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Investigation of the Effects of Different Types of Traditional Timber Load-Bearing Systems Used in Turkey on Building Behaviour

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Abstract

Recently historic timber structures in Turkey are unfortunately not given the value they deserve. Although timber structures are unique symbols of our cultural heritage, they are forgotten for natural and human reasons. On the other hand, when traditional timber structures standing today to repairs and / or reinforcements and restorations are examined, it is seen that timber elements according to the knowledge and skill of construction foreman are constructed with different types of structural systems. This matter reveals that choosing the right timber structural system is very important. This study the effects of their behaviour of traditional timber structural systems of different types widely used in the construction of timber structures in Turkey were comparatively examined. With this purpose, teen different structural system models with the Sta-stell program of the timber-framed (with Çatkı) Safran mansion which is widely used in Turkey were created and the findings were compared with each other by carried out structural analyses. The findings obtained reveal that buttresses are important in meeting, distributing and transferring the loads acting on the structural system, especially earthquake loads, to the foundation and the displacement distributions in the storey levels of the buttressed building models are less. In addition, the findings obtained show that buttresses that increase the lateral rigidity of timber structures increase the performance of the structure in question and reduce the internal forces of the structural elements. Turkey's widely used timber structural systems (in accordance with the Safran mansion architecture, which received the best restored mansion award) were modelled and analysed. The results presented are aimed to design recommendations and better understanding of the behaviour of different timber structural systems in today's architectural practice.

Keywords:
Buttress, timber structures, timber structure design, timber structural systems

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INTRODUCTION

Historical buildings, which are an important reflection of our cultural heritage, form a link between past civilizations and today. Through these structures, it is possible to understand and interpret civilization. These structures, which are forgotten for many social, cultural and economic reasons, are sometimes protected by the state and sometimes by the private sector and / or individuals. For this reason, protecting of these structures and transferring them to the future generations have a great importance like other historical buildings (Gürsoy et al. 2009). However, many of historical timber structures in Turkey, unfortunately, do not see the value it deserves. Timber structures, which are unique symbols of cultural heritage, have been suffered many damages due to natural and human reasons. Therefore, the protection of timber structures is very important for their permanence. In other words, to periodically repair these unique cultural values and to protect them by developing appropriate rescue projects are necessary.

There are many factors that cause the timber structures to be damaged over time. These may be factors due to the physical, chemical and biological structures of timber, as well as factors caused by people and natural disasters (Örmecioğlu et al. 2013, Saatci & Gürsoy 2019). These factors negatively affect the current situation at the point of inheritance to the future of timber structures. For this reason, to know the problems of timber structures and to take necessary measures against these problems are very important. It is possible to increase the resistance of timber structures by making connection calculations according to the load effects that affect the structure, by considering wind and earthquake effects and particularly the structural system arrangement. On the other hand, it is necessary to make static calculations that include engineering knowledge as well as architectural aesthetics. In addition, it is necessary to obey the current standards and provisions of the regulations in the protection of timber structures and to provide update the standards and/or regulations regarding timber structures depending technological developments and to develop on structural analysis programs.

In studies made on the protection of timber structures; it is necessary to consider along with design, the sizing and combination details calculations. It is necessary to consider statically the negative effects of natural and human damage factors that occur or may occur in historic timber structures on the structural system of the building in question in the restoration studies be carried out. Thus, not only the formalistically restoration of the old will be provided toward preservation of the timber structure, but also by creating durable, useful, and developable structures will be provided to stay standing up longer.

It is possible to classify literature research on timber structures under generally those headings; studies on earthquake behaviours of timber structures (Bayülke 2001, Ahunbay & Aksoy 2005, Doğangün et al. 2006, Cakir et al. 2016), studies examining protection of materials used in timber structures, their physical and mechanical properties and studies examining on resisting capacity of timber structural systems (Çobancaoğlu 2003, Yaman 2007). In addition to; Cruz et al. (2015) have given information's on the criteria to be used in the assessment of structural timber structures in heritage buildings. Wang et al. (2018) have reviewed and contrasted potential sources of biodegradation that exist for traditional wood construction with those in mass timber

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construction and have identified methods for limiting the degradation risk. Cura & Eyüpgiller (2019) urban space analyses made through field surveys to document the present situation in Şile Balibey district, identify the problems, assess the potentials and recommendations developed to reveal these potentials. Koca (2019) focused on the evaluation of Şirince according to sustainable construction principles and suggested some interventions to increase the sustainability. Aloisio et al. (2020) assessed the fragility functions and behaviour factors of cross-laminated timber (CLT) structures. With this purpose the Aloisio et al. derived from the assembly of single CLT wall panels, the structures of which are characterized by different configurations. Gündoğdu & Birer (2021) revealed the relationships between vernacular traditional houses of Mersin and ecological architecture and suggested as a guide and reference for architects to design and construct in a way that they do not harm the natural environment and ecological balance by learning from vernacular architecture.

By adhering to the Safran Konak architecture in Safranbolu Bağlar-Köyiçi Square chosen as an example in this study, behaviours against all load effects including the earthquake by creating different models of timber structural system applied in Turkey are examined comparatively. In addition, the effects of buttresses, which are widely used in timber structures, on the dynamic behaviours of the structure are investigated.

TIMBER STRUCTURE STRUCTURAL SYSTEMS USED IN TURKEY

Timber structures are generally made of stone (masonry) material up to the basement storey and/or subbasement elevation of the structure according to the topographic structure of the land. This part of the structure made using stone material is mostly used as warehouse, coalbunker and the entrance is provided from outside. A structural system constructing of timber material is established on the wall built with stone material. Timber structural system elements consist of timber posts, beams, buttresses and connecting elements. After the timber base groundsill beams are placed corner posts are placed on them, intermediate posts and buttresses are placed between them. In addition, in accordance with the architectural project door and window gaps are left and short beams called "kuşak" are placed on required points at the lower and upper parts of doors and windows for the purpose of strengthen the structure to. The timber posts lengths are generally up to the storey height and for to carrying the load of the upper flooring are placed on the groundsill beams of the upper floor to timber posts headpiece.

Timber structures are classified in different ways in terms of architecture and structural systems. Because different structural systems have been applied depending on the material existing in timber structures, the knowledge and skill of the master, the climatic conditions of the region and the economic power of the owner. Depending on the structural system elements applied on the walls of a timber structure and the working styles of these elements under load effects, it is possible to classify the timber structures as follows (see Figure 1). There are timber structures creating from the timber logs, panels, and the frame in Turkey. In order words, there are different types of timber structure structural systems in Turkey.

