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Traditional wooden buildings and their damages during earthquakes in Turkey

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Abstract

Wood is one of the oldest structural materials used in structures in many parts of the World. Woodframe buildings were also commonly constructed in Turkey until approximately 1960. After that, as reinforced concrete and masonry buildings have been preferred, wooden buildings have almost been forgotten. But, in 1999, Kocaeli and Duzce earthquakes reminded traditional buildings. Since reinforced concrete buildings presented high level of damage and traditional buildings relatively performed well during these earthquakes. In this study, types of traditional wooden buildings used in Turkey are mainly introduced and their damages in earthquakes are discussed. Damaged and undamaged wooden building photos are illustrated. Some structural weaknesses are highlighted by the earthquake damages including cracking and falling of plaster, failure of mortar, loosening or failing of connections, large lateral displacements, dislodgement of the masonry infill, loosening or failing of connections and failure of connections to foundation.

Keywords: Earthquake damages; Turkish traditional wooden buildings

1. Introduction

Three types of structural systems, *reinforced concrete*, *unreinforced masonry* and *woodframe* have been commonly constructed in Turkey. Modern buildings in the cities are generally built as reinforced concrete. Traditional wooden buildings were generally constructed in the ancient parts of city. Seismic resistance of these buildings became nearly universal in Istanbul from the 17th to the 19th centuries. But as safe as it may

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have been in earthquakes, wood construction was deadly in fires. Several huge fires swept the city in the early 19th century persuaded authorities to bane further wood construction unless protected by brick fire breaks [1]. By the late 19th century multiunit brick apartment buildings were replacing traditional timber framed buildings. But, woodframe construction is by far the most common housing type in Canada, the USA and New Zealand for single family and low-rise multi-family dwellings [2]. Over two million housing units are built annually in North America and Japan [3]. The general range of the fraction of wood structures to total structures seems to be between 80% and 90% in all regions of the USA [4].

In 1999, Kocaeli and Duzce earthquakes reminded traditional buildings to Turkish community. Although there were clusters of traditional buildings in the heart of earthquake areas, many of the ancient traditional timber framed houses remained intact, only a few were heavily damaged. However reinforced concrete buildings presented high level of damage [5]. This finding was confirmed by Turkish researchers such as Gülhan and Güney [6] who conducted a detailed statistical study in several areas of the damaged district. They found a wide difference in the percentage of modern reinforced concrete buildings that collapsed, compared to those of traditional construction. In one district in the hills above Gölcük where 60 of the 814 reinforced-concrete structures were heavily damaged or collapsed, only 4 of the 789 two-to-three-story traditional buildings collapsed or had been heavily damaged. The reinforced-concrete buildings accounted for 287 deaths against only 3 in the traditional structures. In the heart of the damage district in Adapazari, the research showed that 257 of the 930 reinforced concrete structures were heavily damaged or collapsed and 558 of moderately damaged. By comparison, none of the 400 traditional structures collapsed or were heavily damaged and only 95 of total were moderately damaged.

The widespread failure of reinforced concrete buildings in the 1999 Kocaeli and Duzce earthquakes not only forced Turkish academicians, engineers and architects to reassess reinforced concrete construction, but also pushed a few of them to reconsider a discarded technology, traditional timber framed systems. Figs. 1 and 2 show two views for traditional wooden houses survived both 1999 earthquakes without damage close to collapsed and heavily damaged reinforced concrete structures. There were relatively very few studies and information about earthquake damages of traditional wooden buildings in Turkey. But, investigations about the seismic behavior of traditional buildings are important due to two reasons. First one is, if possible, to reduce the loss of human lives and economic, building with traditional structural systems should be used in the earthquake regions. Second one is the fact that most of these wooden buildings constructed in 4000 various sites around seismic zones make important part of Turkish culture (there are almost 45,000

Fig. 1. View of traditional and reinforced concrete buildings after the 1999 Duzce earthquake.

Fig. 2. A view for neighbor traditional and reinforced concrete buildings after the 1999 Duzce earthquake [7].

registered monuments and dwellings in Turkey). These historical and monumental structures have been assumed to be cultural inheritance to the next generations, it is very important that these buildings need to be survived or only slightly damaged during future earthquakes.

The main purpose of this study is to introduce types of traditional wooden buildings in Turkey and to evaluate their earthquake damages. As the seismic response of these traditional buildings in Turkey was rarely be discussed speculatively up to 1999 earthquakes, there were so little published papers on the subject. It is hoped that this paper meant to open scholarly dialogue concerning traditional Turkish wooden buildings and earthquake damages and aimed further debate and in doing so encourage future research about these buildings.

