Survivors among the Ruins: Traditional Houses in Earthquakes in Turkey and India

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Many traditional timber and masonry houses defied today's conventional wisdom about the safety of masonry by surviving the great Turkey earthquakes of 1999 and India's Bhuj earthquake of 2001 that felled many modern buildings.

Throughout history, many masonry buildings have collapsed in earthquakes. This paper looks at some remarkable survivors. The images of death and destruction from Turkey's Marmara and Düzce earthquakes shocked the world in August and November 1999. In those terrible scenes, relatively new concrete apartment buildings were devastated, with heaps of formless debris lying in even rows, much like Lego blocks knocked over by children.

Not often seen on television, however, were the many old and seemingly rickety timber and masonry vernacular buildings that remained standing, often unscathed, next to the collapsed modern buildings (Fig. 1). These old houses defied today's conventional wisdom about the safety of masonry. Many of these survivors resemble Tudor cottages, with lightweight timbers laced into the masonry. They are clearly different from the masonry construction in India that proved to be unsafe when the Bhuj earthquake struck that country in 2001. It would seem that the record created by the surviving buildings in Turkey should be worthy of study, but most of the visiting engineering researchers who combed the earthquake-stricken areas paid little attention to them.

Fig. 1. A timber and masonry house in Adapazari, Turkey, remains standing, having lost only its stucco, next to a collapsed reinforced-concrete apartment house. All photographs © the author.

This is not the first display of comparative earthquake resistance in certain types of traditional structures. Examples can be found among the seemingly unpretentious, weak, insubstantial, but common buildings that have been maintained and continued to be built in the same style for generations in many earthquake-affected countries. The circumstances that have led to the survival of these traditional timber-laced masonry buildings are likely the successful byproduct of technologies developed as much for their economy as for their strength. The masonry may consist of mud blocks, rubble stone, fired-clay brick, or a combination of materials set in either mud or lime-and-mud mortar. The timber may form a frame or may be laid only horizontally. Variations on this type of construction can be found across the broad, seismically active belt that extends around the globe from Africa and Europe across Asia to Central America. This paper examines a particular type of masonry construction that takes different forms in many regions around the globe — masonry constructed with timber lacing in the walls.

Timber-laced masonry can be divided into two subcategories: timber frame with infill masonry (infill-frame) and bearing-wall masonry with horizontal timber lacing (laced bearing wall). Variations on these two types can be found sometimes in the same building, as has been observed in Turkey and Greece and in both Kashmir and Ahmedabad in India.[1] The recent earthquakes in Turkey and India provide an opportunity to compare the performance of the two types of timber-laced masonry construction with that of masonry buildings without timber lacing, as well as with the performance of nearby modern buildings constructed of reinforced concrete.

The Ottoman Method of Construction in Turkey

Traditional Turkish construction falls mostly into the infill-frame category, which is known as half-timbered in the English-speaking world. It can be found in Europe and the Middle East in both earthquake-prone and non-earthquake-prone areas.[2] Unlike in England and other parts of Europe, however, this form of construction has continued to be used in Turkey for new buildings almost until the present day, and its comparatively good performance in the earthquakes that have frequently struck the Anatolian peninsula may have contributed to this continuity of use.[3]

Timber-with-brick-infill vernacular construction is documented to have first appeared in Turkey as early as the eighth century.[4] One hypothesis is that the building tradition traveled from Europe into Asia as a result of the reach and influence of the Ottoman Empire, which at one time extended almost from Vienna to the Caspian Sea. Observing where this method did *not* become a predominant building type — in regions not within the reach of the empire — supports this notion. For example, this type of construction is not found in Kathmandu, Nepal, which may have resulted from the fact that this Himalayan mountain–protected kingdom has never lost its independence, thereby isolating it from the cultural influence of the Ottoman Empire. It also is rare in Kutch, the area of western Gujarat in India recently devastated by the 2001 Bhuj earthquake, though it is common in the nearby Gujarati city of Ahmedabad. Western Gujarat remained a largely Hindu region of princely kingdoms, while Ahmedabad was a Mogul city. While construction practices in Ahmedabad were under the direct influence of the Moguls with their cultural connections to the Ottoman Empire, the Moguls had less influence on Kutch than on other parts of the Indian subcontinent.

The Ottoman-style house prevalent in Turkey, with its tiled roof and overhanging timber-and-brick bays above a heavy stone first-floor bearing wall, has become an icon known worldwide. Where they survive, the overhanging upper stories, or jetties, of these houses contribute to the visual vitality and delight of historic Turkish towns. The jetties strengthen the buildings because the joists that cantilever over the walls below hold those lower-story walls firmly in place with the weight of the infill-masonry overhanging upper story. This compressive force gives the heavy walls below added strength against lateral forces.

Fig. 2. *Hımış*-style wall with stone infill laid in mud mortar, in Safranbolu, Turkey.

