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ICCROM: Integrating traditional knowledge systems and cultural heritage into risk management.

Preventing Pancake Collapses:

Lessons from Earthquake-Resistant Traditional Construction for Modern Buildings of Reinforced Concrete

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Figure 1: Detail of traditional *himis* construction in Turkey in mid-20th century house in Gölcük.

ABSTRACT: It seems counter-intuitive to assert that simple, unsophisticated, non-engineered, timber and masonry structures might be safer in large earthquakes than new structures of reinforced concrete, but such has proven to be the case in a number of recent earthquakes, including the Izmit and Düzce earthquakes in Turkey of 1999, the Bhuj earthquake in India of 2001, and the Kashmir earthquake in Pakistan of 2005. The question of what lessons can be derived from this information in present times is even less obvious, as these buildings now seem so archaic as to be more easily associated with the medieval rather than modern world. However, in many different regions of the world, the earthquake record with contemporary structures of reinforced concrete frequently has been abysmal. Such buildings are even responsible for what has come to be called a "*pancake*" collapse – where heavy and unyielding floors collapse one atop the other with people trapped and crushed in between.

In fact, before the advent of the strong materials of reinforced concrete and steel, many societies had developed an approach to seismic resistance that is only slowly being re-learned in the present: that it is wiser to build flexible structures than to attempt to build ones that resist earthquakes only by their strength. This paper will explore the specifics of what can be learned from these historical construction practices, by describing the author's concept for "Armature Crosswalls," a concept based on Turkish and Kashmiri traditional construction adapted for reinforced concrete infill-wall construction. The value of this approach for Heritage

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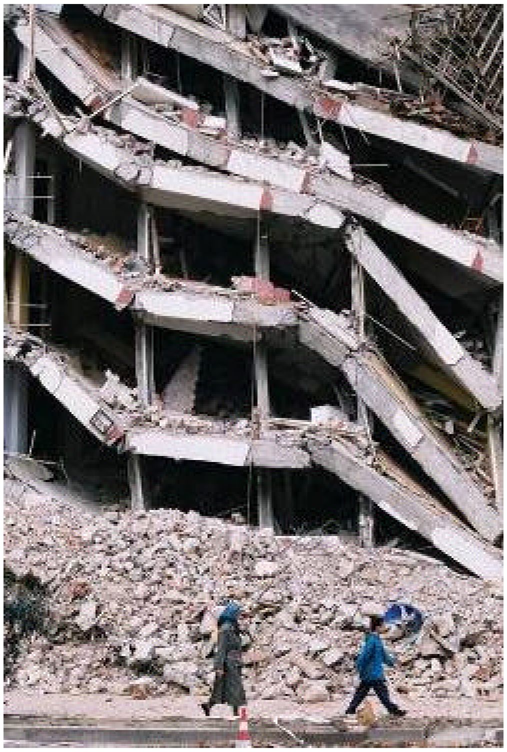
Conservation is that when people understand historic structures not only as archaic and obsolete building systems, but also as repositories of generations of thought and knowledge of how to live well on local resources, societies can begin to rediscover the value of these traditions once again by seeing them in a new light – one that, at its most fundamental level, can save lives.



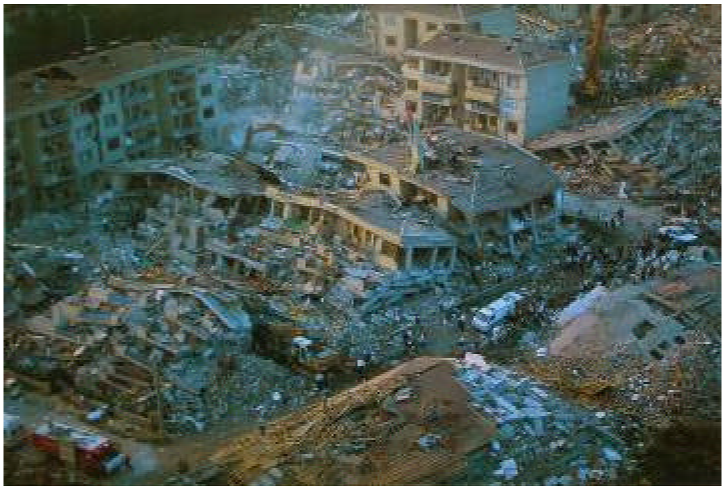


Figure 2: LEFT: Collapsed apartment block, Gölcük.

