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Evaluation of Seismic Response of the Cross-Laminated Timber (CLT) Multi-Storey Residential Building Under the February 6, 2023, Kahramanmaraş Earthquakes

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Abstract

The February 6, 2023 Kahramanmaraş earthquakes exposed the vulnerabilities of existing RC structures, causing thousands of buildings to collapse or sustain severe damage, especially in the hardest-hit provinces. Cross-laminated timber (CLT), one of the industrial wood materials, is used as an alternative to RC in buildings in earthquake zones around the world due to its lightness and many positive features. The aim of the study is to examine the dynamic behavior of multi-storey residential buildings built with the CLT shear wall system, with limited application in Turkey, under earthquake loads and to draw attention to the material selection and sizing to be used in the structural elements of earthquake-resistant buildings. Using TimberTech (2022) software, a five-story building with CLT walls was analyzed under linear dynamic conditions. The study shows while the model provides all the verifications in the solution according to Eurocode for soil type C, it is inadequate under the seismic data of the Kahramanmaraş earthquake.

Keywords: *Cross-laminated timber (CLT), February 6 Kahramanmaraş earthquakes, dynamic analysis, limit state design (LSD), multi-storey residential building.*

Çapraz Lamine Ahşap (CLT) Malzemeli Çok Katlı Konut Binasının 6 Şubat 2023 Kahramanmaraş Depremleri Altındaki Sismik Tepkisinin Değerlendirilmesi

Öz

6 Şubat 2023 Kahramanmaraş depremleri, mevcut betonarme yapıların hassasiyetini ortaya çıkarmış, özellikle depremden en çok etkilenen illerde binlerce binanın yıkılmasına veya ağır hasar görmesine neden olmuştur. Endüstriyel ahşap malzemelerden biri olan çapraz lamine ahşap (CLT), betonarme malzemeye alternatif olarak hafifliği ve birçok olumlu özelliğinden dolayı dünya genelinde deprem bölgelerindeki yapılarda kullanılmaktadır. Çalışmanın amacı ülkemizde uygulama örneği az olan CLT perde duvar sistemiyle inşa edilmiş çok katlı konut yapılarının deprem yükleri altındaki dinamik davranışının incelenmesi ve depreme dayanıklı binaların yapı elemanlarında kullanılacak malzeme seçimine ve boyutlandırmaya dikkat çekmektir. Çalışmada, tüm iç ve dış duvarları CLT'den yapılmış beş katlı örnek bir konut binasının dinamik performansı TimberTech (2022) yazılımı ile analiz edilmiştir. Çalışma sonucunda incelenen modelin Eurocode'a göre C tipi zemin çözümü için tüm doğrulamaları sağladığı ancak Kahramanmaraş depreminin sismik verileri altında yetersiz kaldığı elde edilmiştir.

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Anahtar kelimeler: *Çapraz lamine ahşap (CLT), 6 Şubat Kahramanmaraş depremleri, dinamik analiz, limit durum tasarımı, çok katlı konut binası.*

1. Introduction

Türkiye is located in the Alpine-Himalaya seismic belt, which is one of the most effective and active seismic belts in the world and includes the Eurasian, Anatolian, African, and Arabian plates (Şengör & Yılmaz, 1981; Durmuş, 2004). As it has two active fault zones: the East Anatolian Fault (EAF) and the North Anatolian Fault (NAF) zones, it is one of the most seismically active regions of the world. Therefore, one of the most important and unpredictable and even unpreventable disasters in our country is earthquakes. Many earthquakes of different magnitudes occur in our country throughout the year (Ataman & Tabban, 1977; Kıral & Tonyalı (2023a)). The country has been struggling with earthquakes since the Ottoman period. Especially in the Republican period, the rapid increase in urbanization since the 1950s led to an increase in migration from villages to cities. The unconscious structures built to meet the needs of the rapidly increasing population in cities posed a great risk of earthquakes (Genç, 2007). In Türkiye, a significant part of the population lives in earthquake zones, and critical industrial establishments are in these areas. This situation affects the extent of damage that can occur after an earthquake (Taş, 2003; Durmuş, 2004; Zafer &Tonyali (2020)).

Major destructions in earthquakes can be caused by a wide variety of reasons such as whether there is a suitable architectural and engineering product in the design and design processes of the buildings, problems in the design of the structural system, inadequacies in material and workmanship, damages in past earthquakes, corrosion, additional loadings, and interventions during the use phase. For this reason, architects and engineers should work together and address all these issues holistically for earthquake resistance and safety of structures in areas exposed to earthquake risk (Ayyıldız Potur & Metin, 2021).

Timber constructions have gained popularity over the last few years due to a combination of several factors, such as generating fewer pollutants as compared to mineral-based building materials (i.e. concrete), being prefabricated off-site and transported to the building construction location, being quickly assembled, and the high strength-to-weight ratio of wood. Thus, this type of constructions reduces construction work on-site, resulting in time savings and cost effectiveness. Several studies have been conducted to investigate the seismic performance of multi-story timber constructions (Casagrande et al., 2016; Filiatrault et al., 2010; Tomasi et al., 2015; Van de Lindt et al., 2010). The rising interest in high-rise structures has recently demanded a higher level of seismic performance. As a result, the attention has shifted to larger and more efficient systems notably Cross Laminated Timber (CLT), which is a laminated wood (Brandner et al., 2016). CLT constructions offer higher in-plane rigidity stiffness, stability and load-carrying capability as compared to light-frame buildings. Full-scale testing of CLT structures revealed that the CLT panels behave virtually as rigid bodies, with the connections providing all ductility and energy dissipation (Hristovski et al., 2018). However, an understanding of the dynamic behavior of CLT buildings is necessary for the construction of larger and taller structures. The motions that may be acceptable for small heights and spans are magnified in large structures, and these can increase loads on elements, damage non-structural elements, and cause discomfort to building occupants (Reynolds et al., 2016). High stiffness-to-mass ratios characteristic of CLT can cause high-amplitude responses of entire superstructures subjected to effects of horizontal dynamic forces or displacements (Ussher et al., 2022; Weckendorf et al., 2016).

CLT structure research has expanded into a variety of areas, including seismic applications. One of the earliest research on CLT as an Seismic Force Resisting Systems (SFRS) was conducted at the University of Ljubljana in Slovenia (Dujič et al., 2004). It was established that the kind of anchoring and the vertical load both had a significant influence on performance, and that failure was more likely to come from connector/anchorage failure or from localized failures in the wood material. In 2013, a significant research on the seismic response of CLT structures was undertaken (Ceccotti et al., 2013). The results of the study showed that CLT buildings could survive strong earthquakes without residual displacement. A great deal of understanding on the seismic response of CLT wall systems and steel fasteners has been acquired since then (Gavric et al., 2015), including studies on potential performance factors to be used in their design (Amini et al., 2018), and modelling techniques (Demirci, 2019). Several numerical studies on the seismic assessment of CLT buildings have also been conducted

(Demirci, 2019; Thiers-Moggia & Málaga-Chuquitaype, 2021). However, most past research on CLT buildings has concentrated on determining design seismic forces (base shear or inter-storey shear) and, to a lesser extent, displacement demands (maximum inter-storey drift or roof drift).

In recently, the two significant earthquakes (Mw7.7 and Mw 7.6) that consecutively occurred in Turkey and Syria on February 6, 2023, caused great destruction, not only with their size but also with many different factors such as faulty designs, lack of supervision, and ground-structure incompatibility. According to preliminary estimates, approximately 40000 buildings were severely damaged or destroyed. This constitutes approximately 10-20 percent of the building stock in the four most affected provinces. In the earthquakes that occurred while people were sleeping, 50 783 people lost their lives by being under collapsed structures. Most of the affected buildings are structures built on a reinforced concrete (RC) frame system and multi-storey buildings with unreinforced masonry infill walls (Erdik et al., 2023; Kıral & Tonyalı (2023b). As seen in the February 6 Kahramanmaraş earthquakes, which are recognized as the disaster of the century all over the world, the importance of the measures to be taken against the risk of earthquakes has once again been revealed. Also, this event reminded us again of the significance of earthquake-resistant construction. Most of the buildings in our country are RC buildings and, after the main earthquakes and lots of aftershocks serious damages were observed in the RC buildings. The CLT has gradually become a feasible alternative to other structural materials in our country, owing to its superior features in terms of sustainability, energy efficiency, and speed of construction (Birinci et al., 2020). It has entered the building sector as an alternative to RC buildings, with an interest in using them in structures in strong seismic zones due to their lightweight quality. If CLT buildings are constructed in the earthquake region, it is also a matter of curiosity how their earthquake performance will be and whether they can be an alternative to RC buildings. Thus, one of the objectives of the study is to obtain the dynamic behavior of the CLT shear walls of residential buildings under earthquake loads, which has a growing interest in our country nowadays. Also, it is aimed to draw attention to the correct material selection and sizing of the structural elements in earthquake-resistant building design in this study. In this study, a five-story residential building with all interior and exterior walls constructed with CLT was selected as an example to obtain dynamic performance. For this purpose, TimberTech (2022) software was used to produce the numerical model of the multi-story CLT residential building that can be constructed in areas with high earthquake risk as an alternative to the reinforced concrete frame construction system. In this context, seismic effects are calculated according to Eurocode8 due to the shortcomings of the application of CLT buildings in our country.

1.1. Effects of Earthquakes on Buildings

Every year, 100000 or more earthquakes occur throughout the world, with many of these earthquakes being experienced by people. Earthquakes produce seismic waves, which can cause landslides, destruction of buildings, and even their collapse. Considering that the average life of the buildings is 50 years, it is not economically possible to construct every building completely resistant to earthquakes. Therefore, it is necessary to prepare building projects within acceptable limits, earthquake resistance, and minimum standards that try to balance the construction cost (FEMA, 2010).

There are many reasons why buildings collapse in earthquakes, including ground conditions, poor design, and faulty construction (Kuncoro, Ichwanto & Muhammad, 2023). The effect of the earthquake on the buildings can be determined depending on the behavior of the buildings at the time of the earthquake and the characteristics of the buildings resistant to earthquakes. Earthquake resistant buildings can better cope with inertial forces due to their light weight. The lighter the building, the less the effect of earthquake forces (Bayülke, 1977). The 1755 Lisbon earthquake, one of the most destructive earthquakes in history, caused different destructions from region to region, depending on the type of ground. While the buildings built on soft and clay soils were completely destroyed, the buildings built on sand and gravel were severely damaged, and the buildings built on limestone and basalt were almost not damaged (Levy & Salvadori, 1995). This and many similar examples emphasize the importance of ground conditions and seismic behavior of structures. Conditions such as liquefaction, excessive settlement and slippage in the ground may cause the structures to be exposed to ground-based damages (Elyiğit & Ekinci, 2023). In earthquake resistant building design, static calculations should be made by taking into account the ground and structure condition. Ground conditions of the region affect the degree of seismicity and design diversity (Ateş et al., 2018; Yön et al., 2020). The bearing capacity of the soil and its response to earthquakes are of great importance in the design of structures.