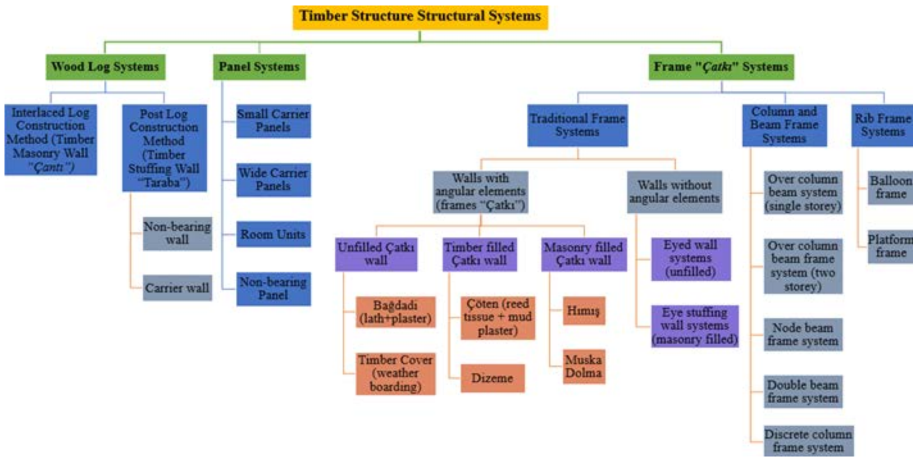

Figure 1. Structural systems and wall shapes of timber structures.

Timber Structures Created to the Structural System from Timber Logs

Such structural systems are encounter on areas where abundant of generally mountainous and forest areas in the Western Black Sea, Bolu and Gerede regions. These systems are also expressed to as block (masonry) timber structures. In their construction two different construction methods are applied impending interlaced and columned.

Interlaced log construction method (timber masonry wall "Çantı")

This system is the most applied construction method in timber masonry structures. These are systems where billets or planks are prepared in advance and are made with the technique of throat overlapping according to the number order (see Figure. 2). In these systems, it is not possible to increase the number of storey due to overweight of the structure. In these, from upper logs to lower logs is transferred vertical load. These structures, which are called square and rectangular planned serender, nayla and paska, which are generally used for warehouse, cellar, purposes, are made with an interlaced logs system. Timber posts placed on the flat large stones transfer the load as a concentrated to the ground (see Figure 3).

Post log construction method (timber stuffing wall "Taraba")

It is a wall system created by passing through the grooves opened in the posts placed to the corners of the structure and between them. In these systems 2,5~6 cm thick and 30~40 cm wide planks and logs are intertwining horizontally and/or vertically. Intermediate posts are used to leave space on the wall surface (see Figure 4).

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a) Systems created from logs (Başkan 2008) b) Systems created from logs (Arun 2009)

Figure 2. Timber masonry wall technique *"Çantı"*

a) Serender structure example (Başkan, 2008) b) Schematic representation of a Serender structure (Güneş, 2014)

Figure 3. Various views from timber Serender structure.

Figure 4. Example of timber stuffing wall *"Taraba"* (Arun, 2012).

Timber Structures Created from Structural System Panels

These systems are generally preferred for offices and for the construction of single storey school buildings. Timber panel elements consist of single or two-wall artificial timber plate panels. The constructions of the exterior wall panels with the construction of the floor panels are similar. The dimensions of the exterior wall panels are selected according to the timber plate sizes.

Timber Structures Created from Structural System Frames

Timber structural systems are the systems the loads affecting the structure are met by posts, beams, purlins, base and diagonal elements and these loads are ensuring the transferred to the foundation of the structure. Considering these structural systems to be applicable, evaluated as the most preferred type of timber structure in Turkey.

The main structural system, which consists of the posts, angular and horizontal elements that form the structural skeleton in traditional timber framed systems, is called the frame (see Figure 5). In these structural systems to increase the strength corner and central posts are supported with angular elements (diagonal elements). These diagonals different forms are placed in a X, V, Λ shape. There is not any rule in the size and location of the diagonals. However, in case of short diagonal elements are placed it can create large shear forces.

Figure 5. Timber frame *"çatkı"* example in Bilecik Osmaneli (Güneş, 2014).

Walls with angular elements (frames "Çatkı")

The gaps between the elements that make up the frame system are sometimes left empty and sometimes filled with timber, adobe, brick, or stone material. In these systems, patterns are created with filling materials such as sometimes brick or stone in the inner and outer parts of the outer walls therefore have this system also possible to come across unplastered timber structures with this system. Also, angular elements (diagonal) elements used on the outer walls of the timber structures that are applied to the frame act as a cross shear wall in the said structure. The walls where the frame is applied consist of two parts namely filling and structural skeleton. Different Çatkı techniques are used according to styles of infilling of the gaps between the posts and the technique used in the creation of the system.

Unfilled Çatkı wall

The gaps between the horizontal, vertical and angular elements that make up the structural system are the walls formed by not filling them using any filling material. These are divided into two as Bağdadi and timber cover, too.

a) Bağdadi (lath + plaster)

The plaster the made over laths which are frequently intervals nailing over the frames (Çatkı) is called the bağdadi plaster. The gaps between the walls during the plastering of the front and back parts of the walls are

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ventilated with the entrance-exit holes. In this way, hot-cold air insulation is provided. Bağdadi plaster is made with thick or thin laths (see Figure 6). After they are covered with wire grid (Rabitz wire) between the laths placed they are plastered. In the 1970 Gediz earthquake, he emphasized that the bağdadi timber structures behaved better than according to hımış timber structures and that the damages were less (Doğangün et al. 2005).

b) Timber cover (weather boarding)

It is a type of wall created by nailing timber veneer boards over the structural system elements. These timber covers are nailed overlapped or straight. This system which is constructed on the purpose of the discharge of rainwater that overlaps and hits the surface is called as weather boarding. There are examples of timber structures made with the bağdadi and weather boarding technique (see Figure 7).

Figure 6. Examples of timber structures made with the Bağdadi technique.

Figure 7. Examples of timber structures made with bagdadi and weather boarding technique (Güneş, 2014).

Timber filled Çatkı wall

The gaps between the horizontal, vertical and angular elements that make up the structural system are the walls formed by filling them timber filling material. These are divided into two as çöten and dizeme depending on the type of material used and the application method.

a) Çöten (reed tissue + mud plaster)

The gaps between the çatkı elements the walls formed by horizontally knitting with thin branches with a thickness of 2~3 cm is called çöten. These are generally applied in the West and Central Black Sea Region. The gaps between çöten are filled by plastering from the externally and internally (see Figure 8).

b) Dizeme

The walls formed by placing horizontally and vertically under-treated timber pieces into the gaps between the frame elements are called dizeme. There are as well as plaster and non-plastered samples between the pieces of timber (see Figure 9). However, if the timber pieces are thick in case of it is difficult to hold plaster. To keep the plaster to be applied better there are also examples where laths are nailed like the bağdadi technique (Doğangün et al. 2005). This case, stiffness of structures therefore makes a significant contribution to the resistance during an earthquake (Köylü 2008). Since these timber elements (dizeme) join the frame elements with nails, they work on tensile and pressure in earthquakes.

a) unplastered b) plastered

Figure 8. Example of timber structure made with *çöten* wall and this technique (Güneş 2014).

a) unplastered b) plastered

Figure 9. Examples of timber structures made with the dizeme technique (Güneş, 2014).