2. Types of traditional wooden buildings in Turkey

The wooden buildings of Turkey are the products of the thousands of year of cultural heritage of people who live in this region. Thus there are many very distinctive styles of traditional rural domestic architecture in Turkey, resulting from cultural attributes, related to material availability and climate. Traditional wooden buildings in Turkey may be mainly classified depending on the structural elements in the walls given as below:

Log houses
Hatıl construction
Hımış construction — Timber-laced masonry
Dizeme construction
Bağdadi construction — Timber-framed (woodframe) buildings

2.1. Log houses

The oldest and, in a way, historical method of construction is called "çanti" (log house) in which logs slightly processed are overlapped and anchored at the ends (Fig. 3). Walls constituted with logs make a

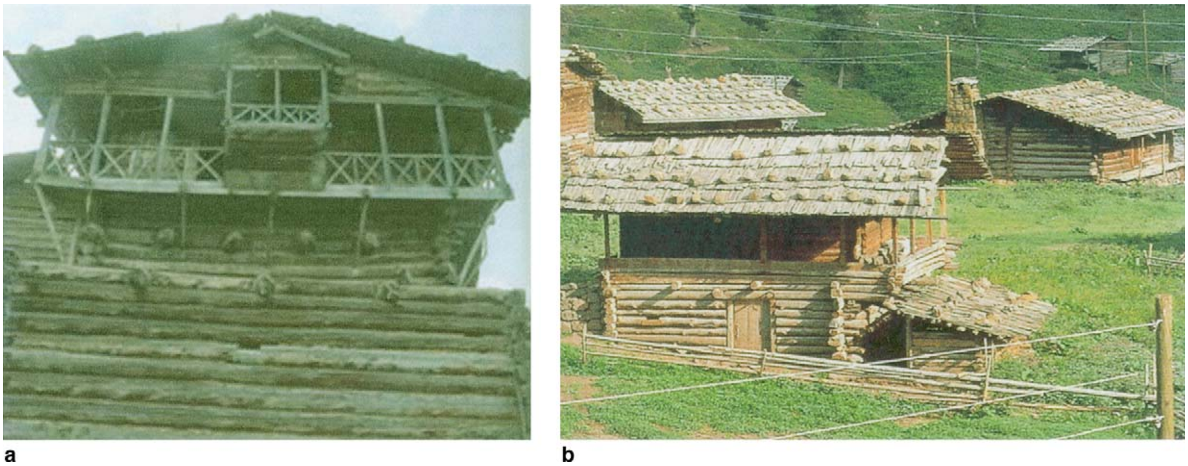

Fig. 3. Traditional log houses in Turkey [8].

function both bearing and dividing. Vertical loads transmitted from up to down through logs that lied horizontally and restrained only both ends in the traditional Turkish log houses. Even if such a bearing system is sufficient for vertical load, it will not be able to resist lateral loads occurred during a destructive earthquake due to loosening of ends impressed by shear forces. If logs are processed and anchored each other mechanically or chemically, it is possible to make it earthquake resistant. Modern log houses have been started to construct using new techniques in Turkey in recent years.

2.2. Hatıl construction

In the Hatıl construction, horizontal timbers embedded into bearing wall masonry (Fig. 4). Many buildings with hatıl construction system in which the main materials of construction are stone with mud mortar and slightly wood were also damaged during the Turkey's small recent earthquakes (July 2, 2004 Doğubeyazıt, March 25, 2004 Erzurum earthquakes). In this particular earthquake the role of timber hatıls, in

Fig. 4. Traditional hatıl construction in Turkey.

modifying the earthquake damage, was not easy to appreciate, but thought to be moderately significant. As previously noted, many of the affected structures were highly decayed; therefore, wall top/roof collapse and granular disintegration occurred. The Hatıls systems as seen could not aid in resisting this sort of failure. It was clear that the hatıls when tied around the facade-side wall junctions did aid in reducing the significance of corner wedge failures. It would appear that long doorway and window lintels aided in redirecting crack propagation [9].

2.3. Hımış construction

Hımış construction is simply described as a timber frame with masonry infill such as bricks (Fig. 5), adobes or stones. This type of construction is a variation on a shared construction tradition that has existed through history in many parts of the world, from ancient Rome almost to the present. In Britain, where it became one of the identity markers of the Elizabethan Age, it would be referred to as "half-timbered." In Germany it was called "fachwerk," in France, "colombage," in Kashmir, India as "dhajji-dewari", in parts of Central and South America, a variant was called "bahareque" [10].

It is possible to classify traditional hımış construction depending on the structural systems and masonry infill. Here, it is divided into two categories for structural system such as; system contained bracing elements and no bracing elements (Fig. 6). In this system studs are themselves tied by only other horizontal timbers. In this buildings, vertical timber elements do not subjected to tension direction to grain whereas timber have high specific strength for this grain direction. Structural timber, with all of its natural defects, shows an unquestionable brittle character under certain when subjected to shear or tension perpendicular to grain direction. Thus, it is not expected to resist lateral forces without damage during an earthquake due to low lateral stiffness of the frame system as shown in Fig. 6.

