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Evaluation of the Effect of Sheet Thickness on Reinforcement of Floors with Steel Sheet in Timber Structures Using Modal and Static Analysis

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Research Article

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Abstract

Steel sheet applications, which are widely used in the reinforcement of timber floors encountered in rural and historical buildings today, may reduce the rigidity of the structure and may cause structural instabilities when applied unconsciously. This study systematically evaluates the effects of the change in steel sheet thickness on the timber floor behavior through modal analysis and static deflection studies. Eight different steel sheet thickness scenarios ranging from 0.1 mm to 20 mm were analyzed on the finite element model created using SAP2000 software. The first mode period value, mode shape and maximum deflection amount were evaluated for each model and the effects on the structural rigidity were compared. The findings showed that thin sheets such as 0.1 mm reduce rigidity and cause torsional mode; while the deflection values increase significantly due to the added mass at thicknesses of 5 mm and above and negatively affect the structural performance. The most efficient sheet thickness was determined between 0.2 mm and 0.5 mm both dynamically and statically. As a result of the study, it was revealed that the understanding of "the thicker the sheet, the stronger the structure" seen in unconscious timber floor reinforcements is invalid. It is emphasized that optimum sheet thickness should be determined based on engineering data in steel sheet reinforcement applications in timber structures. These findings reveal the importance of engineering-based reinforcement approaches in making traditional structures safer and more durable.

Keywords: Timber structures, steel sheet, finite element method, modal analysis, reinforcement

Ahşap Yapılarda Döşemelerin Çelik Sac ile Güçlendirilmesinde Sac Kalınlığının Etkisinin Modal ve Statik Analiz ile Değerlendirilmesi

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Öz

Günümüzde kırsal ve tarihi yapılarda karşılaşılan ahşap döşemelerin güçlendirilmesinde yaygın olarak kullanılan çelik sac uygulamaları, bilinçsiz yapıldığında yapının rijitliğini azaltmakta ve yapısal kararsızlıklara neden olabilmektedir. Bu çalışma, çelik sac kalınlığının değişiminin ahşap döşeme davranışı üzerindeki etkilerini modal analiz ve statik sehim incelemeleri aracılığıyla sistematik olarak değerlendirmektedir. SAP2000 yazılımı kullanılarak oluşturulan sonlu eleman modeli üzerinde, 0.1 mm ile 20 mm arasında değişen sekiz farklı çelik sac kalınlığı senaryosu analiz edilmiştir. Her model için birinci mod periyot değeri, mod şekli ve maksimum sehim miktarı değerlendirilmiş, yapı rijitliği üzerindeki etkiler karşılaştırılmıştır. Bulgular, 0.1 mm gibi ince sacların rijitliği düşürdüğünü ve burulma moduna neden olduğunu; 5 mm ve üzeri kalınlıklarda ise kütle artışıyla birlikte sehim değerlerinin aşırı yükseldiğini ve yapı performansını olumsuz etkilediğini göstermiştir. En verimli sac kalınlığı hem dinamik hem statik açıdan 0.2 mm ile 0.5 mm arasında belirlenmiştir. Çalışma sonucunda, bilinçsiz ahşap döşeme güçlendirilmelerinde görülen "sac kalınlaştıkça yapı daha sağlam olur" anlayışının geçersiz olduğu ortaya konmuştur. Ahşap yapılarda çelik sacla güçlendirme uygulamalarında optimum sac kalınlığının mühendislik verilerine dayalı olarak belirlenmesi gerektiği vurgulanmaktadır. Bu bulgular, geleneksel yapıların daha güvenli ve dayanıklı hale getirilmesinde mühendislik temelli güçlendirme yaklaşımlarının önemini ortaya koymaktadır.

Anahtar Kelimeler: Ahşap yapılar, çelik sac, sonlu elemanlar metodu, modal analiz, güçlendirme

Introduction

Shelter has always been a fundamental human need throughout history. When viewed from this perspective, the lifespan and durability of buildings are a very important problem to be solved. To solve this problem, human beings developed various methods to strengthen their shelters. In the early ages, they applied strengthening techniques without proper technical knowledge compared to today. Today, with the development of civil engineering, efforts are being made to meet these needs more seriously and technically. The evaluation of the effect of sheet thickness on reinforcement of floors with steel sheets in timber structures is an important aspect of structural engineering, especially when considering hybrid systems that combine the benefits of both wood and steel. Serious research needs to be done on this subject to reveal efficient reinforcement systems. The use of wood as a building material dates back much further than concrete and steel. The development process of wooden structures, starting from the earliest times and extending to today's construction systems, has been slow despite the fact that wood is easily obtained from nature and can be easily applied in the construction phase [1]. In the 19th century, with the influence of the Industrial Revolution, the use of new products in the construction sector, especially the widespread use of stone and brick stacking systems, and the emergence and application of steel and reinforced concrete construction systems, has reduced the use of wood as a load-bearing material in structures [2]. The mechanical properties of wood can be called the resistance of wood to external forces. In wood material that shows orthotropic properties; there are three different directions parallel to the fibers, radial (extending from the core to the bark) and tangential (extending parallel to the annual rings). Due to its orthotropic properties, this orthotropic nature can affect both the physical and mechanical properties of wood. This shows that the elasticity and strength of wood depend on its direction. While the elasticity modulus value has the highest value in the direction parallel to the fibers, it decreases in the radial direction and will decrease in the tangential direction [3]. The resistance of wood to the pressure applied to it by forces parallel and perpendicular to the fibers is called the compressive strength. According to TS 647, the compressive strength is determined according to the values parallel to the fibers of the wood. While the compressive strength in the direction perpendicular to the fibers is very low in the wood material, in the direction parallel to the fibers, the material will work like a column and will be very resistant to buckling and crushing [4]. The bending strength is the reaction of the wood material to this force, which acts perpendicularly to the fibers on one or both sides of a beam-supported wood. The bending strength is related to the moisture content of the wood. While 3-5% moisture provides the highest strength to the wood, the strength decreases by 4% for every 1% increase in moisture content [5]. It is the property of an object whose shape changes under the effect of any force to return to its original state when the force is over. Wooden material can withstand the force without deformation up to a certain limit. This situation is called the limit value of wood. In addition, in cases where the force loading continues to increase, deformation occurs and can cause the wood to break. This situation is called the breaking limit of wood. Wooden material is a material considered to be moderately elastic. It is directly proportional to density. Increases in temperature and humidity negatively affect the elasticity modulus [6]. In order to define the behavior of wood, it is necessary to know the elasticity modulus and Poisson's ratio of the structure in particular. Elasticity is the property of wood to return to its original state. Poisson's ratio is the amount of transverse expansion divided by the amount of axial compression [7]. The resistance of wood to cutting and processing is called hardness. In addition to factors such as the moisture content of the material, the type of material and its internal structure, hardness also increases in direct proportion to density. As the moisture content increases, hardness decreases. The hardness rate is at its highest in dry wood [8]. There are currently two popular regulations for wood worldwide. These are Eurocode 5: Design of Timber Structures (EN5), which is regulated by the European Commission, and Design Specifications of Wood Construction (NDS), which is under the responsibility of the American Wood Council. EN5 is taken as a reference for the design of timber structures in TBDY [9-12]. Sheet steel is a steel material produced in the form of thin and flat sheets. It is commonly used in metalworking, construction, automotive, white goods and various industrial applications. Sheet steel is produced in various thicknesses and types and is generally preferred due to its durability, workability and versatility. Steel sheet has high strength and is resistant to impacts, abrasions and mechanical stress. Steel sheet can easily undergo many processes such as shaping, welding, cutting and painting. Steel sheets are produced as galvanized (stainless), painted or coated. This variety allows the material to be suitable for various environmental conditions and uses. Since steel sheets are generally produced in the form of thin sheets, it has been observed that they can have high carrying capacity despite being lightweight [13-15]. Examples of steel sheets of various thicknesses are given in Figure 1.

