PROSTOR

30 [2022] 1 [63]

A SCHOLARLY JOURNAL OF ARCHITECTURE AND URBAN PLANNING
ZNANSTVENI ČASOPIS ZA ARHITEKTURU I URBANIZAM

UNIVERSITY OF ZAGREB, FACULTY OF ARCHITECTURE
SVEUČILIŠTE U ZAGREBU, ARHITEKTONSKI FAKULTET

ISSN 1330-0652
https://doi.org/10.31522/p
CODEN PORREV
UDC 71/72
30 [2022] 1 [63]
1-138
1-6 [2022]

Af

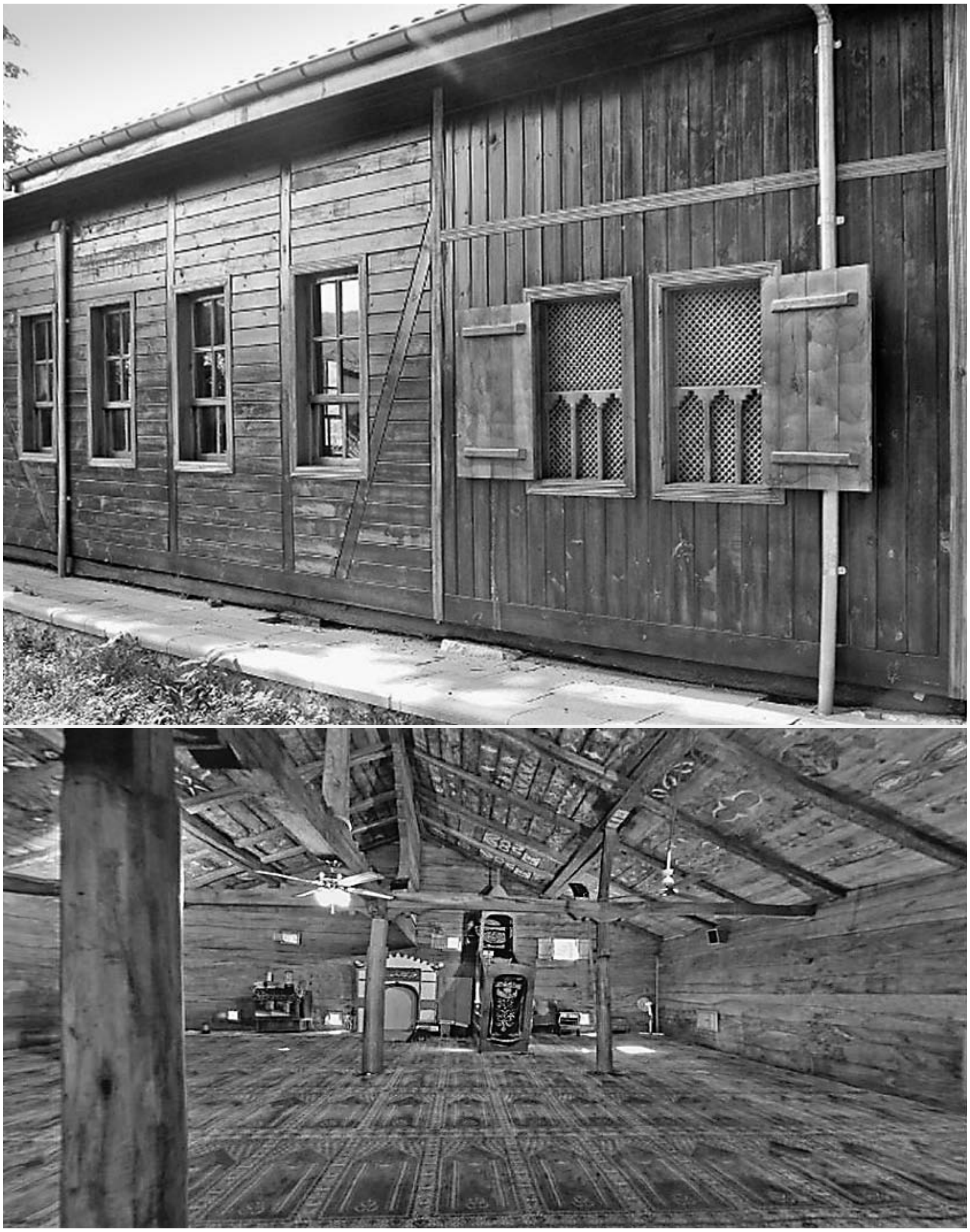

Fig. 1 Orhan Gazi Mosque (up), Göğceli Mosque (down)

Aslı Er Akan

Department of Architecture, Çankaya University, 06790, Ankara, Turkey
orcid.org/0000-0001-5362-8625

aslierakan@cankaya.edu.tr

Preliminary Communication
https://doi.org/10.31522/p.30.1(63).4
UDC 624.04 726:28-523.42 (560.414) "13/14"
Technical Sciences / Architecture and Urban Planning
2.01.03. – Architectural Structures, Building Physics, Materials and Building Technology
Article Received / Accepted: 21. 1. 2022. / 14. 6. 2022.

Structural Behaviour of 13th and 14th Century Seljuk Mosques and Acculturation of Construction Knowledge

Ahi Elvan Mosque, Ankara, Turkey
finite element model
Hanönü Mosque, Kastamonu, Turkey
hypostyle wooden mosques
peripheral walls

This study aims to demonstrate the acculturation of Seljuk architecture and construction techniques by tracing the development of peripheral walls in Seljuk wooden hypostyle mosques built in 13th and 14th centuries. To track the exchange of construction knowledge two Seljuk mosques (the Hanönü Mosque in Kastamonu and the Ahi Elvan Mosque in Ankara) are selected for comparison in this study. The main difference between the two mosques is their structural systems: one has a wooden peripheral wall and wooden skeleton system, while the other has a masonry peripheral wall and wooden pillars. In this study, a comparison of the structural systems and performances of these examples of wooden mosques exhibiting different wall systems was made together with structural analyses under basic loads. A series of structural analyses provides significant data about the structural behaviour of these types of structures, indicating acculturation of elements from Asia and Byzantium within Seljuk architecture and construction techniques.

