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THE EARTHQUAKE RESISTANCE OF TRADITIONAL TIMBER AND MASONRY DWELLINGS IN TURKEY

Polat GÜLKAN[1] and Randolph LANGENBACH[2]

SUMMARY

Figure 1: *Hımış*, traditional Turkish construction.

In Turkey and neighboring countries, even as traditional forms of construction for dwellings are being replaced with new buildings that incorporate steel and reinforced concrete, the chances of survival of their occupants during strong earthquakes has not improved. The astounding human losses in the eastern Iranian city of Bam bear testimony to this truth. The timber frame with masonry infill construction found in many of the countries around the Mediterranean basin, evolved over hundreds of years in response to both of social and economic needs. One of those needs was protection against collapse in the earthquakes that regularly strike the region. Over the last half-century, this traditional way of building has been replaced with reinforced concrete. As recent earthquakes have tragically demonstrated, the initial promise of this new material has not been realized because of failures in the entire building delivery process. Attempts at improving the quality of concrete buildings have been frustrated by an inability to affect what is largely an unsophisticated and unregulated industry. An examination of traditional Turkish *hımış* construction may bear some important lessons not just for cultural heritage conservation, but also for the introduction of creative approaches to hazard mitigation in contemporary buildings as well.

INTRODUCTION: DEATH AND DESTRUCTION IN BAM

Bam! It took only 10 seconds on December 26th, 2003 to turn this name of an ancient walled city in Iran into onomatopoeia. Struck by an earthquake that measured 6.6 on the Richter scale, the mighty walls fell like a child's sand castle on a beach. Newspaper reports fanned out around the globe with the news that a citadel with construction dating back 500 to 2000 years had been destroyed. These same articles reported that, first 10,000, then 20,000, then 30,000, and now over 40,000 people had been crushed under the

[1] Professor of Structural Engineering, Middle East Technical University, Ankara 06531, Turkey.
[2] Federal Preservation Institute, National Park Service, Washington, DC, USA. (www.conservationtech.com)

rubble of the surrounding city. Little was left standing. The predominant perception emerged that the death toll was so high because people lived in old buildings. *"No wonder they died… Mud and unreinforced masonry houses fall down in earthquakes. End of story!*" When it was revealed that in fact nearly all of these people lived and died in buildings that were less than 40 years old, many people express amazement. In truth, the occupied part of the city outside the archeological site enclosed by the walls of the ancient citadel expanded from a population of only 7,000 in 1970 to approximately 90,000, when the earthquake tragically reduced it by half.

Many earthquake engineers remarked that there seemed to be little new that could be learned from the damage they could see in this disaster, because the collapsed buildings were almost entirely non-engineered structures of adobe or low-fired brick of archaic construction types that were already known to be collapse hazards in earthquakes. While this may be true from a structural engineering standpoint, it begs the essential question that a disaster of this magnitude poses to the world: *Why does an earthquake in a region of known earthquake hazard manage to kill half of the population of a city – with almost all of the mortality in buildings of less than 40 years of age?* In Bam in 2004, and in Turkey in 1999, it was the failure of contemporary buildings, not the historic ones, which resulted in the high death toll.

Figure 2: Bam, Iran, after the January 26, 2003 earthquake showing a collapsed residence. The steel beams illustrate that this was recent construction using modern, as well as traditional, materials. The steel beams supported masonry jack arches, but because of inadequate ties and poor connections, the beams separated, dropping the heavy masonry onto the occupants. (Photo by Ahmad Nateghi, Kargah.com)

Recently built buildings, even if of non-engineered and obsolete forms of construction, are modern buildings nevertheless. In addition, the death toll was larger than the number of injured survivors, a graphic illustration of the potential lethality of the buildings. A problem with modern building construction of this magnitude cannot rationally be discounted by saying it could have been predicted by trained engineers who know the deficiencies of the type of construction so commonly used. The problem is not with the engineers' reports. It is with the <u>timing</u> of those reports. When written after the earthquake, it is too late. The truth is that an engineering debate lies at the very periphery of the central problem, for the simple reason that most of the buildings constructed in seismic areas are never going to be visited by properly trained engineers until <u>after</u> such a disaster. There are simply too many buildings being constructed at any one time in the world's seismically active areas for trained engineers to do meaningful checks prior to occupancy.

Earthquake Engineering is a subset of the discipline of Earthquake Hazard Mitigation, but it is not the entire field. In practical terms, the problem must be understood in terms of the "building delivery" process as a whole, from the owner, to the builder, the materials suppliers, and then even to the teachers in the local schools. Rarely is knowledge about the basics of safe construction ever delivered to those who need it the most. The problem in Bam will not be solved simply by switching to reinforced concrete from the masonry and steel that was used there. The 1999 Kocaeli and Düzce earthquakes and 2003 Bingöl earthquake in Turkey, as well as earthquakes in India, Algeria and elsewhere, would also indicate the folly of such an approach. Reinforced concrete can be designed and built to avoid earthquake collapses, but in an unregulated construction market, there is little likelihood that it will be.

