

International Wood Products Journal

SEISMIC RESISTANCE OF TRADITIONAL TIMBER-FRAME HİMİŞ STRUCTURES IN TURKEY: A BRIEF OVERVIEW

--Manuscript Draft--

Manuscript Number:	IWP277R1
Full Title:	SEISMIC RESISTANCE OF TRADITIONAL TIMBER-FRAME HİMİŞ STRUCTURES IN TURKEY: A BRIEF OVERVIEW
Article Type:	Special Issue Article
Keywords:	hımış, timber-frame, vernacular architecture, connections, seismic behaviour
Corresponding Author:	Yasemin Didem Aktas University College London UNITED KINGDOM
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	University College London
Corresponding Author's Secondary Institution:	
First Author:	Yasemin Didem Aktas
First Author Secondary Information:	
Order of Authors:	Yasemin Didem Aktas
Order of Authors Secondary Information:	
Abstract:	<p>Hımış structures have hardly ever found as extensive a role as other traditional timber housing, such as those originating from Japan or Central Europe, within the wide discourse on the seismic performance of timber-frame architecture that has gained significant momentum in the last few decades owing to advancing testing technologies. While the hımış construction technique was perhaps not born as a result of a conscious search for a seismically resistant building form, it was soon widely appreciated for its structural features advantageous under seismic loading - especially from the 16th century when it has become a well-established construction technique in part of the Balkans and in today's Turkey. Despite widely available anecdotal information based on post-disaster studies regarding its performance under earthquakes, robust quantitative data on the seismic behaviour of these structures were practically non-existent until quite recently, and are still somewhat limited. However, we are now able to confirm that hımış constructions do have intrinsic qualities that are very beneficial under seismic action. This paper aims to make a brief review of the current state of our knowledge on structural performance of hımış buildings under earthquake loading, with specific emphasis on infill/cladding techniques, connection details, and energy dissipation characteristics.</p>
Funding Information:	

SEISMIC RESISTANCE OF TRADITIONAL TIMBER-FRAME *HİMİŞ* STRUCTURES IN TURKEY: A BRIEF OVERVIEW

Yasemin Didem AKTAŞ*

Epicentre Research Group, Civil, Environmental and Geomatic Engineering, University College London (UCL),
London, UK
y.aktas@ucl.ac.uk

HİMİŞ structures have hardly ever found as extensive a role as other traditional timber housing, such as those originating from Japan or Central Europe, within the wide discourse on the seismic performance of timber-frame architecture that has gained significant momentum in the last few decades owing to advancing testing technologies. While the *hİMİŞ* construction technique was perhaps not born as a result of a conscious search for a seismically resistant building form, it was soon widely appreciated for its structural features advantageous under seismic loading - especially from the 16th century when it has become a well-established construction technique in part of the Balkans and in today's Turkey. Despite widely available anecdotal information based on post-disaster studies regarding its performance under earthquakes, robust quantitative data on the seismic behaviour of these structures were practically non-existent until quite recently, and are still somewhat limited. However, we are now able to confirm that *hİMİŞ* constructions do have intrinsic qualities that are very beneficial under seismic action. This paper aims to make a brief review of the current state of our knowledge on structural performance of *hİMİŞ* buildings under earthquake loading, with specific emphasis on infill/cladding techniques, connection details, and energy dissipation characteristics.

Keywords: *hİMİŞ*, timber-frame, vernacular architecture, connections, seismic behaviour

INTRODUCTION

Whilst they have been the subject of fervent scholarly attention and fascination from around the globe for their architectural design principles, *hİMİŞ* houses have hardly ever found as extensive a place in the earthquake resistant architecture discourse as other traditional vernacular timber housing such as their Japanese or Central European counterparts, (Figure 1) although their desirable structural performance under seismic loading has long been shown by various post-reconnaissance studies. The first examples that we see of this type of building are found in Western Anatolia, but their general constructive features were established, successfully adapted and tested within a wide geographic area extending roughly from Southern Central Anatolia to the Ottoman Balkans including Black Sea Coasts of Romania, Crimea, Bulgaria, FYR Macedonia and Bosnia Herzegovina to Greece in the west, regardless of significant differences in local climate regime [1, 2]. This wide geographic spread has caused differences in terminology; the most common usages include "Turkish" (e.g. [2]), "Ottoman" (e.g. [3, 4]), "Anatolian" (e.g. [5]), "Turkish-Hayat" (e.g. [1]) and "Post-Byzantine" (e.g. [6]) house. Terminological discourse is beyond the scope of this paper and hereinafter the term *hİMİŞ* will be used to refer to these houses¹.

Timber-housing is believed to have been born in the Anatolian Middle Ages and, as confirmed by the drawings of the traveller Peter Coeck of Aelst [7], was already quite widespread in part of the Balkans and today's Turkey by the early 16th century, well before the famous Lisbon Earthquake that paved the way to earthquake engineering, as we understand it today. This paper, following a review of the post-disaster observations focussing on major earthquakes in Turkey, aims to summarize the basic structural features of *hİMİŞ* houses and

* Previously researcher in Middle East Technical University (METU), Program of Restoration and Department of Civil Engineering, Ankara, Turkey

¹ Terminological heterogeneity in the literature on *hİMİŞ* go beyond its origin and extend to which material and mural techniques it covers, which is very briefly covered in the subsequent sections.