Introduction: Acculturation of Construction Knowledge between Asia and the Byzantine Empire

The first official contacts of Turks with the Islamic World happened in 11th century with Seljuks, who soon became the first Turkish dynasty to rule the Muslim world. In terms of construction culture, Turks were advanced in adobe and brick masonry but they also knew wooden construction techniques. As a culture with its origins in Asia, Turks introduced new construction techniques and in return they transferred new types of buildings from Islam.

Meanwhile, they also encountered Byzantine culture at the border of Anatolia where stone masonry construction techniques were advanced. When Seljuks began to rule in Anatolia, they established a cosmopolitan mosaic of diverse cultures in which Romans, Greeks, Armenians, Turks, Persians and others could cooperate. Under these circumstances, architecture and construction techniques were cultivated rapidly. During this period, Seljuk architecture, which had been based on brick or timber, created a new fusion of stone masonry and wooden carcass by uniting the newly transferred knowledge of Byzantine techniques (Altun, 1988).

This engendered a construction vocabulary that was acculturated between East and West. Uçar and Örmecioğlu (2021: 220) state: "As a nation that encountered various civilizations, Turks learned many techniques and concepts from them and adopted these as practices, customs, and also their semantic network. Architecture is a part of this semantic network in which the transfer of knowledge and technology is embedded in building forms, construction techniques, and/or space culture."

This acculturation of construction knowledge in Seljuk architecture is best observed in hypostyle mosques with timber pillars and masonry peripheral walls. Wooden hypostyle mosques generally have rectangular plans and the roof is supported by timber pillars, placed in between the naves in the main prayer hall (Harim). There is also padding on the pillars, carrying the timber girders placed perpendicular to the mihrab wall. The girders support the timber beams, placed parallel to the mihrab wall. Cross-bracings are placed in between beams for lateral stability (Ministry of Culture, 2005; Katipoğlu, 2013: 75; Katipoğlu Özmen, 2018: 118).

Bayhan (2009: 55) says that the very first examples of timber-pillared mosques were in the Arabian Peninsula, Iran and Central Asia. The type transferred to Anatolia thanks to migrating Turkish groups in the last quarter of the 12th century. As a matter of fact, hypostyle was a structural system which was used for long span halls in Asia and the Middle East.

One of the very first examples of hypostyle halls in Iran are seen in Hasanlu IVb (1050-800 BC; Dyson and Muscarella, 1989: 2; Muscarella, 1966: 121). Additionally, the Ak-Beshim Buddhist temple in Kyrgyzstan is another example based on pre-Islamic constructional traditions. Also, some halls in the Pencikent and Aktepe settlements, which were constructed in the pre-Islamic period, are instances of this construction technique (Er Akan et al., 2021: 2; Ya Staviskij, 1974; Nusov, 1971).

The aim of this study is to express the acculturation of Seljuk architecture and construction techniques between Asia and Byzantium by outlining the development of peripheral walls in Seljuk wooden hypostyle mosques built in 13th and 14th centuries. With this aim two Seljuk mosques (Hanönü Yukarı Küreçayı Mosque and Ahi Elvan Mosque) have been selected for a comparison of their structural behaviour. Hanönü Yukarı Küreçayı Mosque has a wooden peripheral wall and wooden skeleton system while Ahi Elvan Mosque has masonry peripheral wall and wooden pillars.

Therefore, the paper's scope covers the adoption of timber and masonry hybrid construction techniques in Seljukid mosque architecture. In other words, the paper is about the specific effect of the masonry peripheral walls on the structural behaviour of timber pillared mosques.

Transformation of Peripheral Walls in Seljuk Wooden Hypostyle Mosques

O'Kane (1994: 122) states that "The natural resources available for building vary considerably across the region. [In Iran] wooden construction is found in limited areas, principally on the Caspian littoral, and in some mountain villages." In Turkey too wooden construction is found mostly on the Black Sea littoral, an area surrounded by forests. Wood is a sustainable material that is environmentally friendly and renewable, and also has good strength compared to its density. Moreover, it is compatible with other building materials and can be very long-lasting when used properly (Bozkurt, 2011: 115). With these features, it was used as a basic building material in traditional Turkish architecture. In the eastern Black Sea region, especially around Samsun, Ordu and Kastamonu, many wooden mosques are found (Karpuz, 1992a: 20; Karpuz, 1992b; Şahin, 2010: 31; Sümerkan and Okman, 1999). All these wooden mosques in the Black Sea region of Anatolia are from 12^{th} and 13^{th} centuries (Fig. 1).

As we move from the Black Sea region to Central Anatolia, stone begins to take place alongside the wooden architecture. The transformation of peripheral walls in Seljuk wooden mosques starts as a result of the interaction with Byzantine architecture. The wooden skeleton system of Seljuk architecture combined with stone masonry construction system of Byzantine architecture in the 13^{th} and 14^{th} century mosques that are called "hypostyle wooden mosques". The first examples of these hypostyle wooden mosques with stone masonry peripheral walls and timber pillars are from 13^{th} century: Afyon Ulu Mosque (Bayhan, 2009: 55), Eğridir Hızırbey Mosque, Candaroğlu Mahmutbey Mosque (Fig. 2), and Ankara Ahi Elvan Mosque (Öney, 1971).

