analysis was performed according to 4 different cities of Türkiye (Düzce, Ankara, Kahramanmaraş and İzmir). As a result of the analysis, the maximum displacement, equivalent earthquake load and column usage capacity that may occur in the structure were checked and compared. As a result of the study, it was concluded that increases in earthquake parameters directly affect the structure. The maximum displacements and usage capacity were obtained from the Düzce region.
Keywords: *TBEC-2018, earthquake, crusher buildings, steel structural design*

Kırıcı Binalarının Deprem Etkisi Altındaki Davranışının Sayısal Olarak İncelenmesi

ÖZ

Çelik yapılar özellikle endüstride ve bina inşaatlarında sıklıkla kullanılmaktadır. Yaygın kullanımından dolayı birçok araştırmacı çelik yapıların davranışını incelemek için çalışmalar yapmaktadır. Madencilik alanlarında kullanılan çelik yapılar genellikle iletim hatları ve kırıcıların güvenliğini sağlamak için kullanılır. Kırıcılar, madenlerin çalışmaya devam edebilmesi için hayati öneme sahip ekipmanlardır. Bu nedenle kırıcı binaları, kırıcıları korumak için çelik profiller kullanılarak inşa edilir. Bu çalışmanın amacı, kırıcıyı korumak için inşa edilen kırıcı binalarının deprem etkileri altındaki davranışını araştırmaktır. Bu amaçla örnek bir kırıcı binası tasarlanmış ve Türkiye'nin 4 farklı iline (Düzce, Ankara, Kahramanmaraş ve İzmir) göre yapısal analizi yapılmıştır. Analiz sonucunda yapıda oluşabilecek maksimum yer değiştirme, eşdeğer deprem yükü ve kolon kullanım kapasitesi kontrol edilerek karşılaştırılmıştır. Çalışma sonucunda deprem parametrelerindeki artışların yapıyı doğrudan etkilediği sonucuna varılmıştır. Maksimum yer değiştirme ve kullanım kapasitesi Düzce bölgesinden elde edilmiştir.
Anahtar Kelimeler: *TBDY-2018, deprem, kırıcı binaları, çelik yapı tasarımı*

Received: 13/03/2025, Revised: 17/04/2025, Accepted: 24/04/2025

I. INTRODUCTION

Türkiye is located in a region with high seismic activity fault lines.For this reason, earthquake is an inevitable reality for Türkiye. Due to the presence of active fault lines in the region, devastating earthquakes occur frequently in Türkiye. Investigating the earthquakes that have occurred in Türkiye in the last 100 years (1939 Erzincan (Ms = 7.9), 1975 Diyarbakır (Mw = 6.6), 1999 İzmit (Mw = 7.4), 1999 Düzce (Mw = 7.4), 2003 Bingöl (Mw = 6.4), 2011 Elazığ (ML = 5.3), 2011 Van (Mw = 7.1), 2020 Elazığ (Mw = 6.8),2020 Ege Denizi (Mw = 6.9) and Kahramanmaraş (Mw = 7.7) appear to have caused serious loss of life and property [1]. Due to the earthquakes that occurred in the past, the destruction they caused, and the risks shown by the earthquake hazard map, preventing these destructions requires serious effort and work. While earthquakes cause loss of life and property, they also cause industrial activities to stop. The most important reasons for the destructive effects are the density of active faults in the country and the dense residential population in these regions. Türkiye Earthquake Hazard Map (2019) (Figure 1), clearly shows all of these risky areas. For this purpose, various precautions are taken to reduce the earthquake risk and to build earthquake-resistant industrial structures. For this reason, steel structures, which have become increasingly widespread in recent years, are used extensively, especially in industrial construction [2, 3]. Steel has become frequently preferred in the industry because its strength and modulus of elasticity are much higher than other materials and it can be constructed quickly [4]. Due to its widespread use, many researchers have conducted studies to investigate the behavior of steel structures under seismic loads. They have tried to determine the most effective models to analyze the reactions of steel structures and produce the most optimum solutions [2–22] . It is possible to see the use of nonlinear static and dynamic analysis procedures called pushover and time history analysis to determine the seismic response of steel structures. Static pushover analysis is more preferred in terms of simplicity, efficiency and applicability [15, 23–34].

Steel structures used in industry serve different purposes. In mines in Türkiye, steel is also preferred in the design of crusher buildings built to protect the crusher machines required for the active operation of the mine. The function of these structures is to prevent the crusher from being damaged in the event of an earthquake and, in particular, to protect the crusher so that the mine's activity does not stop.

