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

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Abstract:	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.
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SEISMIC RESISTANCE OF TRADITIONAL TIMBER-FRAME *HIMIŞ* STRUCTURES IN TURKEY: A BRIEF OVERVIEW

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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.

Keywords: *hımış*, 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, *hımış* 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 *hımış* will be used to refer to these houses[1].

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 *hımış* houses and

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

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

1. POST-DISASTER OBSERVATIONS

It is known that after the 1509 Great Istanbul Earthquake which resulted in an estimate of 13,000 casualties [8], the Ottoman authorities prohibited masonry and enforced the construction of timber-frame houses, claiming that masonry was responsible for most of the casualties [9]. By the end of the century, the city was "almost entirely built of wood" as stated by the Venetian diplomat Barbaro [10]. Almost four centuries later, D. Eginitis, the director of the Observatory of Athens, who was personally invited to Istanbul after the 1894 earthquake by Abdülhamid II himself for a post-disaster report, "greeted with pleasure that the buildings in Istanbul are not entirely built of masonry as in other regions" [9, 11-13]. Despite the later legislation in the 19th century that highly-regulated or completely banned timber buildings and enforced masonry instead, in order to minimize the fires that swept away Istanbul time and again [9], cheaper and easier-to-use timber remained the building material characterizing the modest residential built environment both in the capital and in the remote provinces with an abundance of wood[2], until the 20th century. In order to give a general idea about their more recent performance under seismic loading, a brief review of the structural damage on the existing *hımış* stock reported following major earthquakes since 1960's in Turkey is given in Table 1.

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

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

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

Hımış is a composite construction system, where the ground-floor is mostly composed of masonry (rubble stone or alternating layers of stone and brick, or adobe with timber posts) with timber tie-beams (*hatıl*s) built on continuous or discontinuous stone foundations, and the upper-storeys and roof of timber[3]. A single timber frame

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

[3] There is a widespread heterogeneity with regards to the use of the term *hımış*: in the relevant literature it is sometimes used to define only the timber-frame wall technique, and/or the timber-frames with infill, rather than with cladding (which is often defined by the umbrella term *bağdadi*). In this paper, however, it is used to define the entire composite building with masonry ground floor and timber-frame upper floor(s) regardless whether they are used with infill or cladding (for further reading on basic terminology see [9]).

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

The infill can be made using adobe, stone or brick depending on the availability (e.g., in the north-western Anatolia adobe and brick prevail, while in the eastern Black Sea coastal area it is stone). Alternatively, a cladding or "lath and plaster" technique that first appeared in the 18th century and is widely known as *bağdadi* is also widely used. In *bağdadi*, 2-4 cm wide laths are nailed onto the timber-frame with around 1 cm gaps in between so that the plaster holds on the surface more easily. This technique has a number of regional varieties and is used without additional infill with a few local exceptions[6].

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

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

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

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

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

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

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 *hımış* 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 *hımış* 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 *hımış* 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 *hımış* 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 *hımış* 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 *hımış* 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].

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, *hımış* 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 *hımış* 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.