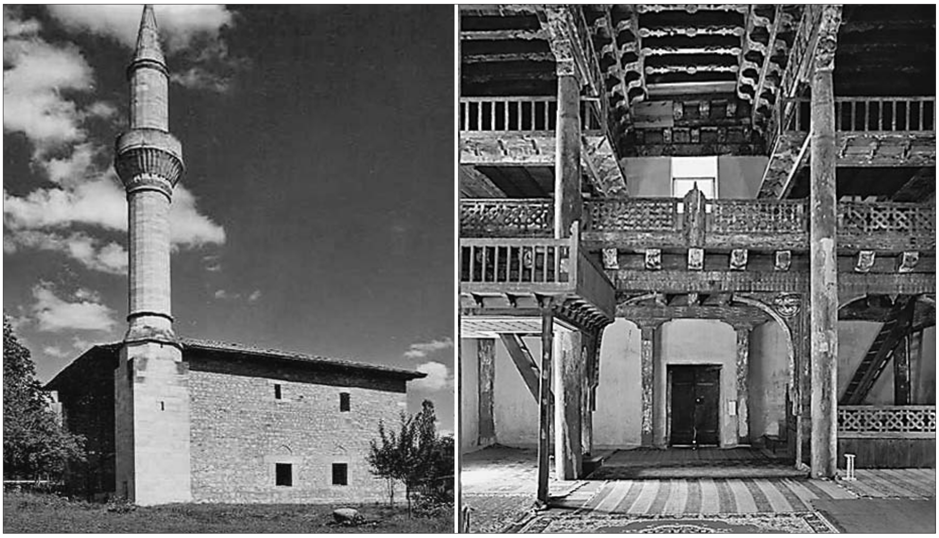

Fig. 2 Mahmutbey Mosque

Most of these remarkable mosques, which date back to 13^{th} and 14^{th} centuries, have survived various natural disasters such as floods, landslides, fires etc. without significant damage. However, Anatolia is on one of the most active seismic belts on earth.

As a result, many similar monuments have been destroyed due to earthquakes or resulting fires. Preservation and strengthening of such valuable historical monuments are high on the agenda of the architectural and engineering community. In parallel with the development of structural analysis software, it became possible to easily and accurately conduct the finite element analysis of historical monuments with very complex geometries in short periods of time (Er Akan, 2004: 60; Er Akan, 2008: 92; Er Akan, 2021: 2; Özmen et al., 2011: 452; Ünay and Özmen, 2006: 255; Özmen, 2021).

Fig. 3 Outer, inner views and plan of Hanönü Mosque, 1285

Fig. 4 Outer, inner views and plan of Ahi Elvan Mosque, 1382

Architectural and Structural Characteristics of Hanönü Mosque and Ahi Elvan Mosque

The first case is Hanönü Mosque (Fig. 3) which is a totally wooden Seljuk mosque located in Kastamonu, and built in 1285. The mosque was restored by the Regional Directorate of Foundations and reopened for worship in 2012 (Tunçay, 2018). The peripheral walls, which form the main prayer hall of the building, were formed by placing wooden planks, 7 cm thick, on top of each other along the height of the main prayer hall, using the dovetail joint technique. The wooden planks are notched at the corner points of the sanctuary, and they are physically interlocked with the wooden planks coming from the other direction. However, it has been observed that nails and clamps are not used frequently enough to provide physical clamping between each plank forming the peripheral wall.

The connection between the peripheral walls of the mosque and the ground is provided by the rubble stone walls. There are three wooden beams that carry the ceiling of the sanctuary on each façade, in the corners and in the middle. In this way, the roof load is transmitted to the wooden external walls, wooden beams and wooden columns and the rubble stones on the ground. There are four wooden pillars on the qibla (kıble) façade and wooden beams connecting them to each other and to the peripheral walls. The wooden structural system of the floor of the loge for women (kadınlar mahfili)[1] was extended to the end level of the main prayer hall forming the roof of the loge. The building was made with the wooden peripheral wall and wooden frame system consisting of wooden columns and beams on all façades (Çelik et al., 2021: 18).

There is a minaret on the south-west façade of the mosque, and a staircase providing access to the women's quarter on the north-west façade. The minaret, located on the south-west façade of the last communion section, was formed by combining a circular wooden log with a diameter of 170 mm and wooden planks with a diameter of 120 cm and a wall 4 cm thick with 2 cm thick wooden steps. The structural system, which goes up to the balcony level by drawing a spiral around the main wooden column, expands in this section and reaches 160 cm in diameter, and thus rises and continues up to the lower level of the minaret cone.

The second case is Ahi Elvan Mosque (Fig. 4), which is a typical timber pillared Seljuk mosque located in the citadel of Ankara, and built by Ahi Elvan Mehmet Bey (1331-1389) in 1382 (Öney, 1971: 23). The mosque has a hypostyle structural system, which consists of masonry external walls and timber pillars. It has an almost rectangular plan, covering 396 square metres. The 1 m thick masonry walls are the main load-bearing element surrounding four sides and supported by 12 timber pillars. Although the roof was first covered with traditional flat-roof made with mud, it was replaced with pitched timber roofing in later periods. As in many other timber mosques, it has a timber balcony, used by women (kadınlar mahfili), and added later. The pillars supporting the balcony have special sections both on their upper and lower ends. The only opening in the north façade is the door of the women's balcony. The supporting walls made up of brick and adobe have stone foundations (Er Akan, 2010: 42).

The minaret is on the northwest corner of the building. The twelve pillars are set in three rows perpendicular to the mihrab. The pillars sit on the base and their heads are connected to each other with massive wooden lintels (Öney, 1971: 24). The mosque has undergone three major restorations in 1413, 1967 and 1985.

1 "Turkish mosques generally allocate some areas, termed loges (kadınlar mahfili), for women congregants; these spaces, however, are often appropriated on Fridays by the large numbers of men who attend services." (Alyanak, 2019: 125).