1 discuss how these affect the overall structural behaviour under earthquakes, with specific emphasis on
2 infill/cladding techniques, connection details and energy dissipation characteristics.
3

4 **1. POST-DISASTER OBSERVATIONS**

5 It is known that after the 1509 Great Istanbul Earthquake which resulted in an estimate of 13,000 casualties [8],
6 the Ottoman authorities prohibited masonry and enforced the construction of timber-frame houses, claiming
7 that masonry was responsible for most of the casualties [9]. By the end of the century, the city was “almost
8 entirely built of wood” as stated by the Venetian diplomat Barbaro [10]. Almost four centuries later, D. Eginitis,
9 the director of the Observatory of Athens, who was personally invited to Istanbul after the 1894 earthquake by
10 Abdülhamid II himself for a post-disaster report, “greeted with pleasure that the buildings in Istanbul are not
11 entirely built of masonry as in other regions” [9, 11-13]. Despite the later legislation in the 19th century that
12 highly-regulated or completely banned timber buildings and enforced masonry instead, in order to minimize the
13 fires that swept away Istanbul time and again [9], cheaper and easier-to-use timber remained the building
14 material characterizing the modest residential built environment both in the capital and in the remote provinces
15 with an abundance of wood², until the 20th century. In order to give a general idea about their more recent
16 performance under seismic loading, a brief review of the structural damage on the existing *himiş* stock reported
17 following major earthquakes since 1960’s in Turkey is given in Table 1.
18

19 As even a cursory glance will show that despite observations regarding poor performance of *himiş* houses in
20 certain cases - mostly attributed to heavy roofs or material deterioration -, they are more commonly reported
21 to have performed better than the other construction techniques used in areas hit by a major earthquake. A
22 similar compilation for areas with a built environment characterized by *himiş* structures in, for example, Greece
23 will lead to the same major conclusions. Indeed, for a set of earthquakes between the beginning of the 20th
24 century and 1980 in Turkey and Greece, Ambraseys and Jackson [43] states that “the number of people killed
25 per 100 houses destroyed by earthquakes of magnitude equal to or greater than 5.0 is” only around 1 for timber
26 constructions. There are plenty of post-disaster reports making a comparative analysis of structural damage
27 observed in various construction types - such comparisons however should be approached with care because
28 they might overlook the construction quality of the analysed building stock (which is known to be exceptionally
29 poor for most reinforced concrete buildings in some Turkish cities affected by seismic activity in the last decade
30 or so, and does not reflect the expected seismic performance of RC construction technique). However, these
31 observations still indicate an overall resilient seismic behaviour of timber buildings.
32

33 The following chapters will outline the constructive features of *himiş* houses, and discuss how these contribute
34 to the seismic performance.
35

36 **2. CONSTRUCTIVE FEATURES OF *HIMIŞ* STRUCTURES AND THEIR EFFECT ON SEISMIC 37 PERFORMANCE**

38 *Himiş* is a composite construction system, where the ground-floor is mostly composed of masonry (rubble stone
39 or alternating layers of stone and brick, or adobe with timber posts) with timber tie-beams (*hatıls*) built on
40 continuous or discontinuous stone foundations, and the upper-storesys and roof of timber³. A single timber frame
41

42 ² See, among others, the descriptions/drawings of other 19th century travellers such as Charles Texier (The
43 principal ruins of Asia Minor), Thomas Allom and Robert Walsh (Constantinople and the scenery of the seven
44 churches of Asia Minor), and Karl Graf von Lanckoroński (Städte Pamphylens und Pisidiens).

45 ³ There is a widespread heterogeneity with regards to the use of the term *himiş*: in the relevant literature it is
46 sometimes used to define only the timber-frame wall technique, and/or the timber-frames with infill, rather
47 than with cladding (which is often defined by the umbrella term *bağdadı*). In this paper, however, it is used to
48 define the entire composite building with masonry ground floor and timber-frame upper floor(s) regardless
49 whether they are used with infill or cladding (for further reading on basic terminology see [9]).
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1 is the smallest module forming the external walls of and partition between various units in timber-frame upper-
2 storeys in a *hımış* house, such as a room, *sofa* or *hayat* (a multi-purpose, transitional semi-open or closed space
3 between rooms, articulated depending on the overall plan scheme⁴) or *eyvan* (a semi-open recessed sitting unit
4 facing *sofa*)⁵. The frame outer boundaries are defined by a wall plate, a foot plate, and two main posts, and the
5 frame interior is divided into smaller compartments by means of horizontal/vertical inner elements, usually but
6 not always thinner than the other members, as well as diagonal members, which also help increase in-plane
7 lateral load-bearing capacity. The horizontal and vertical spacing between these members is estimated by the
8 builder so as to avoid shear cracking and dictated by the door and window openings that frame design requires
9 (Figure 2).
10

11 The infill can be made using adobe, stone or brick depending on the availability (e.g., in the north-western
12 Anatolia adobe and brick prevail, while in the eastern Black Sea coastal area it is stone). Alternatively, a cladding
13 or “lath and plaster” technique that first appeared in the 18th century and is widely known as *bağdadi* is also
14 widely used. In *bağdadi*, 2-4 cm wide laths are nailed onto the timber-frame with around 1 cm gaps in between
15 so that the plaster holds on the surface more easily. This technique has a number of regional varieties and is
16 used without additional infill with a few local exceptions⁶.
17
18
19