Masonry filled Çatkı (frame) wall

The gaps between the horizontal, vertical and angular elements that make up the structural system are the walls formed by filling them masonry filling material. These are divided into two parts as hımış and muska dolma according to the frequency of use on the wall surfaces of vertical elements.

a) Hımış

The walls formed by placing masonry filling materials (such as brick, adobe, briquette etc.) of the gaps between the çatkı elements are called hımış (see Figure 10). This system is the most applied timber construction system in Anatolia. Masonry filling materials placed in the voids differ from according to the climate and properties of the region where the structure is located. These applied filling materials are interlaced in the form of vertical, horizontal, cross and herringbone. The filling materials, which are passed into each other in the form of herringbone, rain waters flowing from the joints cause less damage to the timber elements than others (see Figure 11).

b) Muska dolma

Timber structure posts (40~60 cm apart) are divided into sections with angular timber elements inclined approximately 45˚ and are the walls formed by placing the masonry filling material between the gaps occur in this way. As can be seen from the figure, since the connections

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between the posts are oblique, triangular shaped spaces are formed on the facade. These triangles formed are called muska dolma because these triangles resemble the muska shape. Due to the difficulty of filling the gaps in the shape of a triangle with block stones because generally it is filled with small stones in the streams. In addition, these stones can be plastered painting with lime and a specific appearance can be achieved (see Figure 12). Although there is no need for buttresses in the amulet filled system, it is seen that corner connections are supported with buttresses in some timber structures (see Fig. 13). In addition, angular timber elements secondary buttresses can be found in these structures supported by buttresses and integrity is provided in the facades.

Figure 10. Example of hımış-walled timber structure (Güneş, 2014).

Figure 11. Example of herringbone brick filled wall (Güneş, 2014).

a) unplastered b) plastered

Figure 12. Examples of muska dolma wall in timber structures (Güneş 2014).

Figure 13. View of a timber structure supported by buttresses to corner posts (Güneş, 2014).

Walls without angular elements

Wall systems without angular elements are mostly applied in regions where earthquake hazard is short. In these systems, timber carriers are created by placing them horizontally and vertically. It is seen that the gaps in the frame created in this way as will be left blank seen that it is filled with plaster. On the other hand, timber structures without angular elements do not performing well under the effect of horizontal loads such as earthquake and wind.

Eyed wall systems (unfilled)

These wall systems are created by connecting horizontal timber sash between the posts placed frequent. Since between as the posts are supported flat with horizontal bonding timber kuşak, eye to eye partitions is formed on the structure facade. For this reason, these wall systems are named as eyed systems (Başkan, 2008). Since only vertical and horizontal elements are used in these systems, there are examples in which posts in the corners are supported with buttresses as the resistance against horizontal load effects such as wind and earthquake are weak (see Figure 14).

Eye stuffing wall systems (masonry filled)

These wall systems are formed by filling the gaps masonry filling materials formed by connecting the frequently placed posts with horizontal bonding timber (see Figure 15). In these, smaller cross sections are used by reducing the post spacing as in eyed wall systems. The reason for this is to keep the against effects that may come from

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outside in place the masonry materials. These wall systems are mostly encountered in the Eastern Black Sea region, and these are mostly made without using nails.

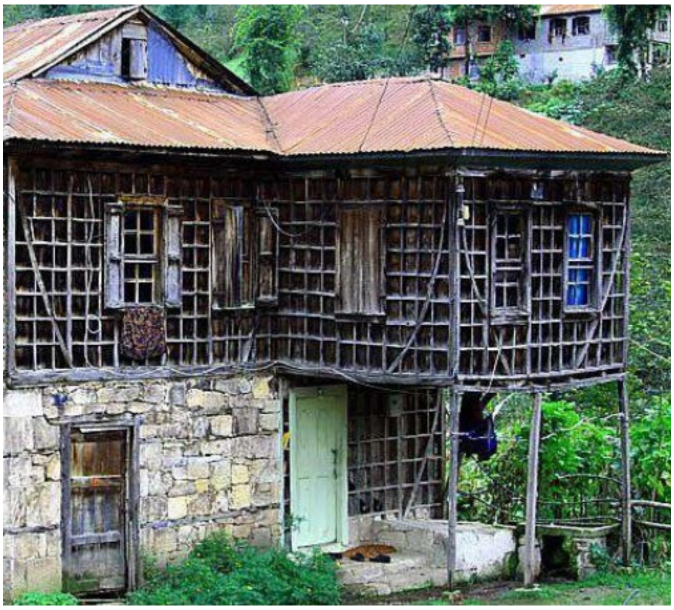

Figure 14. A view of the buttresses placed in the corners in the timber system with eyed (Güneş 2014).

Figure 15. Example of timber structure with eye stuffing wall system (Tunçkol, 2012).

NUMERICAL APPLICATIONS

For the numerical applications of this study Safran Mansion (former name Bağlar Mansion) located in Köyiçi Square in Safranbolu district of Karabük, which was built 150 years ago with timber frame Çatkı technique, was chosen. The exterior of the pavilion is without plaster (see Figure 16). The restoration of Bağlar Pavilion was started in 2010 and it was put into service in hotel concept as Safran Mansion in 2012 concept. Safran Mansion, which was built in the style of last period Ottoman Mansion received the "Best Restored Mansion Award" in 2015.

Modelling of the Mansion with Sta-Steel Structural Analysis Program

This sample which was chosen firstly in this study was modelled with the help of the mansion's structural systems (model-1) Sta-Steel program (Sta-Steel 2019). Then with timber frames (with the Çatkı) widely used in Turkey the same mansion's ten different structural systems models have been created and the findings obtained by performing structural analyses were compared with each other (Saatci 2020). The views of Safran Mansion which are the subject of the numerical applications of this study, from different facades are given in Figure 17.

Figure 16. A view from facade of Bağlar Mansion.

a) front facade b) rear facade c) left facade d) right facade

Figure 17. Views from different sides of Safran Mansion.

Table 1. Other design parameters of Safran Mansion according to TBER

Ground Movement Level (DD)	DD3
Ductility coefficients (R_x and R_y)	4
Resistance excess coefficients (D_x and D_y)	2
Modal analysis *min* load rate (β)	0,90
Earthquake load additional eccentricity (e)	0,05
Building location longitude	32,669
Building location latitude	41,264
Short period map spectral acceleration coefficient (S_s)	0,237
Map spectral acceleration coefficient for a 1s period (S_1)	0,08
Short period design spectral acceleration coefficient (S_{ds})	0,308
Design spectral acceleration coefficient for a 1s period (S_{ds1})	0,12
Soil bearing capacity (kN/m^2)	210
Soil bedding coefficient (kN/m^3)	10000
Snow load (kN/m^2)	0,75
Building height (m)	10 m
young's modulus of the wooden material (kN/m^2)	1x10^7
Shear modulus of wooden material (kN/m^2)	500000
Thermal expansion coefficient of the wood material	5x10^{-6}
Unit weight of wood material (kN/m^3)	4

Today in force Turkey into Building Earthquake Regulation according to (TBER, 2019) due to the fact that Safran Mansion is a social residence, it is building usage class (BKS) 3, building importance factor (I) 1,0 and live load mass participation coefficient 0,3 is considered to be. According to TBER, the horizontal design spectrum corner periods for the building

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coordinate were calculated as TA=0,078 s, TB=0,39 s and TL=6 s. In addition, depending on the building usage class and building design spectral acceleration coefficient, the earthquake design class (EDC) was taken as 4. On the other hand, it is assumed that the for the location of the structure in question local ground class ZC according to TBER and the wind load affect 0,96 kN/m2 the building facades. Other design parameters considered in the structural analyses of Safran Mansion are summarized in Table 1.