In the hımış construction, the timber elements constitute important elements by providing the armature for the masonry infill. Only vertical framing elements (studs, pillars) may be sufficient for vertical loads, but these studs will be insufficient during the strong ground motion. Thinking of improving seismic resistance to horizontal forces caused to use of bracing elements in traditional timber frame buildings on earthquake

Fig. 5. Traditional hımış building with bracing elements and brick infill in Bursa.

Fig. 6. Traditional building with brick infill and no bracing elements.

zones. For the bracing elements to work successfully as a seismic resistant construction system they must be designed correctly, the more diagonal bracing the better. There is also an art to placing and designing diagonal bracing. The wider the base of the triangle in relation to its height the stronger it is. The diagonal should be connected to the vertical member as close to the joint with the horizontal member of the panel as possible. Since corners are the most vulnerable to damage in lateral movement, builders have positioned the diagonals there. X braces are in general stronger than diagonal bracing alone.

2.4. Dizeme construction

In some buildings, wood were used as infill materials instead of masonry some regions such as Bolu. Short rough timbers elements called as dizeme were used as infill and they were lightly nailed studs or horizontal framing elements in this construction (Fig. 7). The purpose of wood infill usage to avoid their common early shear failure and falling out of the frame occurred for masonry infill. Thus, wood infill called as dizeme provides continuous additional support to the building during the course of the earthquake shaking by ‘‘working’’ through many cycles of without loss of their integrity.

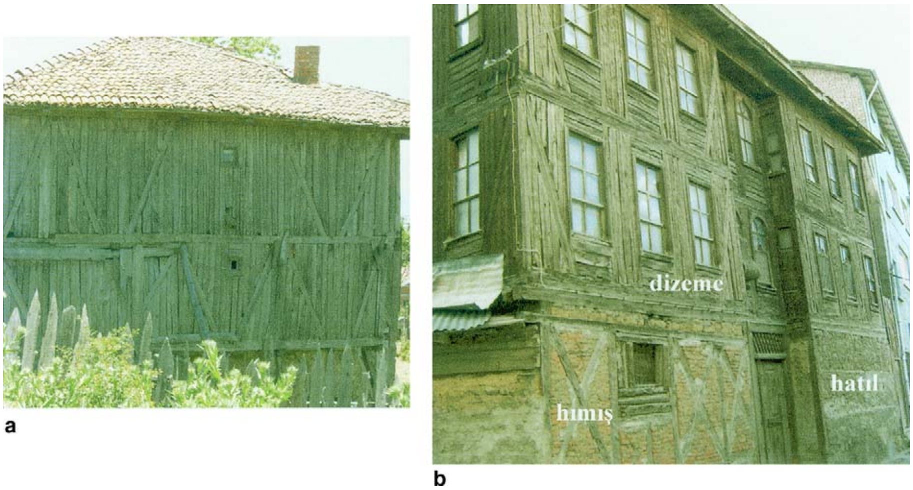

Fig. 7. Traditional timber framed buildings with wood infill (dizeme construction). (a) All stories constructed dizeme technique. (b) Dizeme construction on hımış and hatıl ground story.

Laths were nailed on the main framing elements and dizeme with small distance before plaster work in some buildings (Fig. 8). They help resist lateral loads and help tie framing members and dizeme together. As ductility and energy dissipation, which can be accomplished through hysteretic in connections and friction between the various constructional parts, dizeme construction has more advantage than the other traditional timber framed construction types.

Dizeme constructions that have numerous load paths are considered structurally redundant and provide an extra level of safety in earthquakes. Typical dizeme construction is comprised of hundreds of timber elements and nailed connections. This means that the failure of one load path can often be compensated for by adjacent elements and joints. Thus, this redundancy of dizeme elements with a high level of energy-dissipating capacity leads to the good performance during earthquakes. Many woodframe buildings with dizeme construction behaved well during the 1944 Gerede Earthquake whose magnitude 7.8 [11].

2.5. Bağdadi construction

The other construction is bağdadi where the voids between timber framing members is filled lighter materials or with trunk shells are transformed into a filling material by sand and lime mortar. The interior surfaces of walls are covered by lath and plaster work or wood, whereas the outer surfaces are either plastered or non-plastered or wooden plastered (Fig. 9).

a b

Fig. 8. Dizeme construction with laths nailed to the framing elements and covered with mud plaster. (a) Inclined laths nailed to the framing elements and covered with mud plaster. (b) Horizontally placed laths nailed to the framing elements and covered with lime plaster.

Fig. 9. Traditional some bağdadi constructions types in Turkey [8].

3. Damages of wooden buildings during earthquakes in Turkey

Turkey is frequently exposed to destructive earthquakes and approximately every year one occurs. Besides, it is one of the few countries with the shortest return period in earthquakes causing loss of lives. Earthquakes in Turkey are generally of in-land type and shallow focus earthquakes which are more destructive than offshore earthquakes even their magnitude could be smaller [12].