20 Projections (jetties, *çıkma* in Turkish) are one of the most distinguishing features of *hımış* houses (Figure 3),
21 which actually did not exist till late 16th century [1]; *vakfiyes* (Turkified from Arabic *wakfiy(y)a*, meaning deed
22 documents issued for mortmain properties – *waqf*, in Turkish *vakıf* – managed under a religious, non-profit
23 charity concept) suggest that in the 15-16th centuries most houses were single-storey [45]. When the multiple
24 story housing became widespread, the projections lent themselves to making upper-storeys more spacious and
25 regular in shape in contrast to often narrow and irregular ground-floor plan geometries, as well as to have a
26 more complete view of the street via bay-windows located on the projections (*cumba* in Turkish) [46].
27
28
29

30 A variety of wood types were used for *hımış* houses, depending on the local availability. Pine was most common,
31 while oak, chestnut and cedar were saved for the wealthy houses. Poplar was generally used for roofing [1, 2].
32 Building methods utilized for the construction of a house have evolved to have very simple details [47]. This
33 brings along speed and ease in reconstruction activities after a devastating fire or earthquake [1]. The connection
34 between different timber members is provided almost solely by nails; carpentry joints, even very simple ones,
35 are rare and mostly further supported with nails [48].
36
37

38 Despite widely available information based on post-disaster observations, robust quantitative data on the
39 seismic behaviour of these structures were practically non-existent until quite recently. The experimental work
40 aiming to quantify the seismic performance of and identify the damage mechanisms at *hımış* buildings is, to best
41 of the author’s knowledge, still limited to the extensive testing scheme carried out at METU, Structural
42 Mechanics Laboratory in 2009-2011, as part of a research project titled “Seismic Assessment of Traditional
43 Ottoman Timber-Frame Houses”, funded by TUBITAK. The project included testing of 8 full-scale *hımış* frames,
44 built with different geometrical configurations selected from Safranbolu (UNESCO World Heritage Site) using
45 (unaged) pine and fir under reversed cyclic lateral loading (Figure 4a). The frames were first tested in their bare
46 state, and then repaired and re-tested with infill (brick and adobe; Figure 4b&c, respectively) and cladding
47 (*bağdadi* and *şamdolma*, the latter being a central Anatolian variety of the former, with up to 5 times wider
48
49
50
51

52
53 ⁴ The plan schemes in *hımış* houses are defined on the basis of the shape and location of the *sofa*. Eldem’s work
54 dated 1984 [2] is an excellent source on plan typologies.

55 ⁵ It is important to note that in the early period houses upper floors were commonly constructed of masonry,
56 except for the façade where the projection was located [2].

57 ⁶ Straw infill is sometimes used in houses with *bağdadi* cladding in Birgi, a west Anatolian town in Turkey, for
58 insulation purposes (see [44]). In Beypazarı, a town near Ankara, external *bağdadi* façades facing the prevailing
59 wind direction are sometimes infilled with soil up to a certain height, to make the building envelope more wind-
60 proof (personal communication with some still actively working traditional builders from Beypazarı, 2009-2010).
61
62
63
64
65

laths, see Figure 4d&e, respectively). The findings from the testing scheme were reported in detail elsewhere (see [49-52]). In the following, certain structural features of *himiş* houses are further discussed in the light of the findings of the aforementioned testing scheme and other resources.

- a. **Ductility, damage mechanism and energy dissipation:** The test results show that the high ductility of *himiş* frames is owed mainly to nailed connections. In each test, regardless of the timber type used for their construction, frame size/geometry and infill/cladding type, the damage mechanism is the same: at each loading cycle nails at the opposite side of the loading are partially pulled out and, when the lateral loading changes direction, they are driven back in. When the lateral displacement demand becomes too high, the nails get pulled out completely and in this case they get buckled in the opposite loading cycle. This behaviour causes high ductility and drift, and allows most energy to be dissipated at the connections during cyclic push-in/pull-out movement of the nails under lateral cyclic action. Therefore, as far as the abovementioned test-set is concerned, the nailed connections are the main source for high energy dissipation and ductility within a frame. Also, timber type does not seem to be influential on the overall behaviour and the behaviour is highly non-linear from very low lateral displacements.
- b. **Infill/cladding, strength, stiffness and weight:** As expected, infill/cladding improves the load-bearing capacity and stiffness of bare *himiş* frames. Cladding results in a higher increase in load-bearing capacity and stiffness than infill. However, infill and cladding result in significant increase in weight too - more for former than the latter - and hence also in the seismic demand. Further, the increase in strength and stiffness with infill/cladding is always less than increase in weight, with the exception of *bağdadi*. Among the two cladding techniques investigated, *bağdadi* was found to result in higher seismic capacity-to- demand ratios than *şamdolma* within the frame-set used in the mentioned testing. This is considered to be because in both cladding techniques each lath is nailed to the underlying frame with a nail every time it comes over one of its members, and therefore the average number of nails per unit area is 5-6 times more in *bağdadi*, resulting in a better diaphragm action. Post-disaster observations, too, often confirm that *bağdadi* results in a better seismic performance. Cladding in general decreases drift, while infill increases it.
- c. **Frame geometry:** All *himiş* frames have bracings on both sides, whose importance for a sufficient lateral load-bearing capacity has been long acknowledged [29]. In addition, based on the findings from the testing campaign, the ratio of “total width of all openings” to “remaining width” was found to be a good indicator for rapid geometric evaluation of bare frames; the buildings having frames with the mentioned ratio greater than 2/3 were found unable to survive a design earthquake. The studies further showed that *bağdadi* is able to overcome this disadvantageous geometrical feature of bare frames, and produce a desired structural performance.
- d. **Plan/elevation regularity:** Most of the historic *himiş* houses sit on an irregular parcel of land, especially in cities where the city layout is highly organic, i.e. non-gridal, such as Istanbul. The irregular planar geometry of the ground-floor is then “corrected” in the upper-storeys using projections. Moreover, the height of ground-floor can be considerably different than the other storeys, especially when it is designed to be used as animal shelter or for storage as frequently observed in rural areas, or for carriages or other services in more urban settings. These plan/elevation irregularities might be disadvantageous under seismic loading.
- e. **Connections between various components:** The hybrid nature of *himiş* houses brings together masonry, which is brittle in nature despite the tie beams, and timber framing. A good connectivity between the masonry ground-floor and timber upper-storeys is therefore indispensable for an integrated structural response of the building as a whole under seismic loading. Additionally, the connections between timber-frames are important to avoid loss of physical integrity and keep the box behaviour in place. In Çay Earthquake, for instance, one of the reasons for injuries/casualties was because “most of the walls responded individually” [34].