The upper story is almost always constructed with a timber frame infilled with a single withe of fired brick or stone masonry, referred to in Turkish as "*hımış*" (Fig. 2). This construction utilizes a weak mortar of mud or lime to hold a single withe of masonry into a timber framework of studs rarely more than two feet (60cm) apart. The studs themselves are tied at midstory height by other timbers. Because the masonry is only one withe in thickness, the walls are light enough to be supported on the cantilevered timbers.

The multi-withe masonry bearing walls of the first story are often laced with horizontal timbers, (in Turkish: "*hatıl* (s) *hatıllar* (pl)").[5] These are often very thin timber boards laid into the wall like a course of masonry, at vertical intervals of about 3 feet (1m). They are placed so that they overlap at the corners (Fig. 3). They thus serve to bind the stone layers together without interrupting the continuity of the masonry construction. This method of construction, with its heavy walls below the lighter walls resting on the cantilevered floor joists, together form the technical underpinning of the Ottoman vernacular architecture with its characteristic jetties overhanging the narrow streets (Fig. 4).

The Marmara and Düzce Earthquakes

The Marmara earthquake (also called the Kocaeli earthquake) of August 17, 1999, killed approximately thirty thousand people.[6] The epicenter was just 200 kilometers east of Istanbul. In some areas of two cities, Gölcük and Adapazari, the earthquake destroyed more than a third of all housing units.[7]

There were clusters of *hımış* buildings in the heart of these districts. These houses, mostly dating from the early part of the twentieth century, pre-dated the ruined reinforced-concrete apartment blocks nearby (Figs. 5 and 6).

In Gölcük, within 100 meters of the *hımış* houses, a surface trace of the fault was visible. The land had dropped 2.5 meters, dragging some buildings and their sleeping occupants into the sea. Some of the *hımış* houses near there were damaged, but they survived (Fig. 7).

This scene was repeated in Adapazari. There, if they did not collapse, many modern buildings sank into the soft ground because of soil liquifaction, resettling at extreme angles. Many of the older houses remained intact, but a few were heavily damaged. One had col-

Fig. 3. Detail of lower-story walls showing *hatıllar* imbedded in wall, and lapping at the corners, in Safranbolu, Turkey.

Fig. 4. Street with overhanging jetties, in Safranbolu, Turkey. The cantilever of the upper story over the lower story helps to hold the masonry walls together. The timber lacing is hidden by the plastered surface.

lapsed, killing an occupant, a rare occurrence of a death caused by the collapse of a *hımış* house.

There was little to be learned from the ruins of this collapsed house, except that in the pile were some decayed timbers. However, the partially damaged traditional buildings here and in Gölcük provided evidence of how this type of construction responded to earthquake forces. Once each building was inspected and the damaged area in each building identified, a pattern began to emerge. Of those inspected where structural damage was found, most of the damage was concentrated at areas around rotted timbers. Interviews with residents often revealed that the buildings with the most timber decay had been unoccupied for years. It appeared that decayed timber significantly degraded the buildings' performance in earthquakes.

In occupied houses, the most severe damage resulted mainly from alterations and modernization work that had corrupted the integrity of the original frames and walls. In one case, timber braces had been cut to install large picture windows in the ground floor. The weakened walls containing the windows collapsed completely, but the remaining ground-floor walls only cracked. In another house a bathroom with walls of poured concrete had been installed on the second floor. Being rigid and heavy, this room crashed through the side of the house and fell to the ground almost as a single unit. The rest of the house remained intact and almost without visible cracks on the exterior. Alterations like this bathroom that were heavy and stiff were incompatible with the traditional construction, which tended to be flexible. This flexibility has proved to be one of the buildings' most important characteristics.

Inspecting the interiors of some of these houses provided a more complete understanding of the behavior of *hımış* as a structural system. 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. The only visible manifestation of this internal movement was cracks in the

Fig. 5. This house was constructed in 1955 by the father of the two brothers who currently live there with their families. It survived with only cracks in the interior plaster just a few blocks away from rows of new reinforced-concrete apartment houses that collapsed.

Fig. 6. Gölcük. Partially collapsed reinforced-concrete apartment house.

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 house (Fig. 8).

On the exterior, unless the house was covered with stucco, damage was impossible to see. The bricks themselves were only infrequently displaced sufficiently for a crack to be visible. The movement was primarily along the interface between the timbers and the brick panels. This movement left little trace other than the dust on the ground because it was already a joint. Where there was stucco, the effect was similar to the damage seen in the plaster on the interior walls.

The *hımış* construction method does not usually include 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. In addition, because the timber studs subdivided the infill walls into small panels, the loss of portions or all of several panels did not appear to lead progressively to the destruction of the rest of the wall. Many walls were missing some of their infill, but evidence of X shear cracks, so common in the infill in the modern reinforced-concrete buildings, was practically nonexistent in the *hımış* structures.