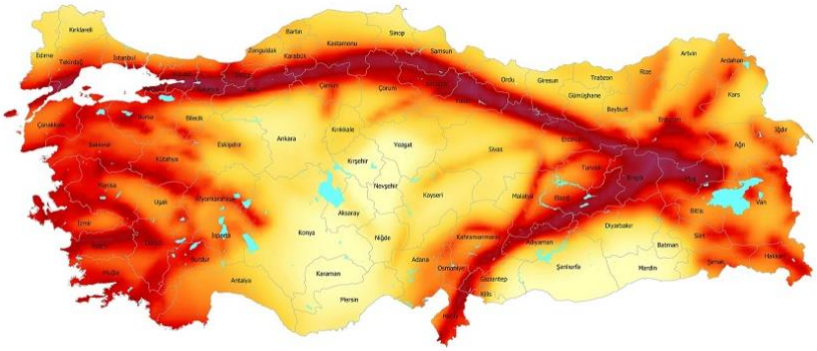


Figure 1. *Türkiye Earthquake Hazard Map* [35]

The aim of this study is to investigate the behavior of crusher buildings constructed to protect the crusher under earthquake effects. For this purpose, cities located in 4 different earthquake zones were selected from the Türkiye Earthquake Hazard Map and crusher buildings assumed to be built here as a single type were designed. The designed crusher building was modeled using the SAP2000 program [36] , dynamic analysis was performed and compared among themselves according to different earthquake zones. Earthquake analysis was carried out on the created models according to Türkiye Building Earthquake Code (TBEC-2018)[37]. As a result of the analysis, the maximum displacement, equivalent earthquake load and column usage capacity that may occur in the structure were checked and compared.

II. DESIGN AND ANALYSIS PARAMETERS

A. CALCULATION OF EARTHQUAKE PARAMETERS ACCORDING TOTURKISH BUILDING EARTHQUAKE CODE-2018

For analyses to be performed using the Equivalent earthquake load method according to TBEC-2018, the total equivalent earthquake load acting on the structure is calculated using Eq. (1).

$$V_{tE}{}^{(X)} = m_t S_{aR}\left(T_p{}^{(X)}\right) \geq 0.04 m_t I S_{DS} g \tag{1}$$

Where, m_t is the mass of the structure, and $S_{aR}\left(T_p{}^{(X)}\right)$ is the reduced design spectral acceleration calculated by taking into account the predominant period of the structure ($T_p{}^{(X)}$) in the earthquake direction under consideration. In addition I is the structure importance coefficient, S_{DS} is the design spectral acceleration coefficient defined for the short period, and g is the gravitational acceleration. The reduced design spectral acceleration of the structure is calculated according to Eq. (3) and the predominant period of the structure is determined according to Eq. (2) by taking into account the earthquake direction (X,Y).

$$T_p^{(x)} = 2\pi \left(\frac{\sum_{i=1}^{N} m_i \, d_{fi}^{(x)2}}{\sum_{i=1}^{N} F_{fi}^{(x)} \, d_{fi}^{(x)}} \right)^{1/2} \tag{2}$$

$$S_{aR}(T) = S_{ae}(T)/R_a(T) \tag{3}$$

In this equation, $S_{ae}(T)$ is the corner period of the horizontal elastic design acceleration spectrum. $R_a(T)$ is the seismic load reduction coefficient. The calculation of the horizontal elastic design acceleration spectrum and the seismic load reduction coefficient is summarized by Eq. (4–9).

$$S_{ae}(T) = \left(0.4 + 0.6\frac{T}{T_A}\right) S_{DS} \rightarrow (0 \leq T \leq T_A) \tag{4}$$

$$S_{ae}(T) = S_{DS} \rightarrow (T_A \leq T \leq T_B) \tag{5}$$

$$S_{ae}(T) = \frac{S_{D1}}{T} \rightarrow (T_B \leq T \leq T_L) \tag{6}$$

$$S_{ae}(T) = \frac{S_{D1} T_L}{T^2} \rightarrow (T_L \leq T) \tag{7}$$

$$R_a(T) = \frac{R}{I} \rightarrow (T > T_B) \tag{8}$$

$$R_a(T) = D + \left(\frac{R}{I} - D\right)\frac{T}{T_B} \rightarrow (T \leq T_B) \tag{9}$$

According to these equation, T_A and T_B are the horizontal elastic design acceleration spectrum corner periods, T_L is the transition period to the constant displacement region, R is the structural system behavior coefficient, and D is the overstrength coefficient, respectively. According to TBEC-2018, S_{DS} and S_{D1} are calculated according to Eq. (10) and Eq. (11). Where SS is the map spectral acceleration coefficient for the period of 0.2 s, S1 is the map spectral acceleration coefficient for the period of 1.0 s, FS is the local soil effect coefficient for the period of 0.2 s, and F1 is the local soil effect coefficient for the period of 1.0 s.