Earthquake resistant buildings must have appropriate design and construction to better cope with the effects of earthquakes. In particular, deficiencies in the design and construction stages of reinforced concrete structures, which constitute a significant part of our country's building stock, incorrectly selected materials, irregularities or inadequacies in structural elements, beam-column joint errors have the potential to affect the performance of these buildings during the earthquake and the damage status after the earthquake (İnan & Korkmaz, 2012).

In the report prepared by the scientists after the earthquake in Kahramanmaraş, the design errors for reinforced concrete buildings were evaluated under the following headings (Kahramanmaraş Earthquake Report, 2023):

- Use of Plane Reinforcement and Reinforcement Corrosion: The durability of reinforced concrete structures is provided by the reinforcing steel inside. However, the use of incorrect or insufficient reinforcement, especially the preference for non-ribbed reinforcement or reinforcement corrosion, may adversely affect the performance of the buildings during earthquakes. In addition, reinforcement corrosion can increase the damage to the building and damage the strength of the buildings.
- Low Concrete Quality: The use of low-quality concrete may cause the buildings to not be sufficiently resistant to earthquake forces and be damaged. The fact that the concrete is not strong and durable enough can cause serious damage to buildings such as collapse or cracking during an earthquake.
- Workmanship Faults: Faults made during the construction process of reinforced concrete buildings may adversely affect earthquake performance. Workmanship faults such as incorrect stirrup connections, incomplete concrete pouring, or insufficient compaction can reduce the durability and strength of structures. The lack of control and supervision also prevents these faults from being noticed and prevented.

When the research made after the Marmara earthquake are examined, it is stated that as the ratio of the reinforced concrete frame structures in the study areas to the total building stock increases, the damage levels also increase, and it shows a tendency from less damaged to medium and heavy damaged. In addition, an interesting finding is that the damage levels in buildings with 5 to 8 floors are much higher than for buildings with 1 to 4 floors. In addition, since the lateral drift is small in the tunnel form reinforced concrete system, which is another construction system, the damage level in the load-bearing or non-bearing elements has remained very low. As a result of these investigations, 2-3-storey wooden frame structures and masonry brick or masonry structures, which are called traditional building systems, have once again proven their durability against earthquakes. Traditional wooden frame structures are classified as less damaged due to their lightness, flexibility, and energy absorption properties that increase earthquake resistance. Although these structures showed non-structural damage such as slight cracks in the masonry parts on the inner and outer surfaces, there was no significant decrease in structural strength in general (Gülhan & Güney, 2001).

Earthquake codes are constantly updated in line with the needs that arise over time and the developments in technology. Especially due to the earthquake zone in which our country is located, the importance of codes in earthquake resistant building design is increasing. In our country, an updated earthquake code was last published in 2018 under the name of "Regulation on Buildings to be Built in Disaster Areas" (Ministry of Environment and Urbanization, 2018). This code contains certain standards and rules in order to ensure that the buildings are built in a safe and durable manner against earthquake risk. Compliance with these regulations in building design is of vital importance for the prevention of earthquake damage and for increasing the resistance of structures against earthquake effects.

The concept of "earthquake-resistant architectural design" is related to the ability of buildings to survive in the face of horizontal and vertical loads and external effects without deteriorating their general structure, and to design structures that protect life safety. Making it earthquake resistant should not be seen as just a static calculation or civil engineering task. For earthquake resistance of buildings, architects and engineers should come together and consider the structural system design and all building design processes together (Garcia, 2000). Bearing elements are the basic components that ensure the strength and durability of the structure. When these elements are designed and placed correctly, they will carry earthquake loads effectively and the shape and integrity of the structure will be preserved.

1.2. Cross-Laminated Timber Material Properties and Earthquake Resistance

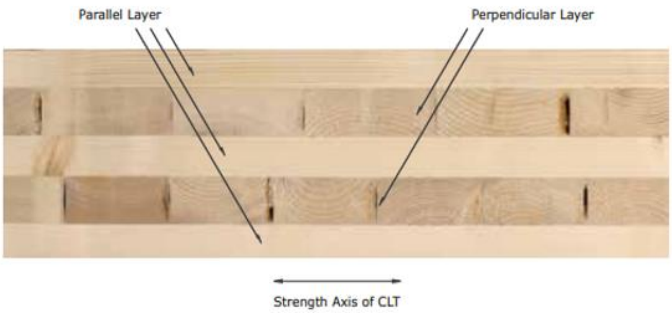
Timber material is lighter than reinforced concrete and steel and has a similar performance in terms of strength to these materials. It gives better results than reinforced concrete and steel in terms of strength/weight ratio (Hegeir et al., 2022). For this reason, timber structures are an option that can be preferred in areas with high earthquake risk and can be used to create safe structures. Thanks to its flexibility and durability, it performs better against earthquakes and reduces the risk of damage. In such structures, strong and flexible columns and beams, and their proper connection as a whole, ensure that the timber walls become resistant to the lateral loads that occur during earthquakes (Tobriner, 2000).

Before the emergence of reinforced concrete buildings, timber buildings have been widely used in countries with earthquake zones (such as China, Japan, Greece, Türkiye, and Balkan countries) for centuries (Porcu, 2017). However, today, when we look at the building stock, it is seen that there are predominantly reinforced concrete buildings, and unfortunately, most of these buildings were not designed or built to be earthquake resistant. The 7.4 magnitude Marmara Earthquake that occurred in our country on August 17, 1999, was effective in 7 provinces and 18.373 people lost their lives. In addition, 317.493 residences and 47.412 workplaces were damaged. However, in the 17 August Earthquake, timber frame structures were damaged less due to their lightness and flexibility (Gülhan & Güney, 2001). Preferring lightweight timber structures in addition to reinforced concrete structures in such high earthquake-risk areas will contribute to reducing the loss of life and property in possible earthquakes by reducing the horizontal dynamic loads.

Despite the many advantages of timber material, it is accepted as a problem that it has orthotropic properties that change in different directions. However, today, this problem is being improved thanks to industrial timber building materials (Gürel, 2018). With industrial processes, the mechanical properties of timber materials are made more homogeneous and the durability of the structures is increased.

Cross-laminated timber material (CLT), an industrial timber product, which has been used frequently throughout the world in recent years and has started to be used in our country, has become a preferred building element in the construction of modern buildings by offering great flexibility in architectural designs thanks to its many features. This material has a wide range of applications, from detached houses to multi-storey residences, from public buildings to industrial buildings, and even bridge construction (Wieruszewski & Mazela, 2017). The high strength and durability of CLT panels, which enable long span to be passed through in architectural projects, helps structures to become safer against earthquakes and other natural disasters. In our country, the codes related to the earthquake performance of CLT and timber materials are insufficient, and Eurocode 5 is used in the design of timber structures and Eurocode 8 is used for earthquake resistance in buildings (TS EN, 1995; TS EN, 1998). CLT structural elements used in modern timber buildings consist of solid timber bearer and partition walls and floors. It has been proven by many experiments and tests that these structures are extremely resistant to earthquake loads, and they behave almost like a closed box during an earthquake. Thanks to CLT technology, earthquake resistant buildings can be constructed over 9 floors or even up to 34 floors (Akça et al., 2014).

CLT is a high-strength and rigid industrial timber construction element, which is glued with a pressure of 0.6 N/mm^2 with the fiber directions perpendicular (opposite) to each other. This building element is formed by combining 3, 5, 7, or more layers (Figure 1). In particular, the fact that the layer directions are opposite each other is an important feature that distinguishes CLT from other glued laminated timbers (Güzel & Yesügey, 2015). Panels produced from cross-laminated wood can be produced in different thicknesses according to structural features. The layers that make up the panels are glued together using environmentally friendly, formaldehyde-free adhesives, making them a sustainable building material. The dimensions of commonly used sizes of CLT panels are given in Table 1.



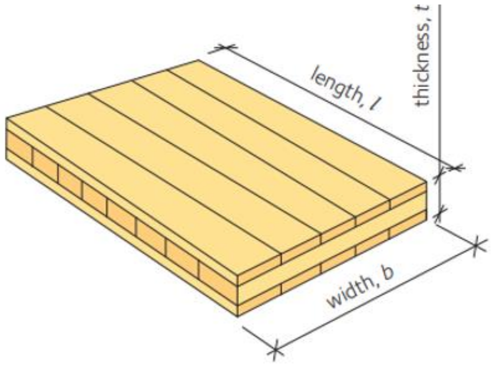


Figure 1. Cross-section of a 5-layer CLT panel (Karacabeyli & Gagnon, 2019; Wood, 2019)

Placing the layers in opposite directions provides the high strength and rigidity of the CLT. This building element is a building material with a high carrying capacity and is used in many construction projects.

Table 1. Common dimensions for CLT Panels (Wood, 2019)

Parameter	Commonplace	Available
Thickness, t	80 – 300 mm	60 – 500 mm
Width, w	1,20 – 3,00 m	up to 4.80 m
Length, l	16 m	up to 30 m
No. of layers	3, 5, 7 or more layers depending on static requirements	up to 25

CLT structural elements, which is a construction system used as an alternative to the increasing steel and concrete construction systems in Europe, are also used as a building system in addition to being a product (Wieruszewski & Mazela, 2017). The CLT construction concept offers almost unlimited architectural possibilities and is fully compatible with other construction materials (Stora Enso, 2021). With CLT panel elements, both wall, floor, and roof flooring can be made (Figure 2). The layers that make up the wall panel must be single and different quality wood can be used in the structure system, inside and outside of the building. While low quality wood is preferred for interiors, it is recommended to use high quality wood for exterior and structure (Ayaz, 2011). In this way, a design that is both durable to the structure and aesthetically appropriate can be obtained.

Figure 2. Examples of buildings using CLT panels (Mestek, Werther & Winter, 2010)

CLT exterior wall panels are used with insulation materials depending on the climatic conditions of the building. In CLT buildings, the load-bearing system can be completely composed of CLT panel walls and floors, or it can be built in hybrid form with steel columns or Glulam material columns. In addition, in some applications, CLT walls are built starting from the ground level, while in some applications, they are built on the ground floor consisting of reinforced concrete shear walls.