There is another lesson from this disaster. In many areas of the world there is a belief that modern materials and means of construction are better than time-honored methods of the past, yet the changes brought by industrialization have been so rapid as to cause great changes in local methodologies of building construction without a full assessment of the consequences. Communities in which building traditions had not changed significantly in centuries have been confronted with radical changes in a single generation. Traditional materials, such as timber, have disappeared, to be replaced with steel and concrete, while other materials, such as mud and low-fired brick continue to be used. While the shortcomings of this amalgam of new and old technologies may be recognized by earthquake engineers, the tragic consequences of some of these combinations of materials and systems in earthquakes are not known to those who construct and live in the buildings.

It is critical to remember that with rare exceptions, buildings in non-metropolitan settlements remain hand-built. Because of their small size, there is not much in-plant industrialization available for most buildings. The partial introduction of modern materials and systems into the building process, such as the steel beams used in the Bam houses, or brittle hollow clay tile block in the Turkish reinforced concrete frame structures, sometimes can result in a poorer earthquake performance than existed for traditional construction. Complicating matters is the fact that popular perceptions of risk may diverge from actual risk. This has frequently been the case for reinforced concrete construction, where poor quality construction in this material has so often produced buildings that are more dangerous than the traditional unreinforced masonry buildings they replaced, despite the promises made about concrete buildings.

As yet we do not have the information to know if the houses in Bam would have performed better or worse, had they been built using entirely pre-modern materials and systems instead of having the steel and masonry jack-arched floors and roofs. For this answer we turn to Turkey, where traditional forms of construction dating from before the Ottoman Empire have been continued to the present. For this paper, we will focus on the construction type that in Turkish is called *hımış* (pronounced approximately as "humush").

TRADITIONAL TIMBER-LACED MASONRY IN TURKEY

Earthquakes are common in many parts of Turkey, providing an opportunity to study the influence of this risk on local building traditions over the centuries. In addition, the traditional construction practices of the Ottoman Period were not limited to Turkey because the Ottoman Empire, which lasted for six and one-half centuries, had a broad cultural influence over the Middle East and southeastern Europe. With the related Moghul Empire to the east, this cultural influence extended across a fifth of the circumference of the globe, into Kashmir and India.

Unlike most of Iran, Turkey has a moderate climate and, historically, an abundance of wood, as well as stone and clay. The Turkish Ottoman-style house, with its tiled roof and overhanging timber-and-brick bays above a heavy stone first floor wall, has become an identifiable icon recognized worldwide. Where they survive, the overhanging upper stories, or jetties, contribute to the visual vitality and delight of historic Turkish towns. The jetties also serve a structural purpose, strengthening the buildings by holding the lower-story masonry walls firmly in place with the joists that cantilever over them to support the bays, and the weight of the infill masonry in the timber frame of the overhanging upper story. This compressive force gives the heavy unreinforced walls below added strength against lateral forces.

Figure 3: LEFT: Street of houses with overhanging jetties of *hımış* construction in Safranbolu.

Figure 4: RIGHT: Early 20th century dwelling in Bayirköy with *hatils* in the masonry bearing ground floor walls, and *hımış* construction above.

A feature of traditional Ottoman construction practice is the use of timber lacing in masonry walls. This timber-laced masonry construction can be divided into two broad types: (I) the use of horizontal timbers ("*hatıl*") embedded into bearing wall masonry, and (II) the insertion of masonry in between the columns, beams and studs of a complete timber frame (Figure 4, 5 & 6), referred to in Turkish as *hımış* (Figure 1 & 4). Both construction types can frequently be found in the same building, with the bearing wall forming a strong, sometimes fortified, first story base to the structure, and the *hımış* used for the upper floors. The timber framework of the *hımış* has studs rarely more than two feet (60 cm) apart. The studs are themselves tied at mid-story height by other timbers. Because the masonry is only one wythe in thickness, the walls are light enough to be supported on the cantilevered timbers. The infill masonry is either brick or rubble stone. The rubble stone type is usually made up with small stones set in a thick lime mortar.

Figure 5: LEFT: Interior of Ancient Caravansary in Safranbolu with *hatil* visible along right wall.

Figure 6: RIGHT: Detail of *hatil* in same building.

Some of the more prestigious monuments of dressed stone construction nevertheless were constructed with *hatıls*, as in the caravansary of Safranbolu (Figure 5 & 6). Over the past two centuries, many of the more common houses throughout the northern part of Anatolia have been constructed entirely in *hımış,* usually with brick infilling. Examples of this later type of *hımış* construction can be found in the areas affected by the 1999 Kocaeli and Düzce earthquakes, which thus provided a unique opportunity to examine their performance in earthquakes that were severe enough to cause widespread collapses of modern buildings.