As known, properties of earthquake, soil and structure affect the damage level of structures during an earthquake. Maximum ground acceleration, duration, depth and distance of hypocenter to the city of an earthquake are the main earthquake parameters that affect the damages of structures. The influence of soil conditions on the degree of building damage is very clear. As this subject is assumed out of scope of this paper, only structural deficiencies and mistakes related to traditional wooden buildings are discussed here.

The damages determined in wooden structures can be classified as: slightly damaged; where vertical cracks were mostly placed either at the corners or at the mid of the walls (0.5 mm.), moderately damaged; vertical and horizontal cracks on the walls (2 mm), corner cracking especially at openings, wall deformation, deformation of walls along the wooden beams and separation of walls from the beams, roof separation from wall, highly damaged; partial collapse in the structural system or total collapse.

It is disappointing that so few official reports or directives have been studied in relation to seismic safety of wooden buildings. Written documents describing traditional Turkish timber buildings in earthquakes are rare but the few that survive provide tantalizing clues. In the aftermath of the Istanbul earthquake of 1894 both experts and ordinary citizens were impressed by how well wooden buildings performed. The Director of the Athens Observatory called to study the earthquake, concluded that timber structures outperformed masonry buildings even if they were old and poorly built [1]. The seismic behaviors of wooden buildings during the recent earthquakes were either been reported only as a few sentences or not been reported at all. Damage assessment results taken from written documents and authors observations for traditional wood buildings subjected to the earthquakes in Turkey are given in Table 1. In this table $a_{\max}$ shows recorded peak ground accelerations, t shows duration of earthquakes considering time interval in which large amplitude occurred, d_{f} shows focal depth of the earthquake, HD, MD and LD show highly, moderately and low damages correspondingly. It has not been found any information related to seismic behaviours of traditional wooden buildings during the other Turkey earthquakes.

The majority of the timber framed buildings performed well, especially from the standpoint of life safety. If the timber framed buildings does collapse, large survival voids are created. Also the building has less concentrated, crushing weight. Brick will cause many injures but less squashed bodies than concrete blocks.

Although the type of traditional wooden buildings varies in different earthquake zones, their damage resulting from earthquakes can be commonly classified. It is observed that the following damage results of timber framed buildings during the destructive earthquakes in Turkey.

3.1. Cracking and falling of plaster

Its survival in the much larger and longer earthquake illustrates that the timber framed buildings is capable of maintaining stability over many cycles. To do this, however, the deflection of the structure and friction in the infill must begin at the onset of shaking. Thus, different from reinforced and masonry buildings, for timber framed buildings the shedding of the plaster and stucco in both the large and small earthquakes was similar. In other words the working of bracing elements in the earthquake dislodged the plaster as the oscillated building. The closely spaced studs reduced the likelihood of the propagation of cracks within masonry infill. The only visible manifestation of earthquake excitation was the presence of cracks in the interior plaster along the walls and at the corners of the rooms, revealing the pattern of the timbers imbedded in the masonry underneath. This level of damage was evident in every traditional timber framed buildings after a moderate or larger earthquake (Fig. 10). On the exterior, unless the masonry was covered with

Table 1
Turkey earthquakes and damages of buildings

Earthquake	M_w or M_s	a_g	d_f	t	Buildings			Behaviour of traditional wooden buildings
					HD	MD	LD	
July 2, 2004 Doğubeyazit [13,14]	5.0	0.09	9	5	300	200	500	There is no detailed information about wooden buildings.
March 25, 2004 Erzurum [14]	5.1	5.45	5.5	5	–	–	–	Especially poorly constructed Hatıl structures were heavily damaged or collapsed
July 26 2003 Buldan [14,15]	5.6	1.2	10.6	25	330		313	Kaplan et al. [15] illustrated damaged traditional wooden building photos
May 01, 2003 Bingöl [14,16]	6.4	5.45	10.5	15	3214	3448	6096	The hatıl construction fared the worst
January 27, 2003 Pülümür [14,17]	6.0	1.13	10	–	21			There is no detailed information about wooden buildings. Especially poorly constructed hatıl structures were heavily damaged or collapsed
February 03, 2002 Sultandağı [18]	6.3	0.94	10	10	4390	1730	9556	Most of the injuries and loss of life took place in the region are associated with the total collapse of the hımıs dwellings built with heavy roofs
June 6, 2000, Cankırı [14,19]	5.9	0.63	10	10				The hatıl barns fared the worst. Collapses were limited to abandoned structures with rotted timbers. Some damaged traditional structure photos illustrated by references [10,19,20]
November 12,1999 Duzce [21,22]	7.2	5.14	20	25	1364	493	825	Wooden buildings have been discussed the most after these earthquakes. Many Traditional timber framed buildings were performed better than the other buildings with different material [5,6,23]
August 17, 1999 Kocaeli [17,22]	7.4	3.22	20	40	41,266	43,618	48,008	
October 01, 1995 Dinar [14,22]	6.1	2.83	24	15	4909			It was reported that 30% of the private buildings either collapsed or suffered heavy damage. Only one photo illustrated for damage to an adobe building [24]
30 October, 1983 Erzurum [14,22]	6.8	1.73	16					Hughes [9] reported some weakness and recommend some suggestion for hatıl construction
28 March, 1970 Gediz [22]	7.2		18					Bağdadi constructions performed better than the hımış constructions, 12% of the bağdadi and 45% of the hımış constructions damaged heavily [25]
1967 Mudurnu [22]	7.1		18					Some timber framed buildings in which framing elements supported on single rock collapsed [26]
1944 Bolu-Gerede [22]	7.2		10					Taşman [11] recommended after this earthquake that wooden buildings should be preferred masonry building
1939 Erzincan [22]	7.9		20					500 wood houses were taken from Austria just after the earthquake and constructed within four months. These houses were well appreciated and used long time by the people lived in Erzincan [27]
1894 İstanbul								concluded that timber structures outperformed masonry buildings even if they were old and poorly built [1]