In those few cases where the timber frame was compromised, the damage was usually manifested as a separation of the timber frame from the sill plate. Timber decay was evident in all cases. In one instance, the collapse of a rotted section of the timber frame led to the sloughing off of an exterior wall. Even in this case, though, the rest of the structure remained standing.

It was particularly noteworthy to find the absence of the characteristic X shear cracks within the masonry walls, in contrast to the infill masonry found in the modern reinforced-concrete buildings. This can be explained by the use of the mud or weak lime mortar in the traditional buildings, which, when the wall deformed, tended to encourage sliding along the masonry bedding planes instead of cracking through the masonry units. The closely spaced studs reduced the likelihood of the propagation of X cracks within any single panel. 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. Had the subdivision been only vertical studs, the tendency for the masonry to dislodge may have increased because of the lack of support at the midheight level.

Fig. 7. *Hımış* house that survived the earthquake with no visible damage to its exterior in the heart of the damage district in Gölcük, Turkey.

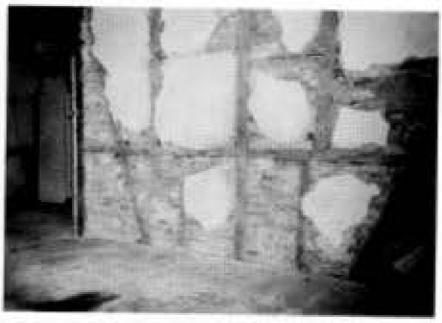

Fig. 8. Damaged interior wall exposing an undamaged brick infill wall behind, in Düzce, Turkey. The plaster cracking and falling at the edges of the panels, where the wood intersects with the brick, is characteristic of the damage to the *hımış* style of construction. This is a more extreme example of plaster shedding.

Strength versus Capacity

The pattern of damage identified in the survey helped explain why these buildings were capable of surviving a major earthquake that had felled modern reinforced-concrete buildings. The basic principle in this weak, flexible frame-with-masonry infill construction is that there are no strong and stiff elements to attract the full lateral force of the earthquake.

While these structures do not have much lateral *strength*, what they do possess is lateral *capacity*. These buildings respond to seismic forces by swaying with them, rather than by attempting to resist them with rigid materials and connections. More significantly, this is not an elastic response, but a plastic one. The swaying and deformation of these structures is different from that of a tree, the suppleness of which allows it to bend elastically. When these structures lean in an earthquake, they do so with incremental low-level cracking that is distributed throughout the wall by the interaction of the timber structural elements with the confined masonry infill.

This controlled damage is what is meant by the "working" of the structure, and it is how a building made with

Fig. 9. This photo of a farming family's living room was taken after the earthquake. The house is in a village near Orta.

Fig. 10. This view of the living room was taken six months after the earthquake, after the family had repaired their house and moved back in.

a disparate assembly of brittle materials is able to survive seismic forces that are far larger than could be resisted in a fully elastic state. In other words, although the masonry and mortar is brittle, the system — rather than the materials that make up that system — behaves as if it were ductile.[8]

As will be explained further, this working during an earthquake can continue for a long period before the degradation advances to a destructive level. The buildings survive the earthquake by not fully engaging with it.

In addition to dissipating energy, the working also affects the natural frequency of the vibration of the structure, or period. Resonance with the earthquake vibrations is a principal cause of earthquake damage to buildings in general. The controlled sliding and cracking of the infill masonry serves to reduce the structure's ability to resonate with the earthquake by providing damping, just as a shock absorber does for a car. This serves to help protect a structure from the more extreme damage that can occur if the structure remained elastic until vibrations from the resonance with the ground became more than the structural system could handle without major failure or sudden collapse. Simply stated, that is the difference between *strength* and *capacity*.

Energy dissipation and damping are well-understood engineering principles that have been embraced with increasing frequency in contemporary seismically resistive design, but they have only rarely been accepted as relevant to the analysis of historic unreinforced-masonry construction. Often, cracked brittle elements — whether they are of concrete or masonry — are described by post-earthquake inspectors as having "failed." As long as the design capacity or intended performance of the element, such as a column, is significantly compromised by the cracks, "failed" may be an appropriate description of the damage. However, in the case of historic masonry construction — particularly of the infill-frame type — to describe earthquake-caused cracks as representing failure is incorrect. The movement and cracking of the masonry or of the wood/masonry combination is the means by which the system has frequently demonstrated its capacity to resist catastrophic damage in large seismic events.