$$S_{DS} = S_S F_S \tag{10}$$

$$S_{D1} = S_1 F_1 \tag{11}$$

The total equivalent seismic load is expressed as the sum of the equivalent seismic loads acting on the floors of the structure in Eq. (12).

$$V_{tE}{}^{(X)} = \Delta F_{NE}{}^{(X)} + \sum_{i=1}^{N} F_{iE}{}^{(X)} \tag{12}$$

B. SPECTRUM CURVES

For the analyses to be carried out according to TBEC-2018, short period map spectral acceleration coefficient (S_s), map spectral acceleration coefficient for 1 second period (S_1), short period design spectral acceleration coefficient (S_{DS}), maximum ground acceleration (PGA) and maximum ground speed (PGV) values were obtained using the Türkiye Earthquake Hazard Map [35]. The design spectra based on the 2018 earthquake codes are shown together in a Figure 2. In order to see different earthquake effects, earthquake parameters belonging to 4 different locations in Türkiye were used. These are Ankara, Düzce, İzmir and Kahramanmaraş. Some of the earthquake parameters that will affect the model prepared for analysis are given in the Table 1.

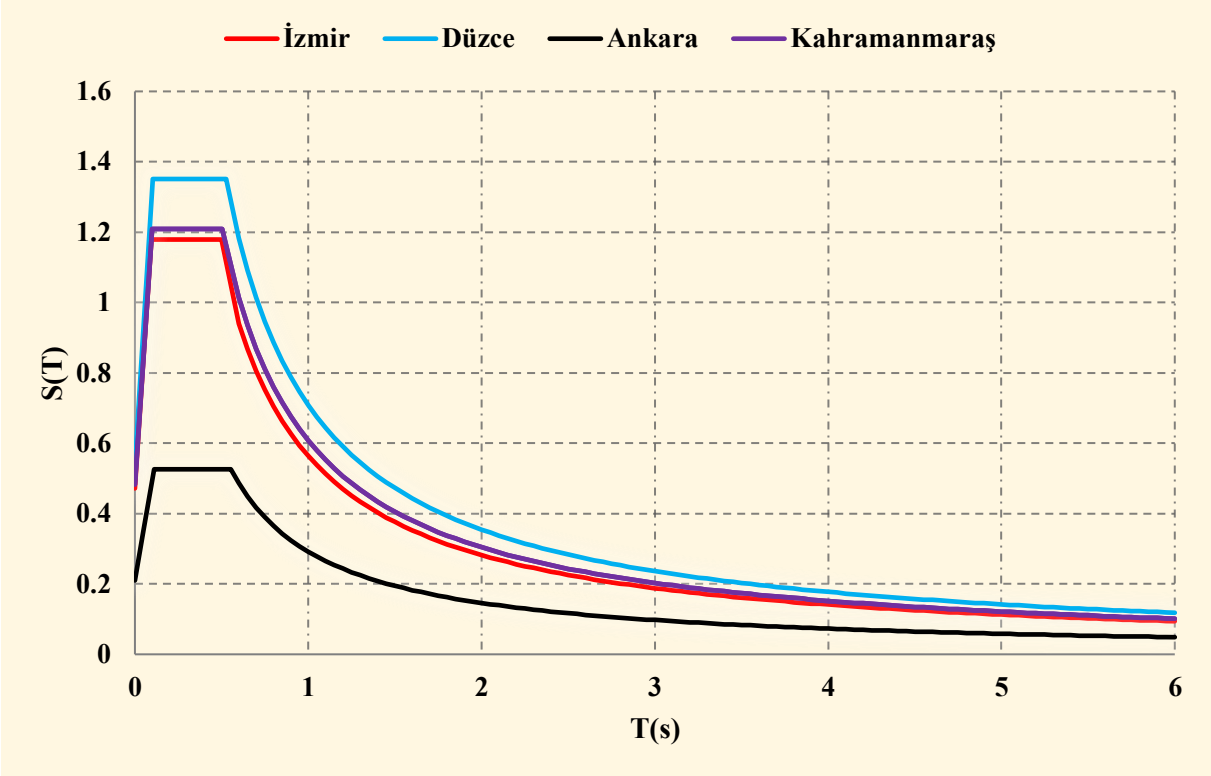


Figure 2. *The design spectra based on the 2018 earthquake codes*

Table 1 *Earthquake Parameters*

ANKARA					
S_s	**S_1**	**PGA** *(g)*	**PGV** *(cm/s)*	**S_{DS}**	**S_{D1}**
0.345	0.124	0.150	10.431	0.526	0.292
T_A *(s)*	**T_B** *(s)*	**T_L** *(s)*	**F_s**	**F_1**	**Soil Class**
0.111	0.555	6.0	1.524	2.352	ZD
DÜZCE					
S_s	**S_1**	**PGA** *(g)*	**PGV** *(cm/s)*	**S_{DS}**	**S_{D1}**
1.351	0.367	0.555	35.782	1.351	0.709
T_A *(s)*	**T_B** *(s)*	**T_L** *(s)*	**F_s**	**F_1**	**Soil Class**
0.105	0.525	6.0	1.00	1.933	ZD
İZMİR					
S_s	**S_1**	**PGA** *(g)*	**PGV** *(cm/s)*	**S_{DS}**	**S_{D1}**
1.122	0.275	0.457	27.749	1.179	0.564
T_A *(s)*	**T_B** *(s)*	**T_L** *(s)*	**F_s**	**F_1**	**Soil Class**
0.096	0.478	6.0	1.051	2.050	ZD
KAHRAMANMARAŞ					
S_s	**S_1**	**PGA** *(g)*	**PGV** *(cm/s)*	**S_{DS}**	**S_{D1}**
1.173	0.305	0.486	31.543	1.209	0.608
T_A *(s)*	**T_B** *(s)*	**T_L** *(s)*	**F_s**	**F_1**	**Soil Class**
0.101	0.503	6.0	1.031	1.995	ZD

C.CRUSHER BUILDING DETAILS

