

“ THE EVOLUTION OF EARTHQUAKE-RESISTANT TIMBER CONSTRUCTIONS IN ANATOLIA BASED ON ARCHAEOLOGICAL DATA ”

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ABSTRACT

Turkey has confronted numerous severe and destructive earthquakes for centuries because of being located on the Mediterranean Seismic Belt. Proven to be safe due to their lightness and ductile nature, wooden buildings have gained importance in the course of time in this land. In this paper, earthquake-resistant timber constructions and the use of wooden material as an absorbing element for seismic forces in Anatolia and Thrace are investigated based on the historical development process with the help of the archaeological data.

The seismic structure, forests and timber residential placements of Turkey are studied in relation with each other at first. Accordingly the sustainable development process of architectural plan types and structural systems that are able to withstand earthquakes were mentioned under the light of archaeological findings. The structural characteristics that render a traditional timber building earthquake-resistant were researched according to the regional distribution, material and structural features and the most advanced structural systems used in both timber and timber-masonry composite systems were demonstrated as living examples today.

1. INTRODUCTION

According to the archaeological findings, the transition to permanent settlement in Anatolia dates back approximately 13000 years from today. The unique nature and fertile lands of the region has been made it an attractive residential area for different cultures and civilizations throughout the history [Dışkaya, 2017]. However, since it is located on the Northern Anatolian Fault Line, the peninsula has undergone numerous devastating earthquakes and it has been quite challenging to settle in this area spatially. The established cultures not only discovered the tools necessary for sustaining their lives but also understood the seismic character of the lands and learned to construct earthquake-resistant buildings. The forested geography of Anatolia brought

in the use of wood. The lightweight and flexible wood took its place as an indispensable construction material in this vast trial and error platform [Dışkaya, 2014].

Although the highly inflammable timber material caused several fires that have wiped out thousands of houses, even whole districts and cities, wood is always used as a lacing element in masonry constructions as well as in timber framed structures against earthquakes throughout the history.

With the awareness of being an earthquake country, timber construction was enforced by Ottoman Period Building Codes (Ebniye Regulations) for rescuing human lives [Cezar, 2002].

After the invention of reinforced concrete, construction with the wood was abandoned in the middle of 1950s. Multi-storey modern buildings were constructed

in and around the cities, causing occupants of timber buildings to leave their dwellings in favour of concrete ones. The timber houses were left to their fate, due to lack of care and improper restorative interventions, these buildings lost their structural integrity.

Finally inadequate control mechanism of the municipalities and institutes for protection accelerated destruction of wooden houses.

Although the information about its usage in the constructions cannot be accessed directly, as the wood is a perishable material due to its biological structure and flammability; it could be understood with the help of archaeological data obtained from excavations, definitions on cuneiform tablets, clay models and drawings of architectural spaces and structural definitions on various pots [Dışkaya, 2006].

Turkey has its specific kind of timber constructions that helped the people to survive the destructive earthquakes. It is seen that these buildings have become more earthquake-resistant in terms of both structural and architectural design over thousands of years. The aim of this research is to emphasize the importance of understanding these structures with an interdisciplinary approach for accessing the proven knowledge of the past. Then, it could be possible to contribute to the sustainable production of man by designing the timber buildings of future.

2. SEISMIC STRUCTURE OF ANATOLIA

The continuous movement of the Arabian Plate in the direction of north-east is blocked by the counter-movement of the Eurasian Plate from the north and this has led to the formation of the Northern Anatolian and Eastern Anatolian fault lines (Figure 1), [Celep, 2004].

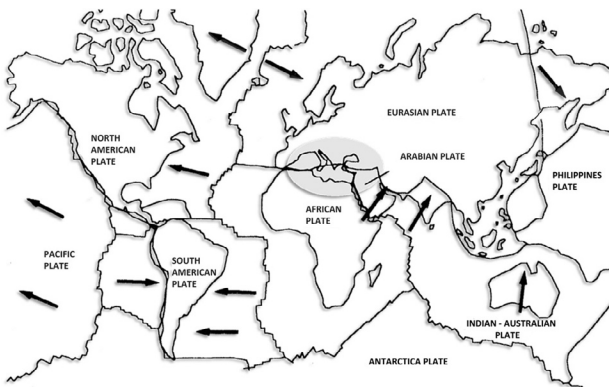


FIGURE 1. The world's earthquake plates and their movement directions [Celep et al., 2004; Interpretation: H. Dışkaya].

The North Anatolian Fault Line starts from 40N-41 Eastern latitude of Turkey and splits into three parts, including the northern, middle and the southern branches, in the Sea of Marmara [Çamlıbel, 1992], (Figure 2). The northern branch of the fault line passes 10 km south of Istanbul, extends 30.5 meridian on the west to Greece and Italy [Barka, et al., 2006].

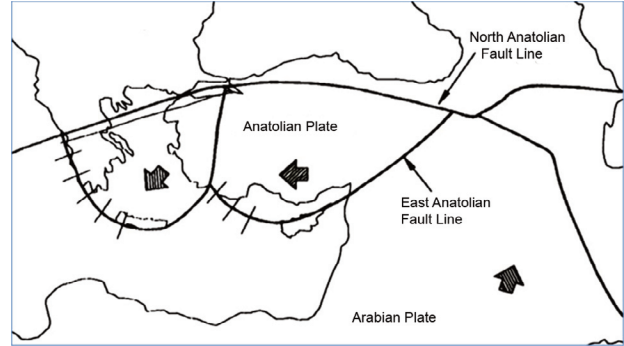


FIGURE 2. Fault lines and terrestrial plates in Turkey [Celep et al., 2004; Interpretation: H. Dışkaya].