In terms of today's building codes and engineering practice, the problem with allowing for the working of a structural system composed of brittle, unreinforced masonry is that the ultimate capacity of such walls cannot easily be modeled mathematically. The overall capacity of a wall to resist destruction by earthquakes is simply not related to its initial elastic lateral strength. In addition, the postelastic behavior of such composite walls cannot be easily quantified, as it can be for a uniform single material, such as steel. This is inherently messy from the point of view of engineering practice. The behavior of these buildings relies on a disorganized combination of materials being stressed in tension, compression, shear, and bending all at once. If the earthquake forces were to become focused on one element in this interlocking puzzle, that element would be shattered. However, because of the combination of weak mortar and stronger masonry units, stress in the wall is relieved over a wide area well before any of the masonry units themselves become overstressed, and the damping from all of the controlled microcracking serves to counteract the motion of the earthquake.

The Orta Earthquake

The full meaning of this difference between perceived failure and capacity for earthquake resistance was demonstrated most effectively by a comparison between the damage in the large Marmara earthquake of June 6, 2002, and that which occurred in the smaller earthquake centered on the village of Orta, north of Ankara, six months later.

The earthquake that struck Orta measured only 5.9 on the Richter scale and thus was small enough to escape international attention.[9] An unparalleled opportunity presented itself for surveying the damage within 24 hours of the earthquake's occurrence, before any of the site had been altered. The level of damage to buildings of traditional construction, including infill-frame construction, appeared to be higher than expected — initially shaking my confidence in the resistance of those types of buildings. The few modern reinforced-concrete buildings in the area showed comparatively little damage.

On closer examination, however, an interesting point of comparison emerged between the effects of this earthquake and that of the much larger Marmara earthquake. Part of the reason why the damage in Orta seemed so extensive was that the typical construction for the barns and outbuildings was of a form of rubble-stone masonry that offered little resistance to earthquake damage. By contrast, the traditional houses in Orta were almost all of infill-frame construction. These generally fared better. On further investigation, timber-laced buildings that did collapse turned out to have been abandoned years earlier, and their timbers had decayed extensively.

However, something striking was observed in the occupied and maintained houses. While none had collapsed, many suffered widespread cracking and shedding of plaster and stucco. In some, the masonry infill was disrupted, although it remained in place. This level of damage was hard to explain when compared to the infill-frame houses subjected to the full brunt of the Marmara earthquake. Those houses on average showed the same level of damage as the Orta houses. This equivalency stands against the background, where the multistory reinforced-concrete buildings in Orta were only lightly damaged, whereas a vast majority of those in the areas of intense shaking from the Marmara earthquake suffered heavy damage or collapse.

What, if anything, can explain this discrepancy between the performance of the infill-frame buildings and that of reinforced concrete in the two earthquakes? The construction quality, which was often poor, was not likely to have been significantly different in the two places.

By linking the Marmara event with the Orta event, a further observation can be made — one that is not often realized when the larger of these two events is looked at on its own. The modern reinforced-concrete buildings go from performing well in the moderate seismic event in Orta to being lethally dangerous in the larger event, as seen in Gölcük, Adapazari, and Düzce. In other words, what in the modern reinforced-concrete buildings in Orta seem to be minor cracks may in fact be the onset of damage that in a larger event may have led rapidly to the collapse of the buildings. This observation is underscored by the fact that many of those buildings in Düzce that were damaged in the Marmara earthquake in August 1999 collapsed in the next earthquake, which was centered on Düzce three months later, on November 12. This observation is significant in that it indicates that only at one's peril could one draw conclusions about a building's performance from observations of a single earthquake in isolation.

By comparison with the ordinary and often poorly constructed modern Turkish reinforced-concrete housing blocks,[10] the traditional infill-frame structures appear to demonstrate a greater ability to sustain an increasing magnitude and duration of shaking without progressing much beyond the level of damage sustained in the more moderate Orta earthquake. This is significant in that there was no loss of human life in a traditional building in the Orta earthquake, although some farm animals were killed when rubble-stone barns collapsed. Of the 25,000 or more who died in the Marmara earthquake, very few of those were trapped in infill-frame structures.[11] Thus, the fact that the traditional buildings suffered a level of damage that was similar in both the larger and the smaller earthquakes illustrates the ability of these buildings to survive massive earthquake shaking even though the onset of damage at lower levels of shaking is immediate. This supports the theory that it is the combination of the timber with the masonry that controls the damage in the system. By comparison, the modern buildings show a progression from minor damage in the smaller earthquake to destruction in the larger. The most important protective characteristic of the traditional construction may be its ability to dissipate the earthquake's energy over a long period, without undergoing rapid structural degradation.

Fig. 11. The ruins of Anjar town center in western Gujarat, India, a month after the earthquake.