Timber Çatkı layout in Safran mansion

Wall details of timber structures consist of differences in the arrangement of bar elements. The Çatkı wall arrangement for one storey of the timber structure consists of three parts as shown in Figure 18. Bottom wooden truss: it forms the part between the middle wooden truss and the floor covering, and in this section, there are bracings, main and intermediate posts. Medium wooden truss: it forms the part between the lower wooden truss and the upper wooden truss, there are intermediate posts and bonding, and the door and / or window gaps are usually left in this part. The upper wooden truss is the part between the middle truss and the top of the ground floor wall. In these, there are bracings, main and intermediate posts as in the lower wooden truss.

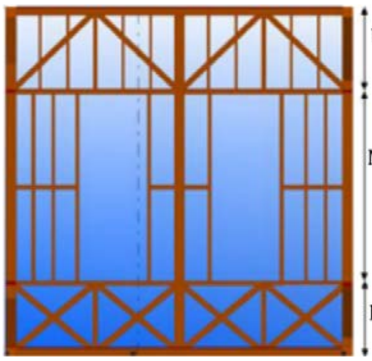

Figure 18. Çatkı wall layout for one storey of the timber structure (Kaplan 2013).

The Safran mansion creating of different models with Sta-Steel program

Creating the current status (model 1) of Safran mansion

The three-dimensional and different facades structural system views of the model created for the structural analysis of the current state of Safran mansion (model 1) with the Sta-Steel program are given in Figure 19. As seen this Figure, the ground storey height of the Safran mansion is 2,79 m. The dimensions of the timber elements used in the created of the structure models in question are given in Table 2.

Here, it would be useful to note that h in Table 2 indicates is the wooden truss height, b is the wooden truss width and n is the number of wooden trusses.

It would be useful to note here that the posts, buttresses, intermediate beams, and sash are modelled in accordance with the architectural projects of the mansion in question. In addition, it will be appropriate to state that the angular elements supporting the posts are called buttresses, and the angular elements that do not support are called bracing members.

Table 2. Dimensions of wooden elements used in Safran mansion

Wooden elements		cm	model 1	model 2	model 3	model 4	model 5	model 6	model 7	model 8	model 9	model 10
Upper wooden truss	Upper flange	h	100	100	100	100	100	100	100	100	100	100
		b	100	100	100	100	100	100	100	100	100	100
		n	12	12	12	12	12	12	12	12	12	12
	Bottom flange	h	320	320	320	320	320	320	320	320	320	320
		b	150	150	150	150	150	150	150	150	150	150
		n	12	12	12	12	12	12	12	12	12	12
	Intermediate posts	h	50	50	50	50	50	50	50	50	100	50
		b	100	100	100	100	100	100	100	100	100	100
		n	300	303	303	303	103	350	303	303	114	303
	Medium struts	h	150	150	150	150	150	150	150	150	150	150
		b	150	150	150	150	150	150	150	150	150	150
		n	30	30	30	30	30	30	30	30	30	30
	Cross elements	h	150	-	150	150	150	150	150	-	50	150
		b	150	-	150	150	150	150	150	-	100	150
		n	49	-	98	98	49	318	49	-	840	98
Medium wooden truss	Wooden sashes	h	100	-	100	100	-	100	100	30	-	-
		b	100	-	100	100	-	100	100	100	-	-
		n	156	-	27	57	-	77	115	1272	-	-
	Bottom flange	h	320	320	320	320	320	320	320	320	320	320
		b	150	150	150	150	150	150	150	150	150	150
		n	12	12	12	12	12	12	12	12	12	12
	Intermediate posts	h	50	50	50	50	50	50	50	50	100	50
		b	100	100	100	100	100	100	100	100	100	100
		n	300	303	303	303	103	103	303	303	114	303
	Medium struts	h	150	150	150	150	150	150	150	150	150	150
		b	150	150	150	150	150	150	150	150	150	150
		n	30	30	30	30	30	30	30	30	30	30
	Cross elements	h	150	-	150	150	150	150	150	-	50	150
		b	150	-	150	150	150	150	150	-	100	150
		n	15	-	98	98	49	318	49	-	840	98
Bottom wooden truss	Upper flange	h	320	320	320	320	320	320	320	320	320	320
		b	150	150	150	150	150	150	150	150	150	150
		n	12	12	12	12	12	12	12	12	12	12
	Bottom flange	h	270	270	270	270	270	270	270	270	270	270
		b	180	180	180	180	180	180	180	180	180	180
		n	12	12	12	12	12	12	12	12	12	12
	Intermediate posts	h	50	50	50	50	50	50	50	50	100	50
		b	100	100	100	100	100	100	100	100	100	100
		n	300	303	303	303	103	103	303	303	114	303
	Medium struts	h	150	150	150	150	150	150	150	150	150	150
		b	150	150	150	150	150	150	150	150	150	150
		n	30	30	30	30	30	30	30	30	30	30
	Cross elements	h	150	-	150	150	150	150	150	-	50	150
		b	150	-	150	150	150	150	150	-	100	150
		n	15	-	98	98	49	318	49	-	840	98

Creating of model 2

The Safran Mansion buttress-free, intermediate-posted and sashless model (model 2) related three dimensional and different fronts structural system views are given in Figure 20. Intermediate posts in these figures were created by using 5x10 cm timber elements with 30 cm intervals.

Creating of model 3

In the Safran Mansion on the model (model 3) created by using intermediate post and sashes where the buttresses used are supported with cross elements the three-dimensional and different fronts structural system views are given in Figure 21. Intermediate post in these figures was created using 5x10 cm timber elements with 30 cm intervals. Also, in this model the sashes pass through the lower parts of the windows.

Creating of model 4

In the Safran Mansion on the model (model 4) created by using intermediate posts, intermediate beams and sashes where the buttresses are supported with cross elements the three-dimensional and different

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fronts structural system views are given in Figure 22. Intermediate posts seen in these figures are created using 5x10 cm timber elements with 30 cm intervals.

Creating of model 5

In the Safran Mansion on the model (model 5) created by using intermediate posts and buttresses the three-dimensional and different fronts structural system views are given in Figure 23.

Creating of model 6

In the Safran Mansion on the model (model 6) created by using crossmembers, intermediate posts, intermediate beams and sashes the three-dimensional and different fronts structural system views are given in Figure 24.

