



Research Article

Examining the effects of different seismic base isolators on the seismic behavior of a real-size steel truss structure

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ABSTRACT

In this study, the seismic behavior of a real-size steel truss structure is examined for elastomeric isolator, double friction pendulum isolator, and fixed support conditions. Hence, the main aim of the study is to examine which type of support is safer for seismic response of a real-size steel truss structure, considering the structural reactions under earthquake and other acting load effects. To do this, the structural models generated with three different support conditions are examined in detail in terms of earthquake characteristic according to conducted structural seismic analyzes. The real-size steel truss structures are modeled in SAP2000 structural analysis program and are designed in accordance with the Turkish Building Earthquake Code-2018 specifications. The snow and wind loads acting on the truss structures are calculated in the direction of TS EN 1991-1-3 and TS EN 1991-1-4 specifications, respectively. The earthquake forces are implemented to the truss structure through mode superposition method. Finally, the truss structure is comparatively examined in terms of the structural weight, base shear force, natural vibration period, and relative drift. As regards to the obtained results, it has been observed that the seismic responses of the steel truss structure are remarkable better when the seismic base isolator is implemented into the structure.

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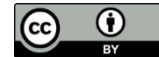
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1. Introduction

Due to its geological location on numerous active faults, Türkiye is in high seismicity region. A large part of Türkiye is located within the earthquake zone formed by these faults. In other words, it is known that 95% of the population is under earthquake hazard and 98% of large industrial structures are located in these regions (Hattap and Eşsiz 2005). Because of country's location on such active faults, structural engineers have been conducted a lot of different construction design to resist on the earthquake behavior utilizing reinforced concrete and steel structures. Although steel structures are safer structural

system due to the high strength and ductility of steel, their initial construction costs limit their usage in site. Hence, steel structures are preferably used in non-residential highway and railway bridges, industrial facilities, and/or low-rise buildings in Türkiye. Besides, the steel truss structural systems, which have recently started as to be in sports facilities, industrial buildings, stadiums, large shopping centers, concert and exhibition areas, etc., are a type of popular steel structure. The steel truss structures are designed based on the principle that structural elements are joined at the nodal points at which moments are zeroed and consequently, the elements forming the structure work only against axial ten-

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sion and compression forces. In terms of static benefits, these structures are much lighter than many other load-bearing structural systems, and the low dead loads reduce costs not only on the roof but also on the foundation and other sub-elements. Steel framed structures, on the other hand, are structures where column, beam, and floor structural elements are used, as in reinforced concrete structures. In such structures, column and beam elements have high bending stiffness, and connection points resist horizontal displacements. When designing seismic resilient construction, steel structures are generally preferred because of their low weight and high ductility. Since the structural weight of steel structures is approximately 50% less than that of reinforced concrete structures, the steel structures reacts to seismic forces at the same rate less (Özdemir 2022). Therefore, the damages caused by earthquakes in steel structures are less than other types of structures. Traditionally, steel structural systems are designed with the aim of damping the energies arising under earthquake loads by means of joints formed at the nodal points. In addition, seismic dampers are used in earthquake resistant steel structure designs in order to increase the stability of the structure under seismic effects. These are generally grouped as active and passive dampers. However, there are special hybrid damping systems that are formed by combining these two damping systems (Artar and Carbas 2022, 2023; Carbas and Artar 2024). Another effective method used to minimize the earthquake effect in steel structures is seismic isolation. Seismic isolation aims to minimize the earthquake damage to the structure by transferring the horizontal earthquake forces caused by the incoming ground motion to the superstructure as little as possible by means of so-called seismic isolator devices placed between the foundation and columns of the structure. The basic working principle of these isolator devices is to increase the period of the structure by increasing the horizontal displacement at the foundation of the structure. By increasing the period of the structure, the intensity of the spectral accelerations caused by the earthquake and the damaging effect of the earthquake in parallel are reduced as much as possible. Seismic base isolator systems differ in size, shape and especially in the material they are made of. The most commonly used ones are elastomeric isolators, lead-core isolators and friction pendulum isolators (Taymus 2021; Özdemir 2022). The usage of seismic isolation has become widespread in our country, as well. Scientific studies on seismic base isolation systems in our country have a substantial impact on the increase in practical applications (Özpalkanlar 2004; Reyhanoğulları and Akyüz 2015; Wieland and Malla 2015; Erdem and Saifullah 2016; Erdem et al. 2016; Yurdakul and Yıldız 2020).

In this study, a steel truss structure was modeled in the SAP2000 structural analysis program according to three different support conditions (double friction pendulum isolator, elastomeric isolator, fixed support), and the seismic response of the structure under earthquake forces was investigated. It was also examined whether the application of seismic base isolators increases structural stability. The handled real-size steel truss structure originally designed with fixed supports and was con-

structed in the form of a tennis court, by implementing elastomeric isolators and double friction pendulum isolators under its load-bearing columns, resulting in a total of three different structural models. The main aim here is to examine in detail whether real-size steel truss structures can be constructed with less structural weight compared to traditional base design methods by placing different types of seismic base isolators, and most importantly, whether the seismic responses of the structure can be improved. For this purpose, the final structural designs were comparatively analyzed based on structural weight, base shear force, natural vibration period, and relative drift. Consequently, comparisons were made based on the results obtained for three different structural models; traditional fixed support, elastomeric isolator, and double friction pendulum isolator application.