Experimental studies over the last decade have provided important information for evaluating the performance of CLT buildings and the strength of the elements used in the interconnection of panels. The load-bearing system of CLT structures develops ductility, usually through the deformation of the joints, while CLT wall panels remain almost linearly elastic, with minimal local crushing at the corners. Therefore, the behavior of the connections affects the behavior of the entire wall and the CLT has a great influence on the behavior of the structure (Karacabeyli & Gagnon, 2019, Li & Tsavdaridis, 2023). Mechanical fasteners, hold-down and angle brackets, small diameter metal fasteners, and joint sealing tapes are used in the connection of CLT walls with each other, floors, or roof (Sandoli et al., 2021; Tandoğan & Lakot Alemdağ, 2023) (Figure 3).

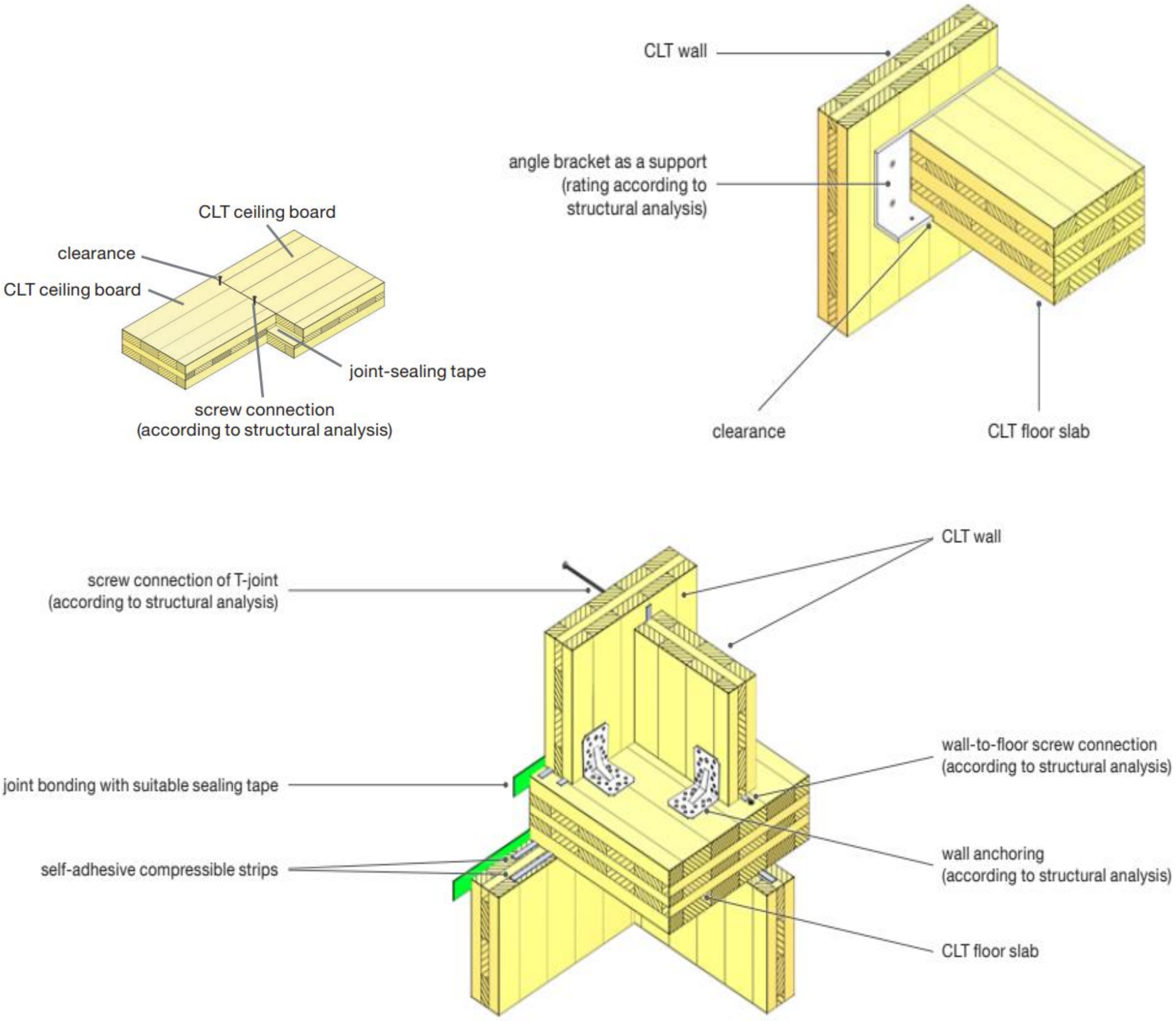


Figure 3. Examples of fasteners used in CLT buildings (Stora Enso, 2017)

CLT structures are highly energy absorbent and ductile during earthquakes. This feature allows CLT panels to absorb energy and minimize damage by showing plastic deformation under high stresses during earthquakes. Thus, the durability and safety of the buildings in earthquakes is increased. In addition, CLT structures provide an effective interaction between vertical bearing elements and horizontal bearing elements. This helps to distribute the building's horizontal loads evenly between horizontal shifts and tilts on the gravitational load-bearing system. Thanks to their lightness and rigidity, CLT buildings can be preferred in areas exposed to high-ground accelerations in earthquakes. However, it is important to comply with local building codes and earthquake codes during the design and construction of CLT buildings. Appropriate design and engineering practices ensure that CLT buildings perform safely and are durable against earthquakes (Cabral & Blanchet, 2021; Trutalli et al., 2019).

2. Numerical Model

Türkiye is one of the most seismically active regions of the world. Therefore, the dynamic performance of the structures constructed in earthquake-prone regions is of great importance. The recent February 6, 2023, Kahramanmaraş earthquakes in Türkiye have clearly demonstrated the poor condition of the existing structures in the region. Thousands of buildings, particularly RC buildings, were damaged and collapsed in the earthquake-affected area. Due to its in-plane rigidity and possibly ductile structural construction design, CLT structure is a fascinating building alternative in seismically sensitive areas. As a result, the dynamic response of CLT structures to seismic loads has been the focus of much experimental and computational research during the last two decades (Demirci, 2019). While the number of buildings constructed with CLT shear walls has been steadily growing since its inception in Europe in the 1990s, this structural system has only recently been introduced in Türkiye. CLT has entered the building sector as an alternative to RC buildings, with an interest in using them in structures in strong seismic zones due to their lightweight quality. One of the objectives of the study is to obtain the dynamic behavior of the CLT shear walls of residential buildings under earthquake loads, which has a growing interest in our country nowadays. In this study, a five-story residential building with all interior and exterior walls constructed with CLT was selected as an example to obtain dynamic performance.

In the seismic design of a multi-story CLT structure, the designer should adhere to the conceptual design concepts outlined in Eurocode 8, which apply to all types of buildings. These principles are especially important for CLT structures to achieve good overall structural behavior of the building (i.e. structural simplicity, uniformity, symmetry, and redundancy, bi-directional strength and stiffness, diaphragmatic behavior at storey level, and adequate foundation) (Follesa et al., 2013). According to Eurocode 8 Part 1, there are three options for seismic analysis of a numerical building model based on the fulfillment of the regularity requirements in plan and elevation: i) the linear static analysis, ii) the modal response spectrum analysis (the linear dynamic analysis) and iii) non-linear methods (non-linear static (pushover) analysis or non-linear time-history analysis). In the study, the linear dynamic analysis was conducted to obtain the dynamic behaviors of the multi-storey CLT residential building.

2.1. Details of the CLT Residential Building

The selected residential building study is a project prepared by TOKI (Housing Development Administration Republic of Türkiye Ministry of Environment, Urbanization and Climate Change) and is a design constructed by a tunnel formwork system, with interior and exterior walls completely RC shear walls. The reason for choosing this project is that all walls are made of the same material and tunnel formwork system is a frequently preferred structural system in our country and it shows a better performance than frame systems under earthquake loads. All the walls of this building were reconstructed with CLT material for the purpose of the study. The interior design and square meters of the interior areas have not been changed in the model. The building has five stories and there are 3 flats on each story. Floor height is 3m and the total building height is 15m. The flats are designed in a 2+1 plan layout of approximately 70m^2. Floor plan of the selected CLT building is given in Figure 4. The building plan is roughly rectangular, with dimensions of approximately 14m*x*26m.

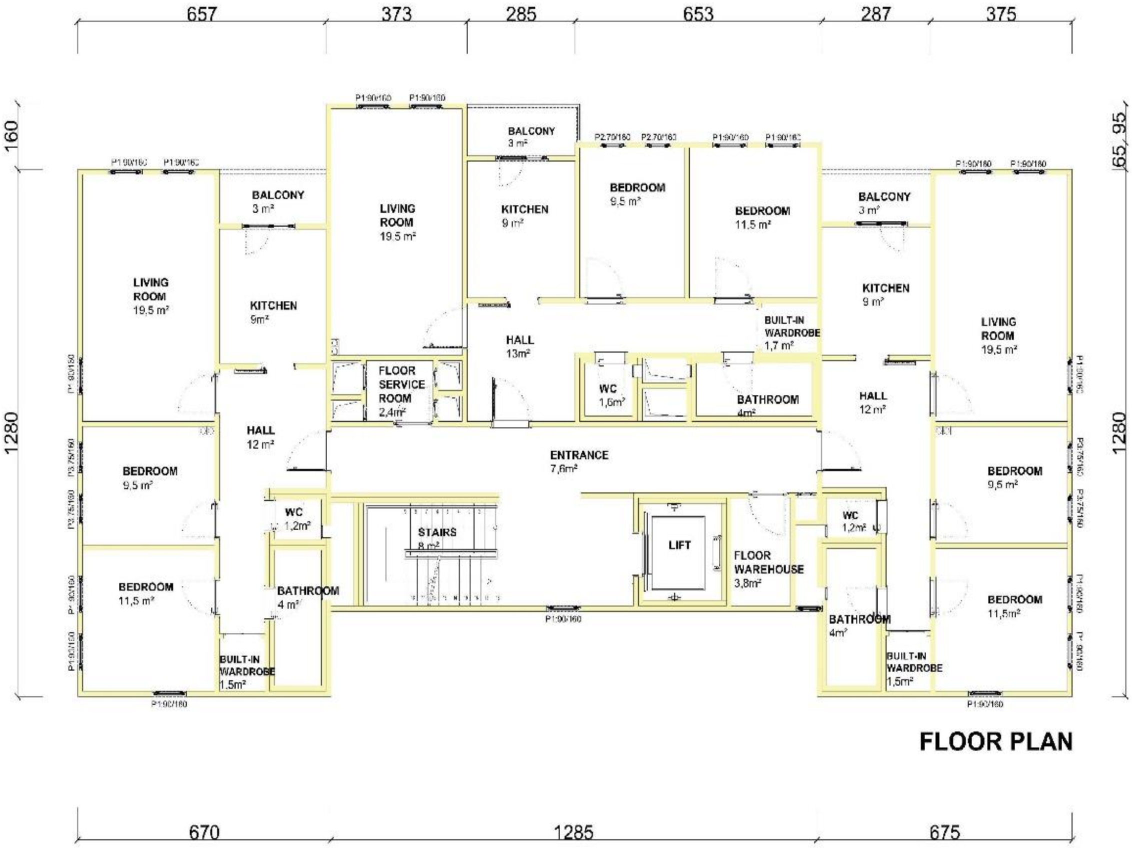


Figure 4. Floor plan of the selected CLT residential building

2.2. Modeling

In numerical modeling, TimberTech (2022) software was used to produce the numerical model of the multi-story CLT residential building, which is a design software for the analysis and design of timber shear wall structures developed at the University of Trento in Italy. The five-story 3-dimensional (3D) model and floor plan are illustrated in Figure 5.