Figure 3: ABOVE: Aerial view of collapsed apartment blocks, Gölcük. (from UN-ISDR).

Introduction: In November 2000, one year after two devastating earthquakes struck near the Sea of Marmara in Turkey, a conference was convened by UNESCO, ICOMOS, and the Turkish Government in Istanbul called <u>*Earthquake-Safe*, Lessons to be Learned from Traditional Construction</u>. The 1999 earthquakes proved that in spite of all of the knowledge gained over the last century in the science and practice of seismology and earthquake engineering, the death toll in such events had continued to rise. At the time of the conference, few would have thought that "traditional construction" would provide any meaningful answers to confront the dilemma of death and destruction in modern buildings of reinforced concrete. Quite the contrary, historic preservation has long been viewed more as being in opposition to seismic safety – with efforts aimed at producing a compromise between the preservation of historic building fabric and its replacement with new structural systems of steel and concrete.

The 1999 earthquakes, however, provided an opportunity to re-visit this issue from a different perspective, as it was the newest buildings in the damage district that suffered the most damage. A new term had emerged in recent years to describe the problem – not with old buildings, but with new reinforced concrete buildings: *"pancake collapse."* The pervasive image of floors piled one on top of another with the walls fallen away completely was heart-wrenching when one realized that between those floors lay the bodies of the occupants – thousands and sometimes tens-of-thousands of people. (Figures 2 & 3)

Figure 4: Surviving *himis* house next to a row of collapsed reinforced concrete buildings, Adapazari, Turkey, 1999.

At the 13th World Conference on Earthquake Engineering in August 2004, Fouad Bendimerad, Director of the Earthquakes and Megacities Initiative, reported that *"approximately 80% of the people at risk of death or injury in earthquakes in the world today are the occupants of reinforced concrete frame infill-masonry buildings."* Concrete frame buildings with masonry infill-walls (RC infill) are commonly constructed with brick or hollow block masonry partitions and exterior walls. Thousands have died in this type of building in earthquakes in different countries around the world, including recently in Turkey and Taiwan in 1999, India in 2001 (Figure 5 & 6), and Morocco in 2003. In Iran, where light steel frames are used instead of concrete, these infill wall buildings also fell down in the Bam earthquake of 2004 (Figure 7).

How can a technology of building construction based on the new strong materials of steel and reinforced concrete be linked to such deadly catastrophes? At the beginning of the last century both steel and reinforced concrete held great promise for earthquake-safe buildings, yet in Turkey one hundred years later, the pre-modern buildings of timber and masonry remained standing surrounded by collapsed concrete buildings. Clearly the original promise of these new materials has not been fully realized.

Figure 5: Demolition workers on collapsed RC infill building in Bhuj, 2001 one month after the Gujarat Earthquake. Women work alongside men in heavy construction tasks in India.

Figure 6: Bare frame of incomplete building next to partial collapse in Bhuj, 2001. Bare frames, even if weak and poorly constructed, often do better than expected in earthquakes that happen before the infill is installed because the buildings are lighter than when finished, and frame action can take place.

Figure 7: Collapsed steel frame infill wall building in Bam, Iran, after the 2004 earthquake. Many light frame buildings with infill masonry collapsed in the Bam earthquake largely because of defective welding and poor layout that resulted in torsion.

After the 1999 earthquakes in Turkey, the world’s scholars and engineers to descended on the ruins of the buildings that took the lives of 30,000 people, pouring over the wreckage and making frequent pronouncements that the collapses were caused by bad design and poor construction. (For examples, see Figures 8 & 9) *“Inspection, quality control, better training, that was what was needed. If that was achieved, then all could be set right. The building codes were not at fault. It was all in the execution. If that is improved, then the promise of safety will be kept, and the magic of the new materials and modern engineering will be realized.”* A number even asserted that “*nothing new can be learned*” because the myriad observed faults were well documented – and the well engineered and constructed buildings had survived. They said that these surviving concrete buildings proved that reinforced concrete frame construction itself is not to blame. From their perspective it may seem that justice had been served, and that bad construction met its rightful fate. Contractors were arrested and developers chased out of town, and so, perhaps in the future people could be taught to pay attention to building codes, and graft and corruption would cease. Then – and only then – could we expect that earthquakes will not result in such massive mortality.