The dimensions of the crusher building in plan are approximately 21.50 x 16.00 meters, while its height changes gradually. The heights of the building are 23.30, 16.80 and 10.90 meters. A 200 kN crane system is used for maintenance of equipment parts in the steel structure system of the crusher building. There is a walkway along the crane walking line on one axis of the structure for maintenance of the crane. The structural steel system of the crusher building consists of a special concentric braced frames (SCBF) in the X direction. It is important to be able to create usable space in industrial structures that usually contain equipment such as cranes or are used for storage purposes. For this reason, a special moment frame (SCF) system was used in the Y direction of the structure. The structure is connected to the reinforced concrete in the base area with a simple connection in the long direction of the structure and a moment transferring connection type in the short direction.

The mechanical properties of the steel materials (profiles and plates) to be used in the designs are given in the Table 2. Additionally, the section properties of the steel elements used in the design are given in the

Table **3**. Structural design of the crusher building is given in Figure 3.

Table 2.*Material details of steel elements*

Structural Element	**Materials**
I Section *(IPE, HEA, HEB etc.)*	S275
U and L Section *(UPN, UNP, UPE, RHS, SHS etc.)*	S235
C Section *(Purlin and Cincture)*	S275
Connection Plate	S235

Material Properties

Material	**F_y** *(N/mm^2)*	**F_u** *(N/mm^2)*	**$EffF_y$** *(N/mm^2)*	**$EffF_u$** *(N/mm^2)*	**S_{Hard}**	**S_{Max}**	**S_{Rup}**	**FinalSlope**
S235	235	360	258.5	396	0.015	0.011	0.17	-0.1
S275	275	430	302.5	473	0.015	0.011	0.17	-0.1

Table 3.*Section details of steel elements*

Section	**Material**	**Shape**	**t_3** *(mm)*	**t_2** *(mm)*	**t_f** *(mm)*	**t_w** *(mm)*	**t_{2b}** *(mm)*	**t_{fb}** *(mm)*	**Area** *(mm^2)*
HE140B	S275	I/Wide Flange	140	140	12	7	140	12	4300
HE180B	S275	I/Wide Flange	180	180	14	8.5	180	14	6530
HE200B	S275	I/Wide Flange	200	200	15	9	200	15	7810
HE400A	S275	I/Wide Flange	390	300	19	11	300	19	15900
HE500A	S275	I/Wide Flange	490	300	23	12	300	23	19800
HE550A	S275	I/Wide Flange	540	300	24	12.5	300	24	21200
HE600A	S275	I/Wide Flange	590	300	25	13	300	25	22600
L90X9	S235	Angle	90	90	9	9			1552
SHS80X80X5	S235	Box/Tube	80	80	5	5			1500
CHS88.9x3.2	S235	Pipe	88.9			3.2			861.6
CHS114.3x5	S235	Pipe	114.3			5			1716.88
CHS139.7x5	S235	Pipe	139.7			5			2115.86
CHS168.3x6.3	S235	Pipe	168.3			6.3			3206.31
CHS193.7x7.1	S235	Pipe	193.7			7.1			4162.17
UPN120	S235	Channel	120	55	9	7			1698
UPN200	S235	Channel	200	75	11.5	8.5			3219