2. Seismic Base Isolators

Seismic base isolators are one of the earthquake resilient systems that isolate the superstructure from the ground by separating it, thus reducing the reactions that may occur from ground motions and increasing the natural vibration period and damping ratio of the structure. They are one of the most effective seismic proof methods for minimizing the damage that seismic excitations can cause. They also play an important role in reducing both story drifts and story accelerations. In structures designed according to the traditional lateral load-bearing method, almost all acting loads originating from ground motions are transmitted to the superstructure, and the risk of these loads damaging the load-bearing elements is quite high. However, in seismically base-isolated structures, since energy absorption is high, the effect of external loads originating from ground motions on the superstructure is significantly less. When seismic isolators are used at the load-bearing columns' base in structural design, the structure initially exhibits an almost rigid behavior, and displacement occurs only in the isolators. As the natural vibration period of the structure increases, the spectral acceleration resulting from the earthquake and the deformation effect of the earthquake on the structure are significantly reduced. While the intensity of seismic forces originating from ground motions and acting on the structure may not be controlled, making the structure safer is achieved by reducing the intensity of the transmission of loads from the ground to the structure. The damping ratio, which is accepted as 5% in steel structures designed with normal traditional methods, increases up to 25% in structures where seismic base isolators are implemented (Kamrava 2015; Makris 2019; Taymus et al. 2024).

Various base isolator devices are used for seismic isolation. The most commonly used types are elastomeric and friction pendulum isolators (Kelly 2001; Naeim and Kelly 2007). The elastomer parts of elastomeric isolators are produced from natural rubber. One of the main reasons why they are preferred is that they can take the desired shape. They have good compatibility with metals and these features facilitate their installation on the

foundation in practice. Elastomeric isolators, which can deform up to four times the height of the rubber layers, have high stiffness vertically and very low stiffness horizontally (Fig. 1(a)). In the design and modelling stages of elastomeric isolators, especially their shear modulus, energy absorption capacity and time-dependent mechanical properties are expected to change as little as possible. In practice, they can be placed at the base of the column, in the middle of the column or between floors. In retrofitting projects, they can be used by creating a rigid platform between the column and the foundation. The working principle of friction pendulum isolators under earthquake loads is as follows; when the incoming seismic forces exceed the design friction force of the isolator, the steel sphere between the upper and lower plates starts to slide on the concavely designed lower plate and increases the oscillation period of the structure and makes the structure make small oscillations (Saiful Islam et al. 2011). In this way, the earthquake energy is damped by the friction force (Fig. 1(b)). Friction pendulum isolators can be designed in three different types: single, double, and triple friction pendulum.

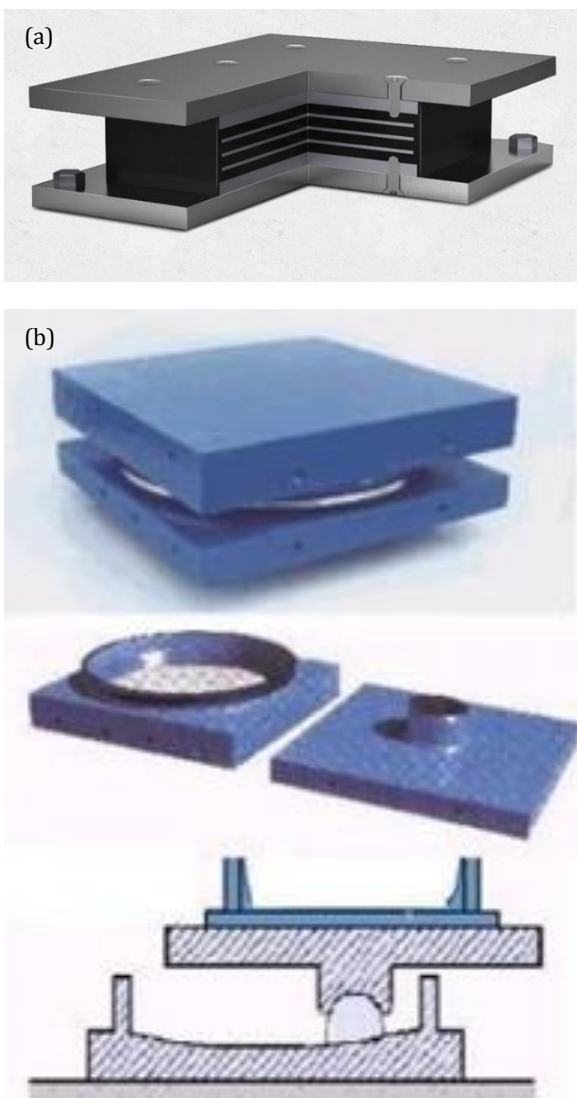


Fig. 1. Seismic base isolators: (a) Elastomeric (Arfen 2023); (b) Friction pendulum (Kan et al. 2017).

Among those triplets, the double friction pendulum isolator preferred in this study due to its popularity and ease of practicability is formed to consist of three components; the bottom and top plates, and the center slider. Such isolators are designed to absorb seismic energy by the movement of the center slider between the bottom plate and the top plate. Thus, a double friction surface is created that will be activated by the seismic loads coming to the structure. Since the friction will not be the same on two sliding surfaces, it is also considered that the sliding surface can always rotate a little. Therefore, the sliders are designed as articulated and irregular deformation is prevented. Since it has a double friction surface, it can be produced in smaller sizes and is often preferred in practice. Due to some rotation of the support body and the slider, this should be taken into account when calculating the displacement capacity. The double friction pendulum isolator cross-section and itself is shown in Fig. 2 (Constantinou 2004; Scheaua 2020).