Timber Houses in Istanbul

In contrast to the rest of Turkey, the traditional domestic architecture of Istanbul historically included large areas of wooden houses and their affluent Bosporus counterparts called "*yali*s." The Istanbul house was mandated by an imperial edict in 1509 when a severe earthquake caused by destruction in the predominantly stone housing stock. This type is remarkably close to American timber frame construction of the mid-nineteenth century, as that country was undergoing a transition from the use of heavy timber braced frames, characteristic of colonial period construction, to the light sawn timbers of balloon frame construction. Like the American counterparts, the Istanbul houses had pocket walls, with plaster on wood lath on the inside surface, and wood clapboards on the exterior (Figure 7 & 8). These urban dwellings were sometimes of four and five stories, and like the wooden Victorians of San Francisco, they were constructed in closely packed rows. In fact, until modern redevelopment had destroyed most of the wooden houses there, Istanbul shared with San Francisco, California, the distinction of being one of the few major city centers in the world with so many buildings with wooden exteriors. It is not a coincidence that both cities share the risk from earthquakes, even while, over the last two centuries, most central urban areas have banned wooden exterior walls to avoid the spread of fires. The predominance of totally wood houses instead of *hımış* in Istanbul may also be explained by the ease of importing the timber from the borders of the Black Sea through the Bosphorus, and the availability of sawmills to make the clapboards and wood lath, in addition to the structural members.

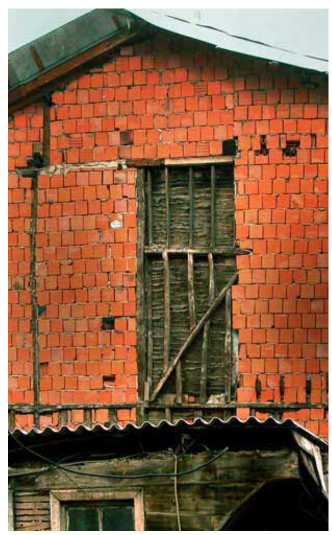

Figure 7: LEFT: Ruinous, but still occupied, timber houses in Fatih section of Istanbul in 2003.

Figure 8: RIGHT: Detail of a timber house in Istanbul where the timber studs remain in only one portion of the wall and the rest have been replaced with hollow clay block creating a condition dangerous for earthquakes.

Bağdadi

Outside of Istanbul, such profligate use of timber was less prevalent, so its combination with masonry was more usual, but one type, known as *bağdadi,* was fairly common in areas where *hımış* was common as well. A sample for *Bağdadi* is shown in Figure 9, below. It is characterized by the use of short rough pieces of timber for the infilling instead of masonry. These were then usually plastered on the interior and exterior to form a solid wall. In using what must have largely been scrap wood that could not be used for structural elements, *bağdadi* houses were light weight, earthquake resistant, economical to build, and did not require industrialized saw mills for the preparation of the timbers. However, *Bağdadi* is subject to increased rot and insect attack. The masonry infill of *hımış* construction has generally been considered to be a more permanent and higher grade of infill material.

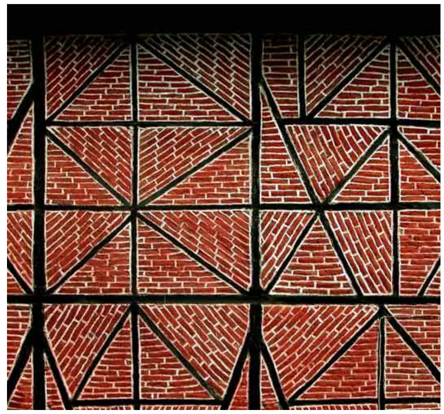

Figure 9: LEFT: Detail of *Bağdadi* wall, Golcuk.

Figure 10: RIGHT: Detail of ornate variation of *hımış* construction near Duzce. Despite their locations, the 1999 earthquakes did not damage these buildings.

Hımış

Hımış 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.*" Langenbach [11] In parts of Central and South America, a variant was called "*bahareque.,*" Langenbach [11], Correia [5] Ancient Roman examples have been unearthed in Herculaneum, several involving interior partitions, but one involving the construction of an entire two story row house, illustrated in Langenbach [12,13]. The palaces at Knossos have been identified as having possessed timber lacing of both the horizontal and the infill frame variety. Kienzle [10] This takes the date of what can be reasonably described as timber-laced masonry construction back to as early as 1500 to 2000 BC.