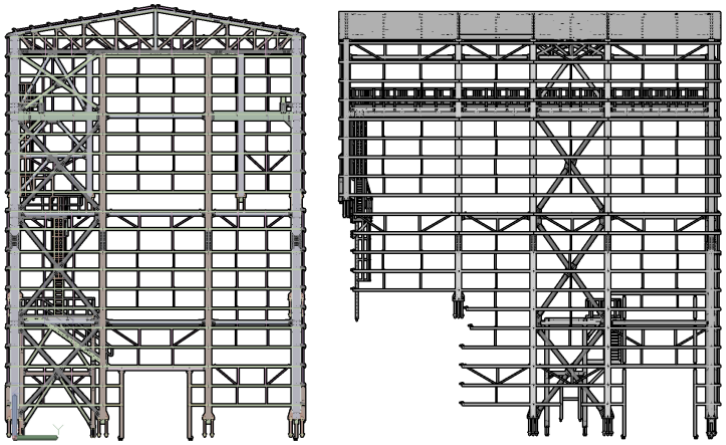


Figure 3.*Structural design of the crusher building*

D.PARAMETERS IN ANALYSIS

In this study, DD-2 was selected as the Design Earthquake Ground Motion Level. The building importance coefficient (I) is taken as 1. The Overstrenght Factor (D) is 2.0 (X direction) and 3.0 (Y direction), and the Earthquake Design Class (DTS) is taken from the relevant tables in the regulation depending on the Building Usage Class (BKS) and the Short Period Design Spectral Acceleration coefficient. In addition, Building Height Class (BYS) was taken from the relevant table in TBEC-2018 depending on the building height and Earthquake Design Class (EDC). Some of the analysis parameters that will affect the model are given in the Table 4. In the design of the crusher building, the load of the elements fixed and mounted on the structure (Dead load), earthquake load (EX and EY), live loads and snow load were taken into consideration. In addition, the load of the crane inside the building and the load combinations are included.

Table 4.*Analysis parameters*

	X Direction	**Y Direction**
R	5.0	8.0
D	2.0	3.0
I	1.0	1.0
Ecc. Ratio	5 *(%)*	5 *(%)*
Design Specification	LRFD *(Load and Resistance Factor Design)*	
Steel Frame Design	SCBF *(Special Concentric Braced Frames)*	SMF *(Special Moment Frame)*

E.ANALYSIS METHOD

In this Study, design and analysis of the structure were performed using the SAP2000 program. The equivalent linear method and mode superposition method was used as the dynamic calculation method. The seismic load calculated according to TBEC-2018 was defined in the SAP2000 program, and the dynamic analysis of the structure was carried out. In adition, torsional moments of at least ±5% eccentricity at the geometric center of the structure, depending on the seismic forces acting on the floors, were included in the calculations. Images of the SAP2000 model are given in the Figure 4.