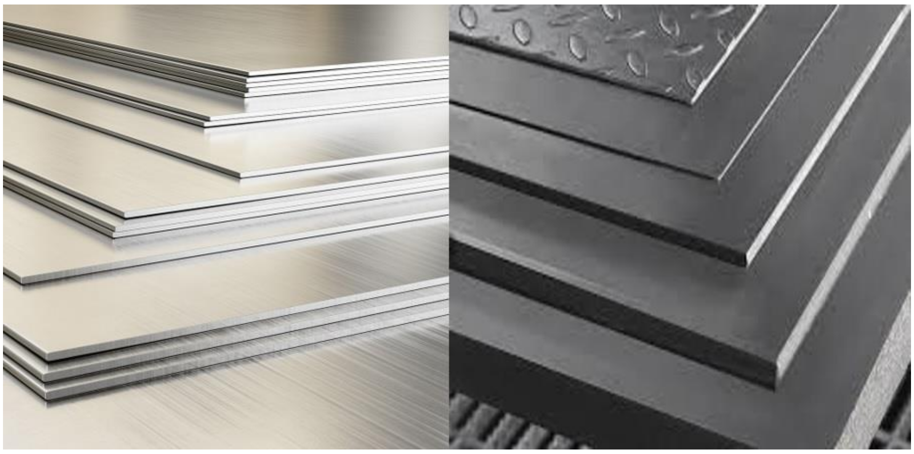

Figure 1. *Examples of steel sheets*

The rigidity of the structure is an important factor in the development of structures. Structures lose their rigidity over time due to wear and tear, or structures that do not have sufficient rigidity in the initial construction phase are in danger of collapse. Especially under the influence of vibrations, structures vibrate and oscillate like all solid objects. When these oscillations are high and uncontrolled, the structure is in danger of collapse. Similar to other physical systems, structures exhibit a natural period of vibration. Buildings vibrate according to their rigidity and the loads they are exposed to. These vibrations have a certain time and a certain order. The period is the time it takes for the structure to complete one full cycle of oscillation, that is, after vibrating, and returning to its original state is called the period of the structure. Vibration does not only occur as a result of external effects such as wind or earthquake. The structure is subject to ambient vibrations, even without significant external excitation. The period of each structure changes according to the characteristics of its carrier system. The two most important factors determining the period are the mass of the structure and the rigidity of the structure. Various strengthening methods are applied to increase the rigidity of structures or to reduce their sway [16-18]. Reinforcing floors with steel sheets is a reinforcement method used to provide additional strength to existing structures or weak floors. Steel sheets are used as reinforcement materials in floor systems due to their high durability and bearing capacity. This type of reinforcement is generally preferred to increase the bearing capacity of the structure, improve seismic performance or increase earthquake safety. Steel sheets can be added under or on top of the existing floor. These additions increase the bearing capacity of the floor and allow it to carry more loads. Steel sheets are usually fixed to the floor by welding, screwing or riveting methods. Steel sheets, especially those placed in harmony with the structural elements of the existing floor, can increase the bearing capacity. In terms of earthquake safety, the use of steel sheets in the reinforcement of floors is quite common. Steel sheets increase the rigidity of the floor, providing a more robust structure during seismic movements [19-23]. Study [24] proposes a strengthening method that improves the horizontal rigidity and strength of wooden floors in order to increase the earthquake resistance in brick wall (URM) buildings. The strengthening with steel plate grid system was evaluated by numerical modeling and experimental tests; it was shown that the method significantly increased the ground rigidity and bearing capacity. Study [25] compares the performance of fiber reinforced polymers (FRP) and steel materials in the reinforcement of timber structural elements by experimental and numerical methods. The load-bearing capacity, stiffness and deformation behavior of FRP and steel reinforced timber beams were evaluated; the high strength and cost-effectiveness of steel were highlighted against the lightness and corrosion resistance of FRP. The study [26] results show that both materials offer effective reinforcement alternatives according to different structural needs. The structural behavior of RCC and timber composite floor systems equipped with innovative shear connections has been experimentally investigated. The results show that these connections can increase the bearing capacity by up to 45% and significantly improve the stiffness. Study [27] analyzed the vibration and impact sound performance of hybrid steel-timber flooring systems by experimental measurements and numerical simulations. Two different section types (closed and open trapezoidal steel sheet) were compared and calibrated by Finite Element Model (FEM) Bayesian optimization. The results showed that the closed section system reduced the impact sound pressure level by 5 dB(A) and reduced the vibration levels by 15%. In the study [28], steel sheets were fixed to the bottom of the wooden panel with structural adhesive and mechanical fasteners (rivets/screws). In systems modeled with Finite Element Analysis (FEA), the effects of sheet thickness and connection spacing on rigidity and maximum bending moment were investigated. The findings showed that increasing the sheet thickness from 1.5 mm to 3 mm increased the flexural strength of the floor by 30–50%. In vibration analyses, steel sheet reinforcement increased the service durability by increasing the natural frequencies of the floor. Previous studies in the literature have not evaluated modal analysis and bending deformation in detail together. In order to eliminate this deficiency, a more comprehensive perspective was presented and analyzed by creating 8 separate models for all steel sheet thicknesses commonly used in the study. The aim of this study is to determine the optimum steel sheet thickness for the selected model by determining the factors in determining the optimum steel sheet thickness in the reinforcement of floors in timber structures. Thus, this study aims to contribute to the field of reinforcement in structural engineering and to prevent unconscious reinforcements that may cause more harm than good to the timber structure.

Materials and Method

In finite element stress analysis, due to the difficulty of formulating the real geometric object exactly, it is formed from elements that are easy to calculate on the computer. Then, all known physical rules are applied to each of these small elements with simpler geometry. A network structure is needed to divide the whole object into elements. The form of the object divided into elements selected according to its size and geometry is called a numerical model. Node points are created on the surfaces where the elements forming the numerical model touch each other. Using as many elements as possible is important in terms of measuring the force distribution more sensitively. The coordinates of all nodes on the x, y, z axes according to a certain starting point are determined and transferred to the computer. In addition, the Poisson's ratio and elasticity modulus values that determine the material properties of all elements forming the geometric shape are introduced to the computer program. In the mathematical model created, matrices are formed for the change situations that occur by applying the simplest external factors and boundary conditions to the nodes, and these matrices are solved with the help of a computer. In this way, the stress and deformation in each element and therefore in the entire object formed by the elements are obtained [29-32]. The finite element method is used for various engineering problems. It divides the solution region of the object and structure (engineering problem) into sub-regions and each sub-region is solved separately to obtain the whole from the part [33]. In this study, finite element method was used in modeling and analysis phase. SAP2000 software was used as software.

Existing model

The existing model is designed as timber. The model geometry is designed symmetrically. The aim of this design is to prevent the stiffness differences in the X and Y directions from affecting the results of the study. This approach ensures clarity in the obtained results. The model consists of 4 openings in the X and Y directions. The opening widths are equal and 3.5 meters. The story height is 2.5 meters. Column dimensions are selected as 15x15 cm timber. Beams are identical and wooden in the entire structure system. Beam dimensions are selected as 15x15 cm timber. The thickness of all floors is selected as 5 cm wooden considering the openings. The element types used in modeling are shell-thin and rod elements. The floors are modeled as shell-thin elements. The rigid diaphragm assumption is not made. Nodes and connection points are modeled as rigid. Information about the model is given in Table 1.