The Anatolian Peninsula shifts 1.5-2 cm in the western direction every year as it is pushed by Arabian Peninsula in the northwest direction, and this compression creates a large energy accumulation and discharge of this energy has caused significant earthquakes in the region throughout the history [Çamlıbel, 1992]. The 92% of the land of Turkey is located in earthquake zones [see: <http://depem.gov.tr/2010/02>].

2.1 RELATIONSHIP BETWEEN FAULT LINES, FORESTS AND TIMBER STRUCTURE SETTLEMENT

The abundance of material that is mostly found around was one of the most effective factors for determining the traditional structure type as well as the fault lines. The dense forests are the reason for using timber material to construct traditional buildings on the fault lines, (Figure 3).



FIGURE 3. Forest Map of Turkey (T.R. Ministry of Environment and Forestry, see: <http://www.ogm.gov.tr/2011/05>).

When the map showing fault lines in Figure 2 [Celep et al., 2004], forest assets in Figure 3, [see: <http://www.ogm.gov.tr/2011/05>] and accordingly the distribution of the traditional buildings maps in Figure 4 [Erüzun, 1990] are examined, the relationship between these three concepts may explain the reason why the 75% of traditional buildings are timber and 25% are masonry in Turkey.

Although the 15% of masonry constructions were of stone and 10% were of mud bricks, it is determined that the timber materials including decoration parts, are used in 90% of the traditional structures in Turkey. It is observed that from the coasts up to an altitude of 1.000 meters the deciduous trees and up to an altitude of 2.000 meters coniferous trees have been used for the timber constructions in The Black Sea, Marmara, Aegean and Mediterranean regions [Erüzun, 2006]. The masonry structures were built in Southeast, Eastern and some Eastern settlements of Central Anatolia; the mud brick structures were built in the Central and Western parts of Eastern Anatolia [Eldem, 1984].



FIGURE 4. Distribution of the Turkish house in the Balkans and Turkey (Erüzun, 1990, Interpretation: H. Dışkaya).

3. RELATIONSHIP BETWEEN ARCHAEOLOGICAL FINDS AND STRUCTURAL DEFINITIONS

The descriptions on archaeological findings have been an important factor in the reflection and dissemination

of historical chronology of former life styles and structural forms. This could cover a wide area such as depiction of weapons in hunting rituals, musical instruments in religious or wedding ceremonies and structural definitions. The resources that provide the link between archaeological findings and architecture can be ordered as follows [Naumann, 1985], [Yakar et al., 1976], [Seeher, 2007]:

- Archaeological findings of structural foundations,
- The gaps in the walls refer to the disappeared timber load bearing elements,
- Post-fire remains and traces of building materials,
- Hieroglyph and cuneiform texts generally written on clay and determinatives describing materials used in the structure such as GIŠ =Wood,
- Architectural depictions on different containers,
- Structural models made of clay material,
- Reliefs made on stones.

For example within the scope of experimental archaeology, beside the foundations of the city walls (Figure 5), the descriptions on clay models of Hittite Era (Figure 6) were used in the reconstruction of fortification walls of Hittite capital Hattuša (Figure 7), [Seeher, 2007].

3.1 CORRELATION BETWEEN THE ARCHITECTURAL FEATURES OF THE HOUSES AND THE ARCHAEOLOGICAL FINDINGS

The room has always been the most important section of the Turkish house -as could be seen in the early masonry settlements or tents of nomadic tribes' examples-, where the main activities like eating, sleeping and having bath were happening. Sofa was the manufacturing area of the house where the whole production of the home was made and the rooms were opening to it.

The data from the archaeological excavations could give some important information for clarifying the plan type evolution in Anatolia. The correlation between the



FIGURE 5. Foundations of the Hittite fortification walls.



FIGURE 6. Clay model of the fortification walls in Büyükkale.



FIGURE 7. Reconstruction of tower and walls (Figure 5, 6, 7 [Seeher, 2007]).

plans of early Bronze Age settlements in Beycesultan (Figure 8), [Naumann, 1985] and the early 17th Century Halil Ağa Mansion in Bursa-Mudanya (Figure 9), [Eldem, 1984] could help to understand the developmental transformation in plan types after approximately 7000 years.

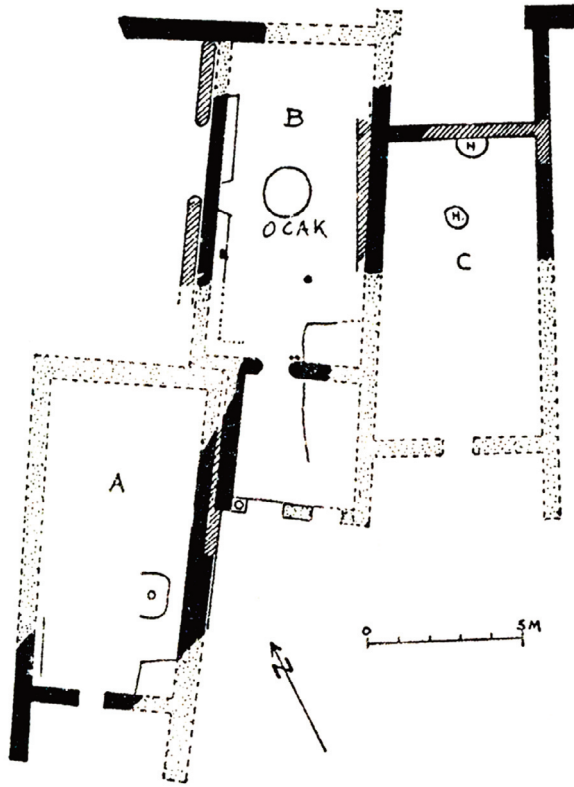


FIGURE 8. Bronze Age House in Beycesultan [Naumann, 1985].