Creating of model 7

In the Safran Mansion on the model (model 7) created by using buttresses, intermediate posts, intermediate beams and sashes the three-dimensional and different fronts structural system views are given in Figure 25. It will be appropriate to state that the intermediate posts shown in the figures are created with 5x10 cm timber elements at 30 cm intervals.

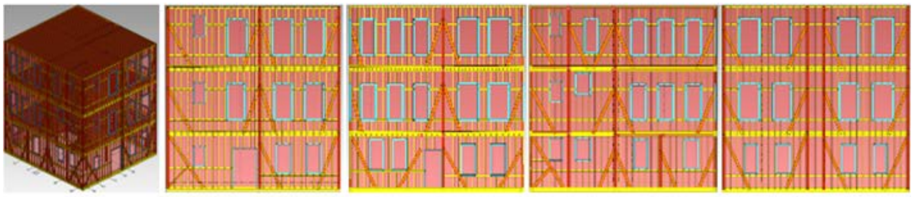

Figure 19. Views from three-dimensional and structural system on different fronts of created model (model 1) of Safran Mansion's.

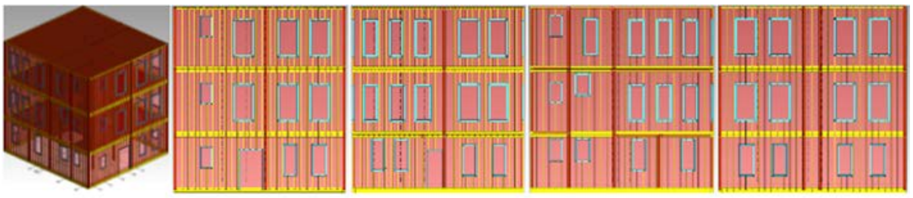

Figure 20. Views from three-dimensional and structural system on different fronts of created model (model 2) with different çatkı system of Safran Mansion's.

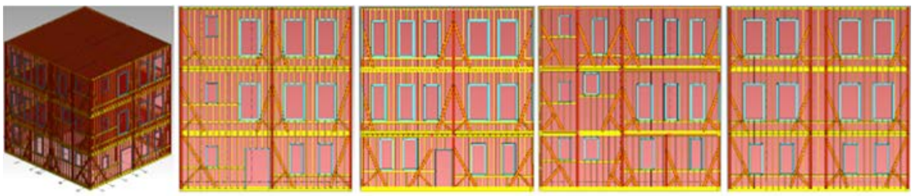

Figure 21. Views from three-dimensional and structural system on different fronts of created model (model 3) with different çatkı system of Safran Mansion's.

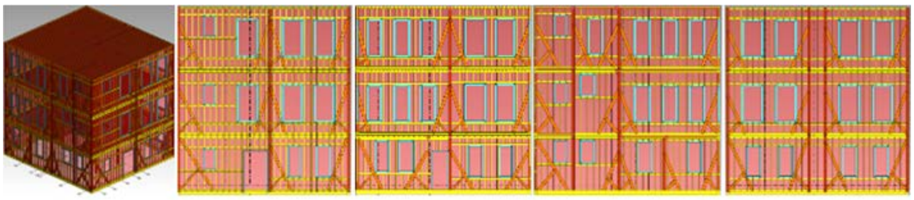

Figure 22. Views from three-dimensional and structural system on different fronts of created model (model 4) with different çatkı system of Safran Mansion's.

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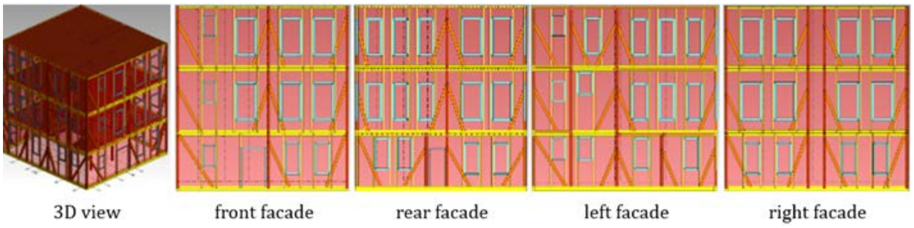

Figure 23. Views from three-dimensional and structural system on different fronts of created model (model 5) with different çatkı system of Safran Mansion's.

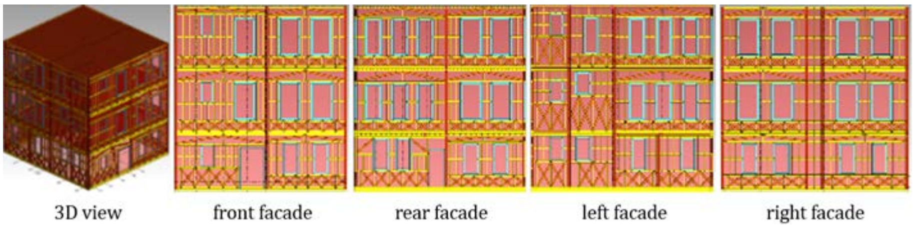

Figure 24. Views from three-dimensional and structural system on different fronts of created model (model 6) with different çatkı system of Safran Mansion's.

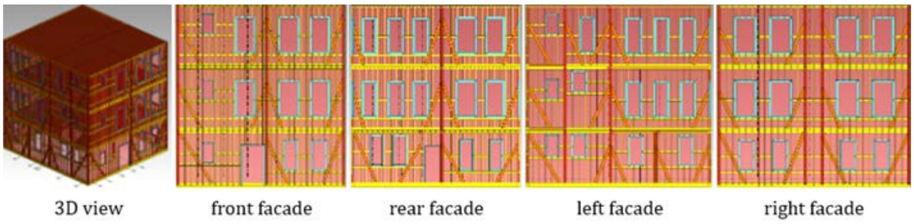

Figure 25. Views from three-dimensional and structural system on different fronts of created model (model 7) with different çatkı system of Safran Mansion's.

Creating of model 8

In the Safran Mansion on the model (model 8) created by using intermediate posts and intermediate beams the three-dimensional and different fronts structural system views are given in Figure 26. Intermediate posts in these figures were created using 5x10 cm timber elements with 30 cm intervals.

Creating of model 9

In the Safran Mansion on the model (model 9) created by using crossmembers and intermediate posts the three-dimensional and different fronts structural system views are given in Figure 27. Intermediate posts seen in these figures were created using 10x10 cm timber elements with 70 cm intervals.

Creating of model 10

Safran Mansion on the model (model 10) created by using intermediate posts and where the buttresses are supported with cross elements the three-dimensional and different fronts structural system views are given in Figure 28. Intermediate posts in these figures were created using 5x10 cm timber elements with 30 cm intervals.

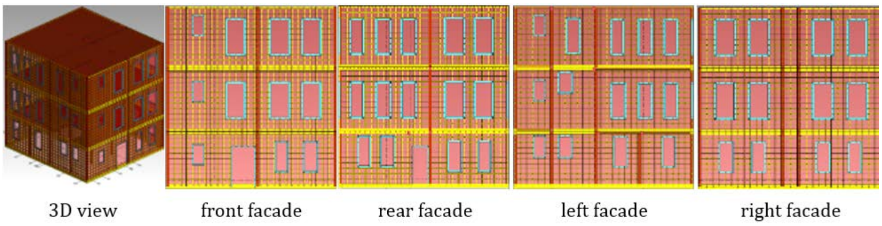

Figure 26. Views from three-dimensional and structural system on different fronts of created model (model 8) with different çatkı system of Safran Mansion's.