Material symmetry axes (1, 2, 3) of CLT plates are thought to be parallel to orthogonal axis directions x, y, z, which determine the length, width, and thickness of elements, respectively.

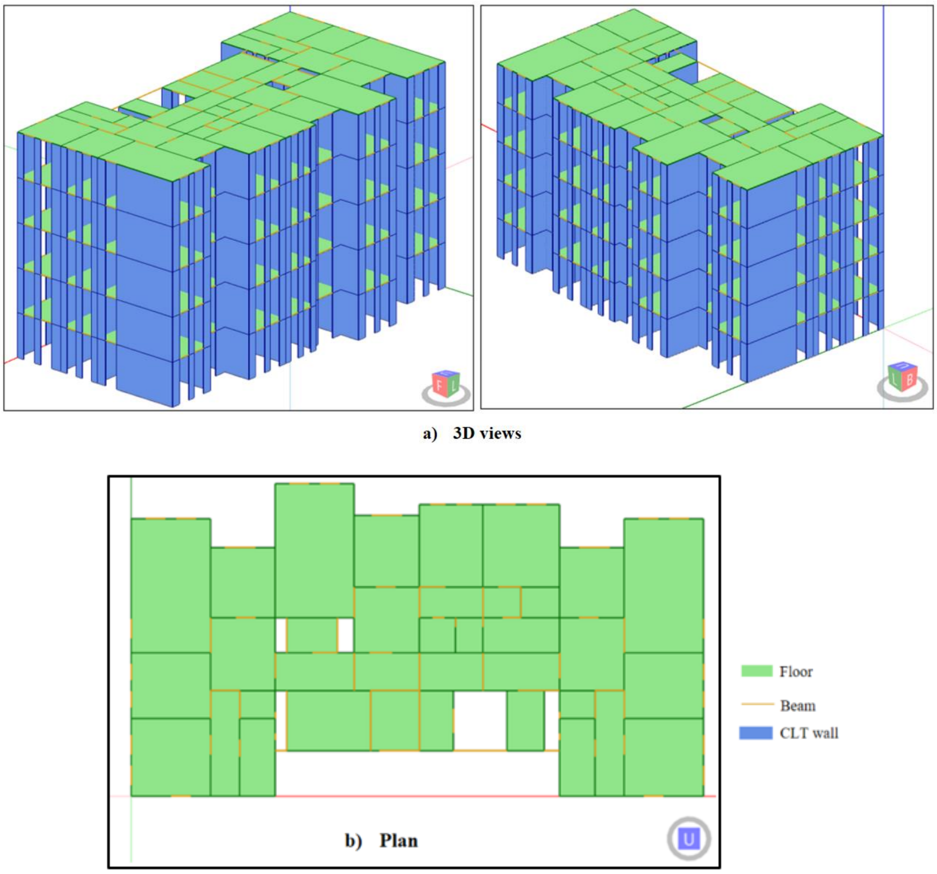


Figure 5. The model of a five-story CLT residential building a) 3D views and b) Plan

The 3D residential building model consists of CLT wall, floor, and beam elements. C24 softwood strength class is used for the beam and floor in the modelling and its characteristic bending strength is 24MPa. The material properties used in the model for beam, floor and CLT wall elements are given in Table 2. The linear elements are used to model beams and columns. CLT panel walls are constrained at the base by connecting systems that can transmit both in-plane and out-of-plane movements. The total stiffness of CLT walls is computed by taking the contributions of the following components into consideration: CLT panel (k_{xLAM}) , shear connections-angle brackets (k_a) and hold-down or tie-down (k_h) as shown in Figure 6. The width and the height of the floor beam are 160mm and 200mm respectively, and it is placed at 700mm intervals on the floor. In the model, the walls are made with 5-layer CLT panels with a thickness of 160 mm for all floors and CLT walls characteristics are given in Table 3. Self-weight of structural materials (i.e. beam, column and CLT panel wall) are 5kN/m^3.

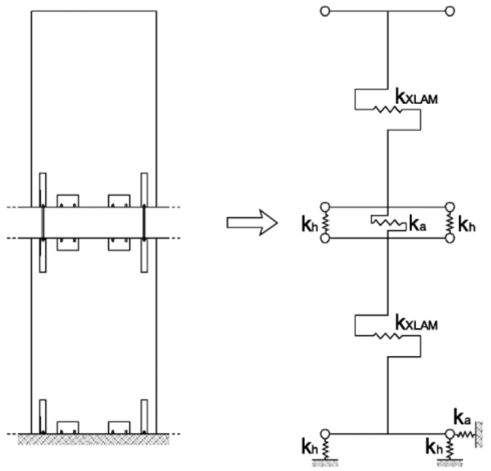


Figure 6. Total stiffness of CLT walls

Table 2. The material properties used in the modelling

Mechanical Properties of the elements	Beam and Floor	CLT Wall
Description	C24	C30 Stora Enso-Pine
Characteristic bending strength, $f_{m,k}$ (MPa)	24	30
Characteristic tensile strength along the grain, $f_{t,0,k}$ (MPa)	14.5	19
Characteristic tensile strength perpendicular to the grain, $f_{t,90,k}$ (MPa)	0.4	0.12
Characteristic compressive strength along the grain, $f_{c,0,k}$ (MPa)	21	24
Characteristic compressive strength perpendicular to the grain, $f_{c,90,k}$ (MPa)	2.5	2.7
Characteristic shear strength, $f_{v,k}$ (MPa)	4	-
Characteristic in-plane shear strength of CLT panel, $f_{v,k,inplane}$ (MPa)	-	4
Characteristic rolling shear strength, $f_{R,k}$ (MPa)	-	1.5
Torsional resistance of crossing surfaces, $f_{T,k}$ (MPa)	-	2.5
Mean value of modulus of elasticity along the grain, $E_{0,mean}$ (MPa)	11000	12000
Fifth percentile value of modulus of elasticity along the grain, $E_{0.05}$ (MPa)	7400	8000
Mean value of modulus of elasticity perpendicular to the grain, $E_{90,mean}$ (MPa)	370	400
Mean value of rolling shear modulus, G_{mean} (MPa)	690	460
Self-weight of the structural material, γ (kN/m^3)	5	5
Characteristic density, ρ_k (kg/m^3)	350	380

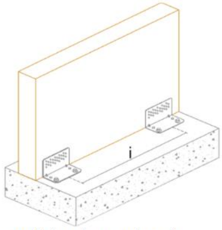
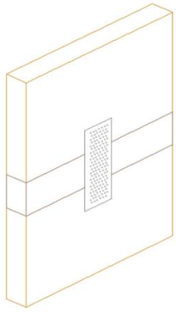
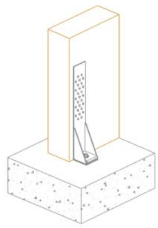
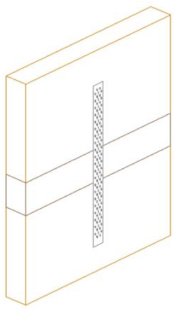
Table 3. CLT walls characteristics

Section Name	Manufacturer	Material	Layer number	Thickness (mm)	Layers	Orientation of the outer layers
CLT 160 C5s	Stora Enso	C30 Stora Enso-Pine	5	160	40-20-40-20-40	Vertical

2.2.1. Connections of CLT walls

The lateral stiffness is significantly dependent on the stiffness of the connection provided by the nails or screws on CLT buildings. While the illustrations and mechanical properties of the connections used in the model are given in Table 4. We can also see on the table that mechanical properties of the shear and tensile connections for ground and upper level used in the TimberTech software.

Table 4. Details of connections and mechanical properties of them

Type of connection			Connection properties	
for shear forces	*Ground level*	 Angle brackets with anchors	***Connection***	
			Connection	:Titan S-TCS 240
			Nailing	:Total
			Fastener type	:14xScrew-HBS Plate 8.0x80
			Side Number	:2
			Shear connection spacing	:500mm
			Connection element resistance	:85.9kN
			Anchors	
			Threaded rod/Mechanical anchor	: Threaded rod INA-8.8- M16x245
			Chemical anchor	: Hybrid chemical anchor ETA-20/1285
			Number of anchors per single connection element	:2
			Anchor resistance per single anchor	:101.8kN
			Safety factor	:1.25
	Upper level	 Timber to timber shear plate	***Connection***	
			Connection	:Perforated plate 200x300 sp. 2mm
			Fastener type	:Anker nail LBA 4.0x60
			Number of rows	:3
			Number of fasteners in one row	:10
			Spacing parallel to the grain a_1	:40
			Total number of fasteners	:30
			Effective number of fasteners	:21.24
			Shear connection spacing	: 500mm
			Nailing resistance perpendicular to the grain	: 59.66kN
			Nailing resistance parallel to the grain	:42.24kN
			Steel connection element resistance	: 43.30kN
for tensile forces	*Ground level*	 Hold down	***Connection***	
			Connection	:WHT 740
			Nailing	:Total
			Fastener type	:75xAnker nail-LBA 4.0x40
			Num. of connect. at each wall end	:4
			Nailling resistance	:117.80kN
			Steel connection element resistance	:158.60kN
			Anchors	
			Threaded rod/Mechanical anchor	: Threaded rod INA-5.8- M27x330
			Chemical anchor	: Hybrid chemical anchor ETA-20/1285
			Num.of anchors per single connect. element	:1
			Anchor resistance per single anchor	:151.35kN
			Safety factor	:1.5
	Upper level	 Tie down	***Connection***	
			Connection	: Perforated plate 140x400 sp. 2mm
			Fastener type	:Anker nail LBA 4.0x75
			Number of rows	:7
			Number of fasteners in one row	:20
			Spacing parallel to the grain a_1	:30
			Total number of fasteners	:140
			Effective number of fasteners	:61.42
			Nailing resistance perpendicular to the grain	:288.93kN
			Nailing resistance parallel to the grain	:126.77kN
			Steel gross section resistance	:70kN
			Steel net section resistance	:62.37kN

2.2.2. Seismic actions

On February 6, 2023, two major earthquakes happened in Türkiye. There was massive devastation and tens of thousands of deaths. A large number of buildings were collapsed and damaged. This occurrence highlighted the need of earthquake-resistant building. Most of the buildings in our country are RC buildings and serious damages were observed in RC buildings in the last earthquake. If CLT buildings are constructed in the earthquake region, it is also a matter of curiosity how their earthquake performance will be and whether they can be an alternative to RC buildings. In this context, in this study, seismic effects are calculated according to Eurocode8 due to the shortcomings of the application of CLT buildings in our country.