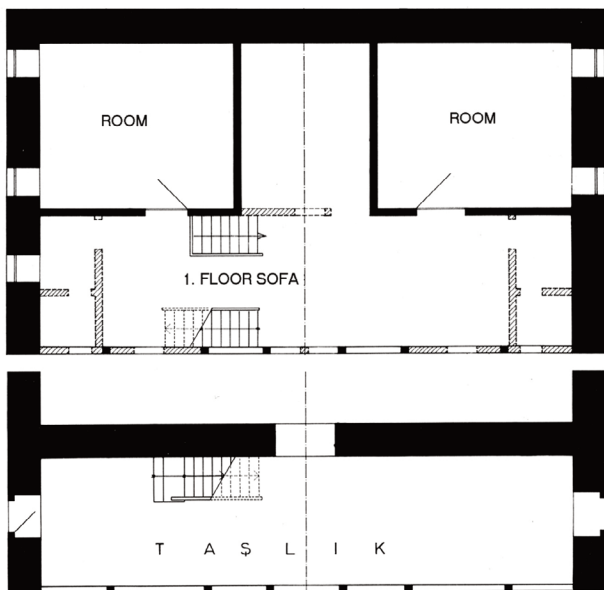


FIGURE 9. Halil Ağa House [Eldem, 1984].

Turkish house plan types have been classified according to their sofa types and, these are: without sofa, with outer sofa, with inner sofa and with central sofa. The plans of the houses are classified also according to having an iwan (eyvan) and a kiosk (köşk) or having both. The interpretation of sofa classification according to their plan development process in time can be monitored in Table 1 [Dışkaya, 2012]. It can be understood from the table that plan types evolve into a progressively symmetric form over the course of time.

Without sofa	With outer sofa	With inner sofa	With central sofa

TABLE 1. Plan Types of Various Turkish House Samples (Eldem, 1984, Interpretation: Dışkaya, H.).

3.2 CORRELATION BETWEEN THE STRUCTURAL FEATURES OF THE HOUSES AND THE ARCHAEOLOGICAL FINDINGS

The structural features of the buildings were changing depending on many factors during historical evolution process. The construction materials were wood, stone and mud. But the material that was found mostly in the region was determining the type of the structure as well as, natural disasters, geographical location, climate conditions, culture of living and economic conditions. The dense forests provided wood material to construct traditional buildings on the fault lines [Dışkaya, 2014] as mentioned in the section 2.1. But the buildings constructed with only wooden materials in the forest areas were showing different development technics in both architecture and structure compared with the buildings constructed in the areas with less forests.

Even if a structure that is constructed entirely from wood which cannot be accessed today, it can be said

that the main structural system was formed on stone foundations with mud brick walls combined with timber load bearing elements according to the archaeological excavations.

In the formation of the foundations the small river stones were used as layers and the orthostatic foundation walls were built on top of them as large cut stones (Figure 10). These cut stones were connected to each other in unique and intricate way to increase their resistance to horizontal and vertical loads. In addition, metal clamps such as bronze and iron were used for the same purpose [Mielke, 2013].



FIGURE 10. Section view of a Hittite foundation in Šapinuva B.C. 1500 (Photo: Dışkaya, N.).

The reasons for the use of these layered river stones under the foundation walls could be to prevent the access of the moisture from soil to the building as well as to damp the earthquake forces before they reach to the structure. Although reaching tangible traces of the use of the wood in archaeological sites is difficult due to the effects of moisture and fire, the gaps and holes in the foundations and walls that belong to the beams and the posts, traces of the burnt wood found in the excavations, the drawn descriptions of the wooden structures on the ceramic vessels, and definitions on cuneiform written tablets provide important clues about its use in the buildings.

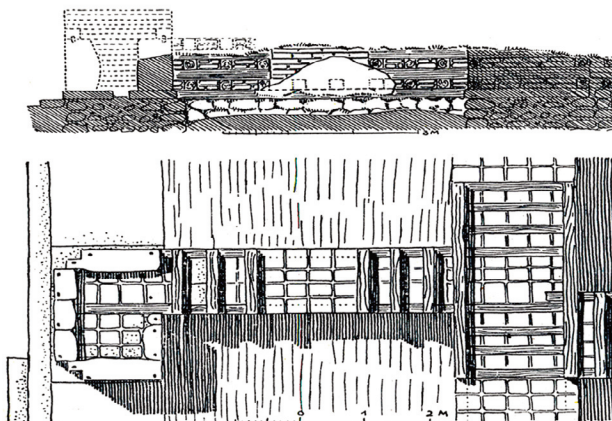


FIGURE 11. 9th Century BC, wall detail, Zincirli Palace [Nauman, 1985].

Timber material was an important lacing element in masonry structures for bearing lateral or vertical loads and maintaining interconnection between structural materials. The example for the timber usage in masonry wall obtained from the excavations in Zincirli Lower Palace 9th Century BC is shown in Figure 11 [Naumann, 1985]. The traditional continuity in using this structure could be seen in the 18th Century still standing wall detail in Antalya in Figure 12.



FIGURE 12. An 18th Century wall detail in Antalya (Photo: Dışkaya, H.).

As for the part which was placed on the foundation walls, timber was working as a distributor, connector and load bearing element between sun dried mud bricks and foundation walls. Some special buildings were especially designed to damp earthquake forces [Mielke, 2013].

It can be said that the whole system was designed for standing still after this significant natural disaster. According to the excavations made in Samsun-İkiztepe in the Northern Anatolia Pre-Hittite finds, it is seen that the buildings were constructed with only wood and mud; because of lack of quarries around the settlements and the burnt wood fragments and heaps of cooked mud were not only describing the material but the construction technique used in the structures [Yakar et al., 1976].