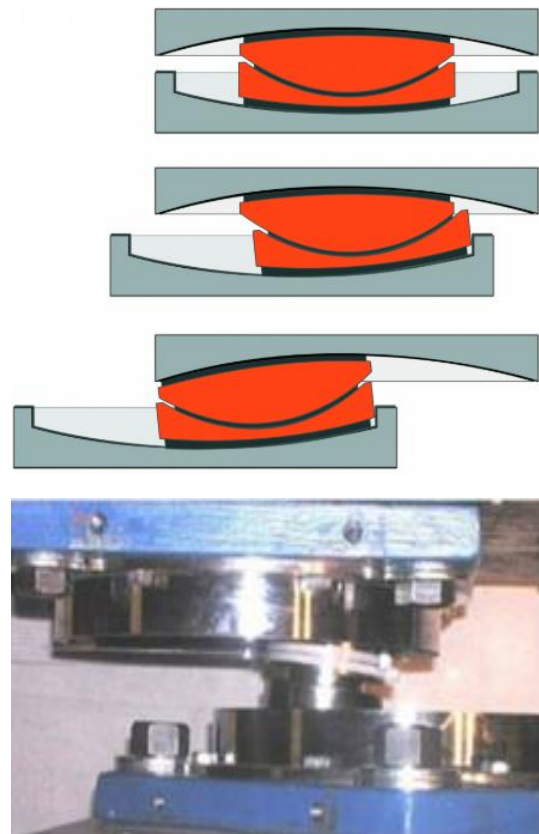


Fig. 2. Double friction pendulum isolators (Constantinou 2004; Scheaua 2020).

2.1. Modelling of elastomeric isolator in SAP2000

The elastomeric isolators can be modeled in SAP2000 structural analysis program. In this context, the ready-defined "Rubber Isolator" element type can be used for this purpose. In elastomeric isolators, since there is no movement (sliding) limiter, a "gap" (clearance) definition is not made. After entering the mass and selecting the element orientations, data entries are made for the mechanical properties of the isolator. Since a nonlinear analysis

is performed, "NonLinear" must be selected and a "Stiffness" value is initially entered as 5025.313 kN/m. The "k1" value, which will be mentioned in the further section, is entered as the "Stiffness" value. The "Yield Strength" value is also entered as the force value of 92.4658 kN at which the "k2" value starts. The value of the "k1/k2" ratio is entered as the "Post-yield Stiffness Ratio" value as 0.1667. The "Rubber Isolator" option readily available in the SAP2000 structural analysis program, as mentioned before, this type of isolator can also be modeled by selecting a single "Link" element. In fact, the "Rubber Isolator" used here is a biaxial hysteretic isolator that exhibits plastic behavior for orthogonal and interactive shear deformations in two directions and shows linear effective stiffness for the other four deformations. The hysteretic concept in this definition is the cyclic response behavior exhibited by the internal force-deformation relationship formed in the element as a result of external seismic loading. For each shear deformation degree of freedom, linear or nonlinear behavior can be defined (Özpalanlar 2004). When modeling the elastomeric isolator in the SAP2000 structural analysis program, a "Link" element definition is initially made downwards from the connection point of the structure with the foundation. A fixed end support is assigned to the bottom point of the defined "Link" element. The defined "Rubber Isolator," as explained above, is assigned to this "Link" element. The visuals of the elastomeric isolators modeled in the SAP2000 structural analysis program are shown in Fig. 3.

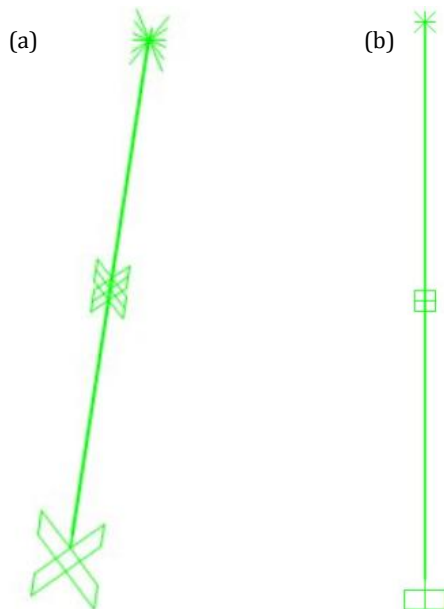


Fig. 3. Elastomeric isolator modeled in SAP2000:
(a) 3D view; (b) x-z plane view.