In effect, such buildings are able to take significant abuse, whereas their modern reinforced-concrete neighbors, with, in general, their poor detailing and construction and their absence of shear walls, show evidence of undergoing rapid degradation of their structural systems over a short period, if the shaking is strong enough.[12] In fact, if one turns to the various reconnaissance reports that visiting engineers prepared after visiting the Marmara district in 1999, almost all describe the many instances where collapsed buildings stood next to architecturally identical ones that by all appearances looked minimally damaged. Those concrete buildings that did survive were probably at risk of the same fate, but they endured most likely because of some different conditions — whether better batches of concrete, cooler weather during curing, more partitions on the ground floor, different orientation to their critical columns, or simply that they hadn't yet collapsed when the shaking stopped. In any case, what these observations from the two earthquakes indicate is that the difference between survival and collapse fell within a very small range.[13] This, again, is a demonstration of the difference between *strength* and *capacity*.

The Human Side of the Story

The story does not stop there — one must go on to look at the human reaction to all of these events to more fully understand the implications of this observation. One of the tragedies stemming from the manner in which the infill-frame buildings manifested the onset of damage at low levels of shaking — fallen plaster and stucco and cracks in the infill walls — is that many people in Orta came to believe that they would be better off in new, reinforced-concrete houses. The government inspectors who circulated through the area after the earthquake reinforced this point of view by treating the *hımış* houses with extensive plaster cracks as dangerous. A second visit to the area six months after the earthquake revealed that this fear and bias had resulted in the demolition of many of the architecturally significant traditional buildings in Orta, destroying what had been a well-preserved historic district. The population of the older section of Orta consisted mainly of retired farmers, and they were largely unaware of the comparatively good performance of the traditional buildings in the much larger earthquakes that had struck farther to the west nine months earlier. They were aware of the reinforced-concrete building collapses and of the death toll, but the connection between these facts and their own situation seemed abstract and irrelevant, in sharp contrast to those who lived through the larger tremor, where one "wizened 92-year-old" observed: "We should build houses the old way—from chestnut wood. They don't collapse."[14]

The local people in a nearby village, who were mainly younger farmers still actively farming, responded differently. They did not wait for the government handouts but instead repaired their houses and went on with their lives. It was thus the younger, rather than the older, people who showed more confidence in and understanding of the stability and restorability of the timber-laced system of construction. Farm families living in tents the day following the earthquake in June had by November migrated back into their repaired houses (Figs. 9 and 10). They had done the work themselves in the traditional manner, with mud and plaster instead of concrete.

This example shows one of the most problematic dilemmas of modern times. The informal handing down of an understanding of the traditional way of building has largely been broken, and when the well-meaning professionals from government and nongovernmental organizations come to help the recovery after earthquakes, they often encourage the abandonment of this knowledge and culture by promoting new technologies. When traditional forms of construction are utilized as they were in the still-active farming village, the techniques are more often rediscovered, rather than handed down.

The Bhuj Earthquake

A year and a half after the earthquakes in the Marmara region of Turkey, an equally devastating earthquake struck a largely rural area of the western Indian state of Gujarat, on January 26, 2001. The devastation was appalling. Unlike the damaged districts in most recent earthquakes, this earthquake left many villages and the small city of Bachau completely leveled.[15] As far as the eye could see, both modern and premodern buildings were either partially or totally collapsed into piles of rubble (Fig. 11).

In Bhuj, Anjar, and Bachau, the three cities surveyed, the building stock was made up of an almost equal variety of older stone masonry and reinforced-concrete structures. The predominant masonry construction was rubble stone laid in mud or weak lime-mud mortar. The reinforced concrete construction consisted of moment frames with brick masonry infill. Often, reinforced-concrete additions were constructed on top of earlier stone masonry. In the areas of greatest damage, most of the rubble-stone buildings were shaken to the ground. Some were left with their walls separated apart into discrete, unstable elements. The rest had become undefinable piles of stone rubble. More substantial buildings with horizontally bedded ashlar walls performed better, but sections of their walls often were blown out. Many of the concrete structures appeared to have collapsed just as readily, particularly if they had been placed on top of earlier rubble-stone buildings.

Fig. 12. This house has survived at least the most recent two major earthquakes that otherwise devastated Anjar's old town center. The balconies on two walls helped to keep this house standing while most buildings around it fell.

It became clear that the timber-laced style of construction, either the bearing-wall type with horizontal timbers, or the infill-frame type, was extremely rare in Kutch. The one observed example found in this survey was part of the Swaminarayan Temple in Bhuj, dating from the late eighteenth or early nineteenth century.[16] This structure survived the earthquake almost completely unscathed, while a modern reinforced-concrete section of the complex partially collapsed.

In Ahmedabad, the situation was very different. The city was shaken badly enough that a number of major reinforced-concrete apartment complexes, each with an open parking area on the ground floor referred to as a "soft story," collapsed, but the historic walled-city section survived nearly intact. Of the tens of thousands of buildings in this area, only one is reported to have collapsed. The shaking in Ahmedabad was significantly less severe than that in Bhuj, but, nonetheless, the performance of the historic Ahmedabad infill-frame buildings was notably better than the rubble-stone buildings in Kutch.