Structural Behaviour of Timber Walled and Masonry Stone Walled Mosques

In recent years, developments in computer hardware and software technologies have dramatically augmented the capacity, speed and graphical quality of structural analysis programs, which in turn increased the demand for the structural analysis of historical buildings with complex geometrical forms. However, structural analyses conducted without paying attention to appropriate analytical modelling procedures may result in serious mistakes in the assessment of the actual structural conditions of these buildings. This is why the analytical modelling phase is very critical in the finite element analysis of historical structures.

In order to investigate the structural behavior of the timber walled vs. masonry stone walled wooden mosques, structural analyses of Ahi Elvan Mosque and Hanönü Mosque were made. However, the structural analyses carried out are not detailed structural analyses of these mosques, but only calculations carried out to raise awareness about the importance of understanding structural behavior in terms of architecture. For this reason, it is different from the detailed engineering calculations which are made to examine the current state, structural capacity and earthquake behavior of similar structures. In order to observe and understand the different structural behavior of mosques, the basic structural behaviors of the mosques were observed under the applied vertical and horizontal loads. Since the overall geometric dimensions of the mosques are not the same, it is not correct to make a comparison with the calculated forces, stresses and displacements. However, the results obtained from both examples give quite comprehensive and explanatory information about the structural behavior of each separately.

There are some examples of structural analysis for stone walled timber mosques in literature. One of these examples is the finite element analysis of Ahi Elvan Mosque, which belongs to the previous studies of the author (Er Akan, 2010). The structural behavior of masonry stone walled timber mosques can be explained by individual structural behavior of the masonry stonewall and the timber frame inside.

As shown in Fig. 5, the finite element model of Ahi Elvan Mosque is assembled according to following conditions.

– 1 m thick peripheral stone walls are modelled with general SHELL element.

– Timber pillars, main beams and other component of the roof structure is modelled with FRAME elements.

– The analytical model is built with 1627 nodes, 1030 shell elements and 1091 frames elements.

– Moment releases and partial fixities are introduced at the connections of frame elements to define the timber connection details of pillar capitals and beams connections.

– The linear elastic material characteristics of the masonry is defined by assuming that stone and mortar have a homogenous material behavior.

Another finite element model is prepared for Hanönü Mosque, which has a very different characteristic in terms of its structural behavior.

As shown in Fig. 6, the finite element model has the following data.

– The finite element model is formed by assembling timber pillars, timber beams and the 7 cm thick wooden planks constituting the walls and the roof plate.

– The walls are modelled with frame elements, based on the principle that wooden planks of 7 cm thickness are connected to each other by T/C (tension-compression) friction isolator elements.