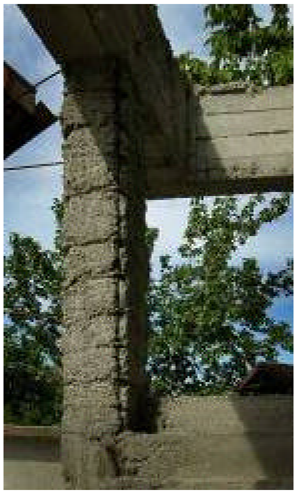


Figure 8: LEFT: House being reconstructed to replace one destroyed in Afyon earthquake. Concrete is being mixed on ground with garden hose and without slump test or measurements.

Figure 9: 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.

The flaw in this reasoning is that, as anyone who has witnessed the rapid expansion of cities around the world knows, this will not happen because, realistically, it cannot ever be expected to happen. Given the pressures to produce so many housing units in a developing country, there will always be poorly built buildings, just as there will always be better ones, and the poor ones will more than likely outnumber the better ones. Thus, the problem of earthquake hazard reduction simply cannot be seen as exclusively, or even primarily as an *engineering* problem. It is fundamentally a *socio-economic* problem. As such, we cannot look to the high-quality reinforced concrete survivors to find the key to solving this problem. What the Kocaeli and Düzce earthquakes demonstrated is that we can look to those humble and unassuming survivors – the traditional buildings – because they have proved that the solution is not sophisticated construction, but, rather, *appropriate* construction.

While poor design and bad construction is indeed a good explanation for many of the concrete building collapses, there is something fundamentally wrong with a pervasive reliance on a construction system for conventional building projects that depends on a level of quality control that is so rarely achieved that large numbers of pancake collapses occur in every major earthquake. By contrast, the traditional buildings that survived the earthquake were not engineered and lacked steel or concrete. No plans for them were ever inspected because none were ever drawn. They were only rarely constructed by anyone who could remotely be characterized as a professionally trained builder or building designer, nor could many of them be characterized as having been carefully or robustly constructed – although the least damaged among them did meet basic levels of craftsmanship. On the contrary, they were constructed with a minimum of tools with locally acquired materials, using a minimum of costly resources, and were held together with a minimum of nails and fasteners. Often the timber was not even milled, being only cut and de-barked. It was sometimes nailed together with only a single nail at the joint, and then the interstitial spaces were filled with brick or rubble stone in clay or weak lime mortar.

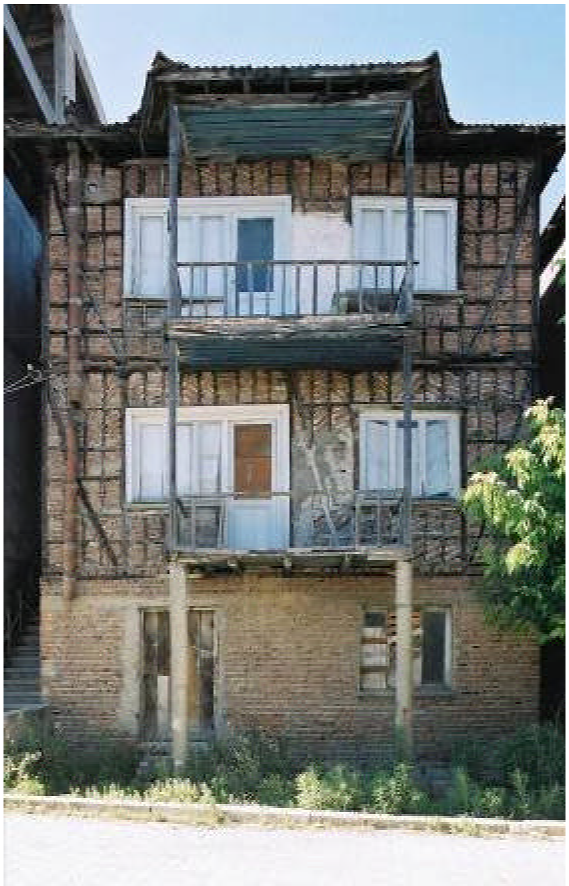


Figure 10: This three story house in Gölcük located less than one km from the fault was undamaged by the 1999 earthquake, while a number of reinforced concrete buildings on the adjacent blocks collapsed.[1]

