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EXAMINATION OF THE SEISMIC BEHAVIOR OF THE HISTORICAL YEŞILDERE BRIDGE

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Highlights

- Historical buildings serve as a link between the past and the present. Historical arch bridges, which are common in Turkey, have an important place as cultural heritage. In order to preserve these historical buildings, it is necessary to know their structural behavior
- In this study, the seismic behavior of a historical masonry arch bridge was investigated.
- The finite element model of the historical bridge was created in SAP2000 program
- Modal analysis was performed to obtain the natural periods and mode shapes of this bridge.
- Response spectrum and time history analyzes were performed to examine the seismic behavior of the bridge.
- Acceleration records of the Pazarcık and Elbistan earthquakes that occurred in Turkey on February 6, 2023 were used in time history analyses.
- The values of displacements and stresses obtained as a result of response spectrum and time history analyzes and the regions where they are concentrated were determined and evaluated.

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ABSTRACT: Historical buildings serve as a connection between the present and the past. Historical arch bridges, which are widespread in Turkey, hold significant cultural value. To preserve these structures, it is essential to understand their structural behavior. This study discusses the seismic behavior of historical masonry arch bridges, focusing on the Yeşildere Bridge located in Yeşildere Village on the Ulaş-Kangal-Hekimhan highway route in Sivas province. The historical bridge was modelled using the finite element method (FEM) with SAP2000 software. Modal analysis, response spectrum analysis, and linear time history analysis were conducted on the model using earthquake ground motion levels defined in TBDY 2018. The acceleration records of the Elbistan Earthquake and Pazarcık Earthquake that occurred in Turkey on February 6, 2023 were used for the time history analysis. The results of the modal analysis provided the mode shapes and period values of the bridge. The stress and displacement values on the bridge and the regions where they reached the highest values were determined as a result of the time history and response spectrum analysis.

Keywords: *Arch Bridge, Modal Analysis, Time History Analysis, Response Spectrum Analysis, Masonry*

1. INTRODUCTION

Historic masonry arch bridges are an important aspect of cultural heritage. They are vulnerable to damage or destruction from earthquakes, wind, and traffic loads, particularly in areas with moderate to high seismic activity. Due to their weight and rigidity, they are particularly susceptible to significant earthquake forces. Therefore, it is essential to evaluate their seismic behavior to preserve their structural integrity.

Historical masonry arch bridges typically comprise arches, basic gusset filling, and wall materials. These historical structures are susceptible to damage or destruction from natural disasters, such as earthquakes and floods. Therefore, it is essential to assess the seismic performance of these bridges to ensure their structural integrity [1].

Numerous studies have been conducted in the literature on the dynamic response of masonry arch bridges. Karaton et al. [1] modeled the Malabadi Bridge using FEM in the ANSYS [2] computer software to examine the bridge's behavior under synthetic acceleration records produced for different earthquake levels. The researchers concluded that the bridge is at risk of collapsing during an earthquake with a probability of 2% over the next 50 years. Therefore, it is recommended that the bridge be reinforced to withstand seismic activity.

Brencich and Sabia [3] analysed the Tanaro Bridge, a masonry arch bridge. They conducted tests to obtain the bridge's mode shapes and natural periods, and used this data to construct an FEM model of the bridge. The model was analysed at different stages of the bridge's service life and demolition.

Özmen and Sayın [4] analysed the Dutpınar Bridge, a historical masonry arch bridge, using acceleration records from the Bingöl earthquake that occurred in 2003. The bridge was modelled using FEM, and the authors obtained the largest and smallest shear stresses and shape changes as a result of their analysis.

Özmen and Sayın [5] conducted a study to compare the influence of far and near fault lines on the seismic response of a masonry arch bridge. They analyzed the arch bridge, which they modeled with FEM,

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using the acceleration records of different earthquakes. The study concluded that earthquakes occurring on distant fault lines are equally significant as those occurring on close fault lines.

Yılmaz et al. [6] examined the Murat Bey Bridge, a single-span historical masonry bridge. They created a three-dimensional FEM model of the bridge using the SAP2000 [7] program and analyzed it statically, modally, and through time history. The bridge was analyzed under different earthquake acceleration records. The study evaluated the stress and displacement values obtained.

In their study, Nemutlu et al. [8] examined the earthquake behavior of a historical masonry bridge. They performed a nonlinear analysis of the bridge using five different ground motion recordings. The analysis revealed that tensile cracks occurred in both the middle and heel area of the arch.

Gönen and Soyöz [9] analysed the seismic response of a masonry arch bridge using three different methods and compared them.

Altunışık et al. [10] analyzed the effect of arch thickness on the structural response of a historical masonry arch bridge under dead and moving loads. Their study revealed a correlation between arch thickness and structural behavior.

In their study, Güllü [11] analysed the dynamic behaviour of the Cendere bridge, a masonry arch bridge, using modal analysis and linear time history analysis. Time history analyses were performed using acceleration records from various earthquakes, while modal analysis was used to obtain the period values of the bridge. The study identified regions with the highest tensile stresses.

Sakcalı et al. [12] examined the Irgandı Bridge in Bursa using a FEM model. The bridge is a masonry arch bridge, and modal and linear analysis were performed under different earthquake acceleration records. The study found that the upper part of the arch bridge experienced the greatest displacements, while the support area experienced the largest shear stresses.

In their study, Milana and Lourenço [13] created models of two masonry arch bridges in 3D and analysed their non-linear behaviour.

Kumbasaroglu et al. [14] conducted a study to evaluate the seismic performance of a masonry arch bridge. The bridge was modeled using FEM and analyzed under its own weight and acceleration records of past earthquakes. The stress and displacement values obtained from the analysis were evaluated.

Harapin et al. [15] conducted a dynamic and static analysis of a masonry arch bridge. The study investigated the effects of vertical load, seismic activity, and temperature changes. The authors found that the deformation and crack regions obtained from the computer model were consistent with the real model.

Karalar and Yeşil [16] investigated the impact of arch altitude on the dynamic and static behavior of single-span masonry arch bridges. The study examined a bridge in Karabük under far and near fault ground motions. The results showed that the arch height of the bridge increased while the maximum movements decreased as a result of the far fault and near fault ground motions.

Özodabaş and Artan [17] examined the Muş Murat Bridge, which is a masonry arch bridge. They analyzed the bridge under traffic, flood and earthquake loads. To investigate the bridge's dynamic behaviour, modal and earthquake analyses were conducted in the frequency domain. The modal analysis yielded the bridge's period and mode shapes, while the earthquake load analysis evaluated the displacements and stresses experienced by the bridge.

Akin et al. [18] analysed the dynamic behaviour of the historic Tağar Bridge, a masonry bridge, using different damping rates. The bridge was modelled with FEM in the SAP 2000 software and its behaviour was analysed with earthquake acceleration records. The study evaluated the stresses and displacements obtained.

Laterza et al. [19] conducted a study on the seismic performance of an existing historical arch bridge. They created a finite element model of the multi-span bridge and performed a pushover analysis. The analysis showed that the bridge provided the displacement values required by the capacity spectrum method.

Oztürk et al. [20] modelled the historical Sultan Hamit I-II and III bridges in Erzurum using the SAP2000 program. They conducted static, modal, and dynamic analyses on the models, considering only their own weights. For dynamic analysis, they utilised the acceleration records of the 1992 Erzincan

Earthquake and the 2020 Elazig Earthquake. The results of the analysis showed that the maximum displacement occurred during the 1992 Erzincan Earthquake.

Saydan et al. [21] conducted a study on the behaviour of Mısırlıoğlu Bridge, a historical masonry arch bridge in Konya, under the effects of freezing and thawing. The mechanical properties of the building materials that make up the bridge were determined through experimental studies. Subsequently, a finite element model of the bridge was created using the ANSYS program. Modal analysis was conducted to investigate the impact of freeze-thaw cycles on the period and mode shapes of the bridge. The results showed an increase in the period values after the rotation-dissolution event.