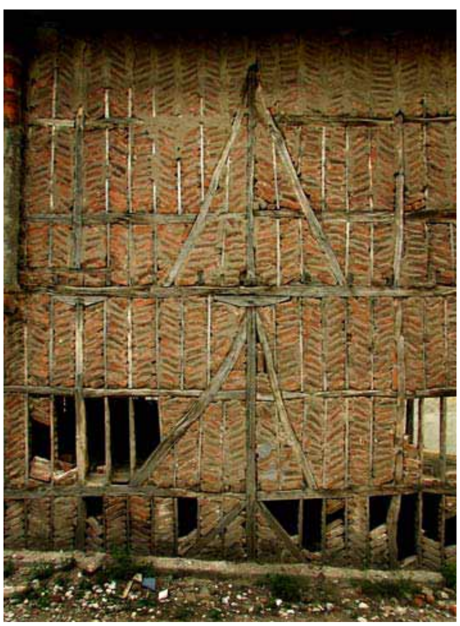

Figure 11 & 12: Partially demolished house in Golcuk showing the single brick wythe thickness of typical *hımış* wall. On the LEFT is the exterior and on the RIGHT is the interior face of the same wall.

This house was abandoned and partially demolished at the time of the earthquake. Despite its condition, the earthquake had little affect on it. It was photographed in 2003.

The masonry in *hımış* is very different from bearing wall masonry. The timber frame remains an important element by providing the armature for the masonry infill. The masonry is usually only one wythe of brick, or a thin membrane of rubble stone set in a thick mud or lime mortar. If bricks are used, they are sometimes placed at angles so as to form a decorative pattern on the façade (Figure 10 & 11). The light timbers and brick infill form walls that are only 10 to 12 cm (4 to 5 inches) thick – a seemingly fragile sheet of thin masonry reinforced with small timbers only lightly nailed together, which would seem to be too heavy and vulnerable for safety in earthquakes (Figure 12).

Hımış has continued in common use in Turkey, up until it was rapidly displaced by reinforced concrete frame construction beginning in the middle of the twentieth century. This is a relatively late date for the survival of a construction method that is little different from what was common throughout Europe in the Middle Ages, but which has long since gone out of use in those other countries. Thus, one must ask whether its relatively recent continued use resulted to any extent from the perceptions of earthquake risk. Should it be recognized as an example of a "local seismic culture?" Ferrigni [7] The answer to this question is complicated by other contributing factors, such as the efficiency and economy of the system compared to using thicker dressed unreinforced masonry, or timber alone. However evidence that seismicity influenced its development and longevity can be found by turning to 18th Century Portugal and Italy where almost simultaneously (undoubtedly because of some cross-fertilization) in Lisbon after the great 1755 earthquake, and in Calabria and Sicily in the late 18th century, similar timber frame and masonry infill wall types were devised and promulgated (and even patented) *specifically* for resistance to earthquakes.

"*POMBALINO*" AND "*CASA BARACADA*" CONSTRUCTION IN PORTUGAL AND ITALY

Following the 1755 earthquake in Lisbon, which destroyed the city center area known as Baixa, the Marquis of Pombal gathered a group of engineers to determine the best manner of earthquake resistant construction to use for the rebuilding. The type of construction selected became known as the Pombalino wall. In its complete form, it is also referred to as "gaiola" or "cage," construction. Most, if not all, of the buildings reconstructed in the reconfigured planned Baixa area were constructed with Pombalino walls, and sometimes (but not always) with complete "gaiola" timber frames. Langenbach [13]

The Pombalino system used on the interior of buildings consisted of timber frames with vertical and horizontal timbers of approximately 10 cm to 12 cm square, with internal braces, forming an "X" otherwise referred to in Italy and Portugal as the "Cross of St. Andrew" (Figure 13). The timbers for the cross are 9 cm by 11 cm in section. The frame was then "nogged"(i.e., filled with brick) in the triangular spaces formed by the crosses with a mixture of stone rubble, broken brick, and square pieces of Roman brick in different patterns in each panel. The interior walls were then covered with plaster, hiding the infill and the timber frame. The exterior facades of the Baixa buildings were reconstructed with load-bearing masonry walls of about 60 cm in thickness, some of which had a timber frame on the inside face. Langenbach [13]

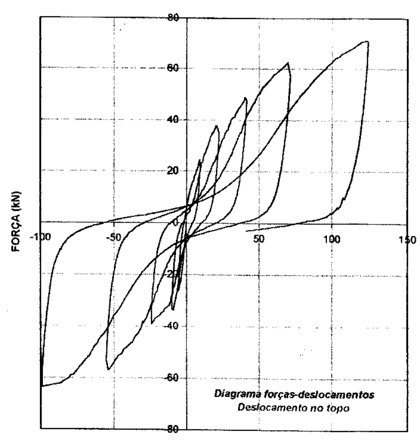

Figure 13 & 14: One story frame section removed from "gaiola" building tested for strength and stiffness in Portuguese National Lab by Cóias e Silva recently. Fig.18 shows one of three walls after cyclical tests to a point just short of collapse, and Fig.19 shows hysteretic behavior of one of the walls. The loss of the plaster and the wide hysteresis loops show that the walls were able to dissipate energy over many cycles without losing their structural integrity. (Cóias e Silva, 2002) [4]