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
- f. **Material degradation and structural damage/modifications:** As almost the whole current timber-frame building stock is composed of historic buildings, the material degradation due to water ingress, biological attack etc. and accumulated structural damage due to past earthquakes should be seen as an intrinsic feature of these. In addition, *himiş* houses have often been structurally modified within their service lives by the residents themselves without any engineering considerations, such as by creating new openings (door, window) or enlarging the existing ones in the masonry ground-floor, possibly to turn that floor into a shop. As past experiences showed, this type of interventions and poor maintenance, when combined with accumulated material and structural damage, can result in unexpected heavy damage or even collapse.
 - g. **Workmanship:** Workmanship is highly variable even within a limited set of frames built by the same group of traditional builders, in the testing scheme mentioned above. This affects the number of nails at each connection, their driving angles and detailing. The test results showed that workmanship is influential on the resulting lateral load-displacement relationships, which makes it further difficult to draw conclusions about an existing building with unknown workmanship quality. Most constructive details of *himiş* buildings are dependent on the builder's discretion - each builder has a rule of thumb that he will rigorously defend, while this does not necessarily follow a thorough scientific explanation.

22 3. CONCLUSIONS

23 Although we do not have solid evidence as for *himiş* buildings having been designed consciously and deliberately
24 to resist earthquake loading, qualitative post-reconnaissance studies show that these buildings are resilient
25 against seismic action. Additionally, a limited amount of experimental findings focussing on the timber-frame
26 section of *himiş* now suggest that these can bear seismic forces in the inelastic range. It should however be born
27 in mind that the overall seismic behaviour is dependent also on the masonry base or ground-floor, and the
28 connections between different floors/structural members. Even when the timber skeleton is intact, during an
29 earthquake the structural damage can be initiated by the masonry infill shaken off of the timber-frames or failure
30 of ground-floor with little out-of-plane strength, or of non-structural masonry elements such as chimneys. In
31 addition, the fact that workmanship plays an important role in the overall seismic behaviour makes it even
32 harder to draw generally applicable conclusions.

33
34
35
36 For a more robust appraisal of the seismic safety of the existing building stock, future research should focus on
37 more holistic assessment methods, considering the masonry component also, and the complex of various factors
38 threatening the physical integrity and performance of these buildings under seismic loading, such as aging,
39 material degradation, structure amendments, cumulative effect of past earthquakes etc. that were not taken
40 into account in the experimental work outlined in this paper. Turkey and other earthquake-prone countries
41 having the prominent tradition of this particular construction type should take steps to integrate *himiş* into their
42 current urban planning strategies, with improvements to raise their expected seismic performance to the code-
43 compliant levels. Restoration/rehabilitation efforts should be attentive to keep the ductility and high energy
44 dissipation characteristics of the nailed connections in place.

45 ACKNOWLEDGEMENTS

46 This paper has been encouraged by COST action FP1101 "Assessment, Reinforcement and Monitoring of Timber
47 Structures". The author would like to thank the action chair, Prof Dina D'Ayala. The invaluable contributions of
48 Profs Ahmet Türer, Uğurhan Akyüz and Neriman Şahin-Güçhan, and Dr Barış Erdil during the frame tests
49 mentioned in the paper are also kindly acknowledged. Lastly, the author is grateful to Prof Neriman Şahin-
50 Güçhan for the extremely useful discussions regarding the terminology.