Thus, the traditional buildings possess the kind of deficiencies in construction quality that are identified as reasons why the modern buildings fell down, yet they remained standing. It appears that we have one system constructed with the full benefit of strong materials that is subject to catastrophic failure in large seismic events if it deviates from a sophisticated level of design and construction perfection, and another considerably less sophisticated one constructed of comparatively weak materials by relatively untrained craftsmen that is, with few exceptions, robust enough to withstand major earthquakes.

From New England Factory Towns To The Hidden Mountain World Of Kashmir: The inspiration for this research on traditional construction in earthquake areas came from a combination of my earlier decades of research on the textile mill towns of New England and the discovery of the traditional architecture of Indian Kashmir. The mill towns demonstrated that the massive brick masonry walled buildings with timber floors were able to sustain the vibrations of the machinery every working day for sometimes more than a hundred years. This observation contradicted the conventional wisdom that masonry buildings inevitably will be destroyed by earthquakes, as one need only step onto a weave room floor with hundreds of looms oscillating back and forth to understand that the vibrations they impart to the structure are significant: the floor is literally bouncing. The looms, in fact, had to be carefully programmed to avoid being synchronized, or the kinetic energy they impart would throw the building over. But so long as that simple principle was observed, these buildings lasted in continuous use for a century or more.

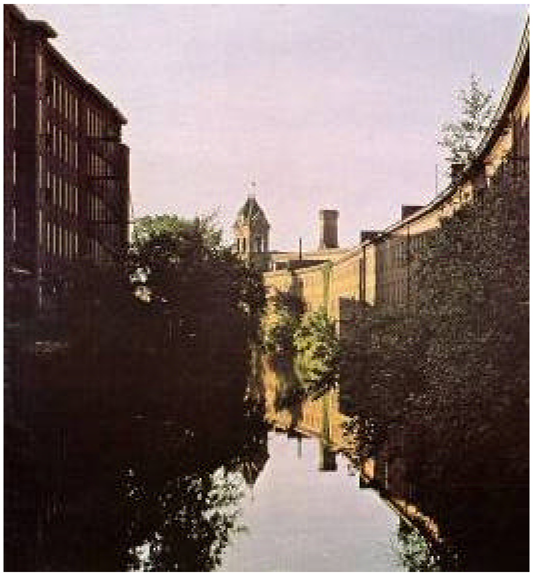


Figure 11: Nineteenth century mills and canal of the Amoskeag Millyard, Manchester, New Hampshire, USA, 1968.

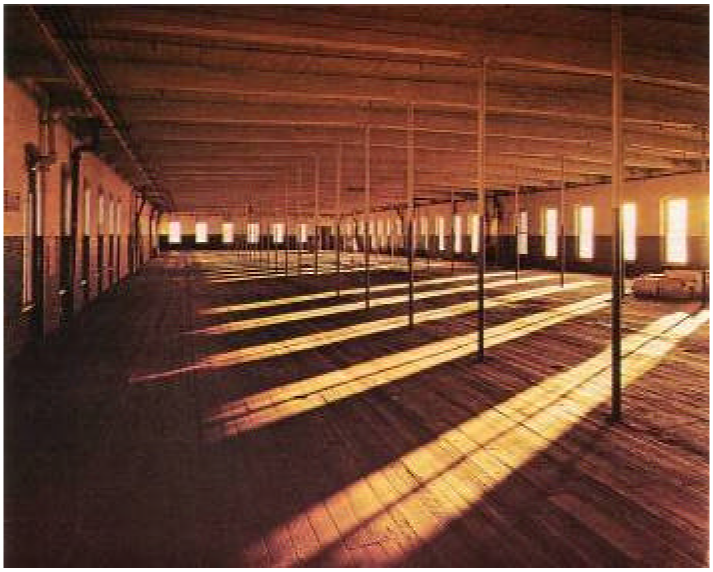


Figure 12: Interior of an 1840 Amoskeag mill building constructed with heavy timber floors, iron columns, and brick exterior walls connected to the floors with iron anchors.