2.2. Modelling of double friction pendulum isolator in SAP2000

Within the scope of this study, the double friction pendulum isolator has been modeled in the SAP2000 structural analysis program by utilizing "Plastic (Wen)" option as link/support data. The elements to be defined as

"Plastic (Wen)" are considered as plastic hinges. Also, a gap is defined in the form of a "gap" element. Namely, the element definitions have been made as "Plastic (Wen)," i.e., plastic hinge, and "gap," i.e., gap element. All solutions made other than the "NonLinear Link" element definition is calculated assumed as linear behavior. Another data entry is made to define the orientations and mechanical properties. Here, for mechanical properties, the "Effective Stiffness" and "Effective Damping" properties to be used in "Linear" analysis are entered. Then, the element properties "Stiffness" and "Open" to be used in "Nonlinear" analysis. The selected "U1" direction means to make a definition equivalent to the x-direction in the coordinate system if the global axis system is defined in the SAP2000 structural analysis program. Later, the mechanical values of the "gap" element are entered. When modeling the double friction pendulum isolator, it should be taken into account that it will move horizontally and slide, and when it displaces to the edges of the concave surface, it should not displace further due to the limiters at the edges of this surface. So, the isolator has a certain displacement capacity. In the "gap" element, this represents the displacement capacity. In the SAP2000 structural analysis program, the "Open" option is defined as the displacement capacity. The "Stiffness" option represents the bearing capacity stiffness of the isolator after it displaces up to the limiters. Naturally, this value should be entered as a large value that will prevent deformation during isolator modeling. The assumption that the "Effective stiffness" value is 1/500th of the normal "Stiffness" value can be accepted. After mass definition, the "U2" and "U3" directions are selected. To define the properties of these directions, the "Stiffness" value is entered as the stiffness value in the nonlinear analysis. Thereby, the double friction pendulum isolator will not displace, i.e., will not move, until the friction force is reached. When making the "Plastic (Wen)" element definition, calculations are made assuming very high stiffness and a slight amount of displacement. The "Yield Strength" value is the force value at which sliding, i.e., yielding, begins. In this study, since a simulation is performed and to be exactly the same in reality, the "Plastic (Wen)" element type was used when modeling the double friction pendulum isolator. The "Post Yield Stiffness Ratio" value is defined as the ratio of the stiffness at the moment yielding starts to the stiffness after yielding ends. The "Yielding Exponent" value is generally taken as 22. In Friction Pendulum Bearings, transitions between sliding regimes occur sharply. The Yielding Exponent parameter should be a value that reveals this sharpness. Thus, the reason for taking "Yielding Exponent" value as 22 is that the hysteretic curve of double friction pendulum isolators should be sharply cornered, i.e., square or rectangular in shape. Here, the larger the area under the curve, the more the energy damping capacity against earthquake effects for steel structures is increased.

When modeling the double friction pendulum isolator in the SAP2000 structural analysis program, first, the concave surface of the lower part of the isolator is considered, and 5 "link" element definitions are made. This element type is defined to the start, end, and joint points of the "Link" elements. Then, fixed supports are defined

at the corner points. Displacement of the bottom 5 points of the isolator is prevented. In the upper part of the isolator, movement under seismic forces is considered. The upper part of the isolator also has 5 "link" element definitions just like the bottom, and this element type is defined to the start, end, and joint points of these elements. The "Plastic (Wen)" link element is assigned to the defined vertical links, and the "gap" link elements are assigned to the horizontal links. Since the three points defined on the upper plate of the isolator will not move independently, it is assumed that they will move together. Hence, "Joint constraints" are defined and assigned to these 3 points in the SAP2000 structural analysis pro-

gram. The 2 points in the middle of the lower and upper plates represent the central slider. Since it is assumed that these two points will move together, "joint constraints" have been assigned. However, different "joint constraints" have been assigned to the 3 points on the upper plate and the 2 points on the lower plate. The reason for this is that the upper 3 points and the middle 2 points need to move separately. The "joint restraints" assignment to the top middle point of the upper plate is made. Since the points on the upper plate will move together, assignment has been made only to this point. The double friction pendulum isolators modeled in the SAP2000 structural analysis program are shown in Fig. 4.

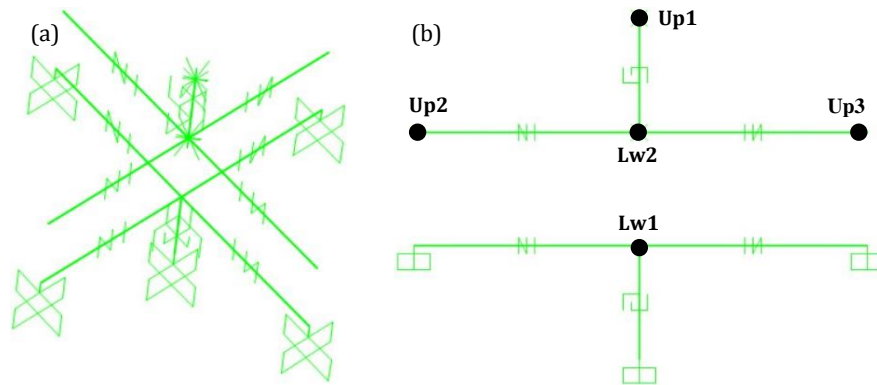


Fig. 4. Double fraction pendulum isolator modeled in SAP2000: (a) 3D view; (b) x-z plane view.