References

- [1] Kuban, D. (1995). *The Turkish Hayat House*. Istanbul: T.C. Ziraat Bankası Kültür Yayınları.
- [2] Eldem, S. H. (1984). *Türk evi: Osmanlı dönemi / Turkish houses: Ottoman period*. İstanbul: Türkiye Anıt, Çevre, Turizm Değerlerini Koruma Vakfı.
- [3] Arel, A. (1982). *Osmanlı Konut Geleneğinde Tarihsel Sorunlar*. İzmir: Ticaret Matbaacılık.
- [4] Cerasi, M. (1998). The Formation of Ottoman House Types: A Comparative Study in Interaction with Neighboring Cultures. *Muqarnas*, 15, 116-156.
- [5] Asatekin, G. N. (1994). Anadolu'daki Geleneksel Konut Mimarisinin Biçimlenmesinde Aile Konut Karşılıklı İlişkilerinin Rolü. In İ. Tekeli, *Kent, Planlama, Politika, Sanat: Tarık Okyay Anısına Yazılar* (pp. 65-87). Ankara: Orta Doğu Teknik Üniversitesi Mimarlık Fakültesi.
- [6] Tsakanika-Theohari, E., & Mouzakis, H. (2010). A Post-Byzantine Mansion in Athens. The Restoration Project of the Timber Structural Elements. *World Conference on Timber Engineering*. Riva del Garda, Trentino, Italy: WCTE.
- [7] Coeck van Aelst, P. (1873). *The Turks in MDXXXIII: A Series of Drawings Made in That Year at Constantinople*. (S. S. Bart, Trans.) London & Edinburg: Privately Printed.
- [8] Ambraseys, N. N. (2001). The Earthquake of 1509 in the Sea of Marmara, Turkey, Revisited. *Bulletin of the Seismological Society of America*, 91(6), 1397-1416.
- [9] Şahin-Güçhan, N. (2007). Observations on Earthquake Resistance of Traditional Timber Framed Houses in Turkey. *Building and Environment*, 42, 840-851.
- [10] Rozen, M., & Arbel, B. (2006). Great fire in the metropolis. In *Mamluks and Ottomans: Studies in Honour of Michael Winter* (pp. 134-163). New York: Routledge.
- [11] Sezer, H. (1997). 1894 İstanbul depremi hakkında bir rapor üzerine inceleme. *Ankara Üniversitesi Dil ve Tarih-Coğrafya Fakültesi Tarih Bölümü Tarih Araştırmaları Dergisi*, 29(19), 169-197.
- [12] Genç, M., & Mazak, M. (2001). *İstanbul Depremleri: Fotoğraf ve Belgelerde 1894 Depremi*. İstanbul: IGDAS Kültürel Yayınları.
- [13] Şahin-Güçhan, N. (2001). Ahşap Karkas Yapılar ve Bunların Restorasyonunda İnşaat Mühendislerinin Rolü. *Türkiye Mühendislik Haberleri*, 414(4), 21-26.
- [14] Ambraseys, N. N., Zatopek, A., Tasdemiroglu, M., & Aytun, A. (1968). *The Mudurnu Valley (West Anatolia) Earthquake of 22 July 1967*. Paris: UNESCO serial no. 622/BMS.RD/AVS.
- [15] Spence, R. (2014). The Full-Scale Laboratory: The Practice of Post-Earthquake Reconnaissance Missions and Their Contributions to Earthquake Engineering. In *Perspectives on European Earthquake Engineering and Seismology* (pp. 1-53). Springer International Publishing.

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
- [16]Penzien, J., & Hanson, R. D. (1970). *The Gediz, Turkey, Earthquake of 1970: A Report to the National Science*. Washington D.C.: National Academy of Sciences for the National Academy of Engineering.
- [17]Mitchell, W. A. (1976). Reconstruction after Disaster: The Gediz Earthquake of 1970 . *Geographical Review*, 66(3), 296-313.
- [18]Mitchell, W. A., & Glowatski, E. A. (1971). Some Aspects of the Gediz (Turkey) Earthquake, March 28, 1970. *Journal of Geography*, 70(4), 224-229.
- [19]Ambraseys, N. N., & Tchalenko, J. S. (1972). Seismotectonic Aspects of the Gediz, Turkey, Earthquake of March 1970. *Geophysical Journal International*, 30, 229-252.
- [20]Erdik, M. (1994). Developing a Comprehensive Earthquake Disaster Masterplan for Istanbul. In *Issues in Urban Earthquake Risk* (pp. 125-166). Dordrecht: Springer Science+Business Media.
- [21]Erdik, M., Yüzügüllü, O., Karakoç, C., Yılmaz, C., & Akkaş, N. (1994). March 13, 1992 Erzincan (Turkey) earthquake. *Tenth Earthquake Engineering Conference*. Balkema, Rotterdam.
- [22]Erdik, M., Yüzügüllü, O., Yılmaz, C., & Akkaş, N. (1992). 13 March, 1992 (Ms-6-8) Erzincan earthquake: A preliminary reconnaissance report. *Soil Dynamics and Earthquake Engineering*, 11, 279-310.
- [23]Williams, M. S., Pomonis, A., Booth, E. D., Vaciago, G., & Ring, S. (1992). *The Erzincan, Turkey Earthquake of 13 March 1992*. London: EEFIT.
- [24]Biricik, A. S., Ceylan, M. A., & Ünlü, M. (1996). Ekim 1995-Dinar depremi. *Marmara Coğrafya Dergisi*, 1(1), 63-102.
- [25]Gülhan, D., & Özyörük Güney, İ. (2000). The Behaviour of Traditional Building Systems Against Earthquake and Its Comparison to Reinforced Concrete Frame Systems: Experiences of Marmara Earthquake Damage Assessment Studies in Kocaeli and Sakarya. *Earthquake-Safe:Lessons to be Learned from Traditional Buildings*. Istanbul: ICOMOS.
- [26]Yoshida, N., Tokimatsu, K., Kokusho, T., Yasuda, S., & Okimura, T. (2001). Geotechnical Aspect of Damage in Adapazari City During the 1999 Kocaeli, Turkey, Earthquake. *Fourth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. USA: ICCHGE.
- [27]Bakır, B. S., Yılmaz, M. T., Yakut, A., & Gülkan, P. (2005). Re-examination of damage distribution in Adapazari: Geotechnical considerations. *Engineering Structures*, 27(7), 1002-1013.
- [28]Bruneau, M. (2002). Building damage from the Marmara, Turkey earthquake of August 17, 1999. *Journal of Seismology*, 6, 357-377.
- [29]Tobriner, S. (2000). Wooden Architecture and Earthquakes in Turkey: A Renaissance Report and Commentary on the Performance of Wooden Structures in the Turkish Earthquakes of