Table 1. *Model information*

Parameters	Dimensions	Piece	Material	Connection Type
X Spanning	3.5 m	4	-	Fixed
Total Length in X Direction	14 m	4	-	Fixed
Y Spanning	3.5 m	4	-	Fixed
Total Length in Y Direction	14 m	4	-	Fixed
Story Height	2.5 m	3	-	Fixed
Building Height	7.5 m	1	-	Fixed
Columns	0.15x0.15 m	75	Timber (Beech)	Fixed
Column Section Area	0.0225 m^2	75	Timber (Beech)	Fixed
Column Moment of Inertia (I_x=I_y)	4218.75 cm^4	75	Timber (Beech)	Fixed
Beams	0.15x0.15 m	120	Timber (Beech)	Fixed
Beam Section Area	0.0225 m^2	120	Timber (Beech)	Fixed
Beam Moment of Inertia (I_z)	4218.75 cm^4	120	Timber (Beech)	Fixed
Floor Thickness	0.05 m	48	Timber (Beech)	Fixed
Floor Areas	196 m2	3	Timber (Beech)	Fixed
Floor Moment of Inertia (I_z)	3645.83 cm^4	48	Timber (Beech)	Fixed
Support Type	-	25	-	Fixed

The material properties employed in the analyses were derived from TS647 [34] and reference [35] for timber, and from [9] and the Turkish Seismic Code TBDY 2018 [36] for steel. Beech was selected as the representative timber species in accordance with the relevant standards. The important material properties are given in Table 2.

Table 2. *Material properties*

Properties	Timber (Beech)	Steel Sheet
Type of Material	Orthotropic	Isotropic
Density (g/cm^3)	0.64	7.8
Modulus of elasticity (E_x)	13800 MPa	200000 MPa
Modulus of elasticity (E_y)	1160 MPa	200000 MPa
Modulus of elasticity (E_z)	2280 MPa	200000 MPa
Poisson's ratio (ν_{xy})	0.44	0.30
Poisson's ratio (ν_{yz})	0.35	0.30
Poisson's ratio (ν_{xz})	0.07	0.30

Finite element view of the existing model is given in Figure 2.

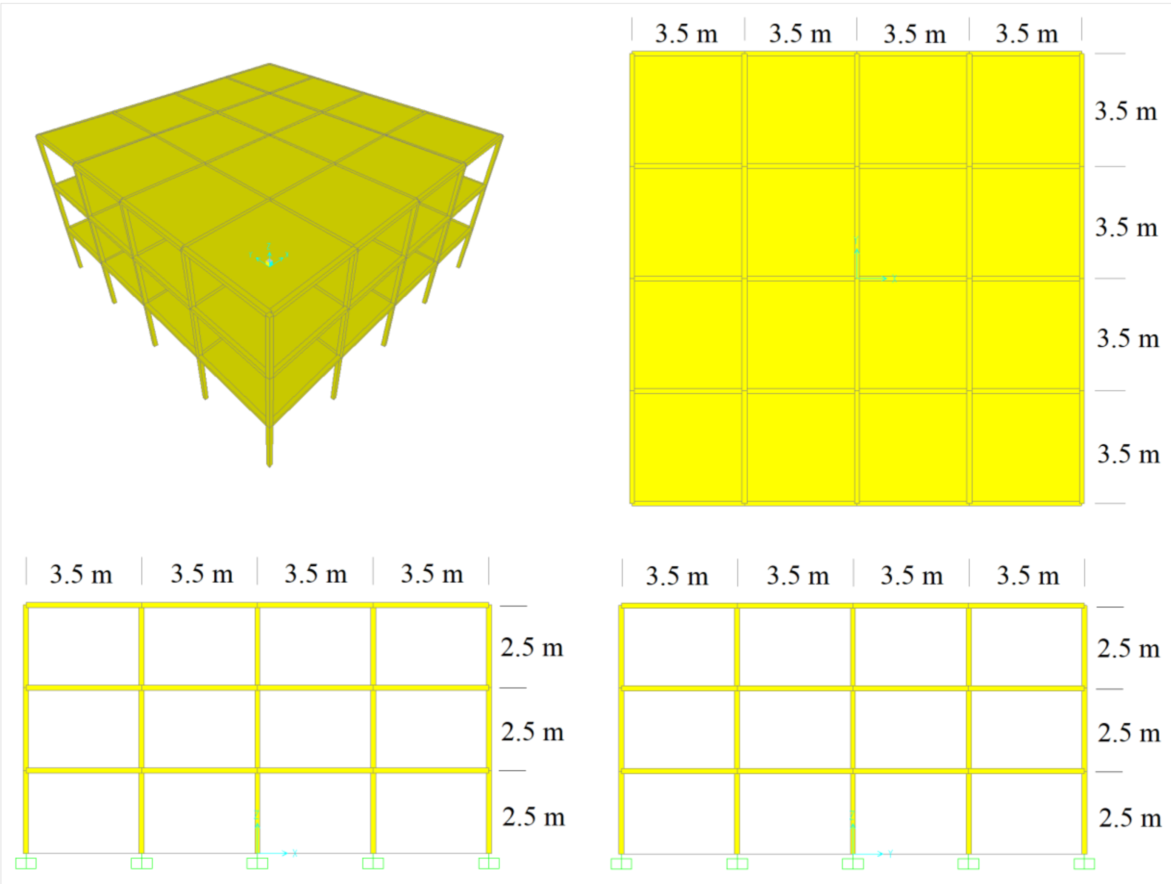

Figure 2. *Finite element view of the existing model*

Reinforced Models

In the existing model, only the floors will be covered with steel sheets fixed along the top surface. The reinforcement process with steel sheet includes all floors. 8 different models were created, reinforced with 0.1 mm, 0.2 mm, 0.5 mm, 1 mm, 2 mm, 5 mm, 10 mm and 20 mm steel sheets, respectively. 8 different models are given as a single finite element view of the reinforced model in Figure 3.