A sacred wedding ceremony description on the vase found in Bitik Höyük from Hittite Era, besides describing the rituals of beliefs and course of actions about these ceremonies, was depicting the architectural environment on it (Figure 13). The similarity between the houses of Boğazköy (Figure 14) or other houses with outer sofa in the different parts of Anatolia indicates the sustainability of structural systems.



FIGURE 13. Bitik vase detail B.C. 16 – 17th Century [Darga, 1985].

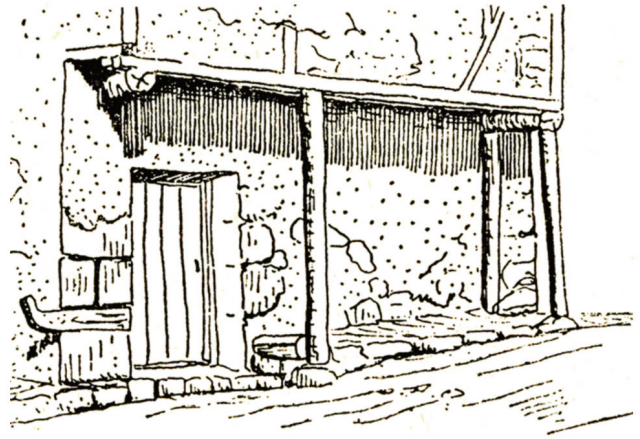


FIGURE 14. A building in Boğazköy [Nauman, 1985].



FIGURE 15. Detail from Hittite bath pot with structural description [Darga, 1985].

From the constructional progress in the use of masonry-wood composite systems, it is understood that the mud was being used only to protect the building from atmospheric conditions. The wood constituted as the main load bearing system and the mud brick was the infill material and that was the main idea of *Hımsı* technique. The 18th Century BC bath pot found in Acem Höyük, which is an informative and unique description about earthquake-resistant timber load bearing system consisting of wooden joists on headers were placed on wooden posts and parapets made of diagonal timbers were carrying the mud brick- filled wall in Figure 15 [Darga, 1985]. Consequently, the façade relieve drawing of a Turkish Mansion in Mudanya in Figure 16 [Eldem,

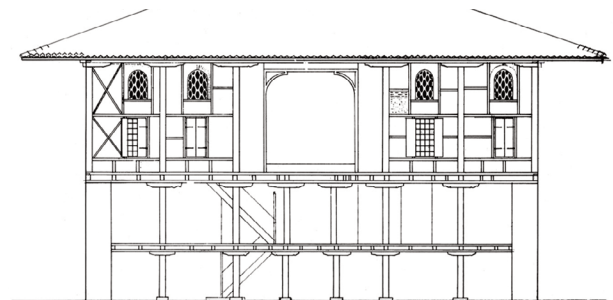


FIGURE 16. Halil Ağa House Mudanya (1634) [Eldem, 1984].

1984] indicates the continuity of tradition despite the difference of 4000 years.

The findings in the burnt mud found in the excavations in Samsun-İkiztepe belonging to 3000-1800 B.C. has showed that the main structural element of the region was timber and mud [Yakar, et al. 1976]. The buildings were constructed with overlapped logs which should take a leading part for “Çanti” technique [Bilgi, 1995] which is quite common in the region today or were constructed with timber poles erected on separate flat stones or directly penetrated into the ground and outer and inner surfaces of these poles knitted with twigs for plastering the both surfaces with mud [Alkım, 1981]. In the Figure 17, a living example of this technique on a rural house in Samsun could be seen. This technique was spread to all of the Balkans and the Caucasus by developing progressively and survived until the end of 19th Century. Finally, it was left its place to cladding of the exterior surfaces of the buildings with timber planks



FIGURE 17. Interlaced twigs on a timber skeleton rural building [Yakar, J. et al.].

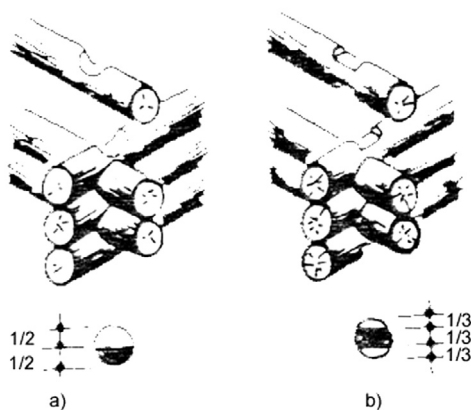


FIGURE 18. Log buildings a) Boğaz joint, b) Karaboğaz joint [Berker, 1982].

after 19th Century but the interior walls of the timber buildings were plastered with this technique until the beginning of 20th Century as described in section 4.2.2.

4. TYPES OF THE TIMBER STRUCTURES IN TURKEY

Due to limits imposed by climate and the availability of structural material, timber buildings have acquired certain characteristics of structure and shape. The most important common feature is their placement on a foundation, basement and first floor of masonry to protect the upper timber part from groundwater effect.

The types of the timber structures were classified as massive and framed buildings. Framed buildings according to their production area, climate and material conditions were also two types as infilled or unfilled systems.

4.1 MASSIVE STRUCTURES

Massive building types were made of logs or sawn block timber and the technique is called “çanti” in the regions where it was used and the treenails were used only for the joints. It had two types as log buildings and block timber buildings. The wood was used as peeled or in its natural condition in the log buildings Figure 18 or sawn and used as lumber in block timber structures, Figure 20, [Berker, 1982]. These buildings were being produced generally in the regions with plenty of wood, cold weather conditions and not located on earthquake zones such as highlands of the Eastern Black Sea or high plateaus of the Mediterranean region. A log house sample in Figure 19 and a block timber warehouse (*serender*) can be seen in Figure 21.



FIGURE 19. A Log building located in the Plateaus of Black Sea Region (Photo: Küçükbaş, A.).