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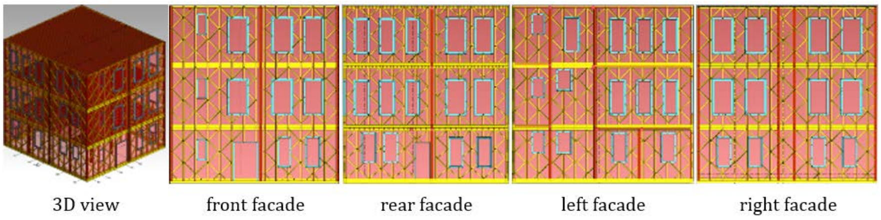

Figure 27. Views from three-dimensional and structural system on different fronts of created model (model 9) with different çatkı system of Safran Mansion's.

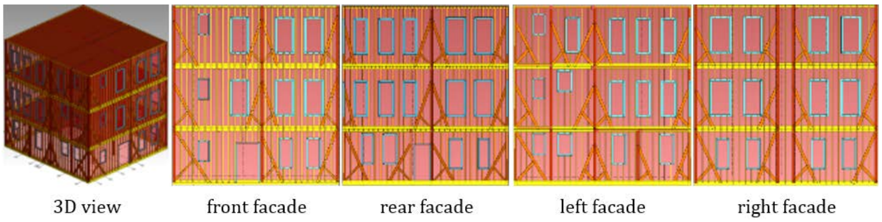

Figure 28. Views from three-dimensional and structural system on different fronts of created model (model 10) with different çatkı system of Safran Mansion's.

Determination of nodal point for comparing displacement values of Safran mansion models

In this study aimed to compare the performance of different *Çatkı* systems currently used in Turkey. To obtain the maximum displacement values of the Safran Mansion models selected for the numerical applications of the study carried out for this purpose, and the internal force in the posts in the middle of the 2nd and ground storey therefore, to compare with each other, the nodal point and timber structural element shown in Figure 29 are selected.

FINDINGS OBTAINED AND DISCUSSIONS FROM STRUCTURAL ANALYSES OF MODELS

The Safran mansion considered in this study, views of inadequate structural elements as a result of structural analyses performed for different models of formed according to the timber *Çatkı* system applied in Turkey are given in Figure 30. In all building models taken into consideration from these figures, it is seen that according to the building architecture especially the 2nd storey ceiling slab beams are inadequate. In addition, it is seen that insufficient elements in the ground storey ceiling beams of the other building models, except model 1. Accordingly, considering 2nd storey ceiling slab the insufficient beam deflexion the best behaviour is model 5 and model 9, while the worst behaviour against it is model 6. Model 1 shows the best behaviour when considering the ground floor ceiling beams. This matter reveals that the timber *Çatkı* systems used significantly affect the behaviour of the building.

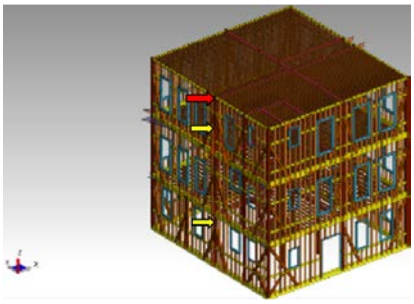

Figure 29. The nodal point selected to compare the findings obtained.

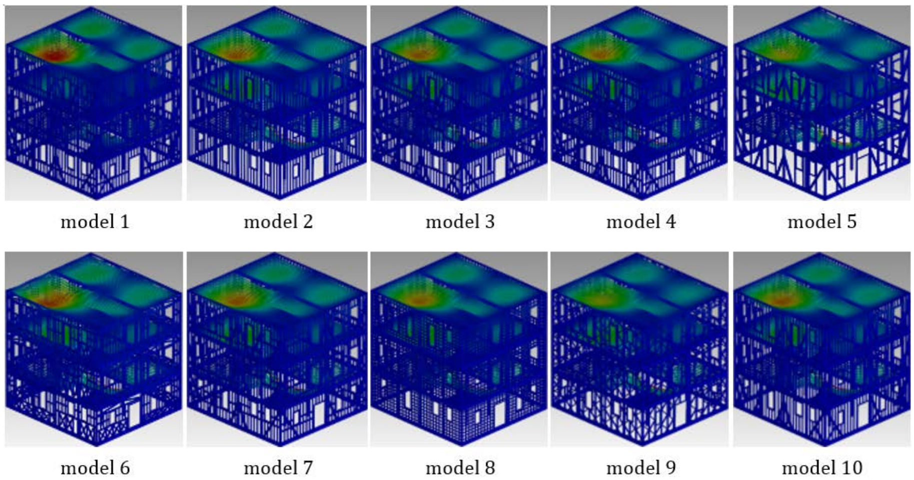

Figure 30. Views from the insufficient structural elements for vertical loads of the models.

Within the scope of this study the 1. natural vibration periods obtained from the structural analyses performed according to the mode superposition method of the building models created according to the different timber frame systems considered are given in Table 3. It can be seen from this table that the periods values obtained from model 5 for the first 3 modes are larger than the period values obtained from models considered. In contrast, the period values obtained from model 8 for the first 3 modes take the smallest value. This situation reveals the contribution of intermediate beams.

The Safran mansion, the displacement views of the structural elements for the earthquake effect in the x direction as a result of the structural analyses of different building models formed according to Çatkı systems that applied in Turkey are given in Figure 31. In addition, the displacement values for the earthquake effect in the x and y directions of the nodal point selected as a result of the structural analyses of the building models are given in Table 4. It is seen that maximum displacements occur at the same points in all building models considered from these tables and figures. Also, the largest displacement value in the x direction for the earthquake effect in the x direction from Table 4 is seen from model 6 and the largest displacement in the y direction is seen from model 5. For the earthquake effect in the y direction the largest displacement value in the x direction is seen from model 7 and the largest displacement value in the y direction is seen from model 2. These findings show that the buttresses and intermediate beams provide positive affect structure behaviour and timber Çatkı systems significantly affect the behaviour of the structure in question.