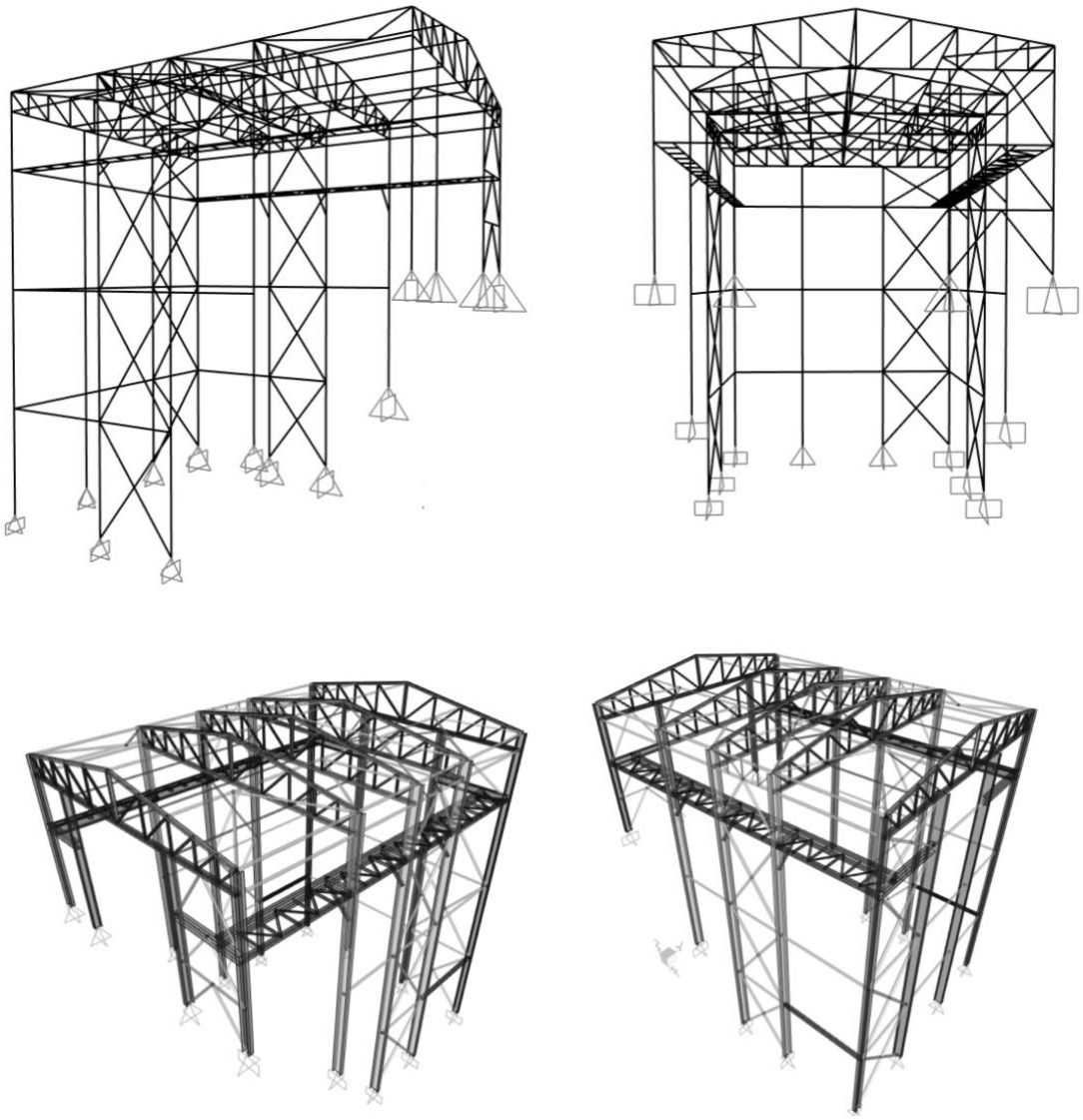


Figure 4.*SAP2000 Model*

III. NUMERICAL ANALYSIS RESULTS

The structural analysis results of the crusher building, which was analyzed in the SAP2000 program are given in Table 5.

Table 5.*Structural Analysis Results*

Region	Period *(s)*		Max. Displacement *(mm)*		Equivalent Earthquake Load *(kN)*	
	(X)	**(Y)**	**(X)**	**(Y)**	**(X)**	**(Y)**
ANKARA	0.533	0.440	59.5	50.0	197.03	137.0
DÜZCE	0.533	0.440	145.0	104.0	487.55	341.0
İZMİR	0.533	0.440	113.0	95.0	387.45	281.43
KAHRAMANMARAŞ	0.533	0.440	120.0	88.0	418.18	297.61

The period of the crusher building was determined using the mode with the highest mass participation in both directions. When the Table 5 is examined, period values of 0.533s in the X direction and 0.440s in the Y direction were obtained. Since no changes are made to the structural system, the period values of the structure are the same in all regions. The equivalent earthquake loads obtained are given in the Figure 5.