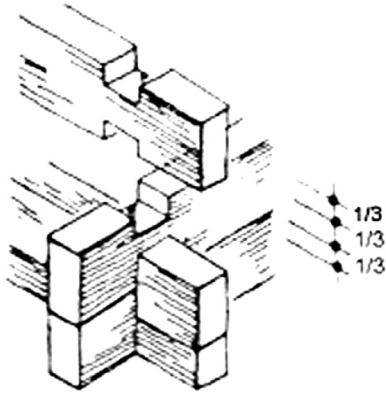


FIGURE 20. Block buildings Block timber joint [Berker, 1982].



FIGURE 21. A block timber grain warehouse in Rize (Photo: Dışkaya, N.).

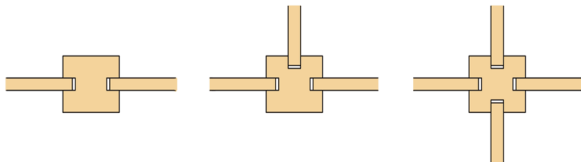


FIGURE 22. Interior wall partition detail of a massive timber structure in Rize (Photo & Drawing: Dışkaya, H.).

Interior wall partitions of these buildings were made with also massive interlaced block timbers with 2, 3 or 4 wings (Figure 22).

4.2 TIMBER FRAMED STRUCTURES

Timber framed buildings indicates different features, like whether they were filled or unfilled, depending on the seismicity of the geographical location as well as connections of their structural elements and tree species mostly found in the region. Therefore they were spread across Black Sea Region and its hinterlands, Istanbul and Marmara Region, Aegean and its hinterland, Mediterranean, Eastern and Northern parts of Central Anatolia Regions [Eldem, 1984]. The unique (particular) frame construction and infill systems of Black Sea

Region demonstrating difference from the other regions of the country could be related with fact that the region is having less seismicity than the rest. Although the masonry parts were depicting some architectural and structural differences according to the climate and economic conditions, skeletal systems of the timber buildings in the regions located in earthquake zones were two types: the infilled (*himiş*) and unfilled (*timber sheathed or bağdadi plaster*) systems. However, the timber skeleton part of the buildings were generally sitting on a masonry basement serving as the service spaces and barns. The connections of wooden structural elements could be linear or angular as shown in Figure 23.



FIGURE 23. Connection types of wooden structural elements [Talat, 1923].



FIGURE 24. Different sizes of wrought iron nails (Photo: Dışkaya, H.).

The tongue-and-groove joints or according to the structural place, region and the sizes of the timber materials different sizes of wooden or wrought iron nails were used in the connections of node points (Figure 24). In the short term loadings these iron nails [Dowrick, 1987], has the same ductile manner [Eriç, 1994] with the timber material that is used in the construction.

4.2.1 INFILLED FRAME SYSTEMS

In the regions that generally not having earthquake the infilling techniques with stone had been used in the Eastern Black Sea Region quadrangular shape “*göz dolması*” (Figure 25) or triangular amulet shape “*muska dolgu*” (Figure 27). The frame holes and shapes of these structures were rectangular or triangular in shape and smaller that the regions having large scale earthquakes. A sample for quadrangular shape (*göz dolması*) house in Figure 26 and a triangular amulet shape (*muska dolgu*) house can be seen in Figure 28.

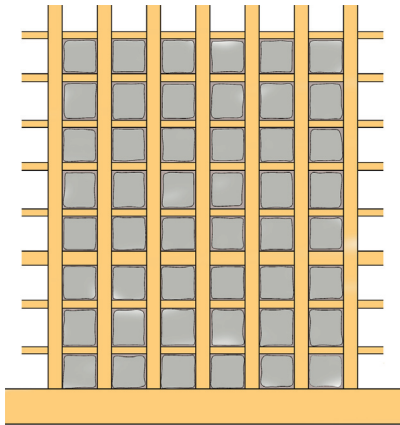


FIGURE 25. “Göz dolması technique” (Drawing: Dışkaya, H.).



FIGURE 26. A sample building in Hemşin, Rize (Photo: Dışkaya, H.).

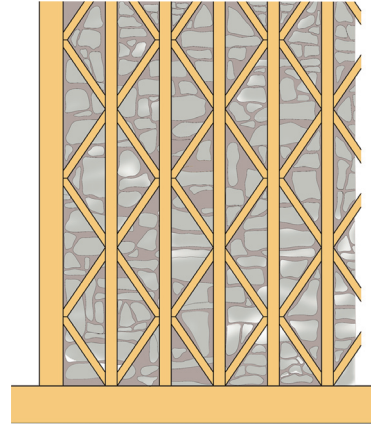


FIGURE 27. “Muska dolgu technique” (Drawing: Dışkaya, H.).



FIGURE 28. A sample building in Hemşin, Rize (Photo: Dışkaya, H.).

From a structural point of view the most refined and developed construction type preferred in seismic areas were the timber framed structures. The diagonal elements that were used in the frame systems in the regions having large scale earthquakes, were longer than the samples of Black Sea Region in order to make the system more resistant. The infilled material could be mud brick, brick or stone. Mud brick or brick material could place to the spaces as herringbone style (Figure 29) or flat infill system (Figure 31), [Dışkaya, 2014]. A sample for herringbone style house in Figure 30 and a flat infill system house can be seen in Figure 32.