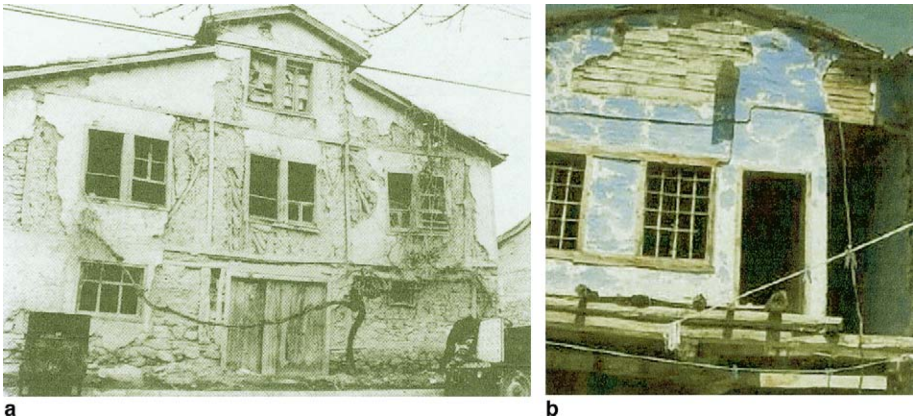

Fig. 10. Views of cracked and fallen plasters during earthquake excitations. (a) A view of hımış construction after the 2002 Sultandağı earthquake [29]. (b) A view of bağdadi construction after the 2003 Buldan earthquake [15].

stucco, it is difficult to see damage with the naked eye. It should be noted that many walls were missing some of their infill, but evidence of 'X' cracks, so common in the infill in the modern reinforced concrete buildings [28], was non-existent in the traditional timber framed buildings.

3.2. Failure of mortar

An important factor in the performance of the walls was the use of weak, rather than strong mortar. Fig. 11 shows failure of mortar in stone masonry infill during the 1999 Düzce earthquake. As a result of the different types of people constructing houses, it is not surprising to see that construction quality is variable. It is poor when; field rubble is used and bonded with mud mortar, without quoins and with no through stones etc. Especially during the moderate earthquakes (Doğubeyazit, Erzurum, Pülümür and Çankırı Earthquakes), as given in Table 1, since the energy release was relatively small, none of or only

Fig. 11. View of failure of lime mortar during 1999 Düzce earthquake [30].

a few of reinforced concrete structures, slightly were damaged during these earthquakes. However, mud-stone masonry and Hatıl constructions destroyed due to poor mud mortar and weak anchorage between mud and stone. The mud or weak lime mortar encouraged sliding along the bed joints instead of cracking through the masonry units when the masonry panels deformed. This served to dissipate energy and reduced the incompatibility between rigid masonry panels and the flexible timber frame.

3.3. Loosening or failing of connections

The connections of roof, floors, vertical framing elements and bracing elements make the building a single solid structure unit and are important features for holding a building together during earthquakes. Thus, the connections between the members must be strong enough to hold together without loosening or worse yet completely failing. It is extremely unlikely that a traditional timber framed building have not bracing element, could ever effectively resist lateral movements. As lateral earthquake effects are resisted by stiffness of connections, it would simply deform and collapse. Fig. 12 shows two connection failures during the 1999 Kocaeli earthquake and 2003 Buldan earthquake.

It should be noted that nailed connections have been commonly used for Turkish traditional timber framed building. These nailed connections allow the building to flex thereby absorbing and dissipating energy during earthquakes.

3.4. Large lateral displacements

During the earthquake, the presence of a soft story results with increased deformation demands significantly, and puts the burden of energy dissipation on the first-story framing elements. In structural system for some traditional timber framed buildings there are no strong and stiff elements such as bracing to attract the full lateral force of the earthquake. In these cases it is difficult to survive during a strong earthquake for such a traditional frame. Thus, while these structures do not have much lateral strength, they do have lateral capacity. These buildings respond to seismic forces by swaying with them, rather than by attempting to resist them with rigid frame that have bracing elements.