The incidence of the use of the complete “gaiola” frame is not entirely known. Cóias e Silva [4], Correia, [5] The significance of the Pombalino system lies in the fact that it was deliberately developed and selected as earthquake-resistant construction for a major multi-story urban area. Recent tests at the Portuguese National Lab show that the Pombalino walls possess a good hysteretic behavior. Figure 13 shows one of three walls after cyclical tests to a point just short of collapse, and Figure 14 shows hysteretic behavior of one of these same walls. The loss of the plaster and the wide hysteresis loops show that the walls were able to dissipate energy over many cycles without losing their structural integrity. Cóias e Silva [4]

A parallel development of infill-frame construction in Calabria, and Sicily, Italy was called the *“Casa Baraccata”* system. This system also was spawned in reaction to the frequent devastating earthquakes in the region. Its origin was contemporaneous with the Gaiola in Portugal, and each may have been influenced by the other. In Italy, the *Casa Baraccata* became the underlying basis for a whole series of manuals of practice, and even of patent applications for seismic resistive construction techniques, through the Nineteenth Century and the first two decades of the Twentieth Century. Barucci [2] These two types were variants of medieval forms of construction that had been common throughout Europe and other parts of the globe, but for the first time, at least on record, these variants had been adopted at a governmental level as earthquake resistant.

The fact that masonry and timber infill frame construction was considered in both Italy and Portugal as earthquake resistant for a century and a half has now largely been forgotten, even in Italy and Portugal. When reinforced concrete began to be introduced in the early part of the twentieth century, it was thought to offer much greater strength and seismic protection, all with an open flexible floor plan. This claim was central to the work of the master French architect, LeCorbusier, who produced the drawings for the ethereal prototype, the *Maison Dom-Ino* that had a profound influence on architecture around the world. It was not until the middle of the 20th century that the bare reinforced concrete frames with hollow clay block infill became so universal as the default form of construction, with less than ideal results in earthquake areas. Langenbach [13]

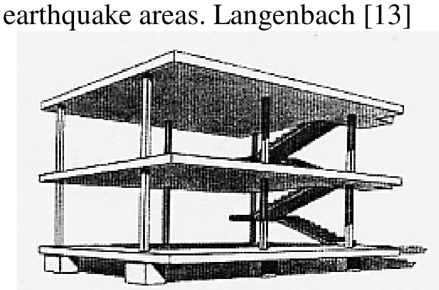

Figure 15: Le Corbusier, Maison Dom-Ino reinforced concrete structural frame, 1915. (Frampton, 1980)

Figure 16: Eight-story reinforced concrete frame structure in Gölcük under construction at the time of the İzmit, Turkey earthquake in 1999, which collapsed many occupied buildings around it. From a street-level inspection, this building did not appear to be damaged. Undoubtedly, the absense of the masonry infill allowed the frame to deflect evenly, rather than causing a soft story at the base of the structure where it is most vulnerable. Had the building been finished at the time of the earthquake, the results may have been quite different.

The almost universal adoption of reinforced concrete in many parts of the world has thus been remarkably rapid. It is a more revolutionary change than the mere substitution of one construction system for another.

It is a change from a system suitable for small-scale itinerant builders to one only suitable to specialized and industrialized contractors, producers, and suppliers. More profoundly, while concrete is thought by its users to be simple and capable of being used by untrained work crews, it is routinely dangerously misunderstood by ordinary builders, resulting in risks from structural faults that remain hidden – until disaster strikes.

HIMIŞ AND REINFORCED CONCRETE CONSTRUCTION IN THE TURKEY EARTHQUAKES OF 1999

The epicenter of the Marmara earthquake (also called the Kocaeli earthquake) of August 17, 1999 was just 100 kilometers east of Istanbul. Three months later, a magnitude 7.2 earthquake occurred near Düzce, a town that had been already struck earlier. In some areas of Gölcük and Adapazari, the earthquake destroyed more than a third of all housing units, almost all of them in reinforced concrete buildings. Youd et al. [14] 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. Many of the older *hımış* houses remained intact, but a few were heavily damaged.

This finding was confirmed by Turkish researchers who conducted a detailed statistical study in several areas of the damage district who found a wide difference in the percentage of modern reinforced concrete buildings that collapsed, compared to those of traditional construction. Gülhan and Güney [8] In one district in the hills above Gölcük where 60 of the 814 reinforced-concrete, four-to-seven-story structures collapsed or were heavily damaged, only 4 of the 789 two-to-three-story traditional structures 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, where the soil was poorer, their research showed that 257 of the 930 reinforced concrete structures collapsed or were heavily damaged and 558 were moderately damaged. By comparison, none of the 400 traditional structures collapsed or were heavily damaged and 95 were moderately damaged.

Even with evidence that the *hımış* construction has shown good performance in the 1999 earthquakes compared to concrete construction, one can reasonably ask the following question: even if it did do better, how is this relevant when the reinforced concrete buildings are generally so much larger and taller, and how can its performance be comparable to a well designed and constructed concrete building?