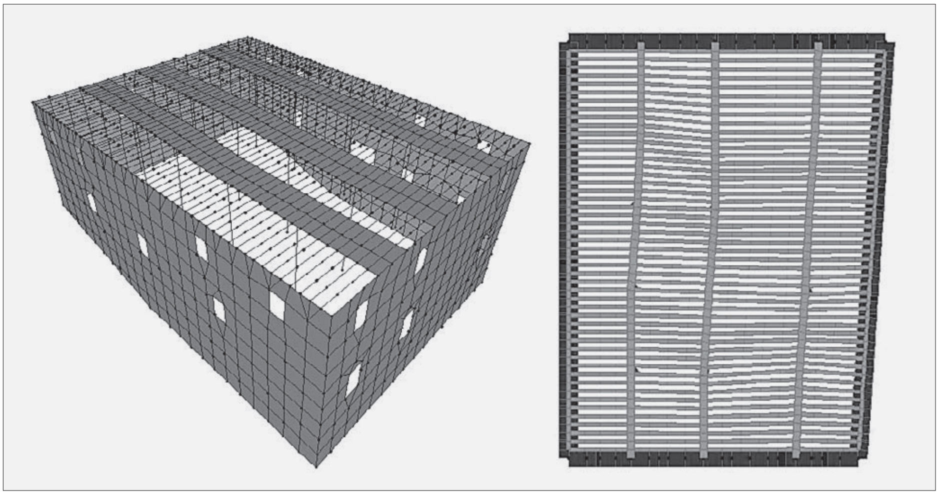

Fig. 5 Finite element model of Ahi Elvan Mosque

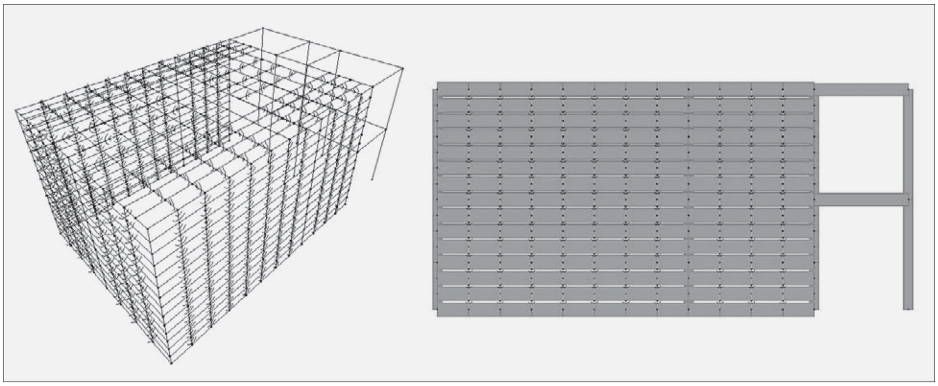

Fig. 6 Finite element model of Hanönü Mosque

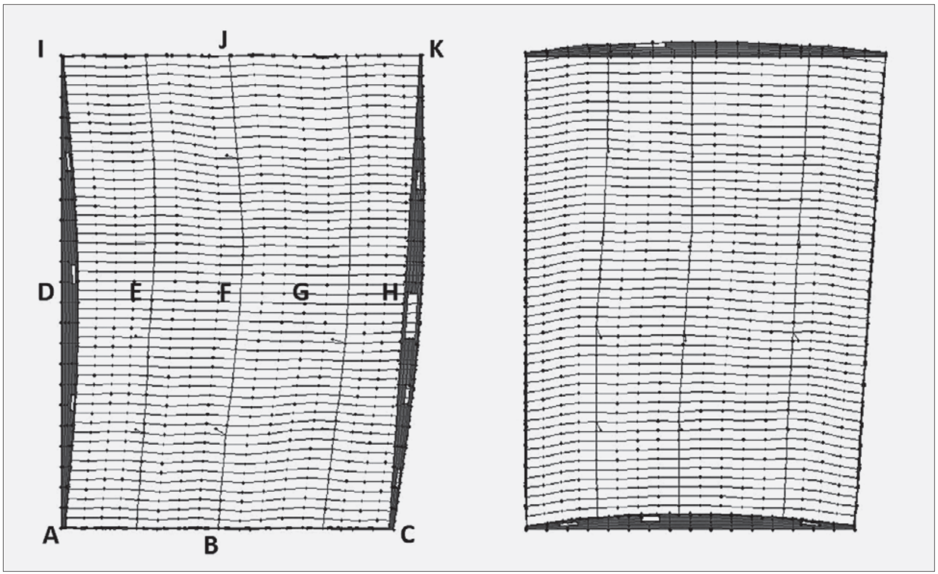

Fig. 7 Deformed shape of Ahi Elvan Mosque for the horizontal loads

– Square-sectioned 30×30 cm timber pillars and rectangular sectioned 25×40 cm timber beams are modelled by FRAME elements.

– Since the beams, pillars and planks are connected to each other with the dovetail joint technique, rigid connections and element end releases are introduced at particular nodes according to their assembly details.

– The wooden planks forming the outer walls of the mosque with the dovetail joint technique are modelled by introducing T/C friction isolator elements. T/C friction isolator elements provide shear resistance due to friction at contact surface of the planks in case of tension and compression forces and stresses between them.

Planks are connected to each other at every 1 m by T/C friction isolator elements according to the following principles. Link elements have certain stiffness in compression, while zero stiffness in tension. Therefore, a gap arises between the planks due to tensile forces and full contact and stress transmission occurs between the planks due to compressive forces. In case of horizontal loads, by defining friction coefficients to LINK elements according to tensile and compressive forces, a shear resistance develops between the planks when compressive forces are transmitting through the LINK elements, while no shear occurs due to tensile forces. This provides the most accurate way to observe the transmission of forces through structural elements and presents reasonable displacements under vertical and horizontal loads.

Following loads cases are applied to observe the structural behavior of Ahi Elvan Mosque and Hanönü Mosque. As vertical loads, the self-weight of all structural members, weight of the roof and other auxiliary elements are considered. Since the total mass of the structure is not too large, instead of the response spectrum analysis, horizontal gravity loads equal to 40% of the total weight of the structure are applied in both horizontal axes perpendicular to each other. Material properties for the finite element analysis of Hanönü Mosques and Ahi Elvan Mosque are summarized in Table I.

A precise description of the structural behavior of a building is not possible with structural analysis results alone. A structural analysis usually depends on how joint restraints, member dimensions and loads are defined and applied. Within this definition, the structural analyses for Ahi Elvan Mosque and Hanönü Mosque aim to evaluate the structural behavior of inner timber frames and planked timber walls in particular.

In the previous publication of the authors for Ahi Elvan Mosque, which essentially aims to investigate seismic behavior of the building, seismic forces induced by recommended earthquake spectrum for that region is considered along two perpendicular horizontal axes.

In this study, the structural analysis based on the 40% of the total weight of the building as horizontal loads with the simplified analytical model intending to inspect the structural behavior of the building achieved almost identical displacements along the x-axis and y-axis.

Base reactions are calculated as 18066 kN in the global z-axis (vertical direction, the total weight of the structure) and as 6800 kN along the x- and y- global axes (horizontal direction due to 40% of the total weight applied as horizontal loads) in the structural analysis of Ahi Elvan Mosque. Whereas, base reactions are calculated as 186 kN in the vertical direction as the total weight of it and 93 kN along the x- and y-axes as the horizontal base shear

Table I Material properties for the finite element analysis of Hanönü Mosque and Ahi Elvan Mosque

Mosques	Structural element type	Modulus of elasticity (E) kN/m²	Unit weight kN/m³	Mass t/m³
Hanönü Mosque	Wooden planks	9000000 (9000 MPa)	5	0,50
	Timber pillars	9000000 (9000 MPa)	5	0,50
	Timber beams	9000000 (9000 MPa)	5	0,50
Ahi Elvan Mosque	Stone masonry walls (mortar included)	450000 (450 MPa)	24	2,45
	Timber pillars	9000000 (9000 MPa)	5	0,50
	Timber beams	9000000 (9000 MPa)	5	0,50