17 August and 12 November 1999. *Earthquake-Safe: Lessons to be Learned from Traditional Buildings*. Istanbul: ICOMOS.

- [30]Spence, R., Bommer, J., Del Re, D., Bird, J., Aydınoğlu, N., & Tabuchi, S. (2003). Comparing Loss Estimation with Observed Damage: A Study of the 1999 Kocaeli Earthquake in Turkey. *Bulletin of Earthquake Engineering*, 1(1), 83-113.
- [31]Gülkan, P., & Langenbach, R. (2004). The Earthquake of Traditional Timber and Masonry Dwellings in Turkey. *13th World Conference on Earthquake Engineering*. Vancouver, B.C., Canada: 13WCEE.
- [32]Langenbach, R. (2007). From “Opus Craticium” to the “Chicago Frame”: Earthquake-Resistant Traditional Construction. *International Journal of Architectural Heritage*, 1, 29-59.
- [33]Demirtaş, R., İravul, Y., Erkmen, C., Baran, B., Yaman, M., & Baykal, M. (2000). 06 Haziran 2000 Orta (Çankırı) Depremi. *Jeoloji Mühendisleri Odası Haber Bülteni*, 6-15.
- [34]Erdik, M., Şeşetyan, K., Demircioğlu, M. B., Celep, U., Biro, Y., & Uçkan, E. (2002a). *Sultandağı Earthquake, Turkey*. Retrieved November 23, 2015, from Earthquake Engineering Research Institute, Learning From Earthquakes - Turkey: http://eeri.org/lfe/pdf/turkey_sultandagi_report_erdik.pdf
- [35]Erdik, M., Şeşetyan, K., Demircioğlu, M. B., Celep, U., Biro, Y., & Uçkan, E. (2002b). *Special Earthquake Report from the May 2002 Newsletter: Preliminary Observations on the Sultandağı, Turkey, Earthquake of February 3, 2002*. Retrieved January 14, 2011,. Retrieved November 23, 2015, from Earthquake Engineering Research Institute, Learning From Earthquakes - Turkey: http://www.eeri.org/lfe/pdf/Turkey_Sultandagi_Insert_May02.pdf
- [36]Koçyiğit, A., Bozkurt, E., Kaymakçı, N., & Şaroğlu, F. (2002). *3 Şubat 2002 Çay (Afyon) Depreminin Kaynağı ve Ağır Hasarın Nedenleri: Akşehir Fay Zonu (Jeolojik Ön Rapor)*. Retrieved December 08, 2013, from <http://www.metu.edu.tr/~akoc/Afyon.pdf>
- [37]Erdik, M., Demircioğlu, M., Beyen, K., Şeşetyan, K., Aydınoğlu, N., Gül, M., . . . Kaya, Y. (2003). *May 01, 2003 Bingol (Turkey) Earthquake*. Istanbul: EERI. Retrieved from https://www.eeri.org/lfe/pdf/turkey_bingol_reconnaissance_report_erdik.pdf
- [38]Ramirez, J. A., Yakut, A., Akyüz, U., Gür, T., İrfanoğlu, A., Matamoros, A., . . . Wasti, S. T. (2003). Types of Structures and Observed Damage. In G. Ozcebe, J. Ramirez, T. Wasti, & A. Yakut (Eds.), *1 May 2003 Bingol Earthquake Engineering Report* (pp. 57-124). Ankara: TUBITAK.
- [39]Celep, Z., Erken, A., Taşkın, B., & İlki, A. (2011). Failures of masonry and concrete buildings during the March 8, 2010 Kovancılar and Palu (Elazığ) Earthquakes in Turkey. *Engineering Failure Analysis*, 18(3), 868–889.
- [40]Alyamaç, K. E., Sayın, E., Yön, B. Ç., Karataş, M., Erdoğan, A. S., Ülker, M., & Calayır, Y. (2011). Observations on Damages at Buildings in the Rural Area due to the Başyurt-Karakoçan (Elazığ) Earthquake. *Turkish Journal of Science & Technology*, 6(2), 117-128.