This paper examines the seismic behavior of historical masonry arch bridges by discussing the Yeşildere Bridge. The bridge was modeled in the SAP2000 program and four different EGML defined in the Turkish Building Earthquake Code 2018 (TBDY 2018)[22] were applied. Response spectrum analysis was performed, and modal analysis was carried out to determine the mode shapes and period values of the historical bridge. To investigate the seismic behaviour of the historical masonry arch bridge, we conducted a linear time history analysis on the bridge model using the acceleration records of the Elbistan and Pazarcık earthquakes that occurred in Kahramanamaraş on February 6, 2023. The analysis yielded results for the structure's period, mode deformations, maximum stress and displacement values in both the x and y directions for each level of earthquake ground motion. Additionally, stress and displacement values obtained from the time history analysis were also obtained.

2. MATERIAL AND METHODS

This section discusses the historical Yeşildere Bridge, located within the borders of Yeşildere Village on the Ulaş-Kangal-Hekimhan highway route in Sivas province. The bridge is introduced and its modeling is explained. Additionally, information is provided about EGML and earthquake acceleration records to be used for dynamic analysis.

2.1. Yeşildere Bridge and its modeling in SAP2000 program

The Yeşildere Bridge, which will be analysed, is 26 metres long and 3 metres wide. It features an arch pier in the middle, fixed with inlays on the sides. The bridge has two wide arches with a span of 7 metres. The distance from the keystone to the ground is 3.5 metres. Please refer to Figure 1 for the location and appearance of the bridge.

Figure 1. Location and appearance of Yeşildere Bridge

Figure 2 presents the geometric characteristics of the building, which were determined through interviews and measurements conducted with the 16th Regional Directorate of Highways [23] to assess the bridge's earthquake performance.

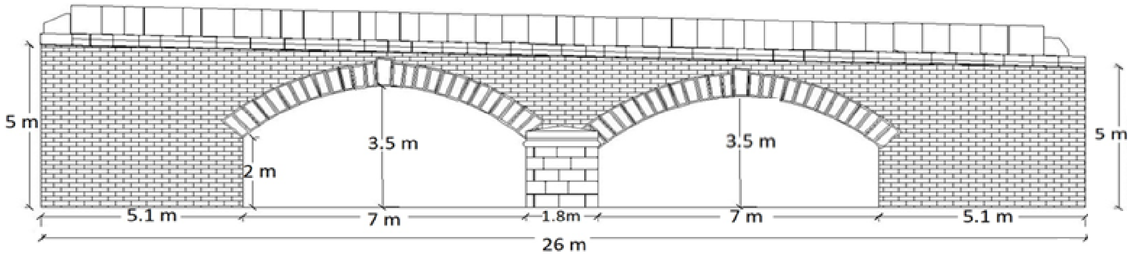


Figure 2. Geometric features of Yeşildere Bridge

Three separate methods are commonly used for numerical modeling of masonry structures: simplified micro-modeling, detailed micro-modeling, and macro-modeling. The choice of method depends on the size and accuracy level of the structural system [24]. In detailed micro-modeling, the material properties of the masonry units and the mortar are evaluated separately. Simplified micro-modeling expands the masonry units by half of the mortar layer, neglecting the mortar and separating the units from each other by interface lines. On the other hand, macro modeling considers masonry as a composite material without distinguishing between the unit and mortar. The macro modeling method is commonly used to examine large building systems due to its significantly shorter solution time. This method neglects the relationship between the mortar and the masonry unit. The material is considered a composite [25]. Figure 3 demonstrates the modeling methods used. This study employed the macro modeling method.

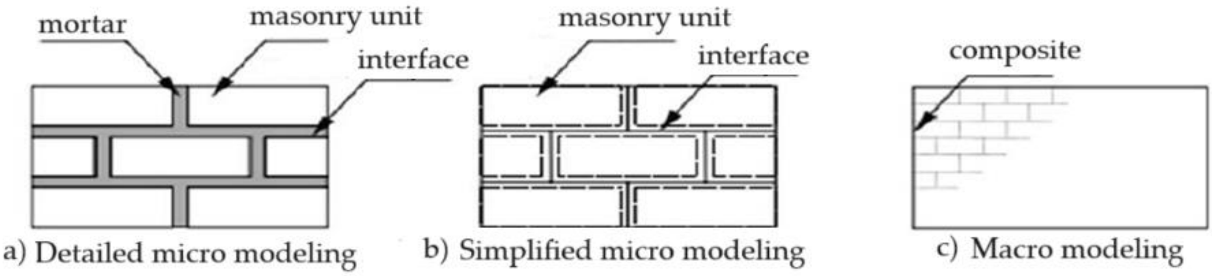


Figure 3. Modeling methods for masonry structures [24]

The Yeşildere Bridge was modelled using solid elements in the SAP2000 computer program. Response spectrum analysis, modal analysis, and linear time history analysis were conducted. Solid elements are eight-node objects used to model three-dimensional structural systems. In the solid element, S11 indicates the stress in the x direction, while S22 defines the stress in the y direction [7]. Figure 4 shows the axes, stresses, and solid element defined in the solid element.

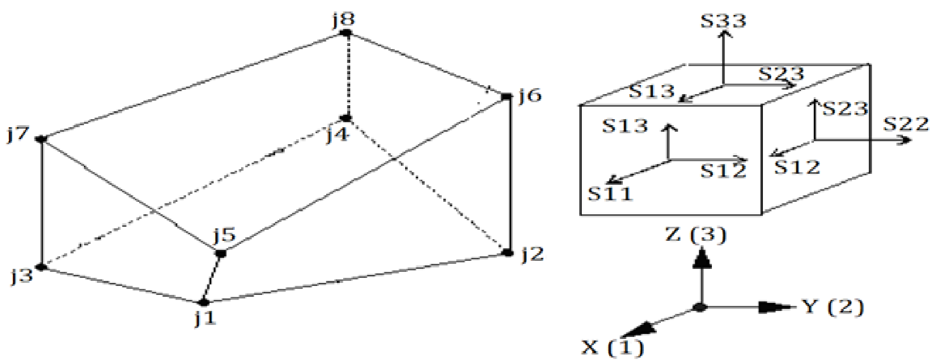


Figure 4. Solid member and stresses in solid member [7]

The Yeşildere Bridge comprises a load-bearing arch, filling material, and spandrel walls. Material properties are crucial in analysing structural behaviour. The properties of the materials used in this study were obtained from similar studies in the literature and are listed in Table 1. Figure 5 displays the SAP2000 model of the Yeşildere Bridge.

Table 1. Characteristics of the materials used in the bridge [26, 27]

Material	Modulus of elasticity (MPa)	Poisson's ratio	Compressive strength (MPa)	Tensile Strength (MPa)
Stone arch	3000	0.2	5	0.5
Spandrel wall	2500	0.2	5	0.5
Filling	1500	0.05	1	0.05

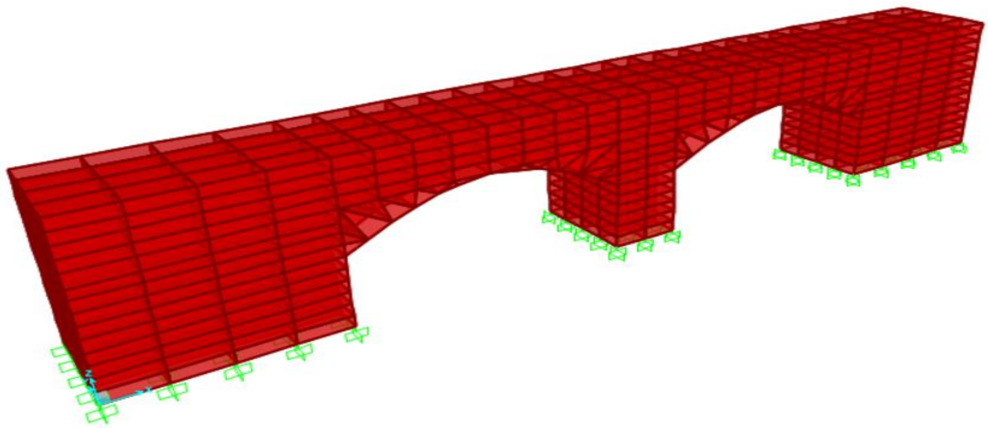


Figure 5. SAP2000 modeling of Yeşildere Bridge

2.2. Response spectrum analysis

The seismic response of the bridge was analysed using response spectrum analysis in both the x and y directions. Four earthquake ground motion levels, as defined in TBDY 2018, were used for this purpose. Table 2 displays the parameters associated with the earthquake ground motion levels used in the response spectrum analysis.