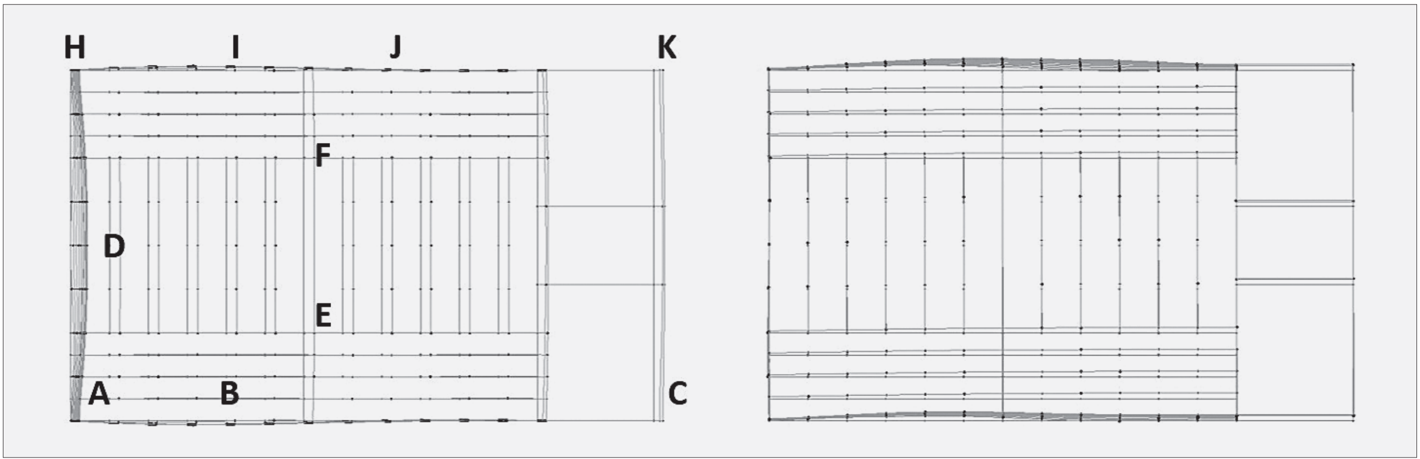

Fig. 8 Deformed shape of Hanönü Mosque for the horizontal loads

in the structural analysis of Hanönü Mosque. The comparison of these two buildings in terms of forces and stress gives irrelevant conclusions because of unequal size, dissimilar materials and construction systems. Therefore, an evaluation of calculated displacements provides reliable interpretation about their structural behavior.

As shown in Fig. 7, at the top of the masonry walls, maximum displacements are determined along the x-axis and y-axis as $\Delta_x = 27$ mm and $\Delta_y = 18$ mm respectively. A realistic explanation of structural behavior of the building considering these displacements only is not possible without the consistency of the applied loads, actual material properties of the masonry walls and the construction technique of the wooden frame elements. However, displacements and forces smaller than expected indicate that the outer walls provide a significant fortification to the inner timber frames, especially against lateral loads.

As shown in Fig. 8, similar results were obtained in the structural analysis of the Hanönü Mosque. At the top of the timber planked walls, the maximum displacements are determined along the x-axis and y-axis as $\Delta_x = 74$ mm and $\Delta_y = 28$ mm respectively. The deformed shape of the building under lateral loads shows that the structural behavior of the Hanönü Mosque, which is constructed by dovetail joints, demonstrates similar structural behavior of the wooden hypostyle mosques with peripheral masonry walls. It is not possible to compare these two unequal size buildings with the calculated displacements only. The ratio of the maximum displacement to the total height of the building indicates that the planked wooden walls provide at least as much lateral resistance as the peripheral masonry walls in a dovetail-jointed wooden structure. This ratio is 0.0034 and 0.0028 along the x-axis and the y-axis respectively in Ahi Elvan Mosque. Whereas, it is 0.011 and 0.004 along the x-axis and the y-axis respectively in Hanönü Mosque. The displacements determined in the structural analyses are summarized in Table II with respect to deformed shapes of Ahi Elvan Mosque and Hanönü Mosque shown in Figs. 7 and 8.

It should be kept in mind that the material properties used in the finite element model were not actual values obtained from the testing of the material samples from the actual structure but values taken from scientific literature. As a result, it is possible for certain partial damage to happen due to the non-homogenous behaviour of the actual structural elements or material deterioration.

Lastly, interpretation of analysis results in terms of the interaction between the timber frame and masonry walls is important. The finite element model of Ahi Elvan Mosque is designed to realistically simulate the behaviour of the connection nodes in-between the timber frame and masonry elements with different levels of rigidity. The thick peripheral masonry walls with a high level of rigidity provide adequate lateral resistance for the slender timber frame structure. With the support of the peripheral walls, timber beams in both directions behave as continuous beams rather than single span beams. Due to this behaviour the timber pillars of the mosque are subjected to smaller bending moments.

Despite this additional support from the masonry portion of the structure, displacements from the vertical axis have been observed in the timber pillars of Ahi Elvan Mosque and similar timber pillared structures. The analyses have demonstrated these displacements are not due to vertical or horizontal load effects but the result of material deteriorations and partial settlements in the timber pillars-beams joints and connection details in-between timber beams and masonry walls.

Table II The displacements determined in structural analysis of Ahi Elvan Mosque and Hanönü Mosque

Ahi Elvan Mosque			Hanönü Mosque		
Joint label	Δ_x (mm)	Δ_y (mm)	Joint label	Δ_x (mm)	Δ_y (mm)
A	6.26	0.90	A	4.21	0
B	7.64	-0.43	B	4.56	-0.90
C	7.74	-2.39	C	4.55	0
D	27.89	0.11	D	8.15	0
E	27.79	-0.66	E	5.29	0
F	27.93	-0.65	F	5.29	0
G	28.02	-1.71	G	4.54	-0.01
H	28.11	-1.98	H	4.38	0
I	3.01	-0.52	I	4.55	0.90
J	4.28	-0.16	J	4.54	0.39
K	4.27	1.06	K	4.56	0