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
- [41]Calayır, Y., Sayın, E., & Yön, B. (2012). Performance of structures in the rural area during the March 8, 2010 Elazığ-Kovancılar earthquake. *Natural Hazards*, 61(2), 703-717.
- [42]Köksal, T. S., Avşar, O., & Yılmaz, N. (2011). 19 Mayıs 2011 Kutahya-Simav Depreminde Meydana Gelen Yapısal Hasarların Nedenleri. 1. *Türkiye Deprem Mühendisliği ve Sismoloji Konferansı*. 69, pp. 981-1001. ODTU, Ankara: TDMSK.
- [43]Ambraseys, N. N., & Jackson, J. A. (1981). Earthquake hazard and vulnerability in the northeastern Mediterranean: The Corinth earthquake sequence of February-March 1981. *Disasters*, 5(4), 355-368.
- [44]Diri, F. (2010). *Construction Techniques of Traditional Birgi Houses*. Ankara: Middle East Technical University, Msc Thesis. Retrieved from <http://etd.lib.metu.edu.tr/upload/12612632/index.pdf>
- [45]Faroqhi, S. (1998). *Osmanlı Kültürü ve Gündelik Yaşam: Ortaçağdan Yirminci Yüzyıla*. İstanbul: Tarih Vakfı Yurt Yayınları.
- [46]Evren, M. (1959). *Türk Evinde Çıkma*. İstanbul: Fakülteler Matbaası.
- [47]Günay, R. (1998). *Tradition of the Turkish Houses and Safranbolu Houses*. İstanbul: YEM.
- [48] Aksoy, D., & Ahunbay, Z. (2005). Geleneksel Ahşap İskeletli Türk Konutu'nun Deprem Davranışları. *İtü Dergisi/a Mimarlık, Planlama, Tasarım*, 47.58.
- [49]Aktaş, Y. D., & Türer, A. (2016). Seismic Performance Evaluation of Traditional Timber Himiş Frames: Capacity Spectrum Based Assessment. *Bulletin of Earthquake Engineering*, 14(11), 3175-3194.
- [50]Aktaş, Y. D., Akyüz, U., Erdil, B., Türer, A., & Şahin Güçhan, N. (2010). Assessment of Seismic Behavior of Traditional Timber Frame Ottoman Houses: Frame tests. *1st International Conference on Structures and Architecture (ICSA)*. Guimaraes.
- [51]Aktaş, Y. D., Akyüz, U., Türer, A., Erdil, B., & Şahin Güçhan, N. (2014a). Seismic Resistance Evaluation of Traditional Ottoman Timber-Frame Himiş Houses: Frame Loadings and Material Tests. *Earthquake Spectra*, 30(4), 1711-1732.
- [52]Aktaş, Y. D., Türer, A., & Akyüz, U. (2014b). Seismic Performance Assessment of Traditional Timber Himiş Frames by Laboratory Testing and Capacity Spectrum Method. *Second European Conference on Earthquake Engineering and Seismology*. İstanbul: 2ECEES.