3. Design of Real-Size Steel Truss Structure in SAP2000 using Seismic Base Isolators

With the nonlinear analysis capability developed in the SAP2000 structural analysis program, the static and dynamic computations and designs of real-size (3D) steel truss structures can be performed by defining nonlinear elements. According to Hooke's law, there should be a linear displacement according to the applied force. However, in nonlinear analysis, the applied force and displacement do not change linearly. The element may flex or deform without flexing under the applied force. Therefore, nonlinear analysis should also be performed in the design of steel structures. This type of analysis performed in steel structure design is called second-order analysis. From this point of view, it is understood that linear displacement occurs in linear analysis under force, and nonlinear displacement occurs in nonlinear analysis. The type of material used is also important in this respect. The resistance shown by the material against force, that is, its yield strength, may not be clear after it is exceeded. In this case, the hardness or stiffness value of the material used play very significant role. Therefore, these values should be considered in the calculations in duration of design. One of the reasons for performing nonlinear analysis during design is that as the force effect increases in linear analysis, the sections in the design grow at the same rate, but in nonlinear analysis, the structure can be designed with smaller cross-sections (Özdemir 2022).

In this study, a real-size steel truss structure taken as a structural design example was modeled with 7 span,

each span has 6 m wide, and a truss span of 21 m. The 3D view of the modelled real-size steel truss structure is shown in Fig. 5. The columns of the structure were designed using Q1685mm pipe profiles, the roof trusses using Q1684mm pipe profiles, the column bracing members using Q763mm pipe profiles, the roof truss bracing members using 603mm pipe profiles, the roof purlins using 40x80x3 mm box profiles, and the bracing members also using 40x80x3mm box profiles. In this study, the snow and wind loads acting on the life-size steel truss structure were calculated by considering the criteria in TS EN 1991-1-3 (2025) and TS EN 1991-1-4 (2022) specifications regulations, respectively.

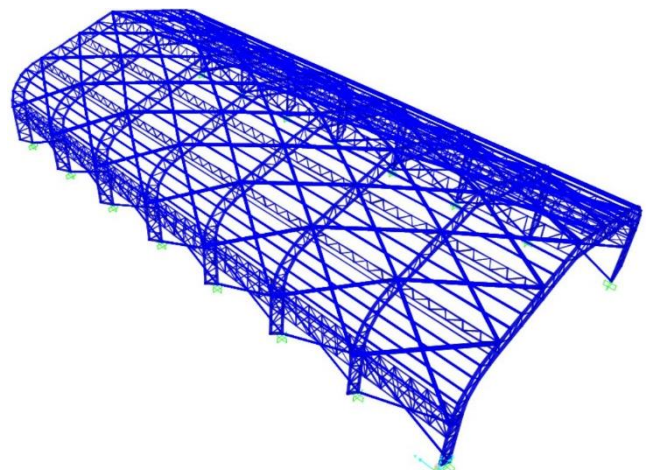


Fig. 5. 3D view of real-size steel truss structure modeled in SAP2000.

3.1. Seismic data identification using mode superposition method

In this study, it was assumed that the real-size steel truss structure taken as a design example would be constructed in Karatay/Konya at coordinates latitude '37.88680' and longitude '32.500621'. Based on these coordinates, an earthquake hazard report and a horizontal elastic design spectrum were generated from the website of the Disaster and Emergency Management Presidency (AFAD) (Fig. 6).

The data considered when creating the spectrum above were selected as $S_s=0.686$, $S_1=0.148$, $S_{DS}=0.841$, $S_{D1}=0.222$, $PGA=0.293$, $PGV=14.219$, and soil class ZD. Afterwards, a reduced design spectrum graph was created by considering the horizontal elastic design spectrum. The reduced design spectrum graph was graphed according to the earthquake load reduction factor design criteria under the title "Earthquake Load Coefficients and Capacity Design Principles" from the Türkiye Building Earthquake Code-2018 (TBEC 2018) as depicted in

Fig. 7. Here, $R=4$ and $D=2$ are taken from TBEC-2018/ Table 4.1, $I=1.2$ is taken from TBEC-2018/ Table 3.1, $TB=S_{D1}/S_{DS}$ is taken from TBEC-2018/ Eq. 2.3 and so the $TB=0,264$ is calculated.

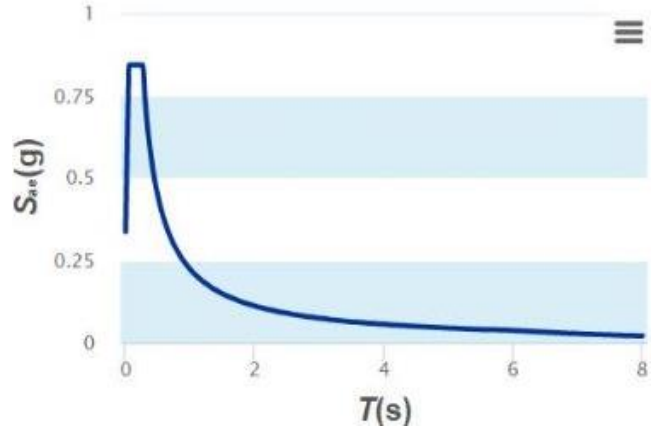


Fig. 6. Horizontal elastic design spectrum graph.