Table 2. Earthquake ground motions given in TBDY 2018 [22]

Earthquake ground motion level	Probability of exceedance in 50 years	Recurrence period (year)	Frequency
DD1	%2	2475	very rare
DD2	%10	475	rare
DD3	%50	72	often
DD4	%68	43	very often

Earthquake data for four levels of ground motion, as shown in Table 2, were obtained from the Turkey Earthquake Hazard Map (TEHM) using an interactive web application, using the effective ground motion level (EGML), building location and local soil class as key parameters. These data are presented in Table 3, which shows the local soil class ZC for each EGML, with the specified building location at 38.901445° latitude and 37.508398° longitude. The local ground class ZC, according to the TBDY 2018 standards, comprises of conditions such as very tight sand, hard clay layers, gravel, or decomposed and highly fractured weak rocks. Additionally, SS is defined as the dimensionless short-period map spectral acceleration coefficient, and S1 as the dimensionless map spectral acceleration coefficient for a period of 1.0 second [22, 28].

Table 3. Data obtained from TEHM

Earthquake ground motion level	Local soil class	Ss	S1
DD1	ZC	0.721	0.232
DD2	ZC	0.341	0.131
DD3	ZC	0.128	0.056
DD4	ZC	0.094	0.040

2.3. Time History analysis

The process of examining the structure's response to dynamic loads on a second-by-second basis is known as time history analysis. For this study, a finite element model was created in the SAP2000 computer program and subjected to linear time history analysis. The analysis employed acceleration records from two major earthquakes that occurred in Kahramanmaraş on February 6, 2023. Analysis was only conducted for the DD2 level as it was given as the standard design earthquake ground motion in TBDY 2018.

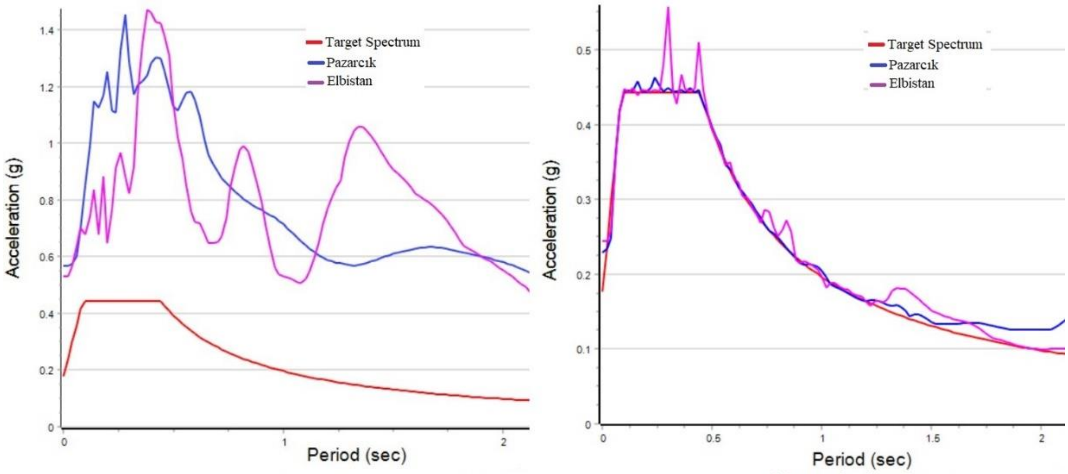
The earthquake behavior of the bridge in Kahramanmaraş during two major earthquakes on February 6, 2023 was investigated using acceleration records obtained from the Turkish Acceleration Database and Archive System (TADAS) [29]. Table 4 provides information on the earthquakes used.

Table 4. Earthquakes used in the analysis

Earthquake	Station	M_W
6 February 2023 Pazarcik	Pazarcık	7.7
6 February 2023 Elbistan	Nurhak	7.6

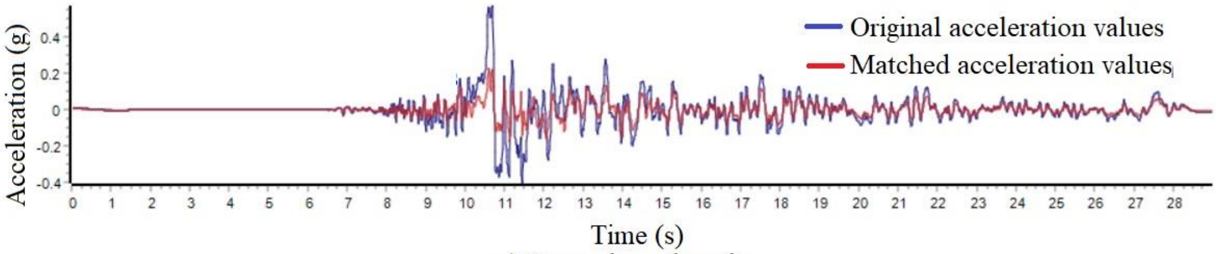
To determine the earthquake behaviour of the modelled historical bridge, we obtained the earthquake parameters for the region where the Yeşildere Bridge is located from the TEHM interactive web application through AFAD (Disaster and Emergency Management Presidency) according to TBDY 2018. The earthquake parameters found for earthquake ground motion level 2 (DD2) are presented in Table 3.

The seismicity of the area where the bridge is located was matched with the acceleration time graphs of the earthquakes given in Table 4 using the Seismomatch [30] program. Figure 6 shows the original and paired states of the horizontal elastic design spectra, while Figure 7 shows the original and paired acceleration time graphs of the earthquakes. For all earthquake loadings, the east component was used.

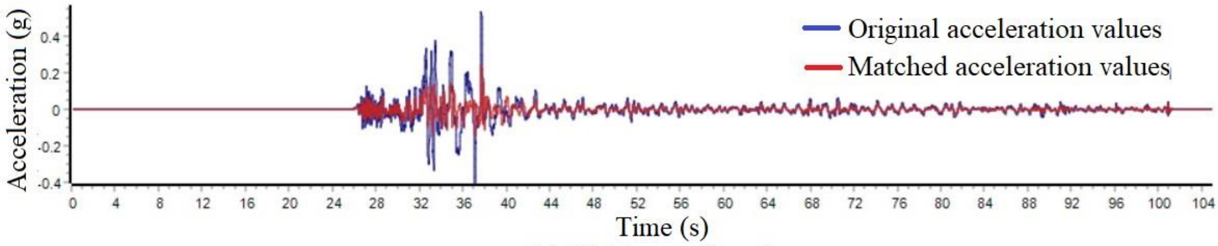


a) Original spectrums b) Matched spectrums

Figure 6. Spectrum of original and matched horizontal elastic design [30]



a) Pazarcık earthquake



b) Elbistan earthquake

Figure 7. Original and matched acceleration time graphs of earthquakes [30]

2.4. Wall characteristic shear strength

The characteristic shear strength of masonry walls can be calculated with the help of Equation (1) as specified in TBDY-2018 [22].

$$f_{vk} = f_{vko} + 0.4\,\sigma \leq 0.10\,f_b \quad (1)$$

In this equation;
f_{vk}: Characteristic shear strength of masonry wall,
σ: Earthquake loads multiplied by load coefficients and vertical compressive stress calculated under the influence of vertical loads,
f_b: It is the average compressive strength of the masonry unit.