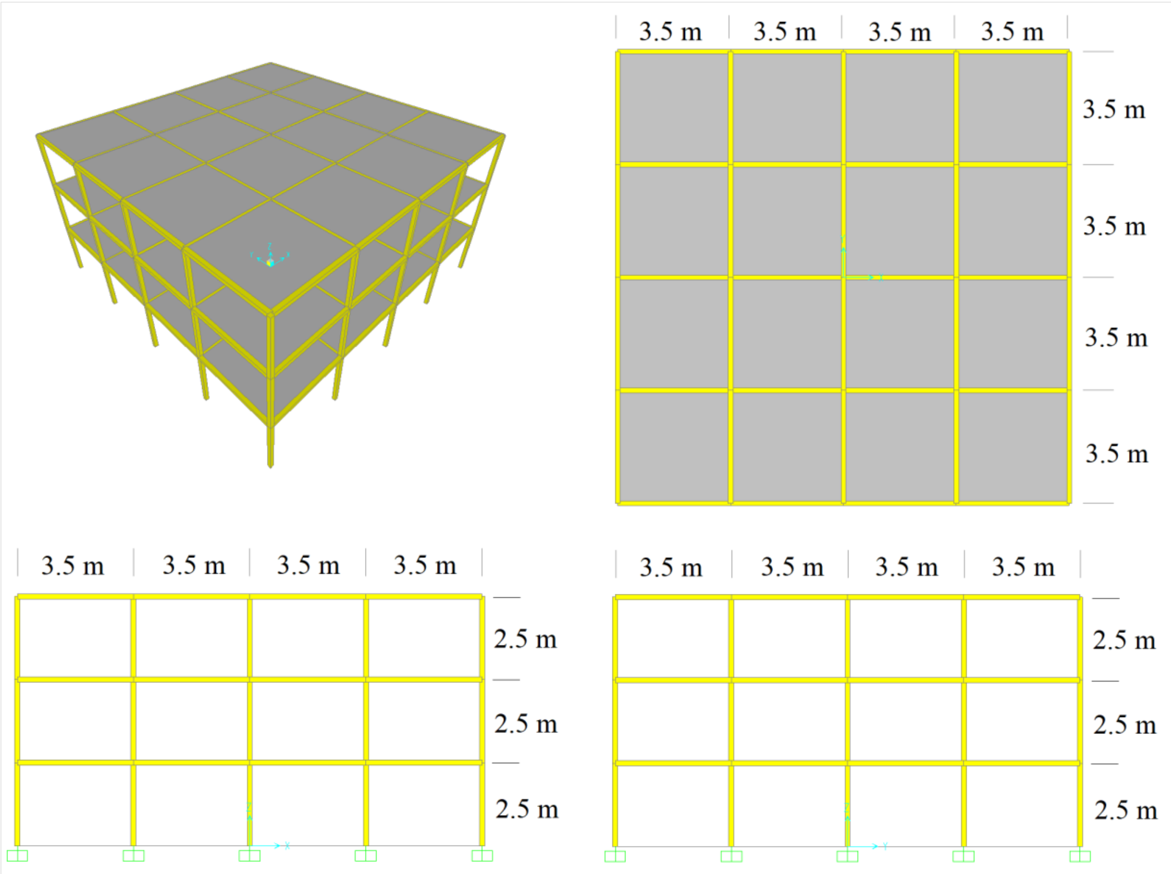

Figure 3. *Finite element view of the reinforced models*

Results and Discussion

Deflection in slabs is considered to be a fundamental parameter to be taken into consideration in terms of structural performance. For this purpose, the deflection capacity of the existing model and slab models reinforced with steel sheet of different thicknesses were examined in the analyses. Dead loads were taken as the primary load case when calculating the deflection amount. In addition to the deflection examination, modal analysis was performed for each model in order to interpret the rigidity of the models. In the modal analysis for both model, 240 modes of the model were examined. Total mass participation ratios were found to be U_x= 99.99, U_y=99.99, U_z=99.99 (Static and Dynamic percents), respectively.

Existing model

Deflection of the existing model slabs was performed using the finite element method. The deflections of the existing model slabs are given in Figure 4.

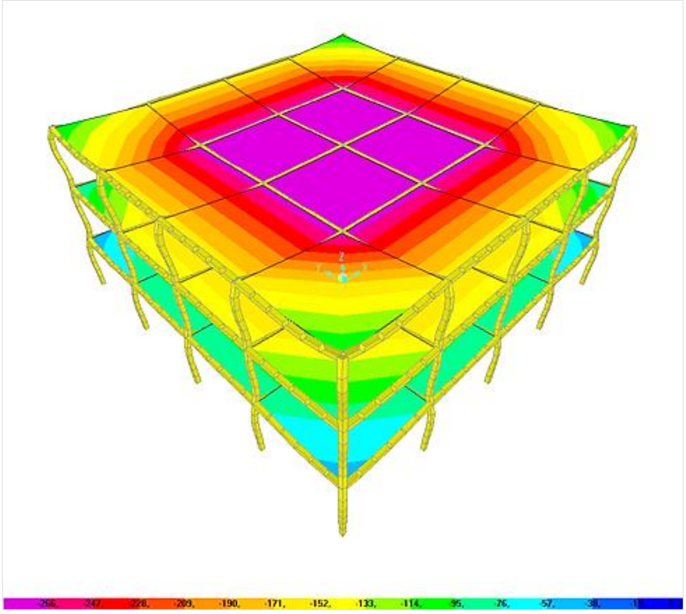

Figure 4. *The deflections of the existing model slabs*

The maximum deflection value of the slabs of the existing model was obtained as 0.277 mm. Modal analysis of the existing model was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 5.

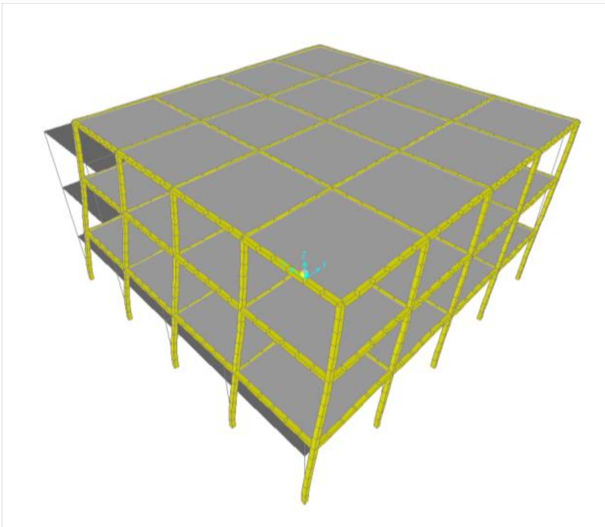

Figure 5. *The existing model first mode (Period value=0.63 s, translation)*

The period value of the existing model was obtained as 0.63 s. The first mode shape of existing model was observed translation X.

Reinforced models

8 different models were analyzed, reinforced with 0.1 mm, 0.2 mm, 0.5 mm, 1 mm, 2 mm, 5 mm, 10 mm and 20 mm steel sheets, respectively.

Reinforced model with 0.1 mm steel sheet

The deflections of the reinforced model with 0.1 mm steel sheet slabs are given in Figure 6.

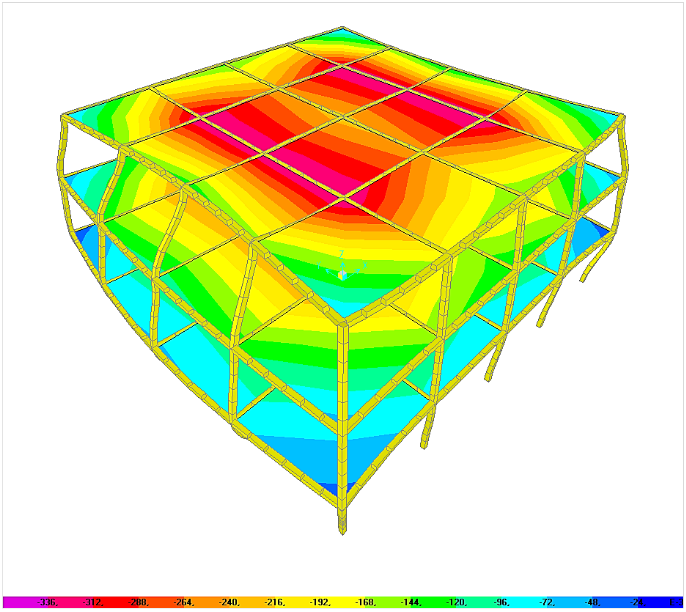

Figure 6. *The deflections of the reinforced model with 0.1 mm steel sheet slabs*

The maximum deflection value of the slabs of the reinforced model with 0.1 mm steel sheet was obtained as 0.339 mm.
Modal analysis of the reinforced model with 0.1 mm steel sheet was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 7.