The difference between the 19th Century mill construction technology in Britain and the United States was emblematic of a different approach. In Britain, where the floors as well as the walls in the mills were constructed entirely of masonry and iron to be fireproof, the looms were always placed in a separate one-story shed adjacent to the multi-story mill which contained all of the other machines. The looms, which were the only machine that generated large lateral force vibrations from the impact of the heavy shuttle, were placed in these separate “weave sheds” on rubber pads resting on the slab-on-grade. In the United States, the elevated timber floors of the mill itself were used to buffer the loom from the shuttle’s destructive impact vibrations. The floors of the American mills were of what came to be called “slow burning” construction – widely spaced heavy timber beams and planks with no hidden pockets. These timbers, unlike the masonry of the fireproof construction, could withstand the forces and served to buffer the machines, but there is no mistaking the fact that the exterior walls of masonry laid in lime mortar also had to sustain a significant amount of lateral load. The looms were placed high up in the mill on the third or forth floor, to allow for a coherent linear work flow from the top floor where the raw material was processed in carding machines, then spun into yarn, which was then woven into cloth, that was then finished in the bleach and die rooms at the ground level (Langenbach 1968, 1979, 1981).

Did hundreds of looms on a single floor high up in a masonry-walled building replicate an earthquake's impact on unreinforced masonry buildings in general? Not entirely, but an understanding of how an entire industry that lay at the core of the country's industrialization could be engineered around an acceptance of daily lateral force vibrations on masonry walls does raise questions about the late 20th century conventional wisdom in California, and other earthquake areas, that masonry buildings as a class should be condemned as unsafe without distinguishing their inherent differences. (In fact, it was soon after beginning this research that California adopted a mitigation program for unreinforced masonry buildings and a new building code, the Uniform Code for Building Conservation (UCBC) Appendix, Chapter 1, that included the tying of the walls to the floors of masonry buildings with bolts and anchors – in exactly the same way that the early 19th century mills had been tied together in New England. This code evolved from the first local URM mitigation ordinances in Long Beach and Los Angeles, and from the 1984 ABK Methodology, for the names of the engineers and scholars who the research under a grant from the National Science Foundation: Agbabian Associates, S. B. Barnes and Associates, and Kariotis and Associates.)

Kashmir first became a subject of study because of the remarkable aesthetic quality of the indigenous architecture found in Srinagar. Srinagar has been and continues to be a city obscured to the world by the decades of regional civil strife. When first viewed in the 1980s, it appeared as a magical world – a city beside a mountain lake with a way of life that seemed unchanged for a thousand years. It was only later that the earthquake resistance of what by all appearances seemed to be fragile and vulnerable buildings was revealed in the historical record. The construction practices used for these Kashmiri buildings, which stand in contrast to today's codes and commonly-accepted practices, include (1) the use of mortar of negligible strength, (2) the lack of any bonding between the infill walls and the piers, (3) the weakness of the bond between the wythes of the masonry in the walls, and (4) the frequent (historical) use of heavy sod roofs. Just such buildings were observed almost a century earlier by Arthur Neve, a British visitor to Kashmir, when he witnessed the 1885 Kashmir earthquake:

> *Part of the Palace and some other massive old buildings collapsed ... [but] it was remarkable how few houses fell.... The general construction in the city of Srinagar is suitable for an earthquake country; wood is freely used, and well jointed; clay is employed instead of mortar, and gives a somewhat elastic bonding to the bricks, which are often arranged in thick square pillars, with thinner filling in. If well built in this style the whole house, even if three or four stories high, sways together, whereas more heavy rigid buildings would split and fall* (Neve 1913).


Figure 13: Traditional timber and masonry buildings in Srinagar, Kashmir, 2005.


Figure 14: View of Srinagar from across the river Jelum, 2005.