An elastic ground acceleration response spectrum represents the seismic motion at a specific location on the surface. According to Eurocode8 (2005), the response spectra are calculated using the design ground acceleration on type A ground: the acceleration is equal to the value of the reference peak ground acceleration (PGA) on type A ground times the importance factor. In the study, spectrum type and ground type are chosen as Type 1 ($M_w > 5.5$) and Soil C, respectively. The damping correction factor is 1 for 5% viscous damping.

The design of timber structures is conducted according to limit state design in Eurocode, in conjunction with the partial factor method for resistance, serviceability and durability. Limit state design (LSD) is a structural engineering design method that is used to estimate how much load is placed on a structure, choose the sizes of members to check, and select the suitable design criteria. In LSD, two limit states must be considered: ultimate limit state (ULS) and serviceability limit state (SLS) as shown in Figure 7.

Limit State Design (LSD)

Ultimate Limit State (ULS)

Buckling
Fracture
Overturning
Sliding
Strength

Serviceability Limit State (SLS)

Loss of durability
Vibration
Crack width
Excessive deflection
Discomfort to occupant

Figure 7. Limit state design (LSD)

ULS is a design method that limits the stress to which materials are subjected to ensure the safety of the building and its occupants. In other words, ULS represents the failure of the structure and its components when subjected to extreme load effects. SLS is a design method that ensures that the structure can be used safely. This method consists of deflection, vibration, as well as durability, and cracking. The horizontal elastic response spectra and the design spectrum for Ultimate Limit State (ULS) and soil type C are given in Figure 8.

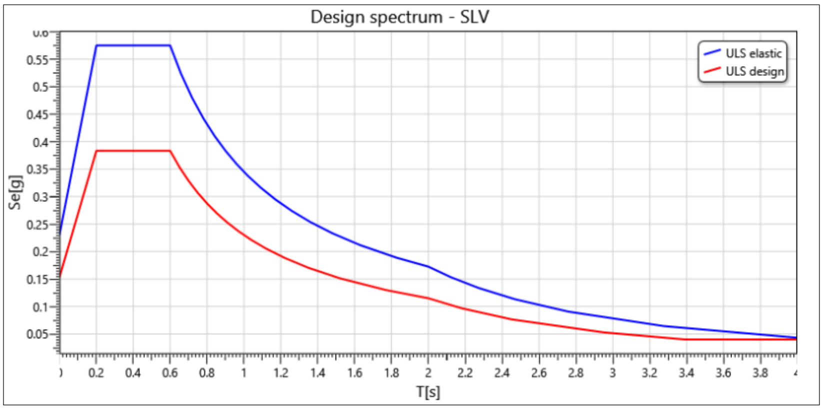


Figure 8. Design spectrum according to Eurocode

A dynamic analysis with a response spectrum is performed on the model to obtain the seismic performance of the CLT building. For dynamic analysis, seismic data were obtained by using the coordinates of Pazarcık district of Kahramanmaraş province where the last major earthquake occurred. Seismic data were taken from the seismic hazard map through AFAD (the Disaster and Emergency Management Presidency of Türkiye). The earthquake ground motion level is selected as DD-2 and the local soil class of the location considered for analysis is ZC with a high seismicity and a PGA value of 0.386g. The serviceability limit state (SLS) and Ultimate limit state (ULS) design spectra belonging to Kahramanmaraş Province are illustrated in Figure 9. In the Figure, there are two types of limit state: i)

Ultimate limit state (ULS) and ii) Serviceability limit state (SLS). The aim of this design is to reach acceptable possibilities that a building will not become unfit for its intended use.

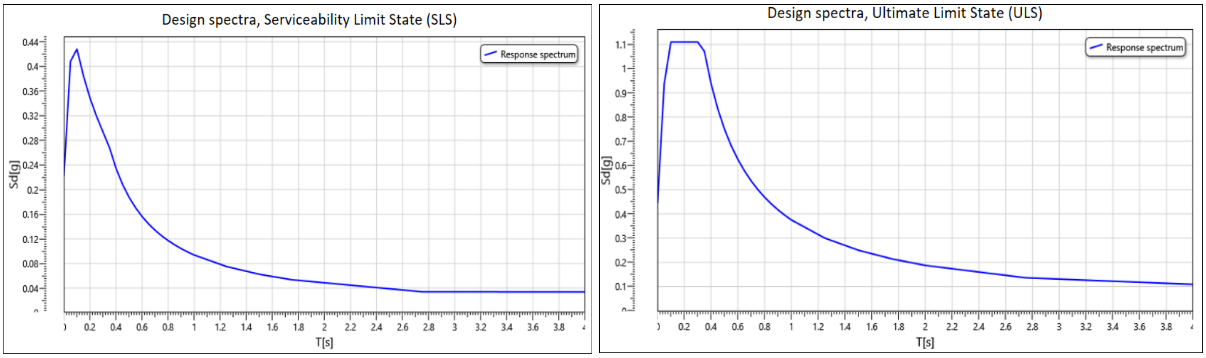


Figure 9. Design spectra of Kahramanmaraş Province according to Eurocode

3. Findings and Discussion

Modal analysis is applied to the model in the study, and it utilizes a building's total mass and stiffness to determine the different periods at which it will naturally resonance. Besides, the results of modal analysis also give us about vibration modes and the seismic behaviour of the building. The mode shape is an important feature in modal analysis. It expresses the deformation that the building load-bearing system is exposed to in case of vibration in the natural frequency range. The first three mode shapes belonging to the model are shown in Figure 10, which are the first two modes with great lateral movement and the last mode with torsional movement.

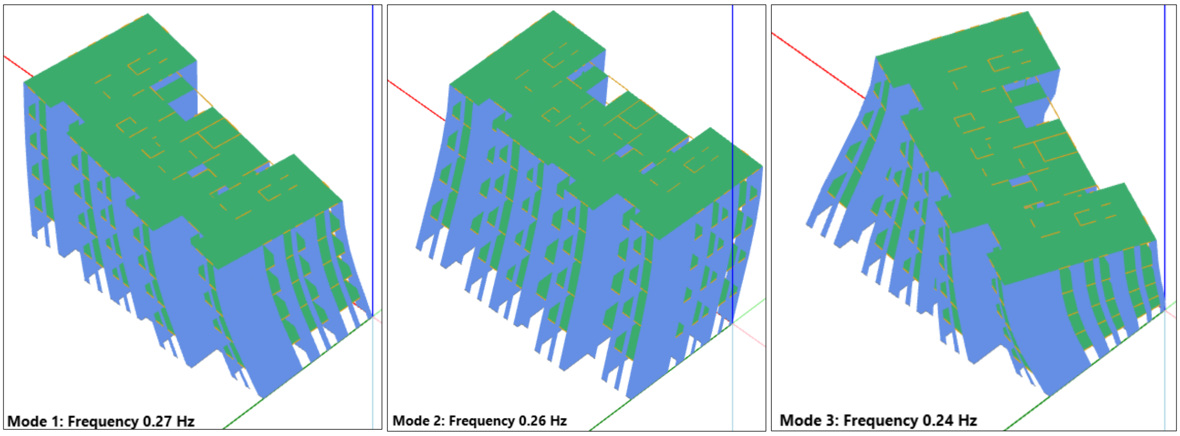


Figure 10. The first three mode shapes

As shown in Figure , third mode is torsional mode as expected in buildings. A torsional mode shape might lead to problems with stability in structures. Torsional troubles emerge when the locations of the center of mass and the center of stiffness differs. The structure is subjected to more torsional moments as the difference between the centers of mass and stiffness increases. Excessive torsion will cause significant damage to walls and columns. An earthquake load acts at the mass center, but the force resisting this load acts on the center of rigidity, which can cause torsion in the structure (Gökdemir et al., 2013). Therefore, a torsion mode is not desired as the main mode of the structural system. Code (2005) also recommends avoiding torsional fundamental mode for seismic research.

Structural periods, natural frequencies, and dynamic mass participation factors are given in Table 5 for the first 15 modes of the CLT residential building. The first period is approximately 0.25s for the building. The larger the number of modes involved, the higher the amplification of response amplification as also can be seen from Table 5. Code (2005) describes the significant modes for this global response from the effective modal mass in two ways: i) the sum of the effective modal masses for the mass considered amounts to at least 90% of the total mass of the structure, ii) all modes with effective modal masses greater than 5% of the total mass is taken into account.

It is seen that from Table 5, the sum of the effective modal masses is higher than 90%. Besides, the modal results show that the contribution of the first mode to the dynamic response is 52% in the X direction, 4.81% in the Y direction, and 30.17% in the Z direction.

Table 5. Modal results

Mode	Period [S]	Freguency	Mx [%]	Sum Mx [%]	M_Y [%]	Sum M_Y [%]	M_Z [%]	Sum Mz [%ı
Mode 1	0.27	3.75	52.37	52.37	4.81	4.81	30.17	30.17
Mode 2	0.26	3.88	5.98	58.35	80.98	85.78	0.15	30.32
Mode 3	0.24	4.22	28.88	87.23	1.31	87.09	56.98	87.30
Mode 4	0.09	10.86	5.38	92.62	0.52	87.61	3.11	90.42
Mode 5	0.09	11.25	0.63	93.25	8.42	96.02	0.01	90.43
Mode 6	0.08	12.21	3.00	96.25	0.14	96.16	5.87	96.30
Mode 7	0.06	16.90	1.58	97.83	0.17	96.32	0.85	97.15
Mode 8	0.06	17.48	0.20	98.03	2.52	98.85	0.01	97.15
Mode 9	0.05	18.97	0.90	98.93	0.04	98.89	1.80	98.95
Mode 10	0.05	21.36	0.52	99.44	0.06	98.95	0.28	99.24
Mode 11	0.05	22.05	0.07	99.51	0.84	99.79	0.00	99.24
Mode 12	0.04	23.92	0.26	99.77	0.01	99.80	0.61	99.85
Mode 13	0.04	23.99	0.15	99.92	0.02	99.82	0.02	99.87
Mode 14	0.04	24.74	0.02	99.94	0.18	100.00	0.00	99.87
Mode 15	0.04	26.82	0.06	100.00	0.00	100.00	0.13	100.00

The dynamic linear analysis is also applied to the model building. The analysis contains the calculation of the seismic effects (represented by the seismic effect design response spectrum) for each of the vibration modes calculated in the modal analysis and the integration of these effects. All results of verification for an ultimate limit state (static and dynamic), life safety limit state (static and dynamic), and are given in a single figure (Figure 11) to compare them more easily. These results are based on the seismic data of Kahramanmaraş province in Türkiye. Besides, the same model is analyzed according to Eurocode8 for soil type C and the obtained results are compared. While the model provides all the verifications in the solution according to Eurocode for soil type C, it is clearly seen from the figure that the model is inadequate under the seismic data of Kahramanmaraş province. These inadequacies are seen in red color in the figure.