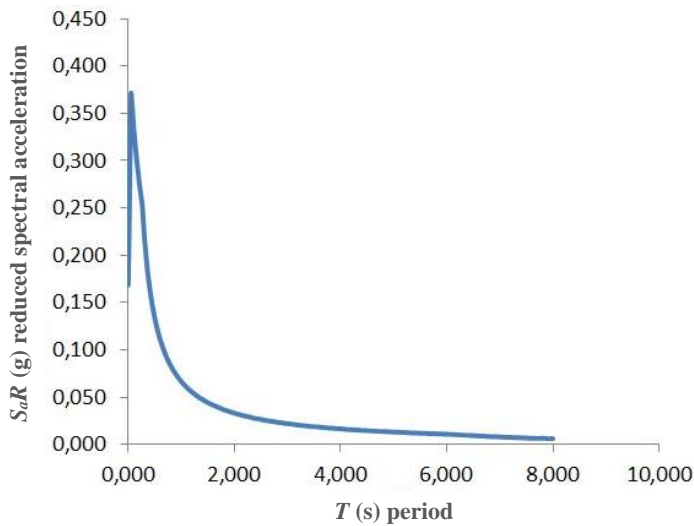


Fig. 7. Reduced response design spectrum graph.

The reduced response design spectrum was created according to the design criteria in the relevant section of TBEC-2018. The method used in this study is the mode superposition method, which is one of the dynamic solution methods. The mode superposition method is solved by statistically combining the maximum internal forces and displacements calculated for each of the natural vibration periods in the structure (İşsever 2012). From the equations under the title "4.2.1. Earthquake Load Reduction Factor" of TBEC-2018;

$$R_a(T) = R \text{ for } T > TB \tag{1}$$

$$R_a(T) = D + (R - D) \cdot \frac{T}{TB} \text{ for } T \leq TB \tag{2}$$

$$S_a R(T) = \frac{S_{ae}(T)}{R_a(T)} \text{ for } T > TB \tag{3}$$

In these equations;
 $S_a R(T)$: reduced spectral acceleration for a specific natural vibration mode,

$S_{ae}(T)$: elastic spectral acceleration for a specific vibration mode,
 $R_a(T)$: earthquake load reduction factor for a specific vibration mode.

Subsequently, the period, elastic design spectrum values, earthquake load reduction factor, and reduced accelerations were created in an Excel program and saved as a ".txt" extension file compatible with the SAP2000 structural analysis program. In the SAP2000 structural analysis program, "Function" was entered from the "Define" tab, and then "Response Spectrum Function Definition". Then, the created ".txt" format text document was loaded to create the response spectrum function graph. The reduced response spectrum graph through the "Load Case Data" tab was defined in the SAP2000 structural analysis program and included in the structural analysis. While identification the data, real acceleration-time records were applied to the structure in both directions in accordance with the TBEC-2018 specifications.

3.2. Modal analysis

It is important to consider modal analysis when making structural designs. This is because most structures tend to vibrate at natural frequencies even when not under any load or force. Due to these natural frequencies, structures exhibit mode changes, even if very slightly. This type of analysis is used to determine the parameters needed to define the design that shows the dynamic behavior of structures. In this way, the created modes, natural frequency, damping, and resulting mode shapes can be determined. If modal analysis is categorized, it can be divided into traditional modal analysis and operational modal analysis. If the vibrations to be applied to the structure are known, the conventional modal analysis method can be used. However, if the vibrations to be applied to the structure are unknown, the operational modal analysis should be preferred. During the analysis, it is assumed that the structure is a whole, its structural behavior does not change over time, the material properties do not change, and the structure exhibits linear characteristic (Şahin et al. 2020). Fig. 8 below shows the behavior of the real-size steel truss structure subjected to modal analysis in the SAP2000 structural analysis program at "mode=1".

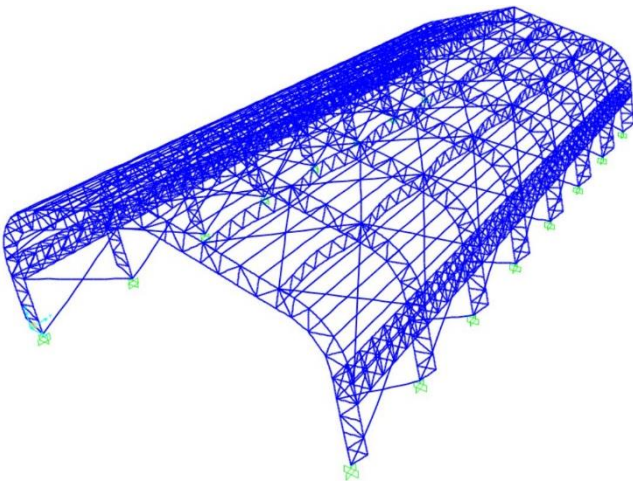


Fig. 8. View in x-z plane of real-size steel truss structure as a result of modal analysis via SAP2000.

4. Discussions

In this study, a real-size steel truss structure modeled in the SAP2000 structural analysis program was first designed using the traditional base method, i.e., with fixed supports. Then, the structure was designed separately again for the cases elastomeric and double friction pendulum seismic base isolators. Consequently, the structural analyses of three different structural design models—fixed supported, with elastomeric seismic base isolators, and with double friction pendulum seismic base isolators—under the load effects were carried out. The obtained structural design solutions were then examined in terms of comparisons of structural weights, base shear forces, natural vibration periods, and relative drifts.