A large number of residential and commercial buildings built in Turkey had soft stories at the first-floor level on the two sides of main streets, because the first stories have been often used as stores and commercial areas [31]. These areas are generally enclosed with glass windows instead of brick infill walls so as to be used as showrooms. If first story of traditional timber building had more voids and fewer walls, it may behave as a soft story during an earthquake. The ground story of the buildings shown in Fig. 13 was heavily damaged,

a b

Fig. 12. Failure of connections in traditional timber buildings during earthquakes (a) Failure of connections during the 1999 Kocaeli earthquake [20]. (b) Failure of connections during the 2002 Buldan earthquake [15].

Fig. 13. Heavily damaged traditional wooden buildings due to soft story. (a) Large laterally displaced traditional building [26]. (b) Laterally displaced traditional building [20].

but damage on the upper stories was limited and even the glass windows were unbroken. As seen from Fig. 13(b) a traditional building displaced laterally due to soft story although it has bracing element. As its bracing elements were not satisfied to resist lateral loads, still they prevented totally collapse.

3.5. Dislodgement of the masonry infill

In many ways, the masonry infill dominated the performance of the frame, stiffening and strengthening it. It was evident that the infill masonry walls responded to the stress of the earthquake by ''working'' along the joints between the infilling and the timber frame; that is, the straining and sliding of the masonry and timbers dissipated a significant amount of the energy of the earthquake. In addition, by dissipating energy, the ''working'' also affects the natural vibration frequency of the structure.

Resonance with earthquake vibrations is a principal factor in the cause of earthquake damage to buildings in general. The controlled sliding and cracking of the infill masonry reduces the infill-frame structure's ability to resonate with the earthquake by providing damping, just as a shock absorber does for a car [23]. The typical hımış construction does not have mechanical ties between the timber and masonry to hold the infill masonry in place. As a result, in some cases, small sections of the infill were shaken out from between the studs near the top of the upper-story walls. Because of the existence of the timber studs, which subdivided the infill walls into small panels, the loss of portions or all of several panels did not lead progressively to the destruction of the rest of the wall. In addition, the subdivision of each structural bay with a tight network of vertical, horizontal, and diagonal timbers, rather than vertical studs alone, appeared to have been successful in reducing the possibility of the masonry falling out of the frames. Fig. 14 shows masonry infill damages for traditional hımış constructions. It should be noted that there is no a problem such as dislodgement of the infill for traditional dizeme and bağdadi constructions.

3.6. Failure of connection to foundation

In either case, the building must be adequately secured to the foundation. Proper connection of the bottom of the frame elements is essential for good earthquake performance. Generally Turkish traditional buildings have foundation consists of rubble masonry with lime mortar. And these buildings were generally built without any anchor bolts to connect the framing elements to the foundation. Experiences have shown

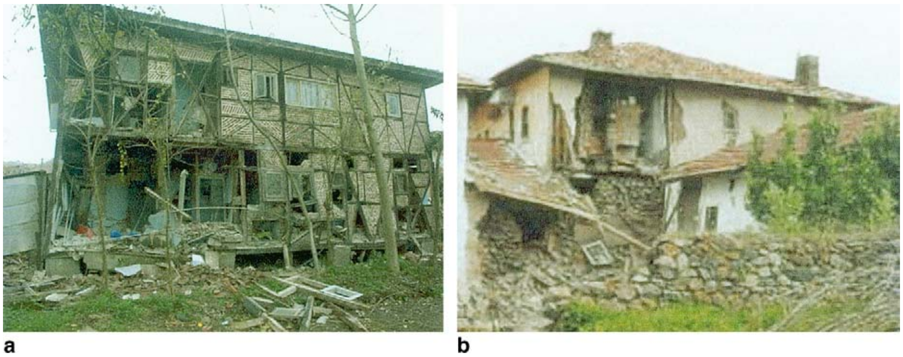

Fig. 14. Masonry falling out of the frames for traditional hımış constructions. (a) Damaged during 1999 Kocaeli earthquake [7]. (b) Damaged during 2000 Çankırı earthquake [19].

that these buildings may slide off their foundation during earthquakes. Fig. 15 shows two hımış constructions whose vertical framing elements were slide off their foundation during the 2003 Buldan earthquake. If reinforced concrete foundation and anchor bold are used, it is prevented structures from moving off its foundation.

Fig. 16 shows failure of stone masonry foundation wall during the 1999 Düzce earthquake. But it should not be accused too much since fault rupture crossed just under the building as shown in the figure. Yet, it succeeded to survive during the earthquake with only repairable foundation failure.

Fig. 15. Slide off frame elements from supporting systems during the 2003 Buldan earthquake [15].