FIGURES AND TABLES

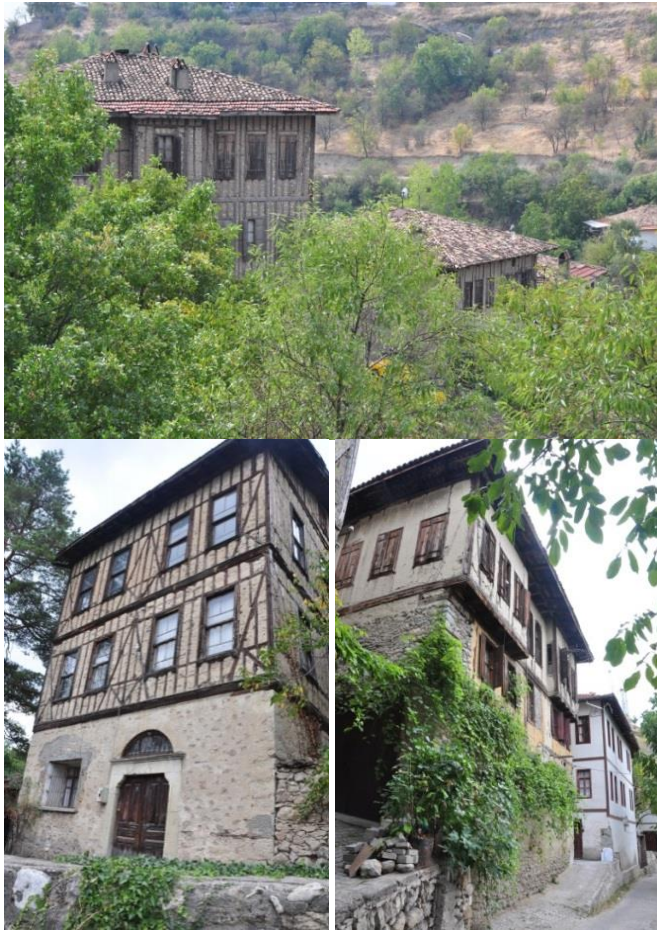


Figure 1: *Hımiş* houses in Safranbolu

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

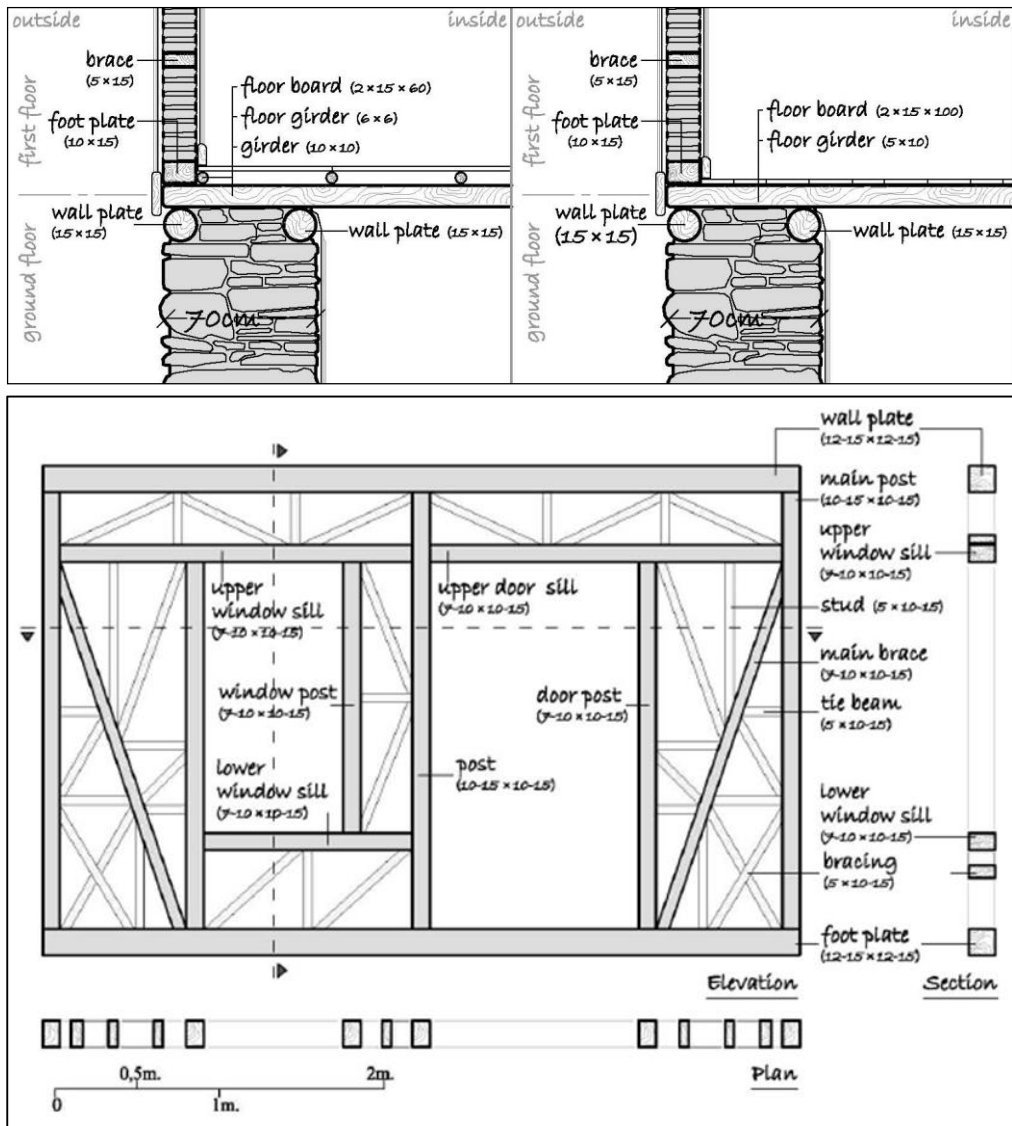


Figure 2: (Top) Schematic drawing of the detailing between masonry ground-floor and timber-frame upper floor and (Bottom) members forming a timber-frame based on an case study structure from Birgi, Turkey (after Diri, 2010)



Figure 3: Braced projections from (a) Safranbolu, Turkey and (b) Chalkis, Greece (this concave variation is known as *eliböğünde*), and (c) simple cantilever projection from Safranbolu

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65



Figure 4: (a) Frame tests under reverse-cyclic lateral loading; (b) brick infill; (c) adobe infill; (d) *bağdadi* cladding; (e) *şamdolma* cladding.

Table 1: Major earthquakes in Turkey from 1960's onwards with notes on the performance of *hımış*

Earthquake	Brief remarks	Selected reading
July 1967 Mudurnu	<i>Hımış</i> performed better than other construction types. While partial/complete collapse was common in masonry, timber buildings suffered only little damage, except for few cases of heavy damage or collapse, attributed to heavy deterioration in timber or triggered by landslides.	[14, 15]
March 1970 Gediz	<i>Hımış</i> with lightweight roofs suffered little damage, but some got damaged beyond repair mostly due to poor masonry infill. Round-post buildings were found to be more vulnerable than sawn timber-post buildings.	[16-19]
March 1992 Erzincan	<i>Hımış</i> houses suffered only insignificant, superficial damage such as falling of plaster.	[20-23]
October 1995 Dinar	<i>Hımış</i> houses with brick/adobe infill behaved well, while reinforced concrete buildings suffered heavy damage.	[24]
August 1999 İzmit	Many of the older <i>hımış</i> houses remained intact, with only a few heavily damaged cases, whilst concrete buildings behaved very poorly. Ground-floor damage was common in collapsed timber houses.	[25-29]
November 1999 Düzce		[29-32]
June 2000 Orta	The damage in <i>hımış</i> was limited to out-of-plane dislodgement of masonry infill, cracked and fallen plaster.	[31-33]
February 2002 Afyon, Sultandağı (Çay)	Poor performance due to "thick perimeter walls and heavy roofs". Observations showed poor connection between perimeter walls, which induced out-of-plane collapse. Liquefaction also played an important role.	[34-36]
May 2003 Bingöl	The performance of the <i>hımış</i> buildings is not so good, mostly for infill collapse. Other observed damage was attributed to the weak connection or lack of the braces. In few buildings where bracing was present and strong, the damage was non-existent.	[37-38]
March 2010 Kovancılar and Palu (Elazığ)	Generally, <i>hımış</i> buildings behaved better than masonry and adobe. Damage concentrated to infill walls.	[39-41]
May 2011 Kütahya, Simav	Despite cases of damage in <i>hımış</i> mostly due to poor workmanship especially in masonry ground-floors, they behaved better than the other construction types.	[42]