Among the surviving buildings in Kutch, however, one thing did stand out. Of the masonry buildings that survived, many had timber floor joists that extended through the walls to support balconies. On partially collapsed buildings, there were often balconies on the parts of the building that did not collapse. This observation suggests that the effect of having the joists continue through a wall to support a balcony was significant. Balconies resting on joists that extend through the masonry walls increase the resistance of the structure, restraining the walls from falling outward. Without a balcony, the joists most often terminate in shallow pockets in the masonry wall without any anchors. This is an important point because balconies may be considered primarily an architectural element rather than an integral part of the structure, and yet, as was also seen with the projecting bays in Turkish Ottoman architecture, this one element can help protect against collapse (Fig. 12).

This observation shows that even in a profoundly devastating earthquake the differences in design that can provide enough protection to prevent collapse may be neither rare nor particularly sophisticated. The basic protection provided simply by strapping a building together might be all that is needed to reduce losses substantially, which is

Fig. 13. The infill wall in this reinforced-concrete building in Turkey offered little resistance once it began to crack in the earthquake, unlike the timber-laced walls of the *himiş* construction.

exactly what the timber lacing does in the masonry construction in Turkey.

Lessons for the Present from the Past

One may wonder why is it important to study the seismic resistance of archaic forms of construction that are not in widespread use or acceptance today. Is there information that can be imported to current construction practice for new buildings? The answer is an emphatic "yes." By embracing time-honored methods that work well, the conservation of surviving traditional buildings is encouraged as well. This kind of recognition and modern adaptation is essential if the vernacular building tradition is to be preserved and remain imbedded in a living cultural context. Traditional construction of all types has to fight against the current perception that, because it does not consist of strong materials like concrete and steel, it is not safe enough to meet modern building codes and standards. Ironically, even the collapse of hundreds of modern buildings in recent earthquakes has not changed this general perception. So long as the blame for this is placed on poor construction, the almost universal reliance on reinforced concrete itself is not questioned.

The standard modern reinforced-concrete frame construction found in Turkey, India, and many other seismically active areas of the globe is also a form of infill-frame construction. However, the infill is not considered as part of the lateral resisting system. Rarely are the infill walls subdivided with studs as they are in traditional construction. Sometimes, to avoid damage to the surrounding reinforced-concrete frame from the "diagonal strut" effect, in which the stiff infill causes the corner column to break, which can cause the building to collapse, the infill material is often deliberately separated from the frame with a soft filler material. In Turkey the infill walls are most often constructed using a very thin-walled, brittle, hollow, clay tile that has barely more strength than a dinner plate. In India solid brick is more often used, but the brick is usually fired at a low temperature and thus is very weak.

While the infill in modern construction has often performed notably badly, the infill in traditional construction has performed well. What accounts for this apparent discrepancy? Two things need to be looked at more closely: (1) the use of weak mortar with strong masonry units in the traditional infill compared with what are often weak masonry units and cement-based strong mortar used in the modern infill walls and (2) the subdivision of the infill-masonry into smaller panels with horizontal and vertical studs within a single bay of the building's structural frame. Modern infill-wall, reinforced-concrete construction generally has strong mortar binding weak masonry units, and these masonry walls fill each structural bay without intervening studs. As can be seen in Figure 13, these infill walls can collapse completely when an earthquake distorts the building's frame.

The principal lesson embodied in comparing the performance of the timber-laced vernacular construction with that of the modern buildings that collapsed in the earthquakes is this: strength and rigidity are less effective than flexibility, ductile behavior, and cumulative nondestructive damping. The object is to make the infill walls act not as shear walls, which they cannot be, but as cross walls, which they are eminently capable of being. A shear wall is designed to be strong enough to carry to the foundation all of the imparted lateral loads of the building. A cross wall, which may be only a floor-to-floor partition, is designed only to take loads and distribute them to other horizontal or vertical elements in the overall structural system. They can also serve to dissipate large amounts of energy by cracking in a controlled manner. With the introduction of studs like those found in traditional construction, shear failure of the entire panel is avoided, and the infill can be restrained from falling out of the frame.

Conclusion

Humble respect for the work of generations past is a prerequisite to fully understanding the contribution that traditional construction can make to the future. Its proper protection and restoration depends on such an understanding. So much of the world's pursuit of so-called progress has been fueled by a belief that people alive today know more and do things better than those in the past. Seeing the unsung and unnoticed indigenous masonry and timber buildings standing among the ruins of the modern ones should give pause. They have withstood earthquakes that brought down many of the more sophisticated buildings around them.