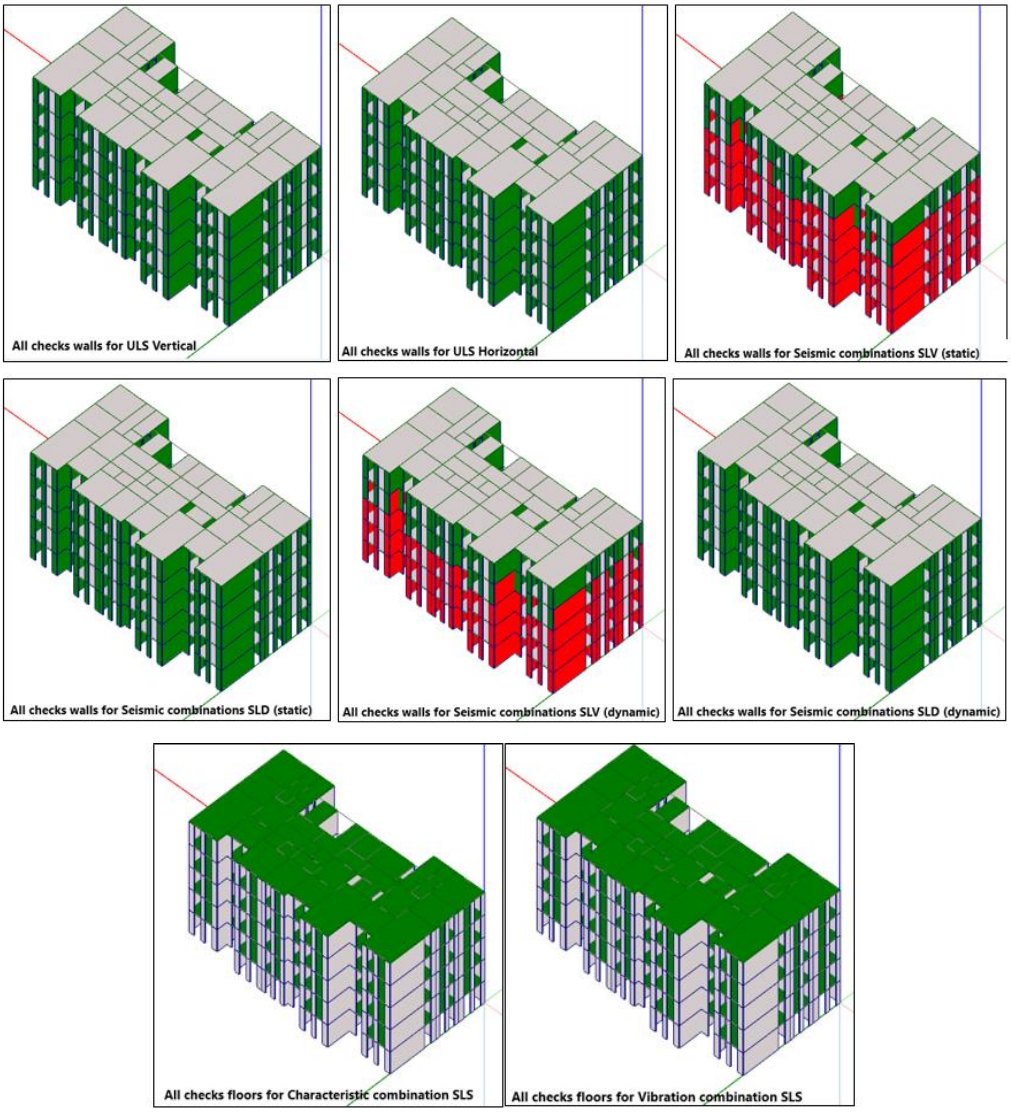


Figure 11. All verification results of the selected CLT building for the seismic data of Kahramanmaraş Province

The design share resistance is used to determine the design resistance of a perforated metal plate: it is done by shear failures of the metal plate and the group of fasteners of the connection. The least value among the resistances for nailing failure and perforated steel strap failure is used to calculate the design tensile force resistance of a perforated belt.

Figure 12 and Figure 13 are demonstrated shear and tension failures in the elements and connections of the model for SLV (Life safety limit state, static and dynamic). We can clearly identify which elements and connections are inadequate from the figures. These inadequacies are seen in red color in the figures.

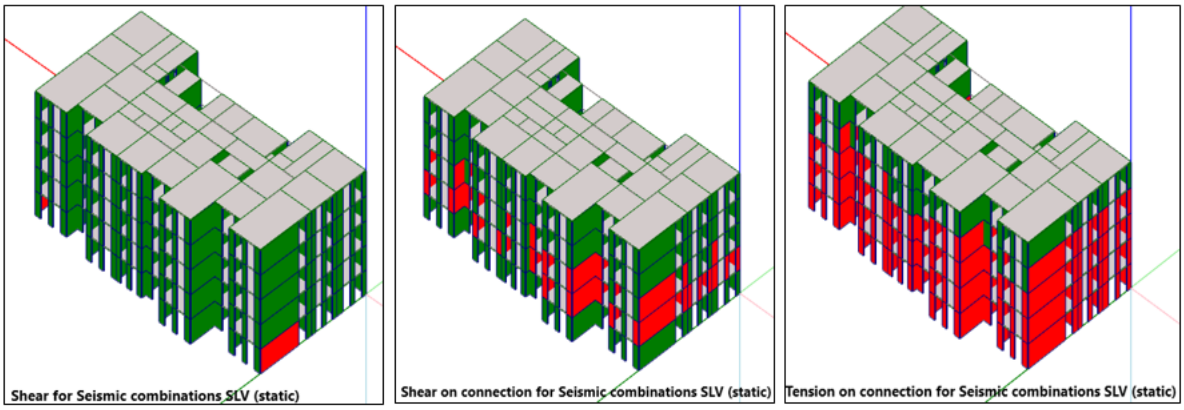


Figure 12. Shear and tension failures in the elements and connections of the model for SLV (Life safety limit state, static)

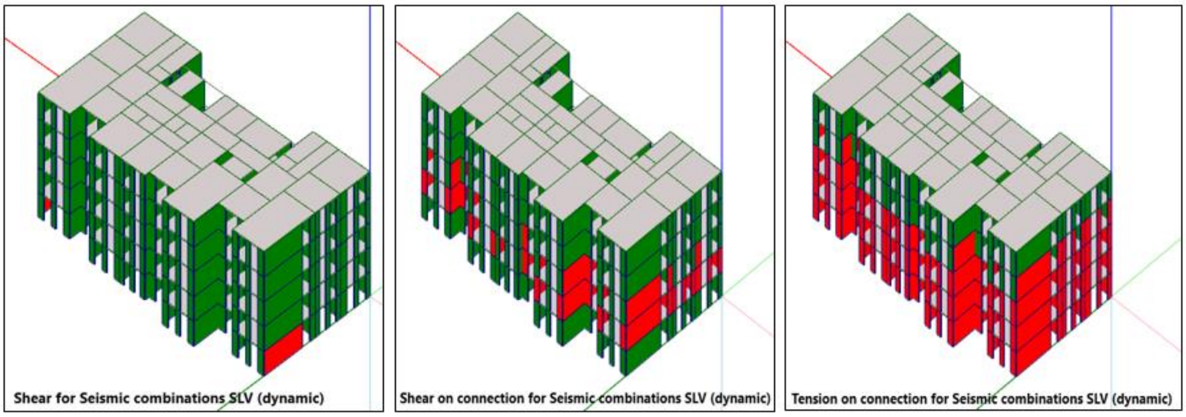


Figure 13. Shear and tension failures in the elements and connections of the model for SLV (Life safety limit state, dynamic)

Figure 14 and Figure 15 are demonstrated that verification percentage of floors and beams, respectively. In the Figures, we can see the bending, shear and deflection verifications for the floors anb beams. We can see from the figures that the floors and beams used are adequate under seismic effects. These adequacies are seen in green colour in the figures.

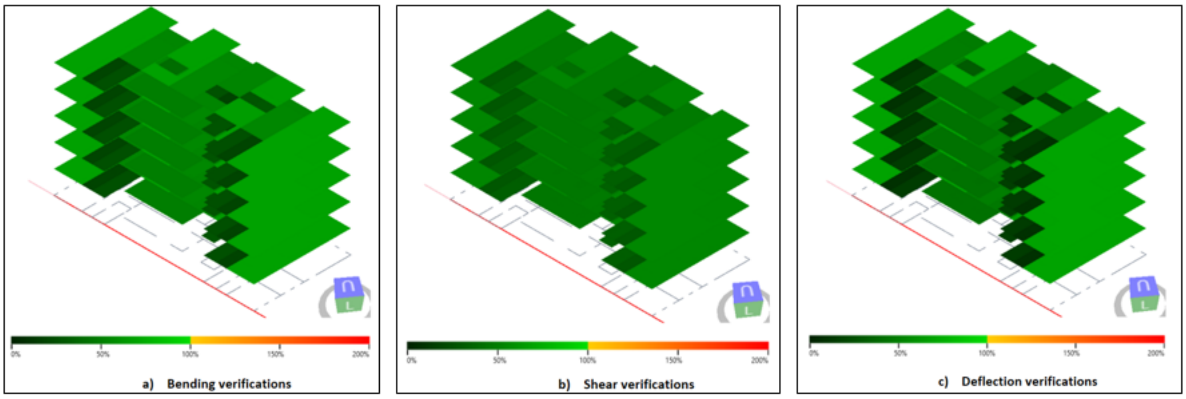


Figure 14. Verification percentage of floors, a) and b) Ultimate Limit State (ULS), c) Serviceability Limit State (SLS)