Conclusions

The analysis of historical structures is different from the analysis of modern buildings. The lack of precise measurements for element sizes; the complexity of defining correct connection and support conditions; and the difficulty of determining the mechanical properties of structural materials make the previous experiences obtained from similar buildings critical in the interpretation of structural behaviour. The comparison of the results of analyses of two different peripheral walls (planked wooden walls and stone masonry) of the cases indicate that in the case of timber pillared mosque with highly rigid stone masonry, the peripheral walls have protected the inner timber frame structure from lateral load effects, such as wind and earthquakes, and provided the survivability of these mosques for centuries. The main parameter defining the lateral resistance of the heavy masonry peripheral walls is their height. These walls, which act as vertical cantilevers, are often built more thickly and therefore more rigidly than the wooden masonry peripheral walls precisely so that they can resist vertical loads. This is most likely because of the experiences obtained from past earthquakes. The continuous frame behaviour of the timber beams supported by the masonry peripheral walls render the timber pillars into structural elements which carry primarily axial loads. Unless there is a buckling problem due to the height of the pillars, these elements do not carry significant bending moments. It should be kept in mind that the buckling problem and related damage may also occur due to heavy snow loads and unexpected loading conditions resulting from careless repair and restoration. No significant lateral structural weakness is observed in the timber pillared mosques due to the above-mentioned interaction between rigid masonry peripheral walls and a light timber frame structure. The simple geometry of the timber frame system is a positive factor in both vertical and lateral resistance of the structure. However, great care should be given to the preservation of the timber material and the details of the connections in-between structural elements in order to ensure the continuity of this lateral resistant structural behaviour. As a result, transformation of peripheral walls in Seljuk wooden mosques stemming from the interaction with Byzantine architecture provided additional resistance to lateral forces. The experience gained from these construction techniques created the acculturation of construction knowledge between Byzantium and Asia. Seljuk mosque architecture, which had been based on timber hypostyle, flourished through the fusion of stone masonry and wooden carcass with the newly transferred knowledge of Byzantine techniques.

[Translated by: Aslı Er Akan, proofread by: Steve Bryant]

Bibliography and sources

1. Altun, A. (1988) Ortaçağ Türk Mimarisinin Anahatları İçin Bir Özet, *Arkeoloji ve Sanat Yayınları*, Istanbul.
2. Alyanak, O. (2019) "When Women Demand Prayer Space: Women in Mosques Campaign in Turkey". *Journal of Middle East Women's Studies*, Vol. 1, pp. 125-134 [online]. Available at: https://doi.org/10.1215/15525864-7273885 [Accessed: 15 November 2021].
3. Bayhan, A.A. (2009) "Ordu'dan Bazı Tarihi Ahşap (Çantı) Camiler". *The Journal of International Social Research*, Vol. 2/7, pp. 55-84 [online]. Available at: http://ktp2.isam.org.tr/detayilhmklzt.php?navdil=ar&midno=6622500&Dergivalkod=0718 [Accessed: 15 January 2021].
4. Bozkurt, Ö. (2011) "Geleneksel Tekirdağ Evlerinde Kullanılmış Meşe Ahşabının Mekanik Özellikleri ve Kimyasalla Koruma Uygulamalarının Mekanik Özellikler Üzerine Etkisi". *Politeknik Dergisi*, 14(2), pp.115-119 [online]. Available at: https://dergipark.org.tr/tr/pub/politeknik/issue/33057/367907 [Accessed: 1 January 2021].
5. Çelik Başok, G., Er Akan, A., Zamur Koçak, S. and Örmeioğlu, H.T. (2021) "Ahşap Sütunlu Camilerin Taşıyıcı Sistem Performansı: Hanönü Yukarı Küreçayı Cami Örneği". *Online Journal of Art and Design*, Vol. 9(3), pp. 17-34 [online]. Available at: http://www.adjournal.net [Accessed: 15 January 2021].
6. *Computers and Structures Inc. SAP2000* (2002) *Structural Analysis Program*, Ver.10.0, Berkeley, California, USA.
7. Culture Portal of Turkey, *Mahmutbey Mosque in Kastamonu*. Available at: https://www.kulturportali.gov.tr/turkiye/kastamonu/gezilecekyer/mahmut-bey-cam [Accessed: 10 January 2022].
8. Düzce Provincial Culture and Tourism Directorate Archive (2022) *Orhan Gazi Mosque*. Available at: https://duzce.ktb.gov.tr/TR-236544/orhan-gazi-camii.html
9. Dyson, R.H. and Muscarella, O.W. (1989) "Constructing the Chronology and Historical Implications of Hasanlu IV". *Iran*, Vol. 27, pp. 1-27, Taylor & Francis Ltd. [online]. Available at: https://www.jstor.org/stable/4299813?seq=1#metadata_info_tab_contents [Accessed: 12 January 2021]. https://doi.org/10.2307/4299813
10. Edwards, C. (2010) "Through, Lapped or Blind: The Dovetail Joint in Furniture History". *Proceedings of the 10th International Symposium for Wood and Furniture Conservation: Reproduction and Reconstruction in Furniture Conservation*, Amsterdam, The Netherlands, November [online]. Available at: https://hdl.handle.net/2134/9326 on 5.27.2020 [Accessed: 10 May 2021].
11. Er Akan, A. (2004) *Some Observations on the Seismic Behaviour of Traditional Timber Structures in Turkey*. Master's Thesis, *Middle East Technical University*, Ankara, pp. 1-108 [online]. Available at: https://etd.lib.metu.edu.tr [Accessed: 10 January 2022].
12. Er Akan, A. (2008) *A Comparative Study on Earthquake Resistance of Reinforced Concrete and Masonry Residential Buildings in Small-Scale Cities of Turkey*. Ph.D. Thesis, *Middle East*

Technical University, Ankara, pp. 1-159 [online]. Available at: https://etd.lib.metu.edu.tr [Accessed: 10 January 2022].