In order to compare the structural weight of the life-size steel frame structure modeled with and without seismic base isolator using SAP2000 structural analysis program, the obtained weight of structures from each structural analysis for the cases with fixed support, elastomeric isolator, and double friction pendulum isolator are tabulated in Table 1. The total reaction weight of the structure was calculated by summing the reaction force values occurring at the supports. When Table 1 is examined, it is seen that the highest reaction force occurs when implementation of the elastomeric isolators, followed by the case where double friction pendulum isolators are implemented, and the lowest reaction force occurs when implementation of fixed supports. When the steel truss structure is designed with double friction pendulum isolators, it gives approximately 60% higher reaction force compared to the case where it is designed with fixed supports.

When the base shear forces of the real-size steel truss structure designed with and without isolators using SAP2000 structural analysis program are compared it can be deduced that considering the resistance of the real-size steel truss structure modeled in the SAP2000 structural analysis program against seismic effects, the values of shear forces play an important role in determining the section properties. As can be understood from the base shear force values resisted by the supports shown in Fig. 9, the highest base shear force is resisted by elastomeric isolators, followed by double friction pendulum isolators, and the lowest by fixed supports.

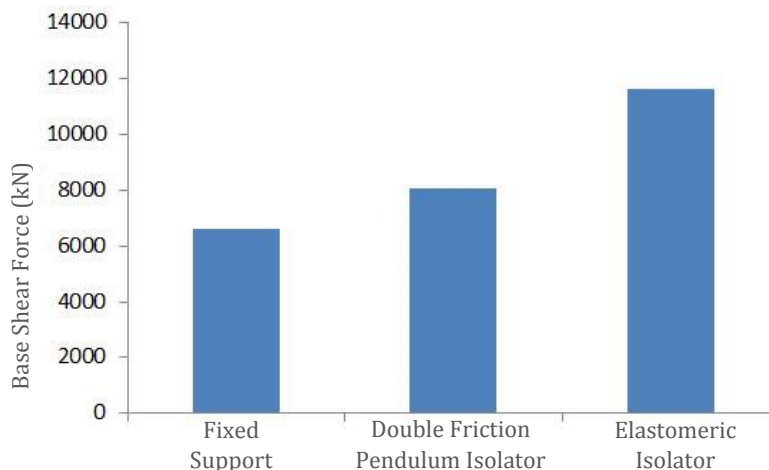


Fig. 9. Base shear forces with respect to support conditions.

Table 1. Structural weights with and without seismic base isolator.

$P_{total}/\text{Fixed Support (kN)}$	$P_{total}/\text{Elastomeric Isolator (kN)}$	$P_{total}/\text{Double Friction Pendulum Isolator (kN)}$
7.583,81	8.215,29	12.058,17

When Fig. 9 is examined, it is seen that the elastomeric isolator resists approximately twice as much base shear force as the fixed support when used in the real-size steel truss structure. When the double friction pendulum iso-

lator is implemented in the real-size steel truss structure, it is seen that it resists approximately 20% more base shear force compared to the fixed support as obviously seen in Table 2.

Table 2. Base shear forces for the support condition according to load combinations.

Support Condition	Fixed Support	Double Friction Pendulum Isolator	Elastomeric Isolator
Maximum base shear force according to load combinations	V_{Max} (kN)	V_{Max} (kN)	V_{Max} (kN)
1.2G+0.2S+Ex	6.644,38	-	-
1.2G+0.2S+Ey	-	8.056,55	-
1.2G+0.2S+Ex	-	-	11.623,03

In Table 2, the maximum base shear force obtained from the structural analysis results executed in the SAP2000 structural analysis program according to the load combinations are given. Here, while maximum base shear force values are obtained in the 1.2G+0.2S+Ex load combination when fixed support and elastomeric isolator are implemented into the structure, the maximum base shear force value is obtained in the 1.2G+0.2S+Ey load combination when double friction pendulum isolators are implemented into the structure. When the isolated steel truss structures are compared among them-

selves, it is seen that approximately 47% more base shear force is resisted in the case where elastomeric isolators are implemented into the structure compared to the case where double pendulum isolators are implemented.

The natural vibration periods obtained for the first, second, and third structural modes as a result of the structural analyses of the real-size steel truss structure modeled with fixed supports and seismic base isolators in the SAP2000 structural analysis program are tabulated in Table 3.

Table 3. Natural vibration periods according to support conditions.

Structural Modes	$T_{\text{fixed support (sec)}}$	$T_{\text{double friction pendulum isolator (sec)}}$	$T_{\text{elastomeric isolator (sec)}}$
1	0.23	0.29	0.41
2	0.11	0.21	0.38
3	0.10	0.11	0.13

If Table 3 is examined, it is seen that the natural vibration period of the real-size steel truss structures increases by approximately two times of magnitude when designed with base isolators compared to the case where they are designed with fixed supports. After the third mode, it is seen that the natural vibration periods of the structure reach almost the same values for all support conditions.

After the structural analyses of the real-size steel truss structures modeled with fixed supports, double friction pendulum isolators, and elastomeric isolators in the SAP2000 structural analysis program, the maximum relative drifts were obtained when the relative drifts at the apex points of the trusses and the relative drifts at the internal joint points where the fully vertical truss members end and the inclined truss members begin, which are in the same alignment as the fixed sup-

ports/isolators, were considered. The maximum relative drifts values of the obtained results are tabulated in Table 4. It is seen that the maximum relative drifts obtained for the fixed supported structural case will be greater than the relative drifts obtained in the cases where the structure is modeled with isolators. The maximum apex point relative drift was obtained in the 1.2G+0.5S+1.6Wy load combination for the isolated structural designs, and in the 1.2G+0.2S+Ex load combination for the fixed supported structural design. On the other hand, the relative drift values at the internal joint points where the fully vertical truss members end and the inclined truss members begin, which are in the same alignment, were obtained from the 1.2G+0.5S+1.6Wy load combination for the isolated structural designs, and from the 1.2G+0.2S+Ex load combination for the fixed supported structural design.