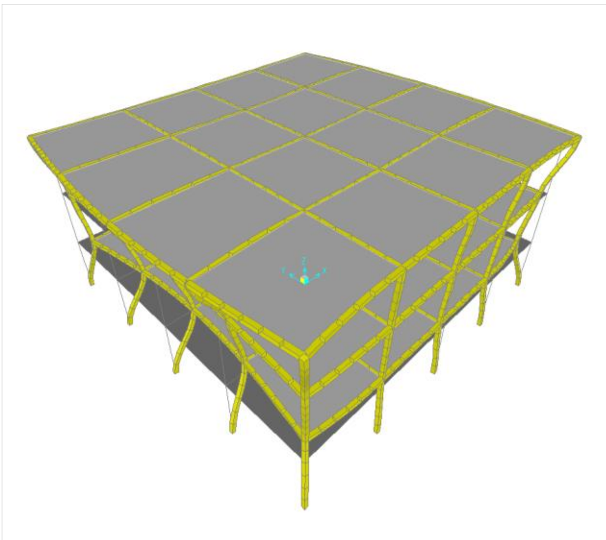

Figure 7. *The reinforced model with 0.1 mm steel sheet first mode (Period value=0.64 s, torsion)*

The period value of the reinforced model with 0.1 mm steel sheet was obtained as 0.63 s. The first mode shape of reinforced model with 0.1 mm steel sheet was observed torsion.

Reinforced model with 0.2 mm steel sheet

The deflections of the reinforced model with 0.2 mm steel sheet slabs are given in Figure 8.

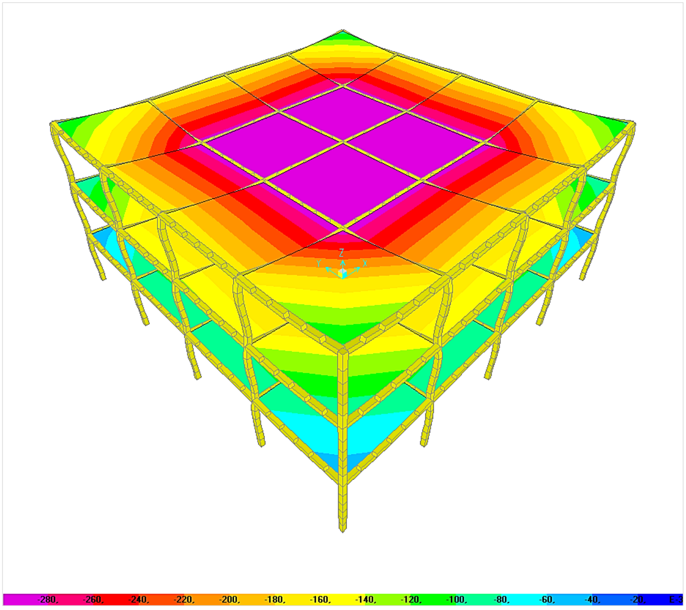

Figure 8. *The deflections of the reinforced model with 0.2 mm steel sheet slabs*

The maximum deflection value of the slabs of the reinforced model with 0.2 mm steel sheet was obtained as 0.292 mm. Modal analysis of the reinforced model with 0.2 mm steel sheet was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 9.

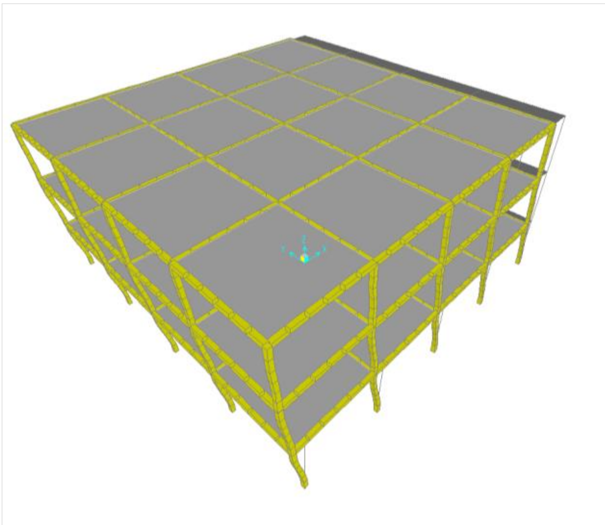

Figure 9. *The reinforced model with 0.2 mm steel sheet first mode (Period value=0.43 s, translation)*

The period value of the reinforced model with 0.2 mm steel sheet was obtained as 0.43 s. The first mode shape of reinforced model with 0.2 mm steel sheet was observed translation X.

Reinforced model with 0.5 mm steel sheet

The deflections of the reinforced model with 0.5 mm steel sheet slabs are given in Figure 10.

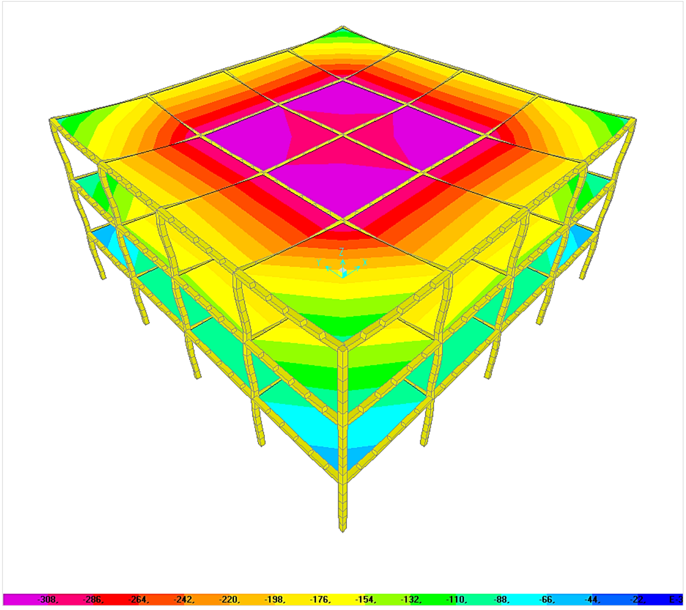

Figure 10. *The deflections of the reinforced model with 0.5 mm steel sheet slabs*

The maximum deflection value of the slabs of the reinforced model with 0.5 mm steel sheet was obtained as 0.310 mm. Modal analysis of the reinforced model with 0.5 mm steel sheet was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 11.

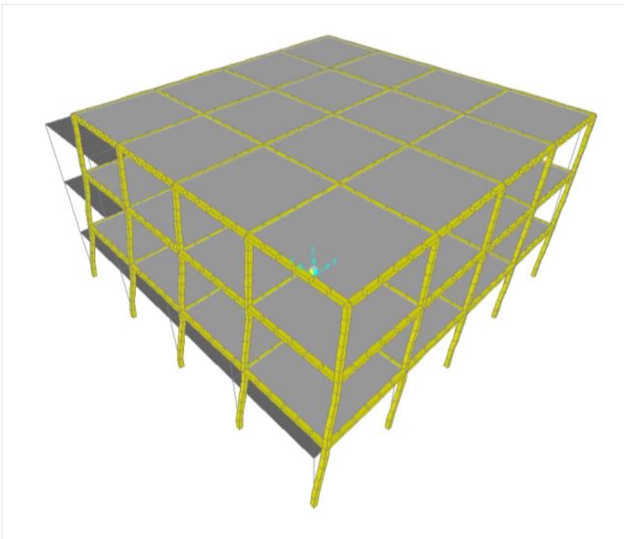

Figure 11. The reinforced model with 0.5 mm steel sheet first mode (Period value=0.45 s, translation)

The period value of the reinforced model with 0.5 mm steel sheet was obtained as 0.45 s. The first mode shape of reinforced model with 0.5 mm steel sheet was observed translation X.

Reinforced model with 1 mm steel sheet

The deflections of the reinforced model with 1 mm steel sheet slabs are given in Figure 12.