Fig. 16. Failure of masonry foundation of a hımış construction just over the fault rupture during the 1999 Kocaeli earthquake.

Fig. 17. A collapsed chimney of traditional building during the 2003 Buldan earthquake [15].

3.7. Failure of chimneys

Failure of the chimneys can generally cause damage to the roof and walls of the building below. But especially in some kinds of Turkish traditional buildings the failure of chimney may cause fire. Fig. 17 shows failure of a chimney during the 2003 Buldan earthquake. Unreinforced masonry chimneys are particularly susceptible to earthquake damage. Also damaged chimneys may be dangerous in aftershocks following the initial earthquake. Bracing chimneys or using chimneys from lighter materials can help prevent damage [32].

3.8. Collapse of other buildings over it

Some traditional buildings were damaged due to collapse of neighbor modern reinforced concrete buildings (see Fig. 1). In at least three cases reinforced concrete structures hit or pounded against the timber frame buildings collapsing them during the 1999 Kocaeli earthquake.

4. Conclusion and recommendation

Types and structural properties of Turkey traditional timber framed buildings are mainly presented under the titles of hımış, dizeme and bağdadi construction. Other traditional log houses and hımış construction in which wood is used for structural element are also introduced briefly. Seismic performance of dizeme construction is superior the other traditional construction system due to its infill in which small timber infill element nailed with ends to the main timber elements.

Damages for traditional timber framed buildings occurred in the past earthquakes in Turkey were such as cracking and falling of plaster, failure of mortar, loosening or failing of connections, large lateral displacements, dislodgement of the masonry infill, loosening or failing of connections and failure of connection to foundation.

Aside from above specific types of damages, the results of damage assessment studies in several earthquake areas show that the Turkish traditional timber framed buildings presented good earthquake resistance even though they were made from weak local materials. They were mostly slightly damaged and structural system stayed stable due to the high strength-to-weight ratio of timber as a building material, the system redundancy, and the ductility of connections.

It can be interrogated to give up timber framed construction for about 40 years before due to its fire resistance and deficiency for high apartment buildings since Turkey lost 50,000 people in the earthquakes during this period. But, timber framed buildings cause less loss of human life during earthquakes deaths due to lightness and spatial character of the response of elements. Thus the timber buildings should be considered even as an alternative to reinforced concrete instead of forsaking totally and investigated to technically improve the seismic performance of these buildings. The problem of anchorage to foundation can be solved using reinforced concrete foundation and mechanical anchor elements, the problem of out of plane falling of masonry elements may be prevented with covering some materials like mesh wire.

To prevent historical monuments and dwellings constructed with wood during earthquakes, use of new mechanical elements for anchor and connection for traditional timber framed building should be investigated. Comparatively studies may be carried out seismic performance of the traditional buildings in which new mechanical elements and infill materials may be included and modern wooden buildings in which shear walls and diaphragms are used.