The more stylized ornaments in the infilled masonry parts of the frame systems could be seen in the houses or mansions that were built in 17th and 18th Century. The walls of the 17th Century *himış* building describes the sun disk and cypress motives in the brick infilled parts that were the most important figures in the *Cultural History of Turkish Art* in the Figure 33. As a result of decreasing of the workmanship quality the exteriors of infilled system walls started to be plastered

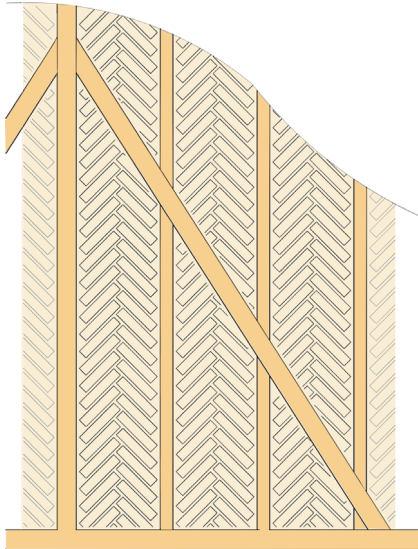


FIGURE 29. Herringbone infill technique (Drawing, Dışkaya, H.).



FIGURE 30. A sample building for herringbone infill style in Amasya (Photo: Dışkaya, N.).

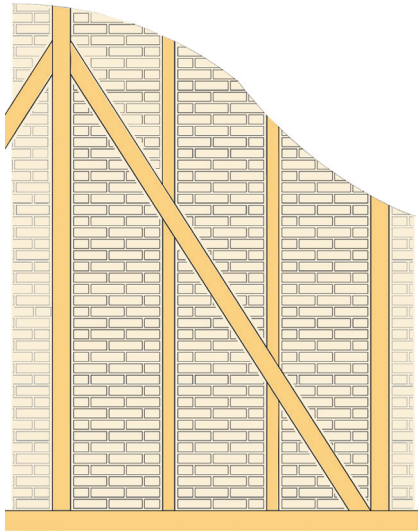


FIGURE 31. Flat infill technique (Drawing, Dışkaya, H.).



FIGURE 32. A sample building for flat infill in Amasya (Photo: Dışkaya, H.).



FIGURE 33. Hımsî infill technique –Bursa (Bitli Ev, 17th Century) (Eldem, 1984, Interpretation: Dışkaya, H.).



FIGURE 34. Baghdadi plastered timber building in Boyabat (Photo: Dışkaya, H.).

after the 18th Century (Figure 34), [Eldem, 1984]. The interior walls of these buildings were generally plastered with baghdadi¹ technique (Figure 35).

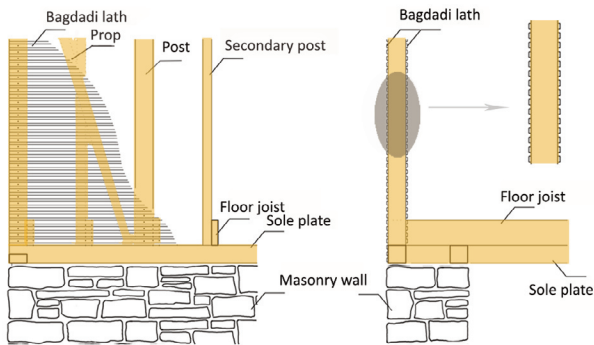


FIGURE 35. The unfilled timber frame system with baghdadi laths (Drawing: Dışkaya, H).

4.2.2 UNFILLED TIMBER FRAMED SYSTEMS (TIMBER SHEATHED OR BAGHDADI PLASTERED)

The most lightest, flexible and beautiful unfilled timber framed structures were produced generally in the Northern Marmara District or in The Thracian Region especially in Istanbul and Tekirdağ. The interior and exterior walls of these buildings were generally plastered with organic fiber additive lime based mortar on baghdadi laths (Figure 35). After the end of 18th Century and early 19th Century the timber buildings started to be covered with boarding planks 2-2.5 cm in thickness. (Figure 36).

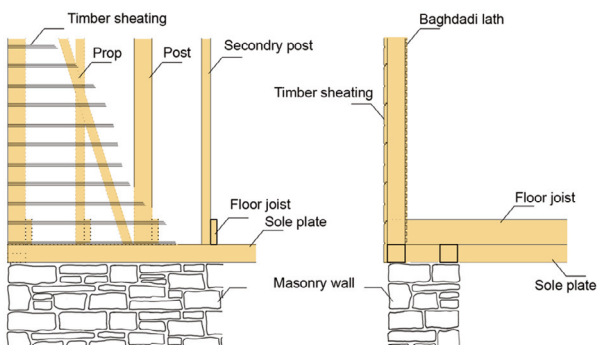


FIGURE 36. The unfilled timber frame system with boarding planks (Drawing: Dışkaya, H).

This boarding system and baghdadi plaster wrapped around the building was acting like a curtain wall. Al-

though there were horizontal and vertical orientated timber sheathings the most preferred covering orientation was generally horizontal one [Güngör, 1969].

When artefacts which have survived are investigated it is seen that the traditional timber skeleton house is generally composed of 2 or 3 storeys consisting of a wooden frame structure settled on a generally half masonry basement and foundation (Figure 35, 36, 39).

These structures are composed of:

- Lateral load bearing elements: Sole plates, top plates, headers, lateral connection elements, joists;
- Vertical load bearing elements: Posts and secondary posts;
- Diagonals: Diagonal props and bracings; (Figure 37, 38, 39).

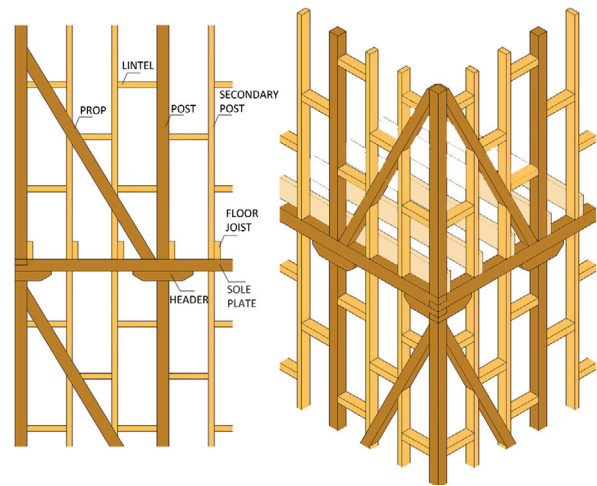


FIGURE 37. Single sole plates on both sides (Drawing: Dışkaya, H).