3. CONCLUSIONS

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

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

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FIGURES AND TABLES

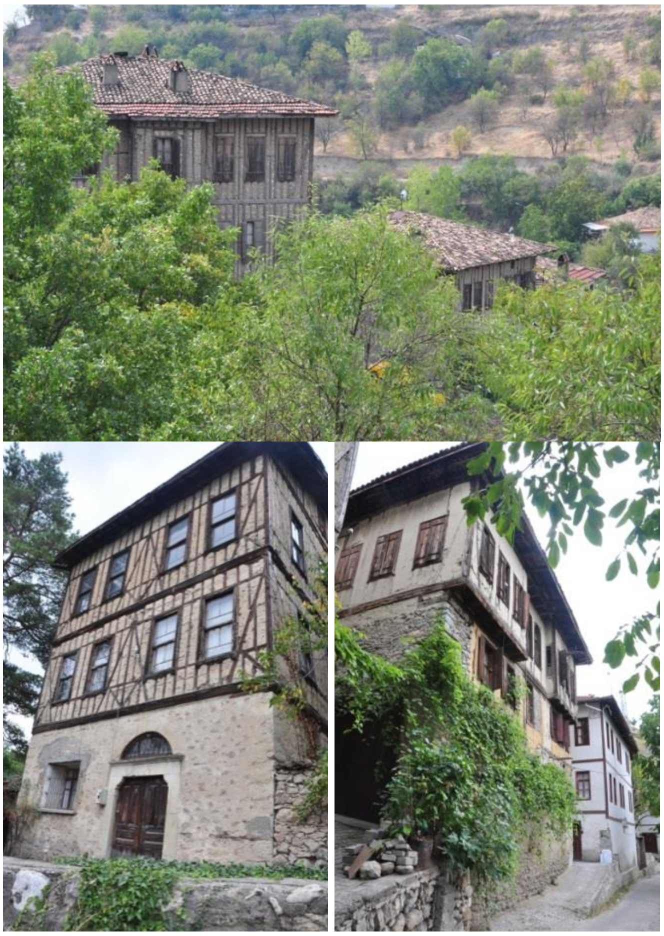

Figure 1: *Hımış* houses in Safranbolu

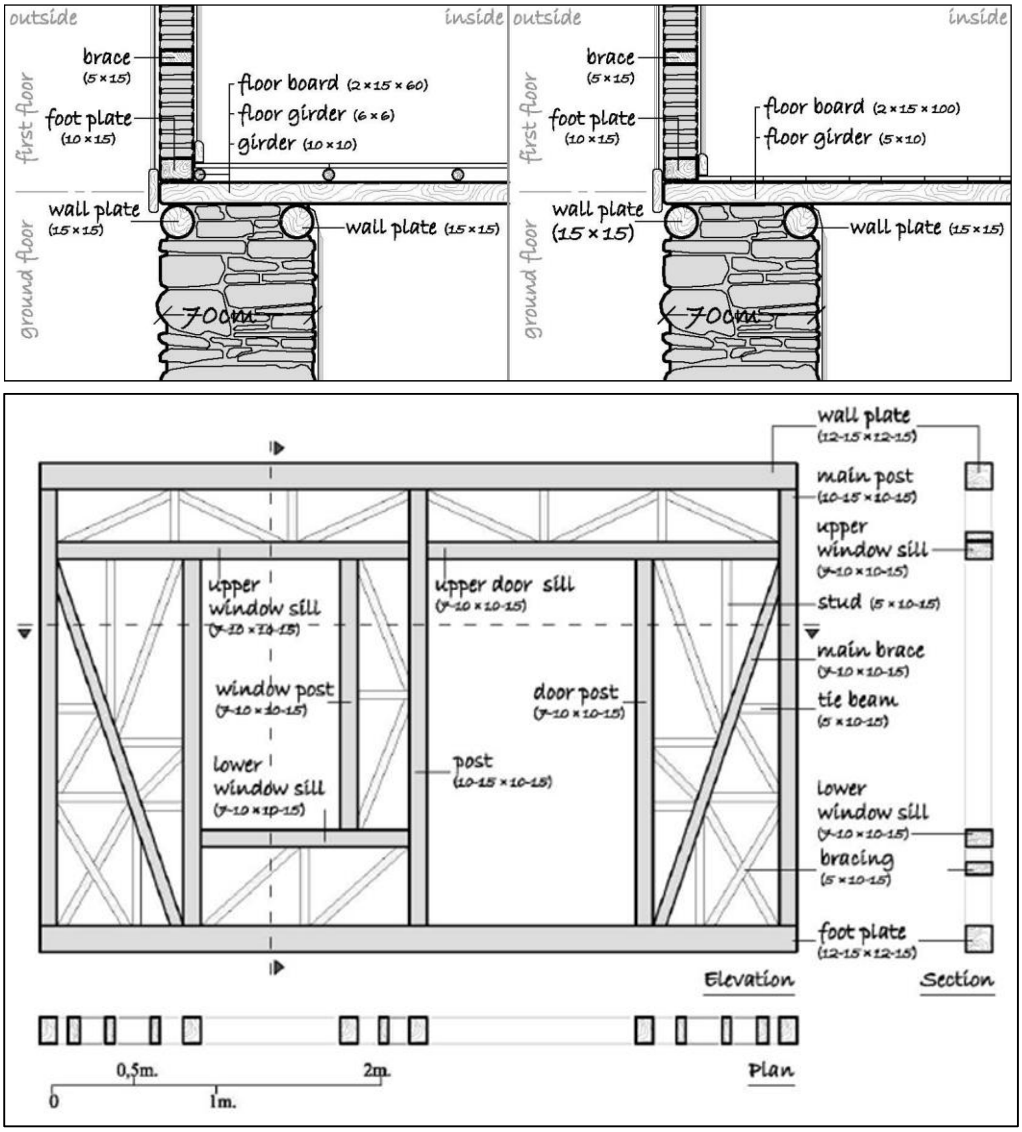

Figure 2: (Top) Schematic drawing of the detailing between masonry ground-floor and timber-frame upper floor and (Bottom) members forming a timber-frame based on an case study structure from Birgi, Turkey (after Diri, 2010)

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

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	*Hımış* 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	*Hımış* 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	*Hımış* houses suffered only insignificant, superficial damage such as falling of plaster.	[20-23]
October 1995 Dinar	*Hımış* houses with brick/adobe infill behaved well, while reinforced concrete buildings suffered heavy damage.	[24]
August 1999 İzmit	Many of the older *hımış* 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 *hımış* 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 *hımış* 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, *hımış* buildings behaved better than masonry and adobe. Damage concentrated to infill walls.	[39-41]
May 2011 Kütahya, Simav	Despite cases of damage in *hımış* mostly due to poor workmanship especially in masonry ground-floors, they behaved better than the other construction types.	[42]