13. Er Akan, A. (2010) "Determination of Structural Performance of Timber Pillared Historical Mosques by Finite Element Analysis". *SDU International Technologic Science,* 2(1), pp. 41-54 [online]. Available at: https://dergipark.org.tr/tr/pub/utbd/issue/25991/273757 [Accessed: 10 January 2022].
14. Er Akan, A. et al. (2021) "Seismic evaluation of a renovated wooden hypostyle structure: A case study on a mosque designed with the combination of Asian and Byzantine styles in the Seljuk era (14th century AD)". *Journal of Building Engineering,* 43 (103112), pp. 1-20 [online]. Available at: https://doi.org/10.1016/j.jobe.2021.103112 [Accessed: 10 January 2022].
15. Erder, E. (2010) "Sustainable Conservation Issues of Four 14th and 15th Century Mosques in Ankara: Ahi Elvan Mosque, Örtmeli, Sabunî And Poyrajı Mesjıds". *METU JFA,* 1(27:1), pp. 45-66. https://doi.org/10.4305/METU.JFA.2010.1.3
16. Karpuz, H. (1992a) "Of İlçesi'nde Ağaçlı Köyü Camii". *Lale Dergisi,* S.8, Haziran, pp. 20-24.
17. Karpuz, H. (1992b) *Rize*, *Kültür Bakanlığı Yayınları*, Ankara.
18. Katipoğlu, C. (2013) "Rethinking Construction and Planning Processes in the Ottoman Provinces". *International Journal of Science Culture and Sport*, 1(4), pp. 70-83. https://doi.org/10.14486/IJSCS34
19. Katipoğlu Özmen, C. (2018) "Challenging the Canon: Reading the 19th Century Ottoman Architecture through Provincial Mosques". *Prostor: A Scholarly Journal of Architecture and Urban Planning,* 26(1/55/), pp. 116-131. https://doi.org/10.31522/p.26.1(55).9
20. Municipality of Çarşamba Archive (2022) *Göğceli Mosque*. Available at: https://www.carsamba.bel.tr/icerik/tarihi-gogceli-camii
21. Muscarella, O.W. (1966) "Hasanlu 1964". *The Metropolitan Museum of Art Bulletin*, 25(3), pp. 121 [online]. Available at: https://doi.org/10.2307/3258835 [Accessed: 10 January 2022].
22. Nusov, V. (1971) *Architecture of Kyrgyzia from Ancient Times till Today*. Frunze, Kyrgyzstan.
23. O'Kane, B. (1994) *The Mosque: Iran and Central Asia: The Mosque, History, Architecture and Regional Diversity*. Ed. Martin Frishman and Hasan-Uddin Khan, pp. 119-278 [online]. Available at: https://www.academia.edu/42970429/Iran_and_Central_Asia [Accessed: 10 January 2022].
24. Öney, G. (1971) "Ankara'da Türk Devri Dini ve Sosyal Yapıları". *Ankara Üniversitesi Dil ve Tarih Coğrafya Fakültesi Yayınları*, Ankara, pp. 20-29 [online].
25. Örmecioğlu, H.T. (2020) "Transfer of Technology and Formation of the Technical Language: The Case of Turkish Terminology of Architecture". *International Journal of Social, Political and Economic Research,* 7(4), pp.1040-1050. https://doi.org/10.46291/IJOSPERvol7iss4pp1040-1050
26. Özmen, C. (2021) "Reconciling Architectural Design with Seismic Codes: A Comparative Architectural Analysis for Mid-Rise Reinforced Concrete Residential Buildings in Turkey". *Prostor*, 29(1), pp. 42-55. https://doi: 10.31522/p.29.1(61).4
27. Özmen, C., Akan, A.E. and Ünay, A.I. (2011) "Proračun povijesne zidane zgrade - Analysis of a Historical Masonry House". *Građevinar*, Vol. 63(5), pp. 449-458, ISSN 0350-2465, https://hrcak.srce.hr/68538
28. Şahin, M.K. (2010) "Samsun-Çarşamba/Yaycılar – Şeyh Habil Köyü Camii". *Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi,* 4(2), pp. 15-36 [online].
29. Sümerkan, M.R. and Okman, İ. (1999) *Kültür Varlıklarıyla Trabzon*. İl Kültür Müdürlüğü Yayınları, Trabzon.
30. Uçar, A. and Örmecioğlu, H.T. (2022) *Art and Architectural Traditions of India and Iran Commonality and Diversity Edited By Nasir Raza Khan, Part III: India and Iran: Historical Perspectives,* Routledge Publishing, pp. 218-239.
31. Ünay, A.I. (2007) "Evaluation of Structural Safety of Historical Masonry Buildings". *Architectural Science Review*, Vol. 50(11), pp. 26-30 [online]. Available at: https://doi.org/10.3763/asre.2007.5004 [Accessed: 10 January 2022].
32. Ünay, A.İ. and Özmen, C. (2006) "Building Structure Design as an Integral Part of Architecture: A Teaching Model for Students of Architecture". *International Journal of Technology and Design Education,* 16: 253-271, https://doi.org/10.1007/s10798-005-5241-z
33. Ya Staviskij, B. (1974) *Arts of Central Asia*. Iskusstvo, Moscow (in Russian).
34. Zamur Koçak, S. (2020) *Ahşap Sütunlu Camilerin Taşıyıcı Sistem Performansları: Kastamonu Örneği*. Çankaya Üniversity, Ms Thesis, Ankara [online]. Available at: http://earsiv.cankaya.edu.tr › xmlui › handle [Accessed: 10 January 2022].

Illustration sources

Fig. 1 up: Düzce Provincial Culture and Tourism Directorate Archive, 2022; down: Municipality of Çarşamba Archive, 2022
Fig. 2 Culture Portal of Turkey, 2022
Fig. 3 Zamur Koçak, 2020: 42-49
Fig. 4 Er Akan, 2010: 43-44
Fig. 5-8 author

Author's biography

Assoc. Prof. Dr. **Aslı Er Akan** is currently working as a vice-dean at the Faculty of Architecture of Çankaya University. She received her B.Sc. degree in Architecture from Dokuz Eylül University. Then, she earned her M.Sc. and Ph.D. degrees in Architecture from METU, 2004, 2008, respectively. Her research interests are Construction Technologies, Earthquake Resistant Design, Structural Integrity, and Damage.