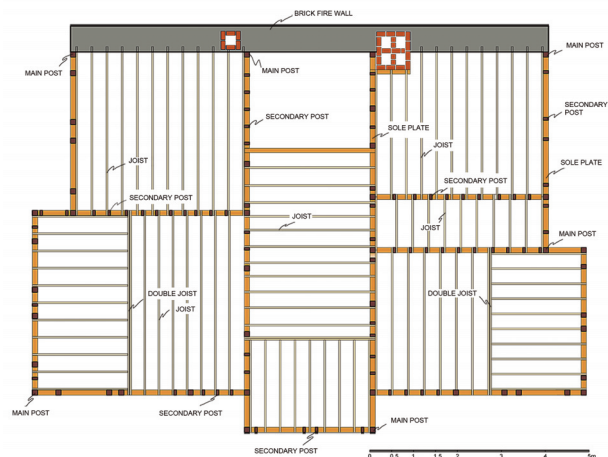


FIGURE 38. Plan of a load bearing system of the 19th Century timber construction in Istanbul (Drawing: Dışkaya, H.).

¹ Baghdadi plaster technique: The plaster which is applied on the laths that were fixed on the load bearing system with dimensions 1x2-3 cm.

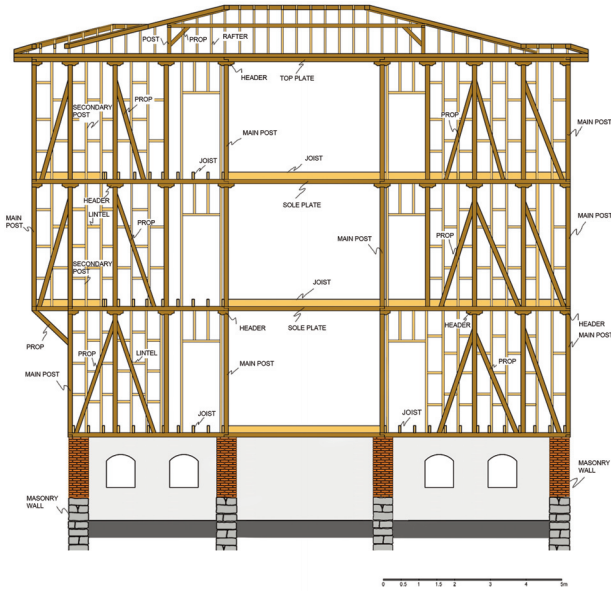


FIGURE 39. A section of the load bearing system of a 19th Century timber construction in Istanbul (Drawing: Dışkaya, H.).



FIGURE 40. A 19th Century timber building in Istanbul (Photo: Dışkaya, H.).

The sole plates of the frame could be single on both sides (Figure 37), one side single the other double or double on the both sides.

If the buildings were semidetached according to the density of population, the masonry fire walls approximately 50~60 cm in width were constructing between them and the joists were placed in or on these walls (Figure 38). Basement or first floors are from 1 to 1.5 meters above the ground. The sole plates are half-overlapped to each other at the corners and the posts are mounted on these sole plates leaving spaces of 1 to 2 meters (Figure 37). The posts are generally supported by the diagonal props in the corners or middle. The secondary posts are placed between the main posts every 40 to 50 centimeters spaced. The posts, props and the secondary posts are tied together with the lacings (*kuşak*) (Figure 37, Figure 39) [İzgi, 1983]. The joists are placed on the soles as their sections generally upright to the front of the structure [Eldem, 1987], (Figure 38). Heights of the structures are determined by building regulations (*ebniye nizamnameleri*) and the heights of the storeys were 3.50 to 3.70 meters (Figure 39).

Structure projections consist of prop, console with joist and overlapped console joists and its load was transferred to the main posts by diagonal braces. In the 19th century curvilinear props, known as *paraçol*, (*timberknee*) or *eliböğründe* (*diagonal braces*) were covered with laths or timber planks and produced in various forms [Çobancaoğlu, 1998], (Figure 39, Figure 40).

Construction of the roof was simple. Generally, a setting roof was constructed. The roof bindings were placed with 1.5, 2.0 or 2.5 meter spaces between them while the purlins were placed every 1.5 to 2.0 meters. The ridge joists were placed directly on the roof post and the rafters were placed on the purlin every 30 to 40 centimeters spaced [Eldem, 1987], (Figure 39). During the 19th century, the bottom surfaces of the eaves, which were made to be supported by a decorative curvilinear bracket (*furuş*) began to be covered, (Figure 40).

5. THE TIMBER AS A LINKING ELEMENT IN THE MASONRY STRUCTURES

Timber was used as a lacing element in the masonry structures with the knowledge of seismicity of the country since ancient times as it is mentioned in supra section for the correlation with the buildings and archaeological excavations. While the lacing elements were bearing lateral or vertical loads of masonry structure it was also connecting the structural elements. This composite system was generally used both in civil and monumental buildings. Some radioscopic examinations made by scientific researchers showed that even if the timber beams were not seen from outside, it is understood that the wooden beams were generally used inside of the masonry constructions for the same purpose.

Although the architectural differences, material and

craftsmanship were determining the exterior expression of the composite structures it could be assumed that the reason for using this technique was similar. When samples from the Eastern Anatolia (Figure 41), Western Anatolia, Aegean and Mediterranean regions are examined, it could be understood that the buildings located on earthquake prone areas were obligated to use timber lacing elements in the constructions.