Figure 17: Three story RC building next to a 2½ story *hımış* house near Düzce showing the repair of severe damage to the RC building (notice the size of the ground floor columns). The *hımış* structure has lost only stucco on the side. Almost all of the hollow clay block on the RC building has been reconstructed after the earthquake. This shows that even low rise RC buildings sometimes suffered more damage than nearby traditional buildings.

It is true that many of the reinforced concrete buildings that collapsed in the 1999 earthquakes were between four and seven stories in height, whereas traditional *hımış* buildings are two to three stories in height. They are not directly comparable, in terms of size, but properly designed and constructed concrete buildings should be earthquake resistant regardless of size. The massive failure of so many of them is not because of their size. Rather, it appears to be a failure of the entire building delivery process, from design to construction and inspection. Gülkan [9]

Figure 18: LEFT: House being reconstructed to replace one destroyed in Afyon earthquake. Concrete is being mixed on ground with garden hose and without slump test or measure-ments.
Figure 19: RIGHT: Concrete column in new mosque being constructed on site of building destroyed in Afyon Earthquake showing rock pockets leaving re-bar exposed. Vibrators are not used in most Turkish construction.

Building delivery must be viewed in the social context, not just in terms of structural engineering. In this context, a comparison needs to be made like-with-like between non-engineered and low-technology construction. The difference between the traditional and the modern systems is not the materials used or the size of the buildings. While *hımış* is an example of a non-engineered traditional building technique, reinforced concrete is meant to be an engineered building system. When reinforced concrete is used for non-engineered construction – where both design and construction departs from correct building practices – the risk of failure leading to collapse in earthquakes is significantly increased. This is not a problem for a traditional technique such as *hımış,* as it is intended to be a non-engineered building system. Variations in quality and methodology are inherent in this system, just as commonly occurs in traditional construction in general.

"Ductile" Behavior?

How does *hımış* resist earthquakes? Inspections of the interiors of some of the *hımış* houses in 1999 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; 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 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 house. On the exterior, unless the masonry was covered with stucco, damage was mostly not visible. The bricks themselves infrequently were displaced sufficiently for a crack to be visible except where in some cases, small sections of the infill were shaken out. The movement was primarily along the interface between the timbers and the brick panels where a construction joint already exists. Because of the timber studs, which subdivided the infill, the loss of portions or all of several masonry panels did not lead progressively to the destruction of the rest of the wall. The closely spaced studs prevented propagation of 'X' cracks within any single panel, and reduced the possibility of the masonry falling out of the frame.

An important additional factor in the performance of the walls was the use of weak, rather than strong mortar. 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. 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. The buildings thus survive the earthquake by not fully engaging with it. This "working" during an earthquake can continue for a long period before the degradation advances to a destructive level.

Figure 20: *Hımış* interior wall in house in Düzce earthquake damage district showing "working" of wall that caused loss of plaster.
Figure 21: Collapse of a brittle interior hollow clay block wall illustrating typical failure pattern for such walls lacking subdivisions.

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 materials and connections. This is not an elastic response, but a plastic one. When these structures lean in an earthquake, they do so with incremental low-level cracking which is distributed throughout the wall by the interaction of the timber structural elements with the confined masonry infill. 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." Aytun [1] has credited the bond beams in Turkey with *"incorporating ductility to the adobe walls, substantially increasing their earthquake resistant qualities."*

THE ORTA EARTHQUAKE OF JUNE 6, 2000

In June 2000, an earthquake that measured 5.9 on the Richter scale occurred near the rural town of Orta, 100 km north of Ankara. This earthquake has provided a chance to evaluate the performance of *hımış* construction in a smaller earthquake in a rural setting, where other construction types included unreinforced rubble stone, and modern reinforced concrete. The rubble masonry construction fared the worst. It was used primarily for barns, and a number of farm animals were killed by collapsing walls. The reinforced concrete construction, however, was, with a few exceptions, only slightly damaged.

What was particularly interesting to find was that many of the examples of *hımış* construction appeared to be damaged to about the same degree as found in the *hımış* houses subjected to the much larger 1999 earthquakes. There was same familiar cracked and fallen plaster, with some dislodgement of the masonry infill. Collapses were limited to abandoned structures with rotted timbers. In a number of instances, government inspectors predictably recommended that the *hımış* houses be replaced by new ones of concrete and hollow clay tile because of what they thought was irreparable structural damage.

Figure 22: LEFT: House in Orta, Turkey one day after the 2000 Orta earthquake – showing plaster cracking that reveals the timber frame.
Figure 23: RIGHT**:** Interior of *hımış* house after the Orta earthquake showing the "working" of the masonry panels.