The question of whether earthquakes have influenced traditional construction is one for further research. People surely must have responded to known earthquake risks in the past. Earthquakes must have been a factor in the evolution of building design and construction in affected regions, but, at the same time, they may not have been a defining one. The economy and availability of building materials and craftsmanship is likely to have had a stronger influence than the infrequent risk from earthquakes. The timber-frame, brick-infill form of timber-laced masonry allowed for the economical use of both timber and stone or brick. Even in the case of timber-laced bearing walls, the use of timbers was a cost-effective way of giving a rubble-stone wall a great deal of added stability when the dressing of stones was impractical.

As we look for solutions to the problems that have been so profoundly thrust on so many by the tragic earthquakes of the last several years, it is important to be open to receiving what the wisdom of the ages may have infused into traditional structures. It is important to realize that the cultural value of indigenous architecture lies in its structural characteristics as well as in its visual image. It is an uphill battle. Too often what passes for conservation is the reconstruction of buildings in reinforced concrete with timber details simply attached to the surface as a way of recalling the vernacular construction. However, there is more to the traditional buildings than their architectural veneer. It is important to preserve more than the facades of vernacular buildings if we are to understand local cultures in more than just a superficial way. Only then can we begin to counteract the detached and ahistorical uniformity so often characterizing the modern urban scene that is now so often interchangeable the world over.

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Notes

1. For a more detailed description of the architecture and construction found in Srinagar, Kashmir, see Randolph Langenbach, "Bricks, Mortar and Earthquakes," *APT Bulletin* 31:3-4 (1989): 31–43.

2. This construction style can be found in almost every part of Europe, including England and Spain, and in Asia, Central America, and even the United States. In the United States it can be found in New Orleans, which is a city of French origins, in some other historic French settlements on the Mississippi, and in parts of Pennsylvania, where it has been derived from the German *fachwork*. In final assessment, it may be impossible to attribute the similarities of all of these traditional construction types to cultural communication. There is enough basic logic to the construction method itself, based on the limited materials at hand, to indicate that the ideas could have emerged independently in several areas, but this fact does not contradict the possibility that in the instance of the spread of cultural influence within the Ottoman Empire, this type of construction could have migrated beyond national boundaries under the influence of the empire's reach.

3. There are a number of fine studies of the Turkish traditional house published in English, including that by Prof. Doğan Kuban, with Prof. Zeynep Ahunbay, but little attention has been focused on the question of how earthquakes may have influenced the evolution of the construction style and thus the architectural form. Earthquakes have always been a part of Turkish history and have undoubtedly been a factor in the evolution of construction practice, but it is likely impossible to isolate such infrequent events as a dominant influence when similar forms of construction can be found as far away as England and Germany, in areas with no record of seismic activity. A recent paper by British scholars Jacqueline Homana and Warren J. Eastwood, "The 17 August 1999 Kocaeli (İzmit) Earthquake: Historical Records and Seismic Culture" (*Earthquake Spectra* 17: 4 [November 2001]: 617–634) does attribute the evolution and continued existence of the timber-laced construction in Turkey to what they characterize as a "seismic culture." Other sources include Evi, Turk, *Turkish House: In Search of Spatial Identity*, Istanbul: Turkiye Turing Ve Otomobil Kurum, 1978; Günay, Rena, *The Tradition of the Turkish House and Safranbolu Houses*, Istanbul: Endüstri Merkezi Yayınları, 1998; Kuban, Doğan. *The Turkish Hayat House*, Istanbul: Eren, 1993.

4. Demet Gülhan, İnci Özyörük Güney, "The Behaviour of Traditional Building Systems against Earthquake and Its Comparision to Reinforced Concrete Frame Systems; Experiences of Marmara Earthquake Damage Assesment Studies in Kocaeli and Sakarya," *Conference Proceedings for Earthquake-Safe: Lessons to Be Learned from Traditional Construction, an International Conference on the Seismic Performance of Traditional Buildings* (Istanbul: ICOMOS, published on the Web at www.icomos.org/iiwc/seismic/Gulhan.pdf, 2000).

5. Houses found in parts of Greece affected by earthquakes also have horizontal wood members. The brick-nogged type of construction is also found in Greece, where it is sometimes used for the upper part of the houses. This improves the seismic performance because unreinforced masonry walls tend to be weakest at the top, where there is no compressive force from the weight of a wall above.

6. Kandilli Observatory and Earthquake Research Institute. http://193.140.203.16/geophy/anasayfa/eanafr.html, accessed June 2002.

7. Ibid.

8. In a 1981 paper "Earthen Buildings in Seismic Areas of Turkey," Alkut Aytun credits the bond beams in Turkey with "incorporating ductility to the adobe walls, substantially increasing their earthquake resistant qualities." In *Proceedings of the International Workshop on Earthen Buildings* 2 (Albuquerque, 1981), 352.1.

9. As reported in the Turkish daily papers the day after the earthquake. The U.S. Geological Survey Web site reported 6.1.