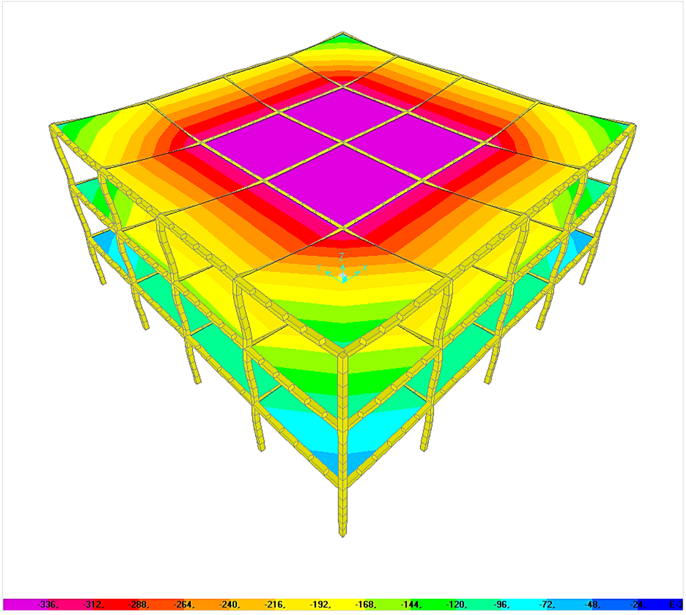

Figure 12. *The deflections of the reinforced model with 1 mm steel sheet slabs*

The maximum deflection value of the slabs of the reinforced model with 1 mm steel sheet was obtained as 0.341 mm. Modal analysis of the reinforced model with 1 mm steel sheet was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 13.

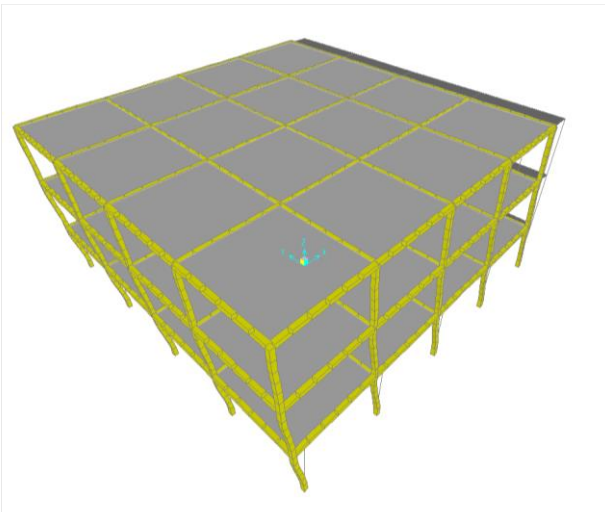

Figure 13. *The reinforced model with 1 mm steel sheet first mode (Period value=0.47 s, translation)*

The period value of the reinforced model with 1 mm steel sheet was obtained as 0.47 s. The first mode shape of reinforced model with 1 mm steel sheet was observed translation X.

Reinforced model with 2 mm steel sheet

The deflections of the reinforced model with 2 mm steel sheet slabs are given in Figure 14.

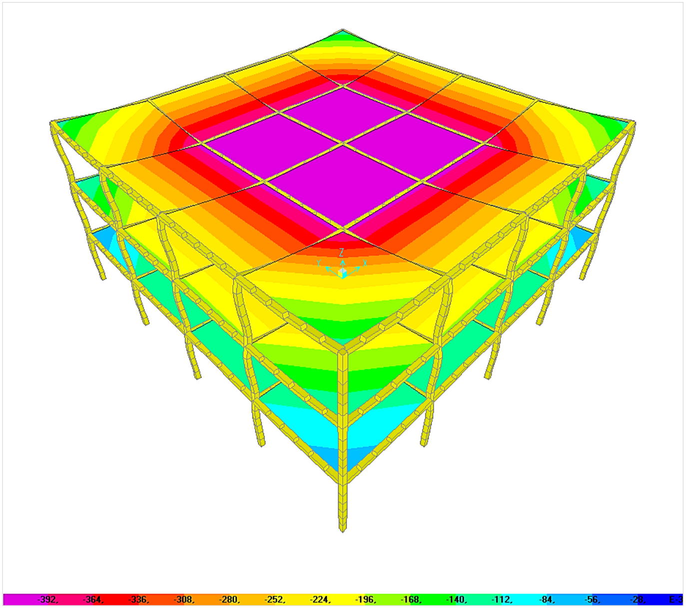

Figure 14. *The deflections of the reinforced model with 2 mm steel sheet slabs*

The maximum deflection value of the slabs of the reinforced model with 2 mm steel sheet was obtained as 0.407 mm. Modal analysis of the reinforced model with 2 mm steel sheet was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 15.

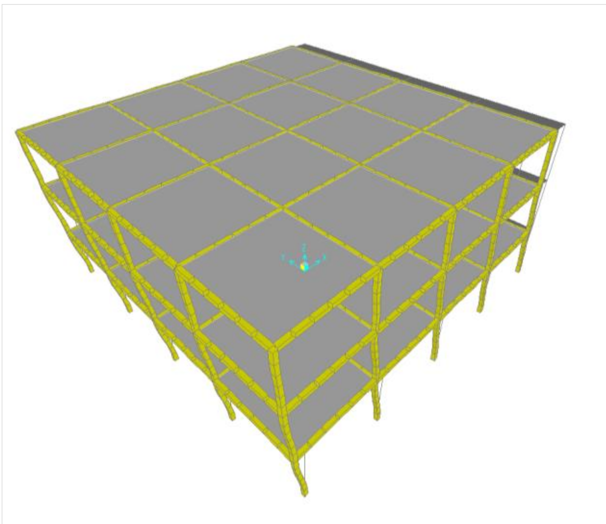

Figure 15. *The reinforced model with 2 mm steel sheet first mode (Period value=0.51 s, translation)*

The period value of the reinforced model with 2 mm steel sheet was obtained as 0.51 s. The first mode shape of reinforced model with 2 mm steel sheet was observed translation X.

Reinforced model with 5 mm steel sheet

The deflections of the reinforced model with 5 mm steel sheet slabs are given in Figure 16.

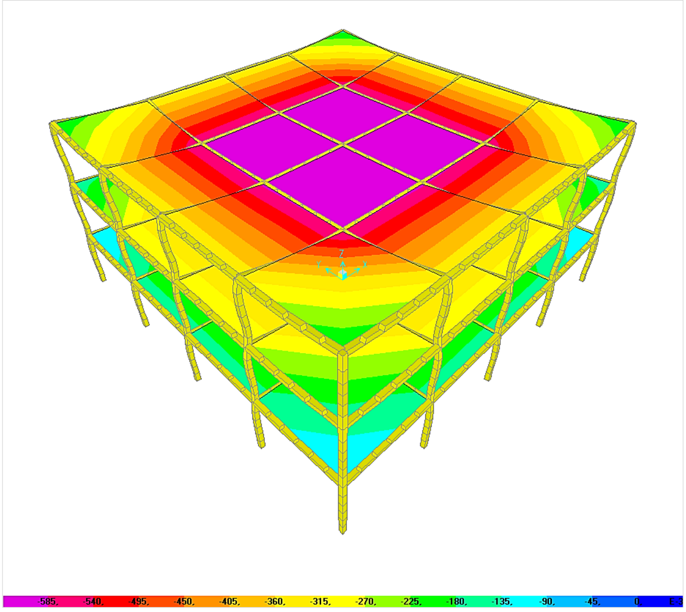

Figure 16. *The deflections of the reinforced model with 5 mm steel sheet slabs*

The maximum deflection value of the slabs of the reinforced model with 5 mm steel sheet was obtained as 0.608 mm. Modal analysis of the reinforced model with 5 mm steel sheet was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 17.