The 2000 Orta earthquake illustrates the problem of comparative analysis of earthquake performance of existing buildings. Looked at superficially, it would appear that *hımış* suffered significant damage, but this fails to take into account the essential mechanism by which the traditional construction is able to resist earthquakes – flexibility and energy dissipation, rather than strength and stiffness. Its survival in the much larger and longer earthquake illustrates that the *hımış* 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 the shedding of the plaster and stucco in both the large and small earthquakes was similar. By comparison, although only lightly damaged in this and other smaller earthquakes, the non-engineered concrete buildings often suffer from a rapid and sometimes catastrophic degradation of strength in larger earthquakes because they are inflexible and lack the reserve capacity that is found in the *hımış* construction. The brittle hollow tile block infill walls in the concrete frame buildings are initially stiff, and then, once cracked, tend to collapse (Figure 21). Langenbach [13]

PUBLIC POLICY IMPLICATIONS

The comparison between the performances of the different types of construction in the two earthquakes has significant public policy implications. Viewed in isolation, the comparatively good performance of reinforced concrete in the smaller earthquake falsely assures people that such buildings are safer. This covers up the consequences of poorly built reinforced concrete construction, which tragically are revealed only in stronger earthquakes.

Problem of Defining the Goals of Earthquake Safety

One of the problems that plague the assessment of existing buildings, and archaic structural systems used for non-engineered buildings is the basic problem of establishing a norm for earthquake safety and performance when "no damage" is not the goal. With wind, for example, one can establish the design wind speed, and add a safety factor. Then, lesser wind forces should not cause any structural damage. With earthquakes, that is not the goal for almost anything other than vital installations, because it is economically infeasible. New code-confirming buildings are expected to be damaged at design level tremors. Thus, how does one evaluate the post-elastic performance of archaic non-engineered structural systems constructed of materials that do not appear in the codes, and for which there are no codified test results?

The problem is not just an academic one. The evaluation of older structures after earthquakes can lead to broadly divergent views on the significance of the damage, and the reparability of the structures. This can have profound consequences for the owners and for the economic and social dislocation of the disaster as a whole. Dusi and Langenbach [6] It can also result in the unnecessary loss of buildings of historical and cultural value. This is a problem that can affect archaic and modern buildings alike. Earthquake damage has often been looked at with little understanding of what it represents in terms of loss of structural capacity. The standards applicable to reinforced concrete, where a small crack can indicate a significant weakness, are applied to archaic systems where even large cracks may not represent the same degree of degradation, e.g., a masonry building with cracks in the walls with fallen plaster, and a reinforced concrete building with only hairline cracks at the beam/column intersections do not correspond to the same level of degradation. It is the reinforced concrete building that may be closer to collapse than the masonry building. In the case of masonry, it is the friction of the moving and cracking materials that produces damping, thus helping to reduce the structure's response to an earthquake. Disruption of plaster or stucco over a significant portion of a wall area can represent a beneficial performance. (Figures 13, 20, 22, 23)

Factors Impeding Achievement of Quality in the Building Delivery Process

Many issues have traditionally conspired to plague quality in private as well as public construction in Turkey. Most of these issues are not limited to Turkey alone. A diagrammatical account is given in Figure

24 that covers the spectrum of human actions that lead to a fragile building stock and poor quality urban fabric.

Broader Problems

At present no formal qualifications are required for either private or institutional building contractors, and no formal proficiency requirements have been established for engineers or architects. Preference for lowest bid in tenders result in low-quality products.

Supervision of Projects

Technical expertise, tools, and resources in local authorities are quantitatively and qualitatively deficient to carry out reliable project supervision. Irrespective of size and complexity, supervision of all projects is entrusted with local authorities despite the wide variation in their capacity to undertake such supervision. Many local authorities are unfamiliar with routine methods and practical standards for the supervision of ordinary buildings, and no higher governmental authority exists with powers of inspection, or the power to levy penalties on the local authorities for their failure to properly execute project supervision functions. The practice of requiring design approvals from the local branch of the Chamber of Civil Engineers has no legitimate basis, and it does not secure the necessary standards.