References

[1] Tobriner S. Wooden architecture and earthquakes in Turkey: a reconnaissance report and commentary on the performance of wooden structures in the Turkish earthquakes of 17 August and 12 November 1999. In: International conference on the seismic performance of traditional buildings, Istanbul, Turkey, November 16–18; 2000.
[2] Rainer JH, Karacabeyli E. Wood-frame construction in past earthquakes. In: 12th World Conference on Earthquake Engineering, Auckland; 2000.
[3] Lam F, Filiatrault A, Kawai N, Nakajima S, Yamaguchi N. Performance of timber building under seismic load, Part 2: Modeling. John Wiley & Sons, Ltd. Prog Struct Engng Mater 2004;6:79–83.
[4] Cooben KE. In: Bozorginia Y, Bertoro VV, editors. Recent developments in the seismic design and construction of woodframe buildings, Earthquake engineering from engineering seismology to performance-based engineering. CRC Press; 2004.
[5] Komut EM. Earthquake resistance: lessons from traditional buildings. J Architect 2001;299:33–40 [in Turkish].
[6] Gülhan D, Güney İÖ. 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. In: Proceedings for earthquake-safe: lessons to be learned from traditional construction Istanbul, Turkey; 2000. p. 1–18.
[7] Bilham R. Duzce earthquake Turkey 12 November 1999, University of Colorado. <http://cires.colorado.edu/~bilham/Duzce.html> [accessed 23.12.2004].
[8] Küçükerman Ö, Güner, Ş. Turkish houses in Anatolian heritage. Book for ministry of turkish culture; 1995 [in Turkish].
[9] Hughes R. Hatıl construction in Turkey. In: International conference on the seismic performance of traditional buildings, İstanbul, Turkey; 2000. p. 1–9.
[10] Gülkan P, Langenbach R. The earthquake resistance of traditional timber and masonry dwellings in Turkey. In: 13th World conference on earthquake engineering, Paper No. 2297, Vancouver, BC, Canada, August 1–6; 2004.
[11] Taşman CE. Gerede-Bolu earthquake. J Gen Directorate Miner Res Explor 1944;31:134–7 [in Turkish].
[12] Aydan Ö. The seismic characteristics and the occurrence pattern of Turkish earthquakes, Turkish Earthquake Foundation, TDV/TR 97-007; 1997.
[13] Kalafat D, Güneş Y, Kekovali K. 2 July 2004 Doğubayazit (Karakose-Ağri) Earthquake, B.U. Kandilli Observatory & ERI, National Earthquake Monitoring Centre, 34684, Cengelkoyİstanbul/Turkey; 2004.
[14] DAD. Earthquake research department general directorate of disaster affairs. Available from: <http://www.deprem.gov.tr>; 2004 [in Turkish].
[15] Kaplan H, Inel M, Senel M, Toprak S, Kayhan, A, Özsoy I., Yazar E, Yılmaz, S. A preliminary engineering report on the Buldan/Denizli Earthquake of 23–26 July, 2003, Pamukkale University, Denizli Turkey; 2003 [in Turkish].
[16] Emre Ö, Herece E, Doğan A, Parlak O, Özaksoy V, Çıplak R, Özalp S.A preliminary report on the Bingöl Earthquake of May 1, 2003, General Directorate of Mineral Research and Exploration. Report No: 10585; 2003 [in Turkish].
[17] KOERI. Kandilli Observatory and Earthquake Research Institute. Available from: <http://www.koeri.boun.edu.tr//default-eng.htm> [accessed 23.12.2004].
[18] Erdik M, Uckan E, Sesetyan K, Demircioglu MB, Celep U, Biro Y. Sultandaği (Turkey) earthquake. İstanbul: Kandilli Observatory and Earthquake Research Institute, BU; 2002.
[19] Demirtas R, Iravul Y, Erkmen C, Baran B, Yaman M, Kılıç T. Preliminary report of the Orta, Çankiri earthquake of June 06, 2000, Earthquake Research Department General Directorate of Disaster Affairs, Ankara; 2000 [in Turkish].

[20] Kasapoğlu KE, Ulusay R, Gökçeoğlu C, Sönmez H, Binal A, Tuncay E. Report on 17 August, 1999 Kocaeli earthquake, Hacettepe University, Ankara Turkey; 1999 [in Turkish].
[21] Sucuoğlu H, Gür T. Düzce: the city subjected to two big earthquakes in three months Engineering report for The Marmara and Düzce earthquakes, METU Ankara; 2000 [in Turkish].
[22] Celep S, Kumbasar N. Introduction to earthquake engineering and earthquake resistant design of structures. Beta publisher; 2004 [in Turkish].
[23] Langenbach R. Crosswalls instead of shearwalls; a proposed research project for the retrofit of vulnerable reinforced concrete buildings in earthquake areas based on traditional *hımış* construction. In: Fifth national conference on earthquake engineering, 26–30 May 2003, Istanbul, Turkey Paper No: AE-123; 2003.
[24] Carydis PG, Lekkas EL, Ersoy U, Uzumeri SM, Ozcebe G, Polat U, Tankut T, Erdik M. The Dinar Turkey earthquake of October 1, 1995, EERI special earthquake report, California; 1995.
[25] Gülkan P, Ergünay O. Usage of domain in attenuation of earthquake vulnerability, city settlements and natural disasters, Chamber of Turkish Architecture; 2000. p. 51–74 [in Turkish].
[26] Bayülke N. Wooden structures and earthquakes, Earthquake Research Department General Directorate of Disaster Affairs. Available from: <http://www.deprem.gov.tr> [accessed 23.12.2004; in Turkish].
[27] Bayülke N, Doğan A. Structural damages for 13 March, 1992 Erzincan Earthquake, Earthquake Research Department, General Directorate of Disaster Affairs, Ankara; 1993 [in Turkish].
[28] Durmuş A, Doğangün A, Hüsem M, Pul, S. A preliminary report on the Kocaeli (Izmit) earthquake of August 17 1999. Turkish Chamber of Civil Engineers-Bureau of Trabzon; 1999 [in Turkish].
[29] Ulusay R, Aydan Ö, Erken A, Kumsar H, Tuncay E, Kaya Z. Site investigation and engineering evaluation of the Çay-Eyber earthquake of February 3, 2002. Turkey, Turkish Earthquake Foundation, İstanbul; 2002 [in Turkish].
[30] Parsa AR. A study on situation of traditional buildings after the earthquake (1999 Kocaeli earthquake). J Architect 2001;299:41–2 [in Turkish].
[31] Doğangün A. Performance of reinforced concrete buildings during the May 1, 2003 Bingöl Earthquake in Turkey. Eng Struct 2004;26(6):841–56.
[32] CWC. Wood-frame construction: meeting the challenges of earthquakes, Building Performance Series No. 5; 2004.