Table 3. 1st natural vibration period values according to the first three modes of building models

Natural vibration periods (s)	model 1	model 2	model 3	model 4	model 5	model 6	model 7	model 8	model 9	model 10
1st mode	0,6310	0,5331	0,6611	0,6145	0,6785	0,6616	0,6554	0,4432	0,4594	0,5169
2nd mode	0,4882	0,4667	0,5173	0,4718	0,5268	0,5494	0,5022	0,3795	0,4046	0,4050
3rd mode	0,2918	0,3183	0,3177	0,3078	0,3206	0,3372	0,3138	0,2329	0,3542	0,2754

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Table 4. Maximum displacement values of node point selected for earthquake effect in the x and y directions

Displacement values (cm)	Earthquake direction		model 1	model 2	model 3	model 4	model 5	model 6	model 7	model 8	model 9	model 10
	x direction	δ_x	0,8701	0,5809	1,0549	0,9331	1,0792	1,0795	0,9708	0,8069	1,0341	0,7904
		δ_y	0,0365	0,0295	0,0487	0,0419	0,0488	0,0399	0,0389	0,0183	0	0,0113
	y direction	δ_x	0,2572	0,1062	0,2647	0,2620	0,2611	0,2160	0,2751	0,1336	0,1675	0,1956
		δ_y	0,2107	0,2624	0,2216	0,1594	0,2424	0,2476	0,1838	0,1192	0,0266	0,0771

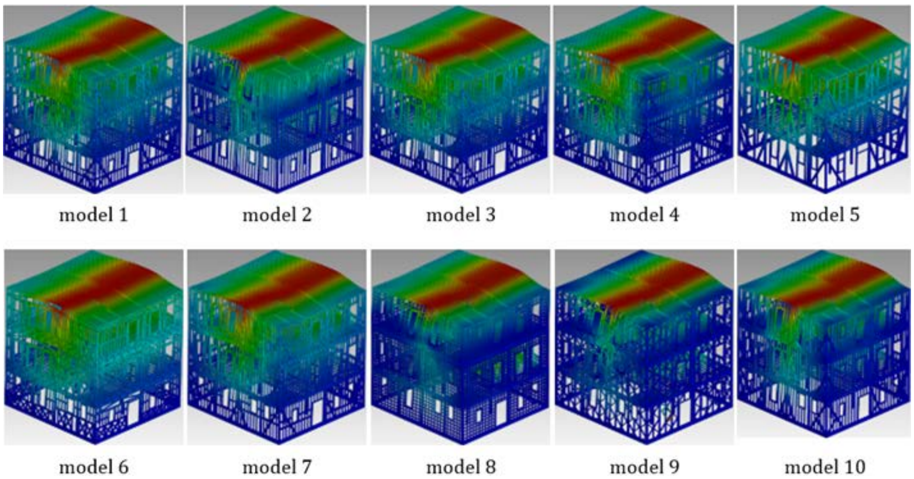

Figure 31. Displacement views of structural elements in the x direction under earthquake effect of models.

Within the scope of this study, the maximum base shear force values obtained in the x and y directions from the structural analyses carried out with the methods of mode superposition and equivalent earthquake load by the help of the Sta-Steel program of the models created according to different *Çatkı* systems are given in Table 5 and Figure 32. The base shear force values obtained by the equivalent earthquake load method (EELM) in both the x direction and y direction from this figure and table are larger than the base shear force values obtained by the mode superposition method (MSM). In addition, according to the equivalent earthquake load method from Figure 32 and Table 5, it is seen that the maximum base shear force value obtained from in both x direction and y direction model 9 is large. in spite of that, according to the mode superposition method, it is seen that the maximum base shear force value obtained from the model 2 in the x direction and the maximum base shear force value obtained from the model 8 in the y direction is large. These findings obtained from structural analyses show that timber *Çatkı* systems that do not have buttresses are exposed to greater shear forces and that these therefore that the models in question will be exposed to larger earthquake loads. This situation clearly reveals the importance of the timber frame systems of the buttresses in terms of earthquake performance.

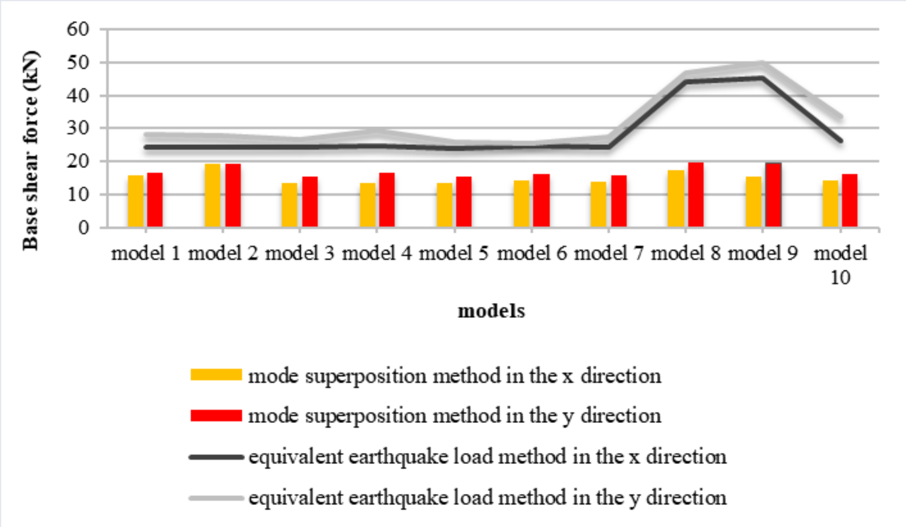

Figure 32. Variations of in the maximum shear force values obtained in the x and y directions of the building models created according to different timber *Çatkı* systems.

Table 5. Maximum shear force values of building models created according to different timber *Çatkı* systems

			model 1	model 2	model 3	model 4	model 5	model 6	model 7	model 8	model 9	model 10
Maximum base shear force values (kN)	Earthquake in the x direction	mode superposition method	15,76	19,17	13,43	13,35	13,39	14,43	13,97	17,34	15,51	14,22
		equivalent earthquake load method	24,44	24,39	24,36	24,55	23,91	24,72	24,34	44,22	45,44	26,28
	Earthquake in the y direction	mode superposition method	16,61	19,41	15,42	16,53	15,37	16,2	15,77	19,71	19,30	16,2
		equivalent earthquake load method	28,35	27,86	26,75	29,56	25,71	25,56	27,53	46,94	49,75	33,54

The overturning moment, moment against overturning, safety coefficient and damping ratio values obtained in the x and y directions of the earthquake effect from the structural analyses of the building models created according to the different timber frame systems considered in this study are given in Table 6. From this table, lowest safety coefficient value according to the overturning moment-the moment against overturning in both the x and the y direction and are obtained from model 1. Also, it is seen from this table that the lowest damping rate value is obtained from model 1. In addition to, it is seen that all the building models are sufficiently safe.

The maximum displacement and effective interstory drift distributions obtained along the structure height (at storey levels) of the structural elements (posts) selected under the effect of earthquake from the structural analyses of the Safran mansion models created according to the different timber frame systems are given in Figure 33 and Figure 34, respectively. These figures are seen that the maximum displacement and effective interstory drift distributions at the storey levels of the building models with buttress and diagonal member are different from models the wall without buttress. As seen in Figure 33, the displacement values at the storey levels obtained from model 6 are larger than the other building models that are considered. It can be seen from Figure 34 that the values of effective interstory drift distributions in the storey levels obtained from models the wall without buttress are that it differs considerably compared to models with buttresses. In addition, it is seen

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that the difference between the effective interstory drift values at the storey levels (especially at the 2nd and 3rd storey levels) in models the wall without buttress is large. These findings obtained reveal that the structure models with buttress will perform well especially in the earthquake effect.