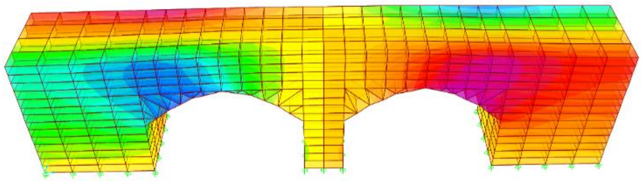
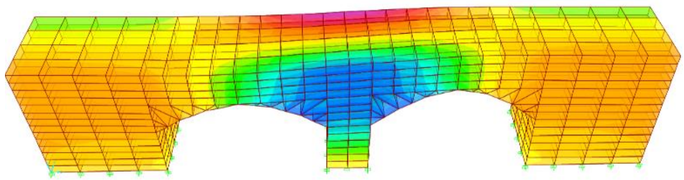
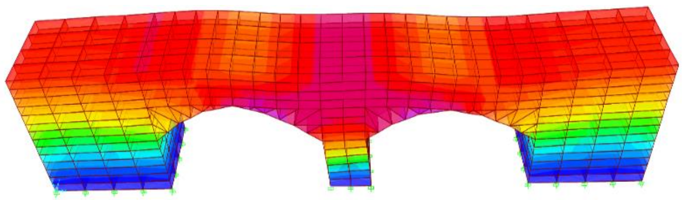
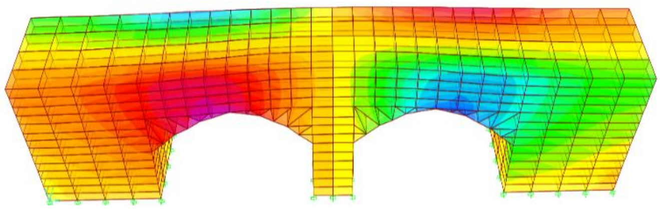
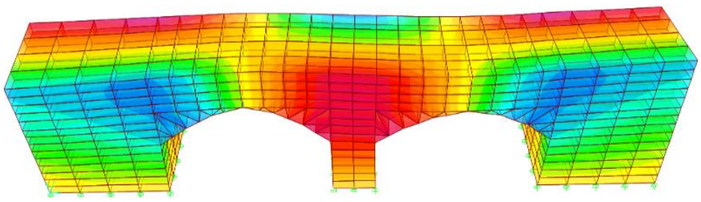
3. RESULTS AND DISCUSSION

The Yeşildere Bridge's FEM model, which was constructed using masonry, was simulated using the SAP2000 program. Modal analysis, response spectrum analysis, and linear time history analysis were conducted in accordance with TBDY 2018.

3.1. Modal Analysis

Mode shapes play a crucial role in understanding the overall behaviour of stone arch bridges. Table 5 presents the first 5 mode shapes obtained from the modal analysis. The first mode has a period of 0.03214 seconds.

Table 5. The first 5 mode shapes of the model

Mode	Mode shape	Period (s)	Frequency (Hz)
1		0.03214	31.110
2		0.02431	41.141
3		0.01853	53.959
4		0.01851	54.032
5		0.01562	64.007

As per TBDY 2018, the effective masses should constitute at least 95% of the total mass of the structure. The analysis of Yeşildere Bridge modeling resulted in obtaining 100 mode shapes and free vibration periods. Table 6 presents the first, third, sixty-third, and sixty-sixth modes out of the 100 obtained. The mass participation ratio of the 3rd mode, which represents the lateral displacement motion of the main mass in the x direction of the bridge, is approximately 70%. The mass participation rate of the first mode, which corresponds to the lateral displacement in the Y direction, was approximately 54%.

Table 6. Mass participation ratios and period values of some modes

Mode	Period (s)	Mass participation ratio	
		X direction	Y direction
1	0.032	0.000	0.537
3	0.019	0.698	0.537
63	0.003	0.94	0.95
66	0.003	0.95	0.95

The effective mass ratios obtained from the modal analysis are provided as a percentage of the total building mass. The structure model has achieved 95% in the sixty-sixth mode for the x direction and 95% in the sixty-third mode for the y direction.

3.2. Response Spectrum Analysis

The TEHM data was inputted into the SAP2000 program and response spectrum analysis was conducted in both the x and y directions. The analysis yielded stress and displacement values for each EGML applied to the bridge model in both directions.

Figure 8 displays the highest displacement values for EGMLs DD1, DD2, DD3, and DD4 in both the x and y directions. Figure 9 shows the locations with the greatest displacements in the x and y directions resulting from earthquake ground motions.

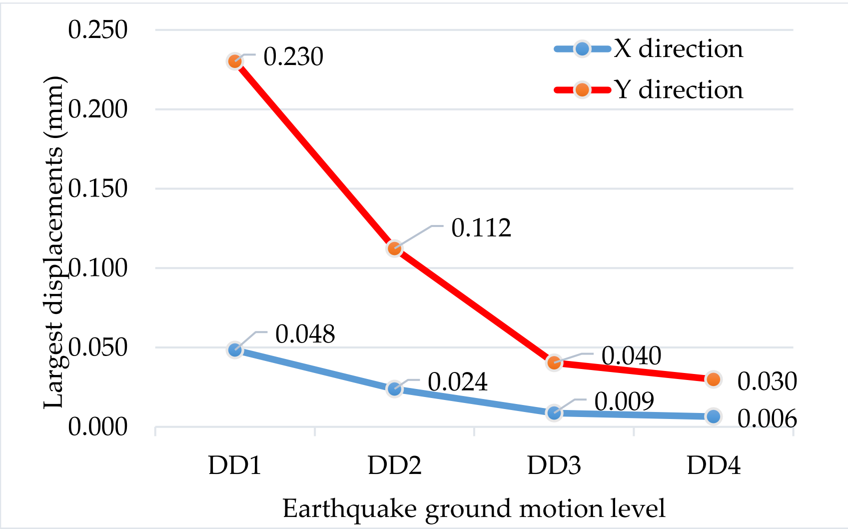


Figure 8. Maximum displacements obtained for earthquake ground motion levels

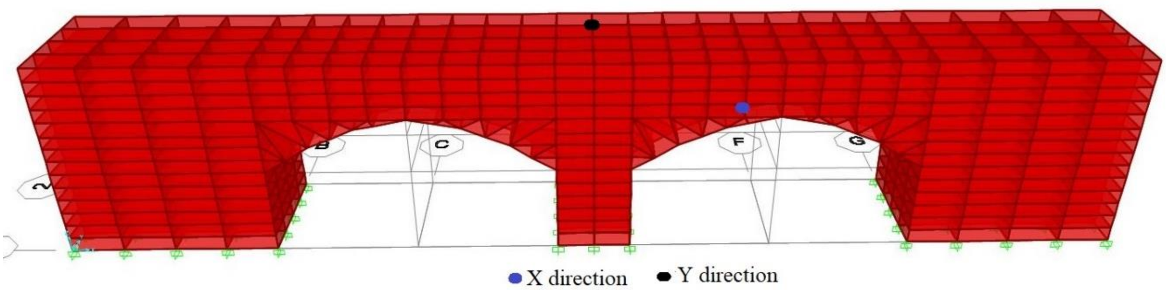


Figure 9. The points where the greatest displacements occur

Figure 8 shows that the largest displacements for all EGML were greater in the y direction than in the x direction.

Figure 10 displays the largest normal stresses obtained in both the y and x directions for the DD1, DD2, DD3, and DD4 EGML. Figure 11 shows the largest shear stresses obtained for the same EGMLs.