FIGURE 41. Rubble stone house with timber lacing, Erzurum, (Photo: Dışkaya, N.).

6. CONCLUSIONS

Turkey is a country that has its specific kind of timber buildings that helped the people to survive the destructive earthquakes. Depending on a variety of reasons the beautiful and earthquake-proof historical timber houses were abandoned and destroyed by disasters caused by nature and humans and gradually decreased over the course of time.

Although these buildings were abandoned in favour of more modern concrete ones, the features of the timber buildings as well as timber material did not lose their importance as living examples produced in this geography.

In this research it is seen that these buildings have not developed only in a structural way but they also have become more earthquake-resistant in terms of their architectural designs and plan types.

The continuity of the transmission and transfer of the information undoubtedly contributed to the perfection of earthquake-resistant timber buildings both architecturally and structurally in the course of time. The 19th century timber frame system Turkish house should be the result of a mixture of various timber structure productions from raised floored house in Şapınuva to a

timber post system linked with twigs and plastered over with mud in İkiztepe-Samsun and diagonal propped houses of Boğazköy-Hattuša-Çorum.

Understanding these structures that proved themselves with the structural systems, durability and strength of their materials against time is important for reaching the past knowledge and future production of timber buildings.

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REFERENCES

- Alkım, U.B. (1981). Excavations in İkiztepe and Samsun Region, *Journal of Archaeology*, XXV-2, Ministry of Culture and Tourism, General Directorate of Antiquities and Museums Publication, Istanbul, 6.
- Barka, A., A. Er, (2006). *Istanbul the City Waits its Earthquake*, Istanbul, Epsilon Publishing, Istanbul.
- Berker, M. (1982). A method proposal for the conservation applications of timber architectural monuments. M.S.U. Institute of Science non-published PhD thesis, Istanbul.
- Bilgi, Ö. (1995). *Archaeological Excavations in Samsun-İkiztepe, Works in the IIIrd Hill: Results in 1995 in Dergipark*.
- Celep, Z. and N. Kumbasar, (2004). *Introduction to Earthquake Engineering*. Beta Publishing, Istanbul, 22-26.
- Cezar, M. (2002). *Ottoman Capital City Istanbul*. Erol Kerim Aksoy Foundation, Istanbul, 327-380.
- Çamlıbel, N. (1990). *A System Investigation on Consolidation of Historical Buildings against Earthquakes in Istanbul*, Yıldız University Publishing, Istanbul, 1.
- Çobancaoğlu, T. (1998). *Method suggestions in the restoration and structural research of timber house in Turkey according to regions*. MSU, Institute of Science non-published PhD thesis, Istanbul.
- Darga, A.M. (1985). *Hittite Architecture/1, Art of Construction*, *Archaeological and Philological Data*,

- I.U. Faculty of Literature, Istanbul, 60.
- Dışkaya, H. (2006). Historical development of traditional earthquake-resistant construction techniques in Anatolia. In: SAHC'2006; Proc intern. Symp. P.B. Lourenco, P. Roca, C. Modena, S. Agrawal (ed.), Delhi, 6-8 November, MacMillan Advanced Research Series, V. I. 167-174.
- Dışkaya, H. (2012). The Wood Species that Used in the Earthquake-resistant Traditional Timber Structures in Istanbul, Transsylvania Nostra, Built Heritage, 2012(3), Cluj-Napoca, 37-45.
- Dışkaya, H. (2014). The evaluation of earthquake-resistant timber-framed buildings in Turkey according to the regional distribution. Proceedings of the 2nd International Conference on Protection of Historical Constructions PROHITECH'14. Mazzolani, F. M., Altay, G. (Ed.). Boğaziçi University Publishing, Istanbul. 675-680.
- Dışkaya, H. (2017). Structural Development of Earthquake-Resistant Timber Buildings in the Light of Archaeological Finds in Anatolia, Proceedings of SHATIS'17, 4th International Conference on Structural Health Assessment of Timber Structures, Arun, G. (ed.), 20-22 September 2017, Istanbul, Turkey, 3-13.
- Dowrick, D.J. (1987). Earthquake Resistant Design for Engineers and Architects, A-Wiley-Interscience Publication, New York, 402.
- Eldem, S.H. (1984). Turkish House Ottoman Empire Period. TAÇ Foundation, Istanbul, V. I, 95-100.
- Eldem, S.H. (1987). Turkish House Ottoman Period, TAÇ Foundation, Istanbul, V.III, 168, 170, 172, 174, 180, 235, 284.
- Eriç, M. (1994). Structural Physics and Material, Literatür Publication, Istanbul.
- Eruzun, C. (1990). Turkey: Pilgrimage to cities, In: Process Architecture. Tokyo, 59.
- Eruzun, C. (2006). Importance of wood in the formation of traditional Turkish Architecture and the Eastern Black Sea houses, Istanbul: MSGSU, Faculty of Architecture.
- Güngör, İ.H. (1969). Knowledge of timber construction. I.T.U. Technique School Publications. Istanbul.
- Mielke, D.P. (2013). Hittites an Anatolian Empire. YKY, Istanbul, 141, 142.
- Naumann, R. (1985). Ancient Anatolian Architecture, Turkish History Institution, Ankara, 197, 359.
- Seeher, J. (2007). Hattuša Mudbrick City Wall A Reconstruction Work. Ege Publication, Istanbul, 17, 20, 21.
- Talât, A. (1923). "Timber Construction Styles", Library of Faculty of Engineering, Istanbul, V.II, 1.
- Yakar, J., Garzon, J.L. (1976). The Survival of Ancient Traditions in the Popular Architecture of North-Central Turkey, Expedition Magazine. 18(2).

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