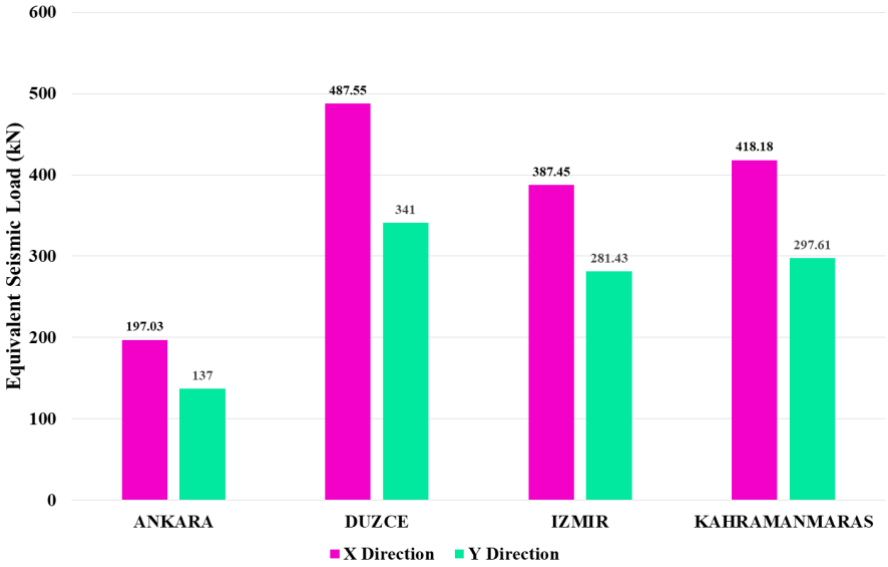


Figure 5. *Equivalent earthquake loads*

When the equivalent earthquake load values are examined, it is seen that the highest value is obtained in the Düzce region in both directions. Especcialy in the X direction, since Düzce is the province with the highest seismicity among the selected regions, it was expected that the highest values would be obtained here (487.55 kN). As expected, it ranks 2nd highest in the results obtained from Kahramanmaraş province, where a major earthquake occurred in 2023 (418.18 kN). These results are followed by İzmir and Ankara respectively.

The maximum displacement in the structure occurred at the top point of the crusher building. The graphical representation of maximum displacements is given in the Figure 6.

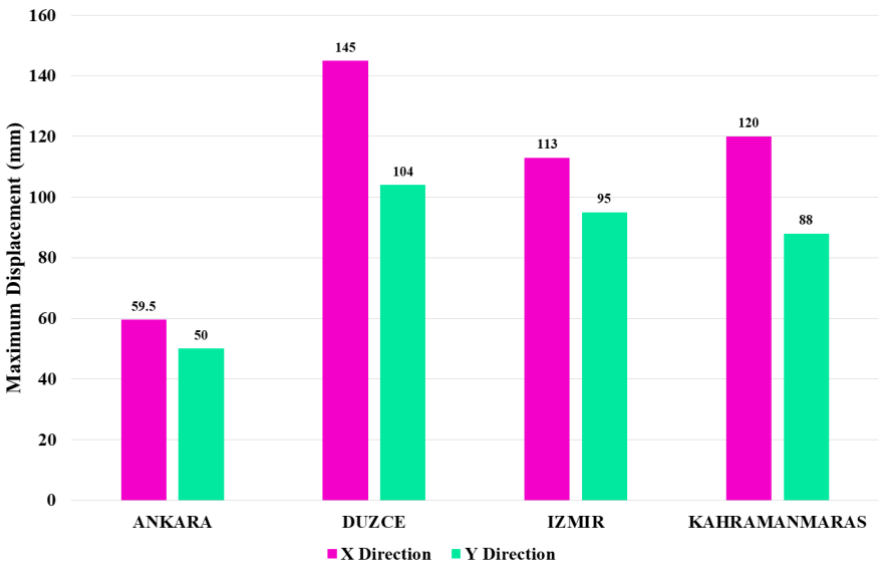


Figure 6.*Maximum Displacement Values*

When Figure 6 is examined, the highest displacement results were obtained in Düzce, where the highest earthquake load was obtained, as expected (145.0 mm). These results are followed by Kahramanmaraş, İzmir and Ankara respectively.

Capacity usage values of some selected columns are given in the Figure 7.