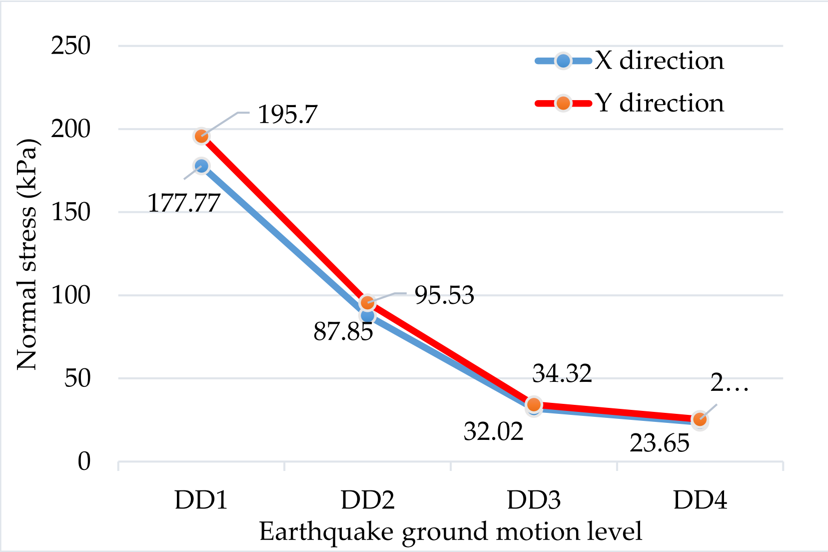


Figure 10. Maximum normal stresses obtained for EGML

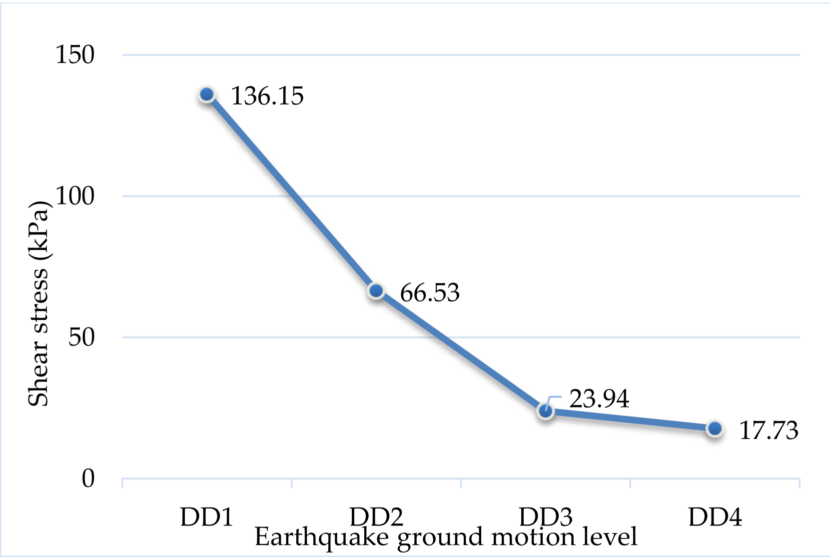
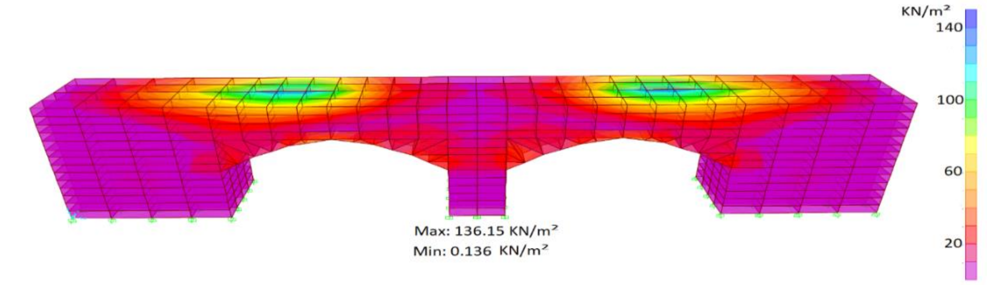
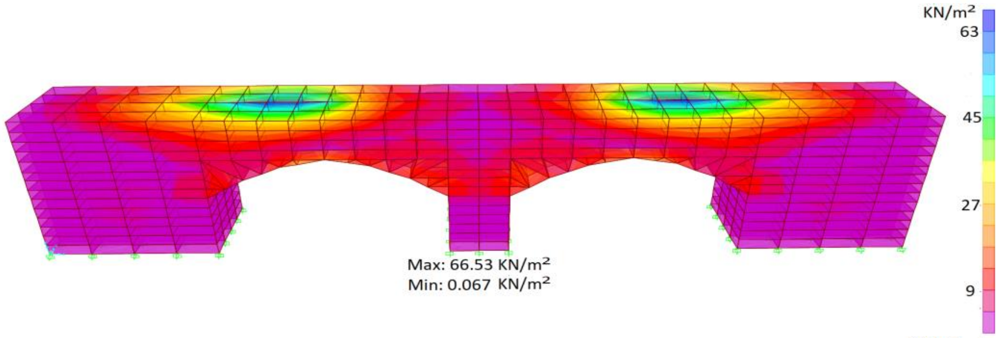
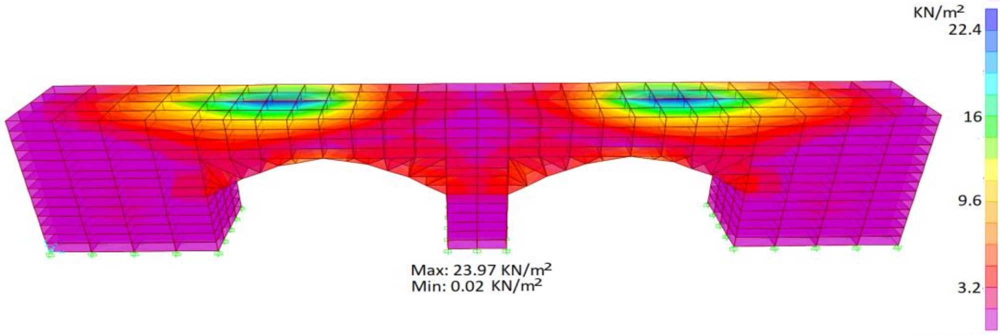
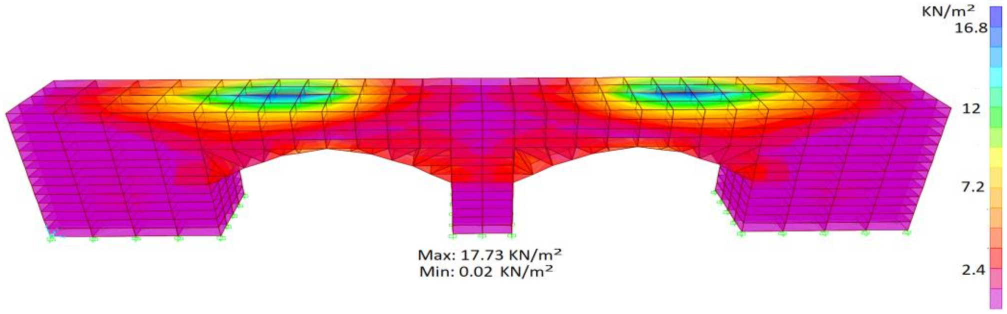


Figure 11. Maximum shear stresses obtained for EGML

Upon examining Figure 10 and Figure 11, it can be observed that normal and shear stresses decrease non-linearly from DD1 to DD4, in accordance with the decreasing values of parameters Ss and S1 as shown in Table 3. Similarly, the analysis of Figure 8 reveals that this trend also applies to displacements.

Table 7 displays the shear stresses obtained from the FEM model analysis conducted in the SAP2000 computer program for EGML.

Table 7. Shear stresses obtained for EGML

<table>
<tr><th>Definition</th><th>Shear stresses resulting from response spectrum analysis</th></tr>
<tr><td>DD1</td><td>
</td></tr>
<tr><td>DD2</td><td>
</td></tr>
<tr><td>DD3</td><td>
</td></tr>
<tr><td>DD4</td><td>
</td></tr>
</table>

Equation (1) is used to calculate the characteristic shear strength of the wall. The equation provides a value of 100 kPa for the characteristic initial shear strength (fvko) of natural or artificial stones in TBDY 2018. The static analysis determined that the wall is subjected to a vertical load of 6159.663 kN, resulting in a vertical compressive stress of 171 kPa. Using Equation (1), the characteristic shear strength fvk is calculated as 168 kPa. Upon examining Figure 11, it can be seen that the maximum shear stress caused by earthquake ground movements in the bridge is 136.15 kPa. This result indicates that the bridge is safe in terms of shear stress.