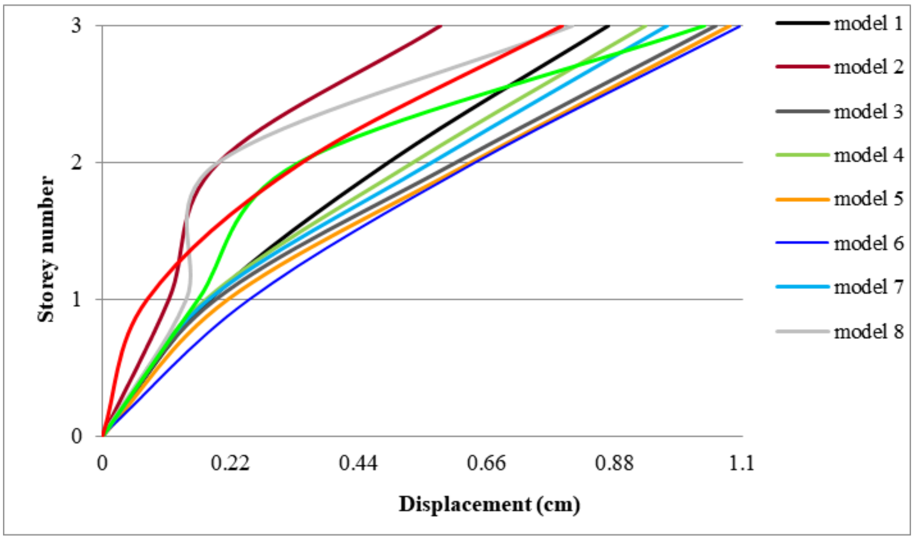

Figure 33. Maximum displacement values at the storey levels of the structural elements (posts) selected in the earthquake effect of the building models created according to different timber *Çatkı* systems.

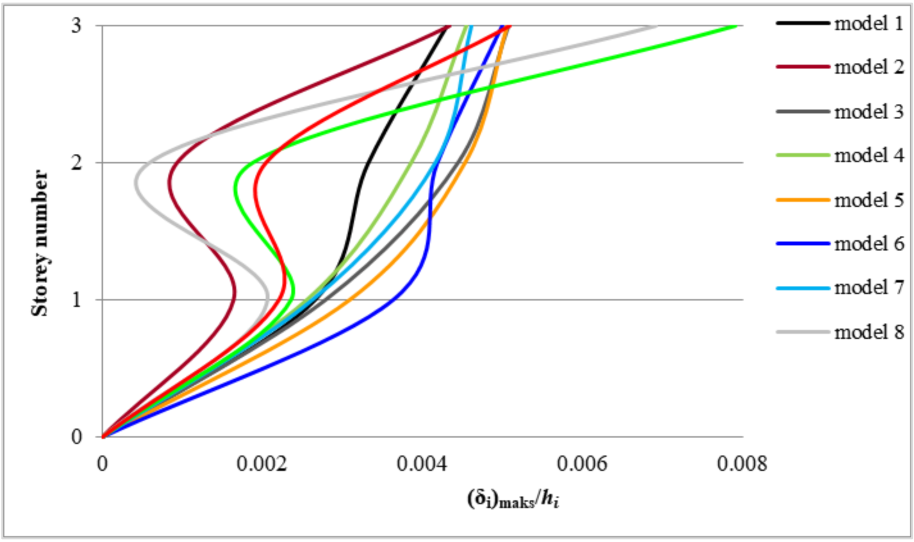

Figure 34. Effective interstory drift values at the storey levels of the structural elements (posts) selected in the earthquake effect of the building models created according to different timber *Çatkı* systems.

Table 6. The overturning moment, moment against overturning, safety coefficient and damping ratio values of the building models created according to different timber Çatkı systems

	earthquake direction	model 1	model 2	model 3	model 4	model 5	model 6	model 7	model 8	model 9	model 10
Overturning moment (kNm)	X	289,3	29,141	271,77	96,536	275,23	268,37	292,94	63,544	89,62	52,708
	Y	322,33	37,077	253,87	94,45	249,02	227	287,58	61,85	75,49	60,982
Moment against overturning (kNm)	X	5209,5	5107	5318,4	5331,2	5263,3	5403,3	5319,7	5328,9	5327	5237,1
	Y	5668,5	5469,1	5701	5728,2	5631,3	5825,4	5707,7	5700,7	5703,3	5614,6
Safety coefficient	X	18,01	175,25	19,569	55,225	19,123	20,134	18,16	83,862	59,44	99,359
	Y	17,586	147,51	22,456	60,647	22,614	25,663	19,847	92,169	75,55	92,069
Damping ratio （ζ）		13,618	120,07	17,112	55,225	16,204	15,233	16	83,862	59,44	92,069

CONCLUSIONS AND RECOMMENDATIONS

In this study, the effects to the structure behaviour of different timber frame (Çatkı) systems that are widely used in the construction of timber structures in Turkey are comparatively examined. The main conclusions and recommendations obtained from the structural analyses carried out within this scope are summarized below.

- The largest displacement values in the x and y directions of the selected nodal point for the x direction of the earthquake effect are obtained from model 6 and model 5, respectively. By contrast with the largest displacement values in the x and y directions of the nodal point selected for the y direction of the earthquake effect are obtained from model 7 and model 2, respectively.
- Base shear force values obtained by the equivalent earthquake load method are larger than those obtained by the mode superposition method in both the x direction and y direction. With the equivalent seismic load method, the maximum base shear force value both in the x and y direction is obtained from model 9. By contrast with it is seen that the maximum base shear force value with the mode superposition method is obtained from model 9 both in the x and y direction. This result obtained shows that the timber Çatkı systems with buttresses are exposed to smaller shear forces. Therefore, the models in question will be better particularly earthquake performances.
- The safety coefficient value obtained from model 1 according to the overturning moment and the moment against overturning is smaller than the other building models considered in this study. This result obtained reveals that model 1 is more unsafe than other building models considered in this respect.
- The damping ratio value obtained from model 1 from the structural analyses performed is smaller than the other building models considered. This result shows that the horizontal stiffness of model 1 is less than the other models considered.
- The displacement distributions of building models that do not have buttresses are more complicated than the building models with buttress. In addition, the maximum displacement values at storey levels are obtained from model 6. This situation shows that the buttresses that increase the lateral stiffness of the building are very important in terms of building performance.
- At the selected top nodal point (2nd storey) in the x direction the maximum displacement value obtained from model 6 24,07% larger than model 1 and in the y direction, the maximum displacement value obtained from model 2 is 24.54% larger than model 1.
- The difference between the effective interstory drifts value especially at the 2nd and 3rd storey levels in the models without buttress is large. This result reveals that buttress building models will behave better in other words, it will perform better.
- When considering the findings of this study, the timber structures that will be built in earthquake zones in Turkey the use of buttresses in terms of safety and performance is recommended.

ACKNOWLEDGEMENTS/NOTES

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Resume

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