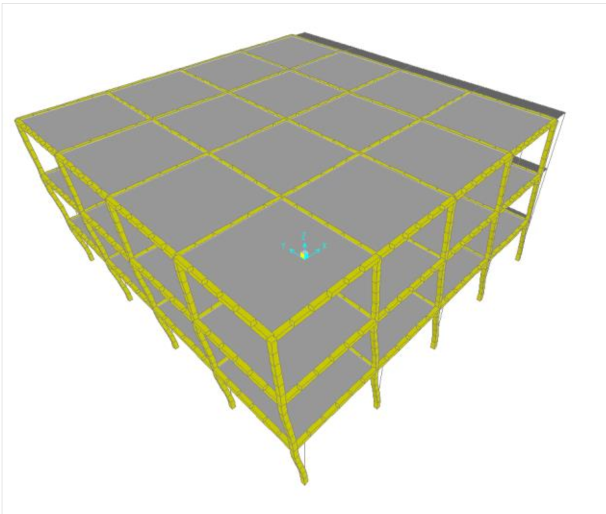

Figure 17. *The reinforced model with 5 mm steel sheet first mode (Period value=0.62 s, translation)*

The period value of the reinforced model with 5 mm steel sheet was obtained as 0.62 s. The first mode shape of reinforced model with 5 mm steel sheet was observed translation X.

Reinforced model with 10 mm steel sheet

The deflections of the reinforced model with 10 mm steel sheet slabs are given in Figure 18.

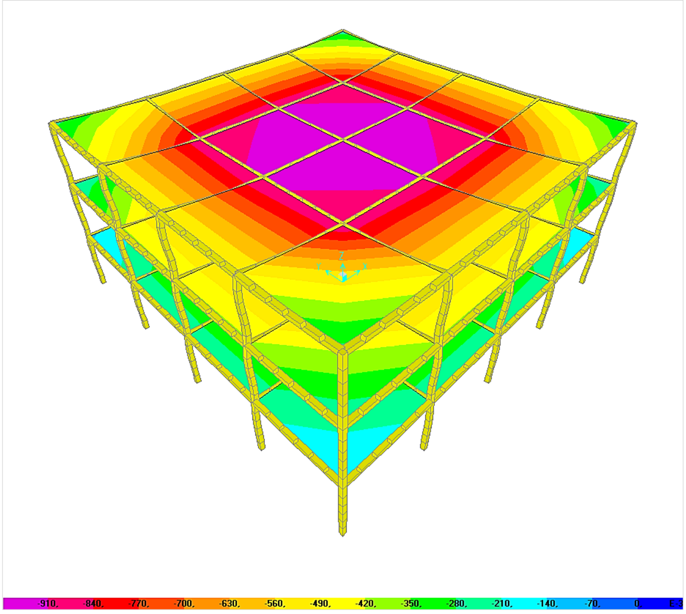

Figure 18. *The deflections of the reinforced model with 10 mm steel sheet slabs*

The maximum deflection value of the slabs of the reinforced model with 10 mm steel sheet was obtained as 0.944 mm. Modal analysis of the reinforced model with 10 mm steel sheet was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 19.

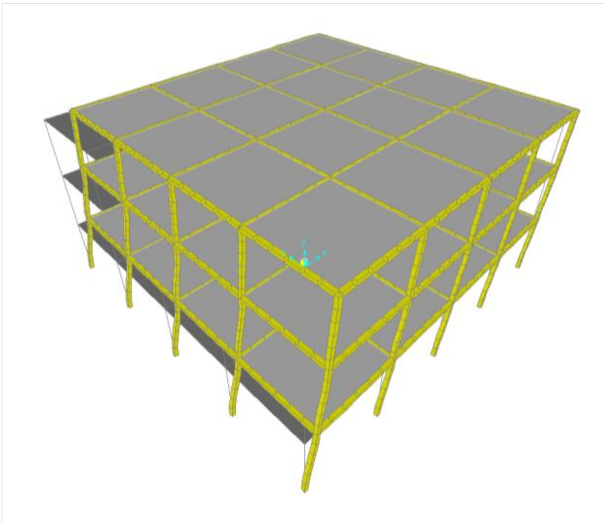

Figure 19. *The reinforced model with 10 mm steel sheet first mode (Period value=0.77 s, translation)*

The period value of the reinforced model with 10 mm steel sheet was obtained as 0.77 s. The first mode shape of reinforced model with 10 mm steel sheet was observed translation X.

Reinforced model with 20 mm steel sheet

The deflections of the reinforced model with 20 mm steel sheet slabs are given in Figure 20.

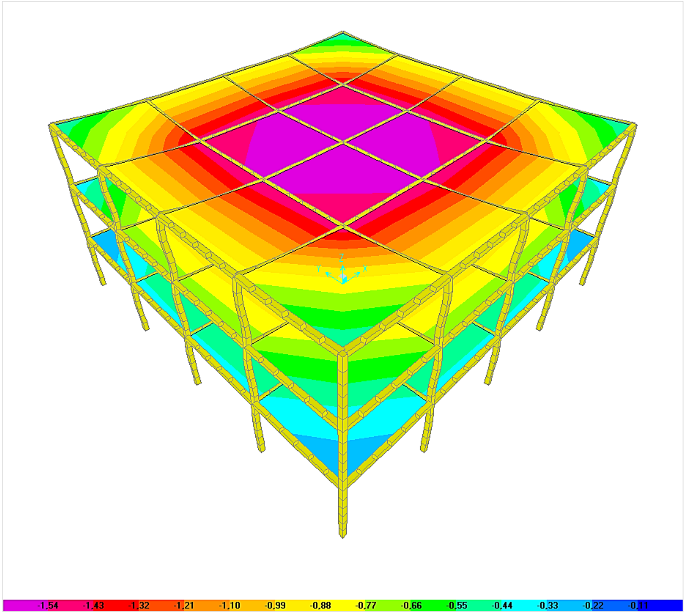

Figure 20. *The deflections of the reinforced model with 20 mm steel sheet slabs*

The maximum deflection value of the slabs of the reinforced model with 20 mm steel sheet was obtained as 1.623 mm. Modal analysis of the reinforced model with 20 mm steel sheet was performed using the finite element method. The mode shape of the first mode (dominant mode) is given in Figure 21.

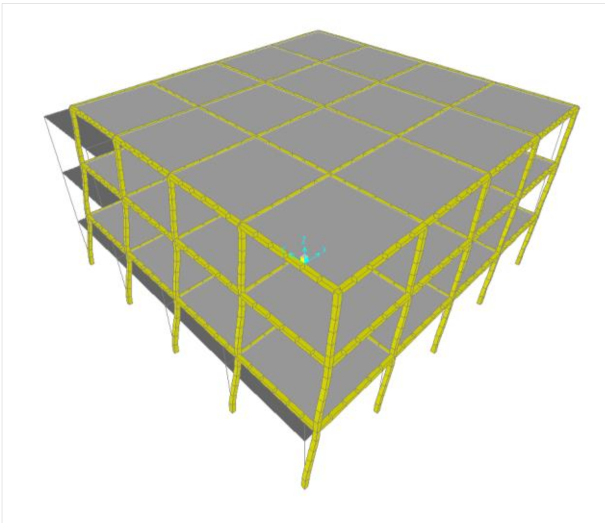

Figure 21. *The reinforced model with 20 mm steel sheet first mode (Period value=0.99 s, translation)*

The period value of the reinforced model with 20 mm steel sheet was obtained as 0.99 s. The first mode shape of reinforced model with 20 mm steel sheet was observed translation X.