3.3. Time History Analysis

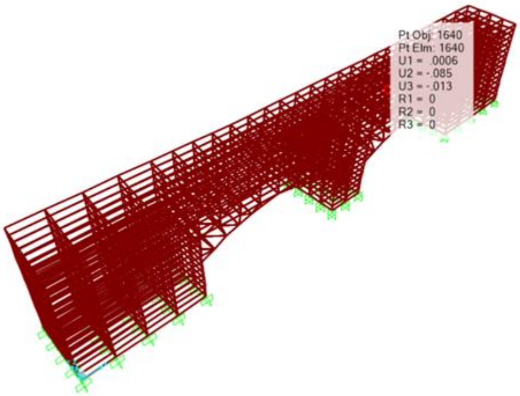
The arch bridge underwent modal analysis, which revealed that the 1st mode shape occurred in the y direction. Additionally, response spectrum analysis indicated larger stresses and displacements in the same direction. Therefore, time history analysis was conducted solely in the y direction (stream flow direction). The historical bridge underwent time history analyses, which yielded the largest relative displacement and stress results for the Pazarcık and Elbistan earthquakes.

3.4. Largest relative displacement results

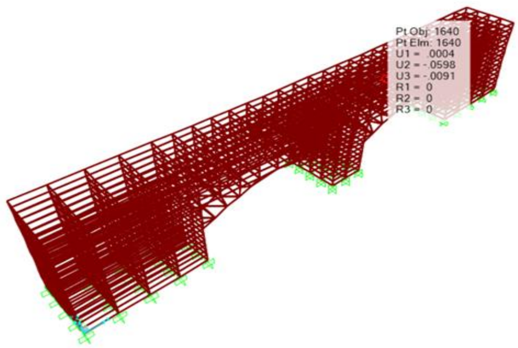
Table 8 shows the largest relative displacement results obtained from the linear time history analysis. The largest relative displacement for the Pazarcik and Elbistan Earthquakes occurred in the y direction at 10.6 and 37.7 seconds, respectively. The largest relative displacement was 0.085 mm in the Pazarcık Earthquake, while approximately 0.06 mm was obtained in the Elbistan Earthquake. Upon comparing the displacement results obtained from time history and response spectrum analysis, it was observed that the displacements obtained from time history were similar to those obtained from DD2 and DD3 earthquake ground motion levels. Table 8 shows that the largest relative displacements for both earthquake loadings occurred at the same point. In both earthquake loadings, the displacements increased from the ground to the top of the bridge and reached their maximum value at the top of the bridge.

Figure 12 shows the displacement time graphs resulting from the time history analysis for both earthquake loadings. The point with the highest displacements was selected, and the changes in displacement over time were examined.

Table 8. The largest displacements that occur as a consequence of the time history analysis (mm)



a) Pazarcık Earthquake (10.6 s)



b) Elbistan Earthquake (37.7 s)

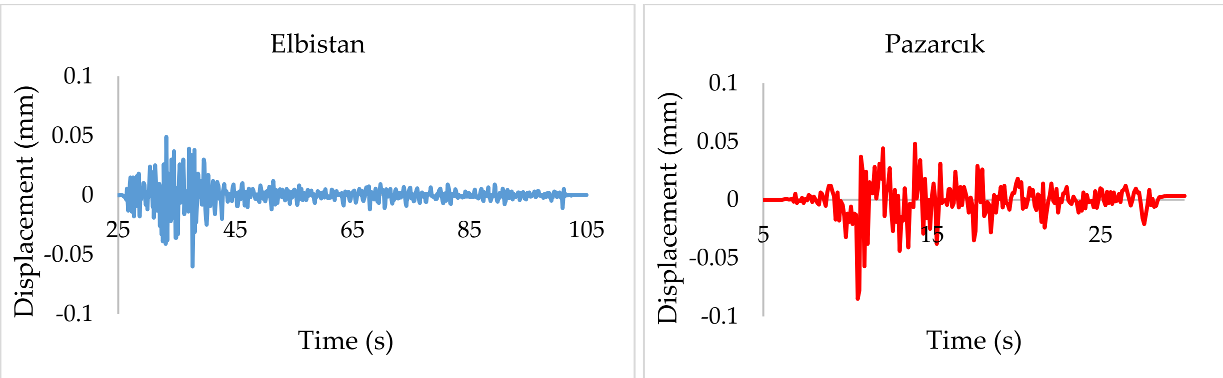
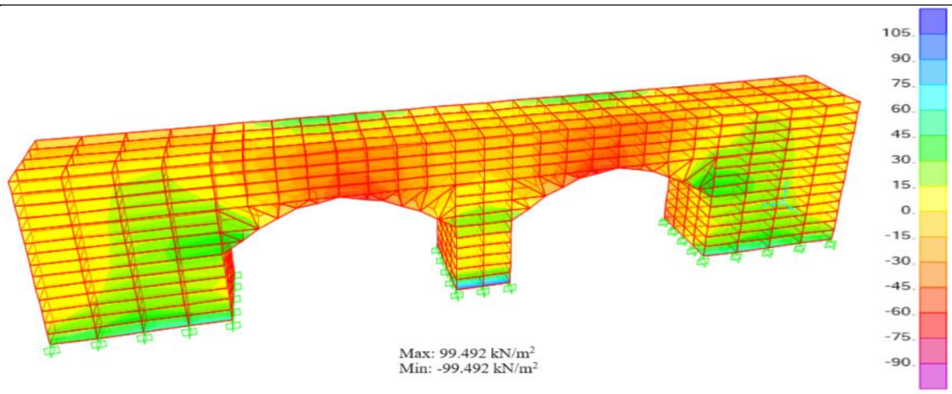
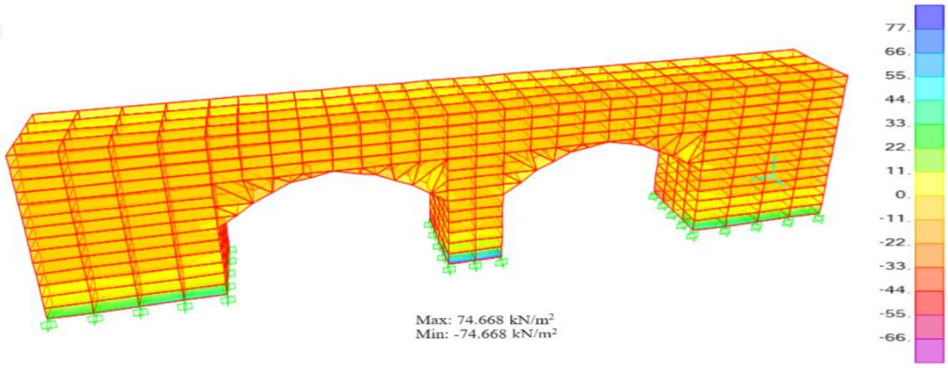
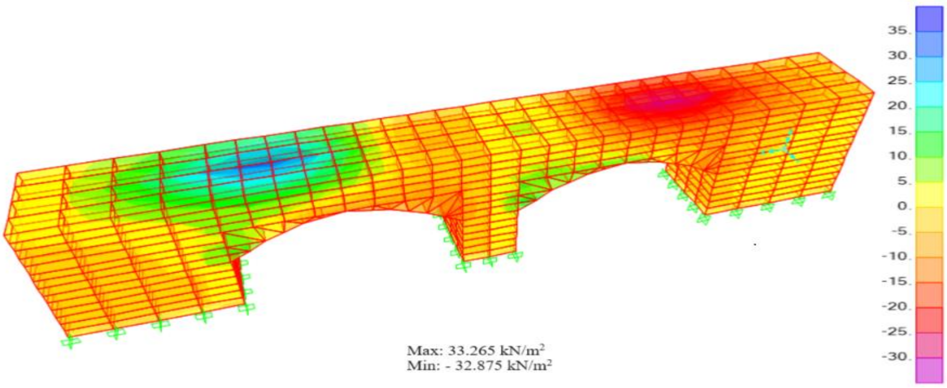