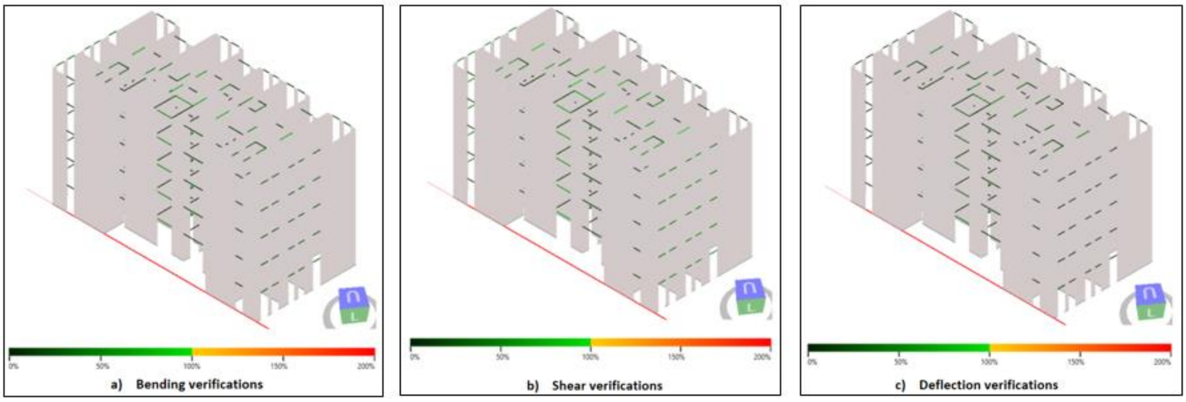


Figure 15. Verification percentage of beams, a) and b) Ultimate Limit State (ULS), c) Serviceability Limit State (SLS)

4. Conclusion

Türkiye is one of the most seismically active regions of the world. Therefore, the dynamic performance of the structures constructed in the earthquake-prone regions is of great importance. The recent Kahramanmaraş earthquakes in Türkiye on February 6, 2023, have clearly shown the alarming state of the region's existing structures, particularly RC buildings. Contrary to the RC material, the lightness of wood, its high strength and sustainability features contribute to its increasing preference in the construction sector and to the increase in the use of innovative wood products such as CLT in earthquake zones. In CLT structures, where effective communication is provided between vertical and horizontal bearing elements, a high degree of energy is absorbed during an earthquake, thanks to the peculiarity of the wood material.

As a result, one of the study's goals is to determine the dynamic behavior of CLT shear walls in residential structures under seismic loads, which is gaining popularity in our country. In addition, it is aimed at drawing attention to the proper material selection and size of structural elements in earthquake-resistant building design. In this study, a five-story residential building constructed with all interior and exterior walls constructed with CLT was selected as an example. For this purpose, TimberTech (2022) software was used to produce the numerical model of the multi-story CLT residential building that can be constructed in areas with high earthquake risk as an alternative to the RC frame construction system. Seismic effects are computed using Eurocode8 because of the inadequacies in the application of CLT buildings in our country. Therefore, linear dynamic analysis (response spectrum analysis) is applied to the model according to Eurocode standard to obtain the seismic performance of the CLT building. For dynamic analysis, seismic data were used by using the coordinates of Pazarcık district of Kahramanmaraş province, where the last major earthquake occurred on February 6, 2023, in Türkiye. AFAD (the Disaster and Emergency Management Presidency of Türkiye) was used to obtain the seismic data of Kahramanmaraş earthquakes and the seismic hazard properties of Kahramanmaraş province on the Turkish Seismic Hazard Map. On the map, the earthquake ground motion level is configured for DD-2, and the local soil class of the area under consideration for investigation is ZC, with a high seismicity and a PGA value of 0.386g. The multi-story CLT residential building was analysed and compared to the seismic data of Pazarcık district of Kahramanmaraş province and Eurocode design spectra for soil type C considering the Turkish Hazard Map of Kahramanmaraş province. It is obtained from the study that while the model provides all the verifications in the solution according to Eurocode for soil type C, it is inadequate under the seismic data of the Kahramanmaraş earthquake.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

1st author % 40, 2nd author %40, 3nd author %20 contributed. There is no conflict of interests.

References

Akça, C., Akarca, H., Erdoğmuş, E. & Demirel, A. (2014). Yapı Ahşabı ve Ahşap Yapı Sektörü, Ulusal Ahşap Birliği. Access Address (07.08.2023): http://www.ahsap.org/assets/pdfDocs/etkinlik-2/Ahsap-Yapi-Sektor-Raporu-2.pdf.

Amini, M. O., Van de Lindt, J. W., Rammer, D., Pei, S., Line, P., & Popovski, M. (2018). Systematic experimental investigation to support the development of seismic performance factors for cross laminated timber shear wall systems. *Engineering Structures, 172*, 392-404.

Ataman, O. & Tabban, A. (1977). Türkiye'de yerleşme alanlarının doğal afetler ile ilişkileri. *Mimarlık Dergisi*, 153, 25-27.

Ateş, Ş., Tonyali, Z., Soyluk, K. & Samberou, A. M. S. (2018). Effectiveness of soil–structure interaction and dynamic characteristics on cable-stayed bridges subjected to multiple support excitation. *International Journal of Steel Structures, 18*, 554-568.

Ayaz, C. (2011). Çok katlı sürdürülebilir yapı tasarımında ahşabın strüktürel olarak kullanım olanakları ve dünyadaki örnek uygulamalar (Unpublished master thesis). Fen bilimleri enstitüsü, Mimar Sinan Güzel Sanatlar Üniversitesi, İstanbul. Access Address (05.08.2023): https://tez.yok.gov.tr/UlusalTezMerkezi/TezGoster?key=EEdeQgIdFRxX5NbvVau-AiW-0KopYGKO5lcWsi8Ww6hbsHKXlASZ9q76_bEF3xeR

Ayyıldız Potur, A. & Metin, H. (2021). Mimarlık eğitiminde depremin yeri ve depremin eğitsel boyutu: Küresel gündem ve Türkiye bağlamı üzerine bir değerlendirme. *Megaron*, 16(2). Access Address (06.06.2023): https://jag.journalagent.com/megaron/pdfs/MEGARON-94210-ARTICLE-AYYILDIZ_POTUR.pdf

Bayülke, N. (1977). Türkiye'deki konut yapılarının depremlerde davranışları. *Mimarlık Dergisi*, 153, 40-48.

Birinci, A. U., Öztürk, H., Demirkir, C., & Çolakoğlu, G. (2020). Structural performance analysis of cross laminated timber (CLT) Produced from pine and spruce grown in Turkey. *Journal of Anatolian Environmental and Animal Sciences, 5*(5), 819-824.

Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G., & Thiel, A. (2016). Cross laminated timber (CLT): overview and development. *European Journal of Wood and Wood Products, 74*, 331-351.

Cabral, M. R. & Blanchet, P. (2021). A state of the art of the overall energy efficiency of wood buildings—An overview and future possibilities. *Materials*, 14(8), 1848. Access Address (12.05.2023): https://www.mdpi.com/1996-1944/14/8/1848

Casagrande, D., Grossi, P., & Tomasi, R. (2016). Shake table tests on a full-scale timber-frame building with gypsum fibre boards. *European Journal of Wood and Wood Products, 74*, 425-442.

Ceccotti, A., Sandhaas, C., Okabe, M., Yasumura, M., Minowa, C., & Kawai, N. (2013). SOFIE project–3D shaking table test on a seven-storey full-scale cross-laminated timber building. *Earthquake Engineering & Structural Dynamics, 42*(13), 2003-2021.

Code, P. (2005). Eurocode 8: Design of structures for earthquake resistance-part 1: general rules, seismic actions and rules for buildings. J Brussels: European Committee for Standardization.

Demirci, C. (2019). Seismic response of multi-storey cross-laminated timber buildings. *Department of Civil and Environmental Engineering, PhD Thesis, Imperial College London, UK*.

Dujič, B., Pucelj, J., & Žarnić, R. (2004). *Testing of racking behaviour of massive wooden wall panels*. Cib-W18 Str. 1-10.

Durmuş, A. (2004). Deprem Mühendisliğine Giriş Ders Notları. Karadeniz Teknik Üniversitesi. İnşaat Mühendisliği Bölümü. 1(2).

Elyiğit, B. & Ekinci, C. E. (2023). Betonarme yapılarda yapısal ve yapısal olmayan hasarlar ve hasar tespiti üzerine bir araştırma. *Engineering Sciences*, 18(2):19-42, Access Address (06.06.2023): https://www.firatakademi.com/articleDetails.asp?lang=2&article=FIRAT-AKADEMI-5504-5595

Erdik, M., Tümsa, M. B. D., Pınar, A., Altunel, E. & Zülfikar, A. C. (2023). Türkiye'de 6 Şubat 2023 depremleri üzerine bir ön rapor. Access Address (05.07.2023): http://doi.org/10.32858/temblor.297

Eurocode8. (2005). Design of structures for earthquake resistance. 1, 1998-1991.

FEMA. (2010). An Introduction to the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures FEMA P-749 / December 2010. Access Address (18.05.2023): https://www.fema.gov/sites/default/files/2020-07/fema_earthquake-resistant-design-concepts_p-749.pdf

Filiatrault, A., Christovasilis, I. P., Wanitkorkul, A., & van de Lindt, J. W. (2010). Experimental seismic response of a full-scale light-frame wood building. *Journal of structural engineering, 136*(3), 246-254.

Follesa, M., Christovasilis, I. P., Vassallo, D., Fragiacomo, M., & Ceccotti, A. (2013). Seismic design of multi-storey cross laminated timber buildings according to Eurocode 8. *Ingegneria Sismica, 4*.

Garcia, B. (2000). *Earthquake architecture: new construction techniques for earthquake disaster prevention.* Spain: Loft Publications. Access Address (10.07.2023): https://cir.nii.ac.jp/crid/1130000795313126784

Gavric, I., Fragiacomo, M., & Ceccotti, A. (2015). Cyclic behavior of CLT wall systems: Experimental tests and analytical prediction models. *Journal of structural engineering, 141*(11), 04015034.

Genç, F. N. (2007). Türkiye'de kentleşme ve doğal afet riskleri ile ilişkisi. TMMOB Afet Sempozyumu Bildiriler Kitabı (s.349-358). ISBN: 978-9944-89-425-8. (Aralık 2007), Ankara: Mattek Matbaacılık Basın Yayın.