Comparison of Results

In this section, the existing model is compared with the new models formed by reinforcing the floors of the existing model with steel sheets of different thicknesses. In order to reveal the differences, the comparison is made based on the existing model results. A comparison of the findings for all models is given in Table 3.

Table 3. *Comparison of the findings*

Models	1. Mode Period Value (s)			Deflection (mm)			1. Mode Shape	
	Period (s)	Difference (s)	Difference (%)	Deflection Max (mm)	Difference (mm)	Difference (%)	Mode Shape	Transformation
Existing	0.63	0	0	0.277	0	0	Translation	No
0.1 mm	0.64	0.01	1.59	0.339	0.062	22.38	Torsion	Yes
0.2 mm	0.43	-0.2	-31.75	0.292	0.015	5.42	Translation	No
0.5 mm	0.45	-0.18	-28.57	0.31	0.033	11.91	Translation	No
1 mm	0.47	-0.16	-25.54	0.341	0.064	23.1	Translation	No
2 mm	0.51	-0.12	-19.05	0.407	0.13	46.93	Translation	No
5 mm	0.62	-0.01	-1.59	0.608	0.331	119.49	Translation	No
10 mm	0.77	0.14	22.22	0.944	0.667	240.79	Translation	No
20 mm	0.99	0.36	57.14	1.623	1.346	485.92	Translation	No

The graph of period values and deflection values in the 1st mode for all models is given in Figure 22.

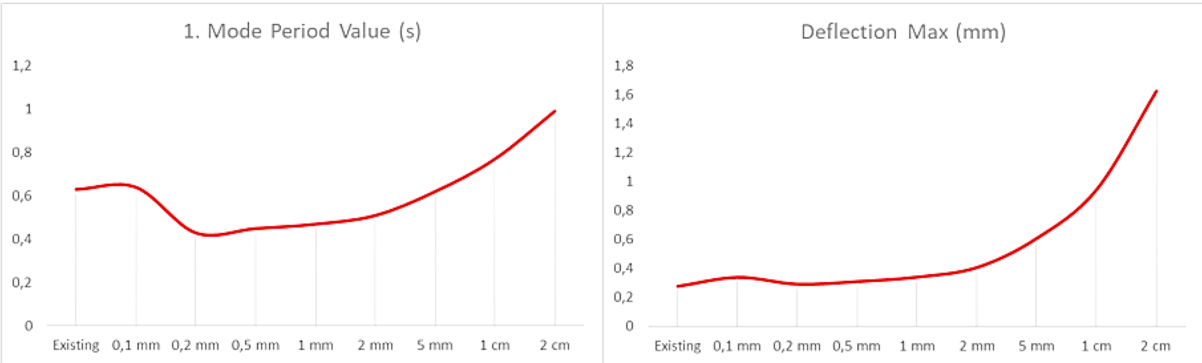

Figure 22. *The graph of period values and deflection values*

In the timber structure model whose floors were reinforced with 0.1 mm steel sheet, the period increase in the 1st mode was 1.59%, the maximum deflection was 22.38%, and the mode shape changed from translational mode shape to torsional mode shape. The reason for this change is that the 0.1 mm steel sheet is too thin and the mass-rigidity ratio is insufficient. In addition, the modal mass participation in the Z direction caused torsions in the horizontal plane. According to these results, it was seen that the rigidity of the timber structure model decreased with the reinforcement with 0.1 mm steel sheet. In addition, it is understood that the formation of torsion in the 1st mode shape further endangers the stability of the structure. In the timber structure model whose floors were reinforced with 0.2 mm steel sheet, the period decrease in the 1st mode was 31.75%, the maximum deflection was 5.42%, and the mode shape has not changed. These findings indicate that the rigidity of the timber structure model was clearly increased with the reinforcement with 0.2 mm steel sheet. It was also observed that the mode shape was preserved. However, a low increase was observed in the maximum deflection. In the timber structure model whose floors were reinforced with 0.5 mm steel sheet, the period decrease in the 1st mode was 28.57%, the maximum deflection was 11.91%, and the mode shape has not changed. These findings indicate that the rigidity of the timber structure model was clearly increased with the reinforcement with 0.5 mm steel sheet. It was also observed that the mode shape was preserved. However, some increase in maximum deflection was observed. In the timber structure model whose floors were reinforced with 1 mm steel sheet, the period decrease in the 1st mode was 25.54%, the maximum deflection was 23.1%, and the mode shape has not changed. These findings indicate that the rigidity of the timber structure model was clearly increased with the reinforcement with 1 mm steel sheet. It was also observed that the mode shape was preserved. However, a significant increase in maximum deflection was observed. In the timber structure model whose floors were reinforced with 2 mm steel sheet, the period decrease in the 1st mode was 19.05%, the maximum deflection was 46.93%, and the mode shape has not changed. These findings indicate that the rigidity of the timber structure model was clearly increased with the reinforcement with 2 mm steel sheet. It was also observed that the mode shape was preserved. However, a significant increase in maximum deflection was observed. In the timber structure model whose floors were reinforced with 5 mm steel sheet, the period decrease in the 1st mode was 1.59%, the maximum deflection was 119.49%, and the mode shape has not changed. These findings indicate that the rigidity of the timber structure model was little increased with the reinforcement with 5 mm steel sheet. It was also observed that the mode shape was preserved. However, an extreme increase in maximum deflection was observed. In the timber structure model whose floors were reinforced with 1 cm steel sheet, the period increase in the 1st mode was 22.22%, the maximum deflection was 240.79%, and the mode shape has not changed. These findings indicate that the rigidity of the timber structure model was decreased clearly with the reinforcement with 1 cm steel sheet. It was also observed that the mode shape was preserved. However, a significant increase in maximum deflection was observed. In the timber structure model whose floors were reinforced with 2 cm steel sheet, the period increase in the 1st mode was 57.14%, the maximum deflection was 485.92%, and the mode shape has not changed. These findings indicate that the rigidity of the timber structure model was decreased clearly with the reinforcement with 2 cm steel sheet. It was also observed that the mode shape was preserved. However, a significant increase in maximum deflection was observed.

Conclusions

According to the timber structure model used in this study, the main findings regarding the reinforcement of timber floors with steel sheet are presented below:

- The use of 0.1 mm and thinner steel sheets has shown that the structure is negatively affected in terms of dynamics, statics and stability.
- Steel sheet with a thickness of approximately 0.2 mm was determined as the most suitable value for reinforcement.

- Steel sheets in the range of between 0.1 mm and 0.5 mm stand out as the most efficient thickness range in terms of both static and dynamic performance.
- Although sheet thicknesses between 0.5 mm and 5 mm increase dynamic performance, it has been observed that static efficiency decreases due to the increase in deflection values. This makes the thickness range less efficient in terms of overall structural performance.
- The use of steel sheet thicknesses of 5 mm and above reduced the rigidity of the structure, caused stability problems and negatively affected the safety of the structure.
- In such reinforcement applications, which are especially common in rural areas and carried out unconsciously, it is thought that using thicker sheet metal will benefit the structure. However, the findings clearly demonstrate that this approach is not supported by engineering evidence.
- As the sheet metal thickness moves away from the optimum value, rigidity decreases, stability problems arise and structural safety is at risk.

In the light of these results, it is suggested that when reinforcing timber structure floors with steel sheet, the sheet thickness should be determined based on optimum design parameters.

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Authors Contribution The author read and approved the final manuscript

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