Figure 12. Time – displacement diagrams

3.5. Stress results

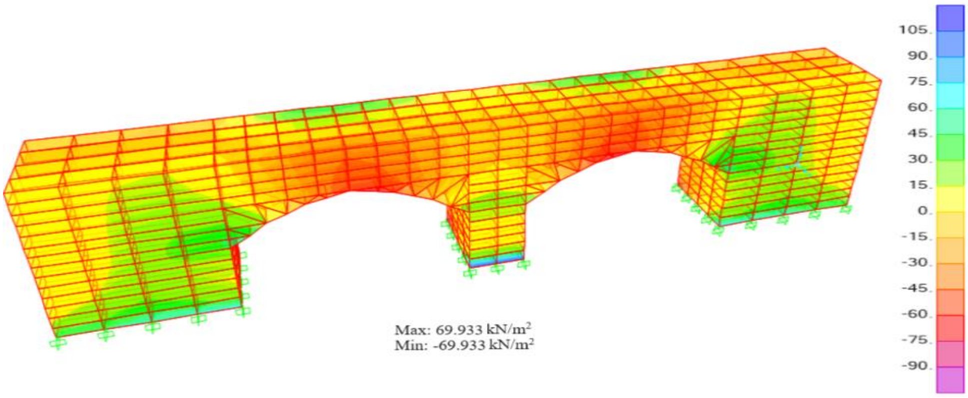
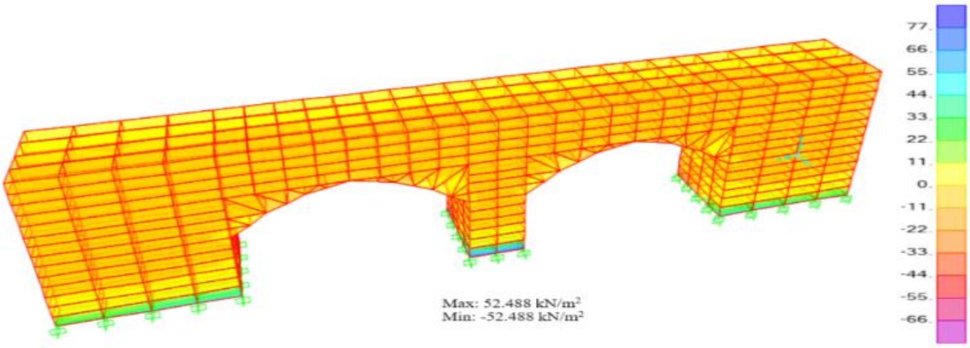
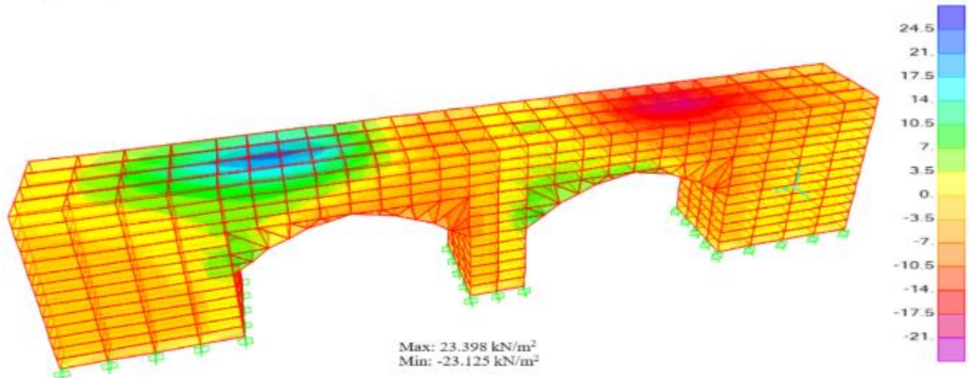
As per the SAP2000 program format, compressive or tensile stresses resulting from time history analysis are denoted as S11 or S22, while shear stresses are denoted as S12. Table 9 presents the stress graphs obtained at the moment of maximum displacement for both earthquake loadings (10.6 s for Pazarcık Earthquake and 37.7 s for Elbistan Earthquake) on the Historical Yeşildere Bridge.

Table 9. Stresses as a result of seismic analysis

Stress	**Stresses as a result of seismic analysis**
S11	
S22	
S12	

Pazarcık Earthquake

Table 9. Stresses as a result of seismic analysis (continued)

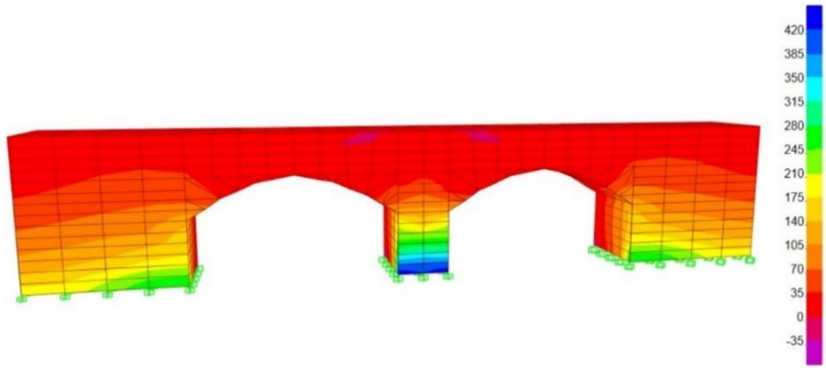
Stress	**Stresses as a result of seismic analysis**
S11	
S22	
S12	
	Elbistan Earthquake

Upon examining Table 9, it was observed that both earthquake loadings resulted in the accumulation of tensile/compressive stresses and shear stress in the same regions of the model. Tensile/compressive stress build-ups were observed at the heel parts of the bridge model for S11 and S22, while S12 shear stress accumulations were observed at the middle upper parts of the model.

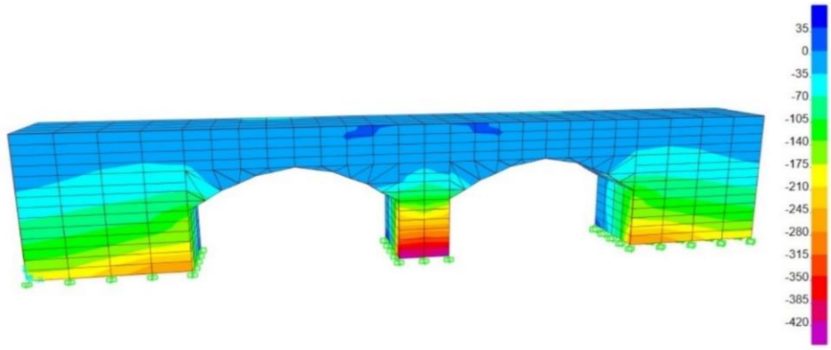
The results of the time history analysis show that the tensile/compressive stresses in the model were higher during the Pazarcık Earthquake compared to the Elbistan Earthquake. Specifically, the absolute values of S11 and S22 stresses were approximately 42.3% larger in the Pazarcık Earthquake. Similarly, the S12 shear stress was 42.2% greater in the Pazarcık Earthquake than in the Elbistan Earthquake.

Upon examination of the effects of earthquakes on the bridge, it was discovered that shear stresses concentrate in the upper middle regions of the structure, which could result in shear damage in those areas. Additionally, normal stresses under seismic loads indicate that compressive damage may occur in the upper part of the arch, while tensile damage could occur in the areas where the structure is supported on the ground. Figure 13 displays the contours of the minimum and maximum principal stresses resulting from the time history analysis.

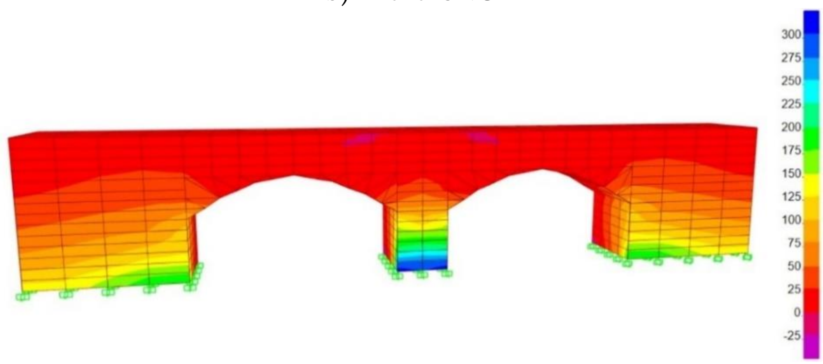
[5, 12, 25, 31].