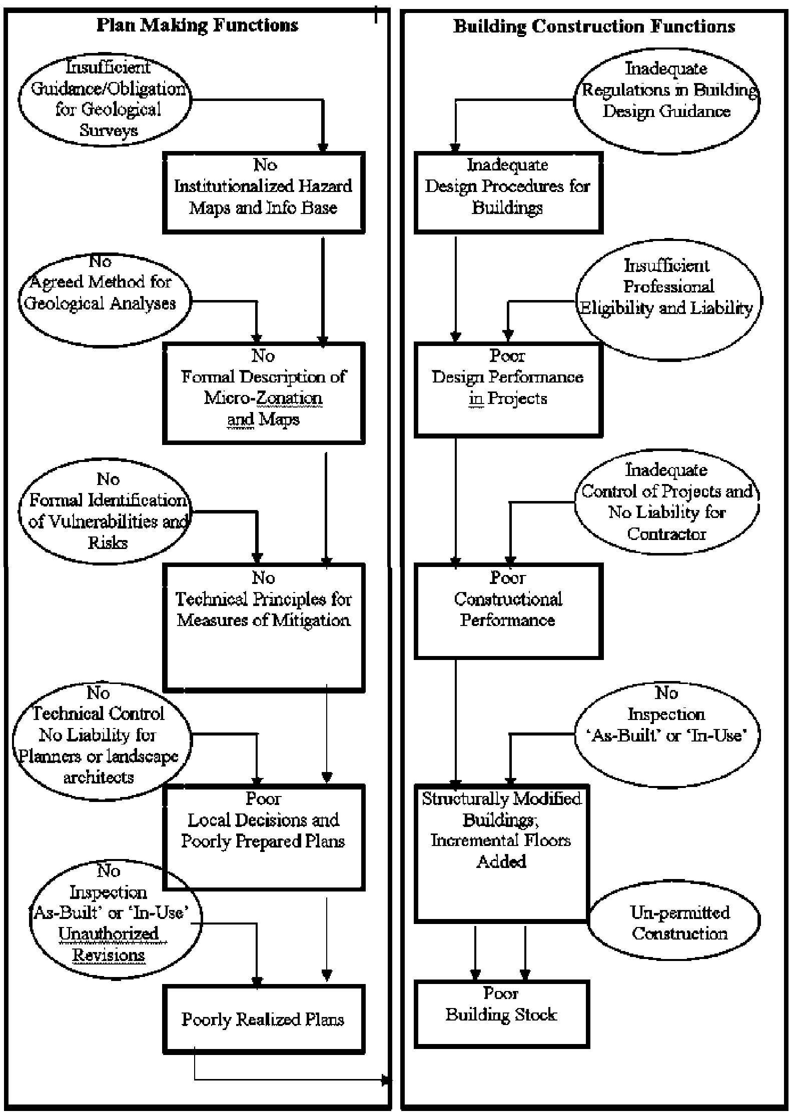

Figure 24: Impediments Facing Achieve-ment of Good Quality Construction in Turkey

Construction Supervision

Other than a diploma, no personal qualifications are required for the site engineer. In addition, since the site engineer, or "technical attendant," is paid by the developer himself and deprived of powers to intervene in the construction activities, he is little more than a passive observer. Professionals like engineers, architects, or even city planners can act as the technical attendant, even though their training may not be appropriate for the specific job for which they are engaged. The hiring of a construction site inspector is not always required or practiced, even in large projects. The risk of fines that developers are liable to pay for deviations from approved plans, according to the Turkish Development Law, is far from being effective. In contravention of provisions envisaged in the Law, unauthorized buildings or those constructed in violation of the permits can in fact be connected to utilities without any party incurring liability. Except for individual efforts by private informers, the local authorities have no means to search for and regulate unauthorized development. The legal procedure that must be followed to remove unauthorized buildings is tediously long, lasting at least a year. Politically local governments are politically reluctant to enforce local city planning decisions. Finally, no meaningful legal liability can be claimed for damages and losses incurred due to construction failures in buildings other than the vague provisions of the Law of Obligations that applies mostly to private financial transactions.

DISCUSSION AND CONCLUSION

Despite the proven track record of good seismic performance found in traditional forms of dwelling construction in Turkey, such construction is now rarely undertaken. Replacement of traditional construction forms has been dictated both by market forces and cultural changes. *Hımış* has been displaced in Turkey not only because of dwindling timber supply, but because of urbanization in what had been closely-knit rural towns.

An interesting and timely exception to this was found near the center of Düzce, where reinforced concrete buildings had collapsed in both the August and the November 1999 earthquakes. The resident of of the earthquake damaged city of Düzce in Figure 25 had begun to construct a home in concrete before the earthquake. After noticing that his father's *hımış* house had survived both 1999 earthquakes without damage near collapsed and heavily damaged reinforced concrete structures, he switched to the traditional construction method, and continued to build his three story house with timber and brick. It was under construction when photographed in 2003 (Figure 26).

Figure 25 & 26: After witnessing the destruction of RC buildings around him in Duzce and seeing that his father's *hımış* house survived undamaged, this resident of Düzce decided to stop building a new RC house and build a house for himself and his family with *hımış* construction.

Pressures to accommodate succeeding generations on each family's ancestral lands in separate housing units each with a greater degree of privacy have lead to the construction of multi-family blocks on what had been agricultural land. This process has been stimulated by developer-contractors who have gained the rights to build such blocks by providing new apartments in exchange for the development rights. Poorly constructed reinforced concrete multistory buildings have been what this process then delivered. With little effective social understanding or demand for seismic quality, and shortfalls in the governmental and legal framework that would ensure it, a huge vulnerable building stock has emerged over a wide region.

Steps are currently being taken in Turkey to address the issues identified in this article, but any transformation in the current situation will take years. Any real judgment of the effectiveness of these measures can only be made when mitigation has run its full course – and after a future earthquake.

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