Table 4. Relative drifts of the apex point and specified joints for three different support conditions according to load combinations.

Support Condition	Fixed Support	Double Friction Pendulum Isolator	Elastomeric Isolator
Maximum relative drifts according to load combinations	$\Delta_{apex_{max}} / \Delta_{joint_{max}}$ (cm)	$\Delta_{apex_{max}} / \Delta_{joint_{max}}$ (cm)	$\Delta_{apex_{max}} / \Delta_{joint_{max}}$ (cm)
1.2G+0.5S+1.6Wy	–	(1.88) / (1.87)	(1.87) / (1.78)
1.2G+0.2S+Ex	(4.3) / (4.27)	–	–

When Table 4 is examined, it is seen that maximum relative drifts at the apex point and at the internal joints, which are in the same alignment as the isolators, where the fully vertical truss members end and the inclined truss members begin, were obtained in the same load combination and in the same direction (y-direction) for the isolated structural designs. It has been observed that the maximum relative drift value in the steel truss struc-

ture with fixed supports is greater than the maximum relative drift values in the seismically isolated structures. In this context, the structures with seismic isolators exhibited approximately 40% less maximum relative drift compared to the structure with fixed supports. When the seismic isolated structural cases are compared within themselves, almost the same relative drift values were obtained (Fig. 10).

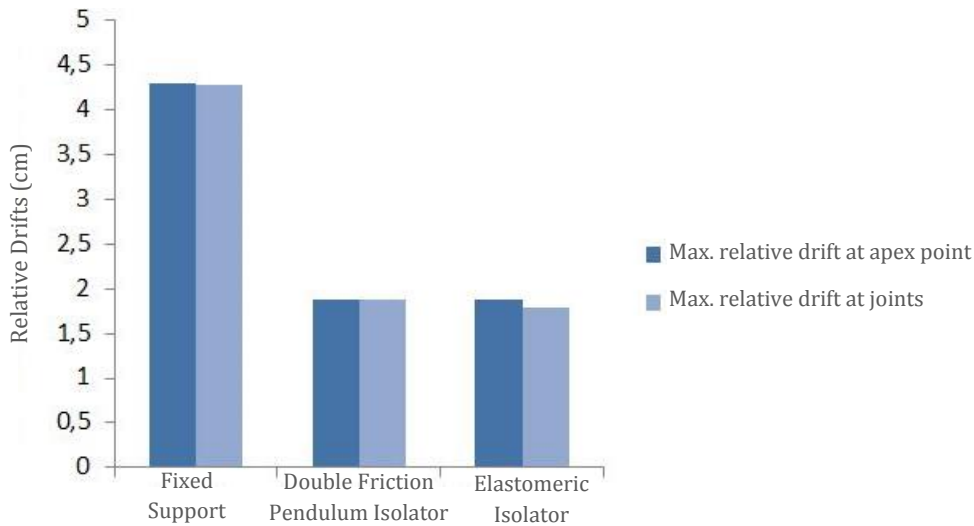


Fig. 10. Comparison of relative drifts according to support conditions.

5. Conclusions

In this study, to investigate the seismic response characteristic of a real-size steel truss structure, the structure was modeled and designed in SAP2000 structural analysis program according to a total of three different support conditions as fixed support, double friction pendulum isolator, and elastomeric isolator. The structural analyses were performed according to the mode superposition method. The achieved structural analysis of real-size steel truss structures were compared in regard of the structural weight, base shear force, natural vibration period, and relative drifts. Thus, in this study, the seismic response characteristic of the real-size steel truss structures with seismic base isolation and a steel truss structure modeled with traditional fixed supports against earthquake forces was investigated. Within the scope of this study, the following main concluding remarks were deduced:

- Considering the structural weight calculated according to the support reaction forces obtained from the

structural analysis results, fixed supported and seismically isolated steel truss structures were compared, and the results are given in Table 1. According to this table, it has been observed that the fixed supported steel truss structure gives a lower reaction force value compared to the seismically isolated structures. In the comparison made according to the base shear force, it is seen that the steel truss structures with seismic base isolators resist a higher base shear force, and therefore, more resilient structural systems against earthquake effects are constructed. This is because a large part of the seismic energy coming into the structure during the completion of the oscillation of the steel truss structures is damped by the seismic base isolators implemented into the structure, so the base shear force has reached its maximum value. In addition, when a comparison is made according to the maximum relative drifts obtained, the drift values in the structure are also low due to the isolators becoming active when the structure starts to oscillate under the influence of seismic forces. From these results, it

is seen that real-size steel truss structures with seismic base isolation become safer against earthquake forces. In other words, it is seen that steel truss structures exhibit effective seismic resilience performance against earthquake forces when they are designed with properly modeled seismic base isolations.

- The most important result obtained mainly in this study is that when seismic base isolators are used practically in real-size steel truss structures, loss of life and damage will be prevented due to the structure exhibiting effective seismic performance against earthquake forces.

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Author Contributions

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Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

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