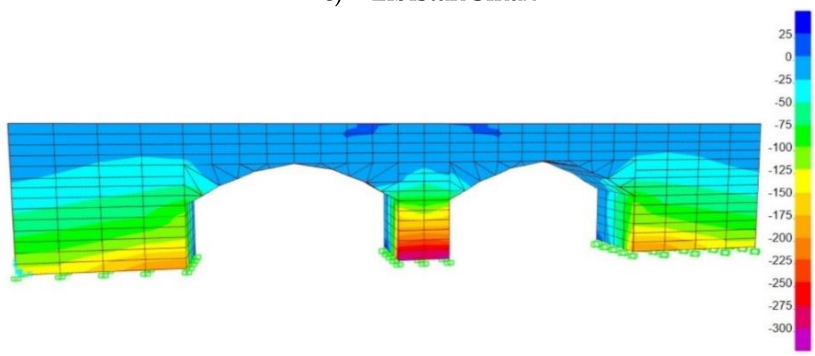
a) Pazarcık Smax



b) Pazarcık Smin



c) Elbistan Smax



d) Elbistan Smin

Figure 13. Maximum and minimum principal stresses (kPa)

Figure 13 shows that in both models, the minimum and maximum principal stresses reached their highest values in the support regions. This is consistent with previous studies on masonry arch bridges [5, 12, 25, 31].

Figure 14 displays the time-dependent graphs of the maximum and minimum principal stresses. This section discusses the time periods with the highest earthquake accelerations. Figures 13 and 14 show that the Pazarcık earthquake resulted in higher minimum and maximum principal stresses compared to the Elbistan earthquake.

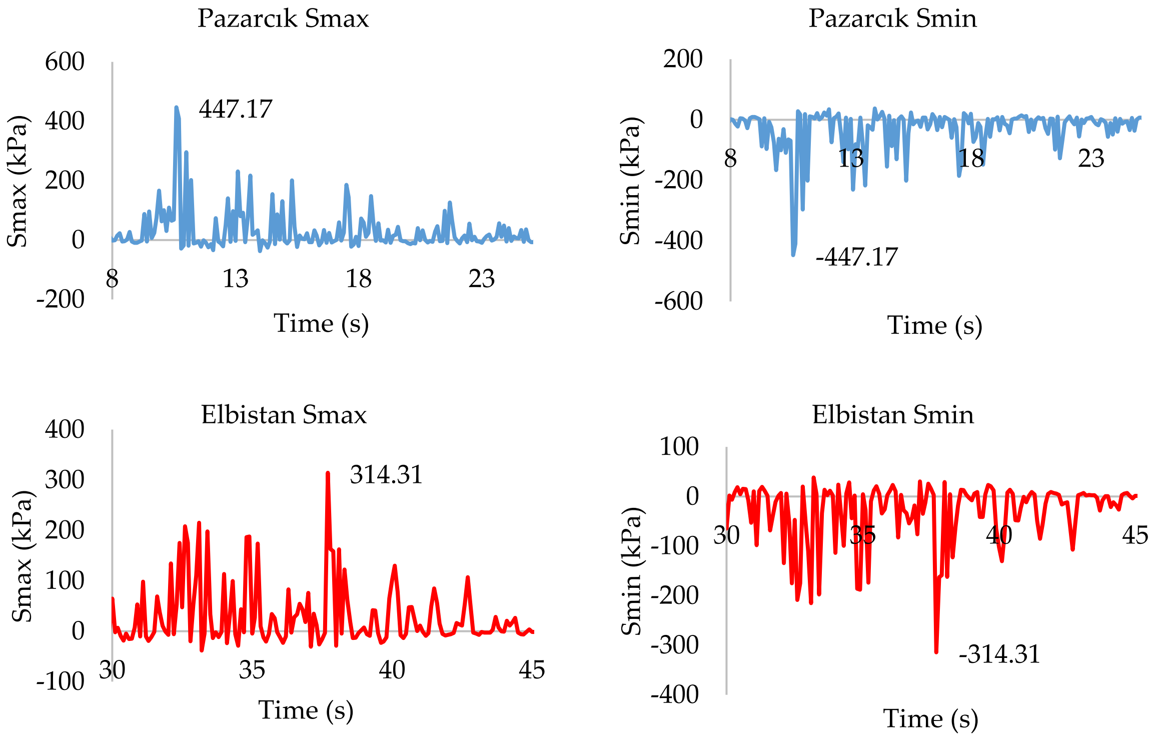


Figure 14. Time-dependent representation of minimum and maximum principal stresses

4. CONCLUSIONS

This study examines the seismic behavior of historical masonry arch bridges by discussing Yeşildere Bridge. To achieve this, the bridge was modelled using solid elements in the SAP2000 computer program. Modal analysis and response spectrum analysis were performed on the historical bridge using 4 different EGML, DD1, DD2, DD3, and DD4 defined in TDBY 2018. To examine the seismic performance of the building, linear time history analysis was conducted using the acceleration records of the Pazarcık Earthquake and the Elbistan Earthquake that occurred on February 6, 2023.

The findings of modal analysis, response spectrum analysis, and linear time history analysis of the FEM model were used to summarize the results obtained for the Historical Yeşildere Bridge.

- The modal analysis resulted in a period of 0.03214 seconds for the structure's first mode.
- The mass participation ratio of the third mode, which represents the lateral displacement of the main mass in the x direction of the bridge, is approximately 70%. The mass participation ratio of the first mode, which represents the lateral displacement movement in the y direction, is approximately 54%.
- The effective mass ratios of the building reached 95% in mode 66 for the x direction and 95% in the 63rd mode for the y direction.
- The response spectrum analysis showed that the largest displacement for the four EGML was in the y direction.
- There was a non-linear decrease in normal and shear stresses as we progressed from DD1 to DD4 to the ground motion level.
- The arch bridge's wall shear strength was found to be greater than the largest shear stress caused

by earthquake ground movements, indicating that it is safe in terms of shear stresses. As a consequence of the linear time history analysis, the largest relative displacement value was obtained from the Pazarcık earthquake. The largest relative displacement value obtained from the Pazarcik earthquake is approximately 41.67% larger than the Elbistan earthquake.

- As a result of the time history analysis, the heel parts of the bridge model experienced accumulations of tensile/compressive stress in S11 and S22, while the middle upper parts of the model experienced accumulations of shear stress in S12.
- The absolute values of the tensile/compressive stresses S11 and S22 in the Pazarcık Earthquake were approximately 42.3% higher than those in the Elbistan Earthquake.
- When examining the shear stresses obtained, it was found that the S12 stress obtained in the Pazarcık Earthquake was 42.2% higher than that in the Elbistan Earthquake.
- The time history analysis revealed that the minimum and maximum principal stresses in both earthquake loadings reached their highest values in the region where the middle bridge pier is supported on the ground. Therefore, it is recommended to strengthen the bridge piers in this region.

To enhance the study's outcomes, nonlinear methods can be used to analyze the bridge.

Historically constructed masonry structures are crucial for maintaining cultural continuity. These structures are susceptible to damage from natural disasters, such as earthquakes and floods. Therefore, preserving these structures is vital to pass them on to future generations. The study evaluated the historical Yeşildere Bridge from a seismic perspective to better understand its seismic behavior. The sentences are grammatically correct and free from errors. No changes in content were made. The study evaluated the historical Yeşildere Bridge from a seismic perspective to better understand its seismic behavior. The text adheres to conventional structure, clear and objective language, formal register, and precise word choice.

Declaration of Ethical Standards

The autohors declare that all ethical guidelines including citation, authorship, publishing original research and data reporting are followed.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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