10. The most common form of reinforced-concrete structural system found in Turkey and in India, as well as many countries of the world, is the moment-frame, masonry-infill wall system. In contrast to the shear-wall system, where the lateral forces are concentrated into reinforced concrete shear walls, the moment-frame system relies on the beam/column intersections to resist deformation and collapse in earthquakes. The most significant problem with this form of construction is that a failure to provide for sufficient ductility in the frame joints can lead rapidly to collapse in an earthquake. The infill for the partitions and exterior walls, although not designed to be a part of the lateral system, does in the end play a significant role that sometimes can help save a building that has weakened joints, but more often, it can contribute to the collapse of a building because its rapid degradation in specific areas can transfer the loads onto localized parts of the frame, which are then overwhelmed. In Turkey the most common infill is a lightweight hollow clay block that is extremely weak and brittle. In India it is commonly a low temperature fired brick that performs better than the Turkish material but nonetheless can crumble.

11. Demet Gülhan, İnci Özyörük Güney, op cit. In a survey of the Marmara Earthquake damage district, Turkish researchers Gülhan and Güney documented that in one district in the hills above Gölcük (a city with some of the largest loss of life), where the soil was firm and the shaking less than in the city center itself, of the 814 reinforced-concrete, four- to seven-story structures, 60 collapsed or were heavily damaged, and 70 were moderately damaged, while only 4 of the 789 two- to three-story buildings of traditional timber and masonry construction collapsed or were heavily damaged and 5 were moderately damaged. The reinforced-concrete buildings accounted for 287 deaths against only 3 in the traditional structures. The numbers of structures were almost evenly divided between the two types (although the size and occupancy of the reinforced-concrete buildings was undoubtedly greater). This comparison is useful because the numbers of each type are almost evenly divided, and the size of the reinforced-concrete buildings in the outlying areas is not as large as in the city center, thus making the comparison with the traditional structures more equivalent in size than in the city center where the traditional buildings are compared to much larger multistory apartment buildings.

In another district in the heart of the damage district in Adapazari, where the soil was poorer, this research shows that of the 930 reinforced concrete structures, 257 collapsed or were heavily damaged and 558 were moderately damaged, while none of the 400 traditional structures collapsed or were heavily damaged and 95 were moderately damaged. Only 15 of the reinforced-concrete buildings remained undamaged, against 115 of the traditional structures.

This is a very important study, but unfortunately it did not distinguish the infill-frame style of traditional buildings from the others, such as frameless, unreinforced masonry. Had that been done, the differences in performance between infill-frame buildings and reinforced-concrete buildings would likely have been more extreme than for all masonry buildings compared with reinforced concrete. Also, the collapsed buildings were categorized with those that were heavily damaged, and no subsets were made to compare buildings of similar story height, which would have been a useful more direct comparison.

12. To avoid confusion, the reference to modern reinforced-concrete construction here and throughout this paper is focused primarily on the common, largely unregulated, concrete construction of housing and office blocks that fill the earthquake-damaged cities and towns. In reporting on the poor performance of these structures, the author does not mean to imply that all structures of reinforced-concrete construction performed poorly. As the engineering surveys established, there were many reinforced-concrete buildings that had been engineered and constructed to a high standard, and for the most part these buildings did perform well. While this was true, the point needs to be made that the vast majority of the people do not live in buildings that are well-engineered and carefully constructed. This is true for more than just Turkey. Traditional construction reveals that systems can be devised that can survive earthquakes of great magnitude based on structural behavior that is dependent neither on formal engineering nor on sophisticated knowledge of construction.

13. There is a significant number of modern buildings that were well-designed and well-constructed, and these generally were observed to have performed well. It is those of poorer construction and detailing that generally did badly. It is important to understand that bad concrete construction is in many parts of the world more common than the good—and most of the population live in such buildings in cities in Turkey, India, and other parts of the world subject to earthquakes. It is not enough to simply explain collapses and their consequential carnage as the result of inadequate design and/or poor construction. As long as reinforced concrete, which should be regarded as a high-tech material, is used ubiquitously in many areas as the default material for ordinary construction, then a large number of the buildings constructed with it should be assumed to be less than well-built. Earthquake safety is thus not achieved by pointing fingers at builders after earthquakes; it can only be achieved by recognizing that a certain amount of bad construction is inevitable and by looking for ways to mitigate it by changing construction practice so that the safety does not depend solely on the quality of the concrete frames.

14. Mehmet Bayındır is quoted in "The Wrath of Gods: The Earthquake in Turkey," *National Geographic* 198:1, July 2000, 50.

15. There were areas in Bhuj, and to some extent, also in Anjar, where the damage was much less, without any apparent difference in construction practice. This may have been related to soil-response characteristics.

16. Further research may be able to determine if it survived the great 1819 earthquake that affected the same region, but most likely it was constructed after that date.