Gökdemir, H., Özbasaran, H., Dogan, M., Unluoğlu, E. & Albayrak, U. (2013). Effects of torsional irregularity to structures during earthquakes. *J Engineering Failure Analysis*, 35, 713-717. Access Adress (01.05.2023): https://www.sciencedirect.com/science/article/abs/pii/S1350630713002288?via%3Dihub

Gülhan, D. & Güney, İ. (2001). Marmara depremi hasar tespiti çalışmalarından izlenimler. *Mimarlık Dergisi*, 299, 43-45.

Gürel, Y. (2018). Çok katlı ahşap yapıların deprem yükü altında performanslarının incelenmesi (Unpublished master thesis). Fen bilimleri enstitüsü, Yıldız Teknik Üniversitesi, İstanbul. Access Address (06.07.2023): https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=yGODf2Fm5gFFzW1p_J9Ng&no=siVOamXUnVITZelwUPOtDg

Güzel, N. & Yesügey, S. C. (2015). Çapraz lamine ahşap (CLT) malzeme ile çok katlı ahşap yapılar. *Mimarlık Dergisi*, 382. Access Address (23.04.2023): http://www.mimarlikdergisi.com/index.cfm?sayfa=mimarlik&DergiSayi=396&RecID=3627

Hegeir, O. A., Kvande, T., Stamatopoulos, H. & Bohne, R. A. (2022). Comparative life cycle analysis of timber, steel and reinforced concrete portal frames: A theoretical study on a norwegian ındustrial building. *Buildings*, 12(5), 573. Access Adress (23.06.2023): http://dx.doi.org/10.3390/buildings12050573

Hristovski, V., Mircevska, V., Dujic, B. & Garevski, M. (2018). Comparative dynamic investigation of cross-laminated wooden panel systems: Shaking-table tests and analysis. *Advances in Structural Engineering, 21*(10), 1421-1436.

İnan, T., Korkmaz, K. & Çağatay, İ. H. (2012). An investigation on plan geometries of RC buildings: with or without projections in plan. *Computers and Concrete*. 9(6), 439-435. Access Address (22.06.2023): file:///C:/Users/HP/Downloads/5511.pdf

Kahramanmaraş Earthquake Evaluation Report. (2023). Evaluation report including Kahramanmaraş earthquakes and their aftershocks, field observations, structural damages and suggestions for the future. Access Address (05.07.2023): https://ktu.edu.tr/apps/file/KahramanmarasDeprem.pdf

Karacabeyli, E., & Gagnon, S. (2019). CLT handbook. US Edition, FPInnovations and Binational Softwood Lumber Council, Point-Claire, Quebec. Access Address (18.05.2023): https://web.fpinnovations.ca/wp-content/uploads/clt-handbook-complete-version-en-low.pdf

Kıral, A., & Tonyali, Z. (2023a). *The February 6, 2023, Kahramanmaras-Turkiye Earthquakes: Seismo-Tectonic Evaluations and Effects on RC Buildings.* Paper presented at the Ege 8th International Conference on Applied Sciences, 2-4 June, Izmir -Türkiye.

Kıral, A., & Tonyalı, Z. (2023b). Evaluating the Kahramanmaraş Earthquakes of February 6 2023 in Turkey Based on New Generation Attenuation Ground Motion (NGA) Models. *2nd International Congress of Health Engineering and Applied Sciences, 2-4 August, Belgrad-Serbia*.

Kuncoro, T., Ichwanto, M. A. & Muhammad, D. F. (2023). VR-Based learning media of earthquake-resistant construction for civil engineering students. *Sustainability*, 15(5), 4282. Access Address (06.05.2023): https://www.mdpi.com/2071-1050/15/5/4282

Levy, M., & Salvadori, M. (1995). Why The Earth Quakes: The Story of Earthquakes and Volcanoes. New York: W W Norton & Company Inc.

Li, Z., & Konstantinos, D. T. (2023). Design for Seismic Resilient Cross Laminated Timber (CLT) Structures: A Review of Research, Novel Connections, Challenges and Opportunities. *Buildings, 13(2*), 505. Access Address (01.12.2023): https://doi.org/10.3390/buildings13020505

Mestek, P., Werther, N. & Winter, S. (2010). *Building with Cross Laminated Timber-Load-bearing solid wood components for walls, ceilings and roofs.* Studiengemeinschaft Holzleimbau eV, Wuppertal, 67-70. Access Address (01.04.2023): https://www.it.brettsperrholz.org/publish/binarydata/Brettsperrholz/downloads/stghb_brettsperrholz_e_150dpi_101207.pdf

Ministry of Environment and Urbanization. (2018). "Deprem Riskine Karşı Yapılacak Binalar Hakkında Yönetmelik". Ankara: T.C. Resmi Gazete. Access Address (01.07.2023): https://www.resmigazete.gov.tr/eskiler/2018/03/20180318M1-2.htm

Mohammad, M., Douglas, B., Rammer, D. & Pryor, S. E. (2013). Connections in cross-laminated timber buildings. CLT handbook: Cross-laminated timber. ISBN 978-0-86488-554-8.Canada US: Issued also in electronic format.

Porcu, M. C. (2017). Ductile behavior of timber structures under strong dynamic loads, Wood in Civil Engineering, Rijeka: InTech Open, 173-196. Access Address (01.07.2023): https://www.researchgate.net/publication/314177636_Ductile_Behavior_of_Timber_Structures_under_Strong_Dynamic_Loads

Reynolds, T., Casagrande, D., & Tomasi, R. (2016). Comparison of multi-storey cross-laminated timber and timber frame buildings by in situ modal analysis. *Construction and building materials, 102*, 1009-1017.

Sandoli, A., D'Ambra, C., Ceraldi, C., Calderoni, B. & Prota, A. (2021). Sustainable cross-laminated timber structures in a seismic area: Overview and future trends. *Applied Sciences*, 11(5), 2078. Access Adress (22.05.2023): https://www.mdpi.com/2076-3417/11/5/2078

Stora Enso. (2017). CLT Technical Brochure. Access Address (10.06.2023): https://www. storaenso. com/-/media/documents/download-center/documents/product-brochures/wood-products/clt-by-stora-enso-technical-brochure-en. Pdf

Stora Enso. (2021). CLT by Stora Enso. Construction. The Renawable Meterıals Company AB. Access Address (07.08.2023): https://www.storaenso.com/-/media/documents/download-center/documents/product-specifications/wood-products/clt-technical/clt-by-stora-enso---technical-documentation---construction---2021.pdf

Şengör, A. C. & Yilmaz, Y. (1981). Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics*, 75(3-4). Access Address (05.06.2023): 181-241. https://web.itu.edu.tr/~okay/geology_turkey_notes/sengor%20&%20yilmaz,%201981,%20turkey%20geology,%20tectonophysics.pdf

Tandoğan Kibar, G. & Lakot Alemdağ, E. (2023). Strength of connection profiles used in cross-laminated timber walls under seismic load. *Journal of Structural Engineering & Applied Mechanics* (Online), 6(1). Access Address (22.05.2023): https://search.trdizin.gov.tr/tr/yayin/detay/1161449

Taş, N. (2003). Yerleşim alanlarında olası deprem zararlarının azaltılması. *Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, 8 (1), 225-231. Access Adress (12.05.2023): https://dergipark.org.tr/tr/download/article-file/202888

Thiers-Moggia, R. & Málaga-Chuquitaype, C. (2021). Performance-based seismic design and assessment of rocking timber buildings equipped with inerters. *Engineering Structures, 248*, 113164.

TimberTech. (2022). Timber Tech Buildings Version 100, Timber Tech srl Via della Villa, 22/A -38123 – Villazzano – Trento (TN) – Italy.

Tobriner, S. (2000). Wooden architecture and earthquakes in Turkey: a reconnaissance report and commentary on the performance of wooden structures in the Turkish earthquakes of 17 August and 12 November 1999. 1.Proceedings, Earthquake-Safe: Lessons To Be Learned From Traditional Construction. (07.08.2023) https://www.academia.edu/51795214/Wooden_architecture_and_earthquakes_in_Turkey_a_reconnaissance_report_and_commentary_on_the_performance_of_wooden_structures_in_the_Turkish_earthquakes_

Tomasi, R., Sartori, T., Casagrande, D. & Piazza, M. (2015). Shaking table testing of a full-scale prefabricated three-story timber-frame building. *Journal of Earthquake Engineering, 19*(3), 505-534.

Trutalli, D., Marchi, L., Scotta, R. & Pozza, L. (2019). Capacity design of traditional and innovative ductile connections for earthquake-resistant CLT structures. *Bulletin of Earthquake Engineering*, 17, 2115-2136. Access Address (10.05.2023): https://link.springer.com/article/10.1007/s10518-018-00536-6

TS EN. (1995). Ahşap yapıların projelendirilmesi-Bölüm 1-1: Genel kurallar ve bina kuralları, Türk Standardları Enstitüsü, Ankara.

TS EN. (1998). Depreme dayanıklı yapı tasarımı - Bölüm 1: Genel kurallar, sismik etkiler ve binalar için kurallar (Eurocode 8), Türk Standardları Enstitüsü, Ankara.

Ussher, E., Arjomandi, K. & Smith, I. (2022). Status of vibration serviceability design methods for lightweight timber floors. *Journal of Building Engineering, 50*, 104111.

Van de Lindt, J. W., Pei, S., Pryor, S. E., Shimizu, H. & Isoda, H. (2010). Experimental seismic response of a full-scale six-story light-frame wood building. *Journal of Structural Engineering, 136*(10), 1262-1272.

Weckendorf, J., Ussher, E. & Smith, I. (2016). Dynamic response of CLT plate systems in the context of timber and hybrid construction. *Composite Structures, 157*, 412-423.

Wieruszewski, M. & Mazela, B. (2017). Cross Laminated Timber (CLT) as an Alternative Form of Construction Wood. *Wood Industry/Drvna Industrija*, 68(4). Access Address (05.04.2023): https://www.researchgate.net/publication/322349301_Cross_Laminated_Timber_CLT_as_an_Alternative_Form_of_Construction_Wood

Wood, S. (2019). *The CLT Handbook-CLT Structures-Facts and Planning*. Föreningen Sveriges Skogsindustrier: Skellefteå, Sweden. Access Address (22.05.2023): https://www.swedishwood.com/publications/list_of_swedish_woods_publications/the-clt-handbook/

Yön, B., Onat, O., Öncü, M. E. & Karaşin, A. (2020). Failures of masonry dwelling triggered by East Anatolian Fault earthquakes in Turkey. *Soil Dynamics and Earthquake Engineering*, 133, 106126. Access Address (22.06.2023): https://www.sciencedirect.com/science/article/abs/pii/S0267726119311388?via%3Dihub

Zafer, K. & Tonyali, Z. (2020). Performance analysis of a reinforced concrete frame system according to TBEC-2018. *Sciennovation, 1*(2), 6-22.