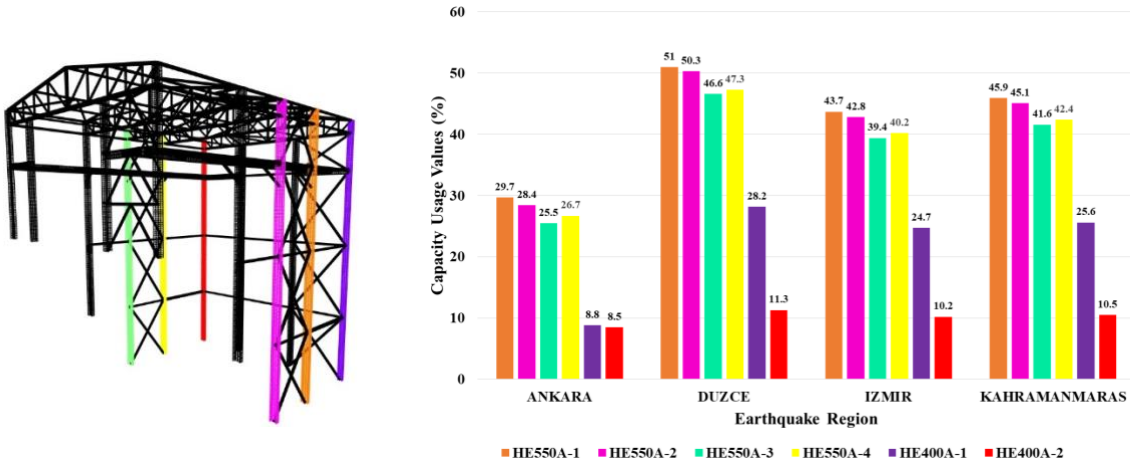


Figure 7.*Capacity usage values of column*

When the capacity usage of selected profiles is examined, it is seen that the profiles of the structure to be built in the Düzce region have higher capacity usage than the profiles in other regions. It is clearly seen that the reason for this situation is due to the earthquake load affecting the structure. As a result of the analysis made according to the data obtained from Düzce, Kahramanmaraş, İzmir and Ankara, it is seen that the profiles withstand the earthquake load without straining their capacities. Some earthquake parameters that affect crusher buildings and increase according to the earthquake region are given in the Figure 8.

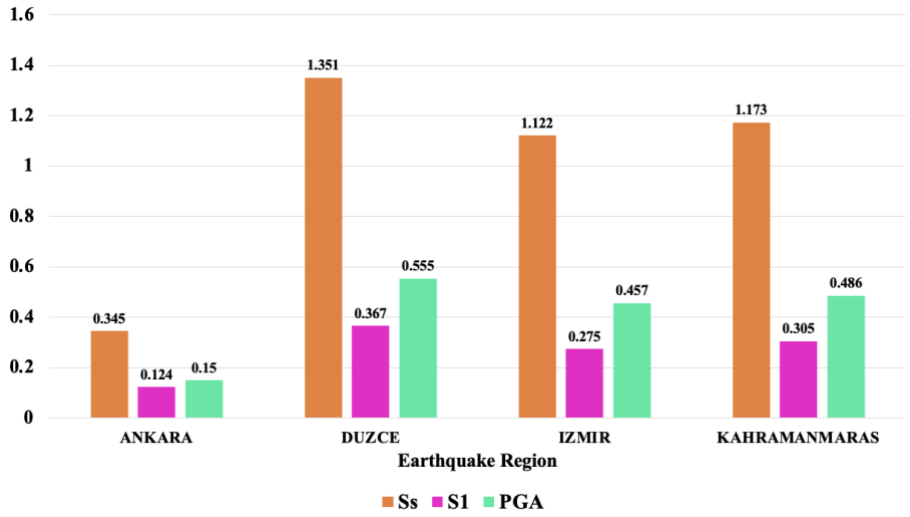


Figure 8.*Change in certain earthquake parameters*

When Figure 7 and Figure 8 are examined together, it is clearly seen that the increases in the capacity usage of the profiles are directly dependent on the earthquake parameters. When looking at earthquake load, maximum displacement and capacity usage, the increase in all results increased due to the increase in S_s, S_1 and PGA values. The highest results were obtained from the Düzce region with maximum S_s, S_1 and PGA values.

IV. CONCLUSION

In this study, where the analysis of the steel crusher building built to protect the crushers used in important industrial structures such as gold mines was made, the equivalent earthquake load acting on the structure, the capacity utilization of selected profiles and the maximum displacements were compared.

As a result of the analysis made according to the data obtained from 4 different cities in Türkiye;

- The period of the crusher building was determined using the mode with the highest mass participation in both directions, and since no changes were made to the structural system, the period values of the structure were obtained the same in all regions. (X Direction 0.533s, Y Direction 0.440s)
- When the equivalent earthquake load values are examined, it is seen that the highest value is obtained in the Düzce region in both directions.
- Maximum displacement results were obtained in Düzce. These results are followed by Kahramanmaraş, İzmir and Ankara respectively.
- As in all results, the highest values of capacity utilization of the selected profiles were obtained from the analysis performed in Düzce.

When all the results are evaluated together, it is seen that the selected crusher building design is suitable for use in 4 different cities (Düzce, Ankara, Kahramanmaraş and İzmir) in Türkiye. Earthquake-resistant design of steel structures, especially those to be used for industrial purposes, is very important in terms of continuing the use of the structure after the earthquake. For this reason, when designing, it is important to choose the appropriate profile and use these profiles without exceeding their capacities. According to these results, it is concluded that the designed crusher building can be used in 4 different earthquake zones.

Article Information

Acknowledgments: The author would like to express their sincere thanks to the editor, the anonymous reviewers, HEMA Proje Danışmanlık Ltd. Şti. and Mehmetcan YÜKSEK for their helpful comments, contribution and suggestions.

Author's Contributions: Writing—original draft, writing—review, analysis and editing, B.A.

Artificial Intelligence Statement: No any Artificial Intelligence tool is used in this paper.

Conflict of Interest Disclosure: No potential conflict of interest was declared by author.

Plagiarism Statement: This article was scanned by the plagiarism program.

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