Even though it was remote from Srinagar, the earthquake that centered on the Pakistan portion of Kashmir on October 2005 provides a new source of data on the comparative performance of the traditional buildings in the regions. This opportunity has been obscured by the fact that most of the buildings in the most severely affected region did not share the resistive attributes reported on by Arthur Neve above; nevertheless, quoting from the structural engineering professors Durgesh Rai and Challa Murty of the Indian Institute of Technology-Kanpur:

> *"In Kashmir traditional timber-brick masonry [dhajji-dewari] construction consists of burnt clay bricks filling in a framework of timber to create a patchwork of masonry, which is confined in small panels by the surrounding timber elements. The resulting masonry is quite different from typical brick masonry and its performance in this earthquake has once again been shown to be superior with no or very little damage."*

They cited the fact that the *"timber studs…resist progressive destruction of the…wall…and prevent propagation of diagonal shear cracks…and out-of-plane failure."* They went on to recommend that: *"there is an urgent need to revive these traditional masonry practices which have proven their ability to resist earthquake loads."* (Rai & Murty, 2005)

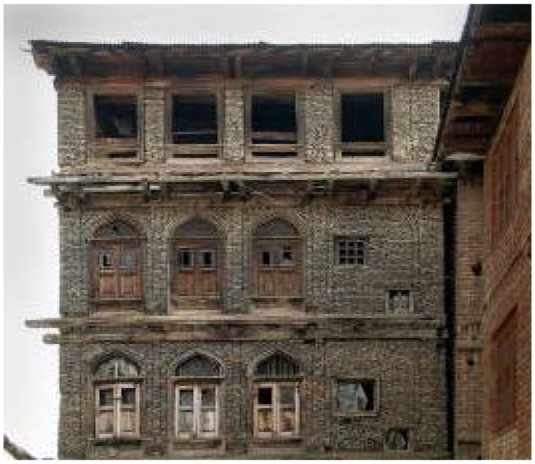


Figure 15: Example of *Taq* construction in Srinagar, Kashmir, 2005. The timbers in the masonry walls only run horizontally parallel to the wall and through the wall.

Figure 16: Example of *Dhajji Dewari* construction in Srinagar, 2005. The timbers form a complete frame, and the masonry is inset into the frame.

There are two basic types of traditional construction with earthquake resistance capabilities found in Kashmir. One, of solid bearing-wall masonry with timber lacing, is known as *"taq"* a word derived from the proportional system used to layout the building, rather than the construction (but no other more appropriate word seems to exist), and the other, a brick-nogged timber frame construction, known as *"dhajji-dewari"* from the ancient Persian "carpet weaver's" language for "patch-quilt wall." Both use timber within the plane of the masonry wall to serve to hold the buildings together. *Dhajji-Dewari* is characterized by having a complete timber frame, with one wythe of masonry forming panels within the frame. For a lengthy description and illustration of these types, please see (Langenbach (1989 & 1992).

***Colombage, Fachwerk, Half-timber, Himis, Bahareque and Quincha*:** In addition to Kashmir's *dhajji dewari*, regional manifestations found in both earthquake and non-earthquake areas alike are called "*colombage*" in France, "*fachwerk*" in Germany, "*half-timber*" in Britain, and "*himis*" in Turkey. A variation that used loose earthen or stone filling in a bamboo or split-lath "basket" between the studs include *taquezal* and *bahareque* in Central America. Other variations that used earthen plaster and sticks or reeds (wattle and daub) include Turkish *Bagdadi* and Peruvian "*quincha*." Despite the ephemeral nature of the material, 5,000 year old *quincha* construction has been unearthed at the Peruvian archeological site Caral. In the United States, the masonry infill version can be found in New Orleans and other historic French settlements on the Mississippi derived from French colombage, and also in parts of Pennsylvania, derived from the German *fachwerk*. (Langenbach 2006c).

Figure 17: *Bahareque* construction in San Salvador showing effects of 1986 earthquake. The loss of the stucco shows that the wall underwent deformations without loss of its underlying structural integrity.

Figure 18: *Colombage* construction in the French Quarter of New Orleans, 2006.

Opus Craticium: When archeologists dug up the port town of Herculaneum that had been buried in a hot pyroclastic flow from Mount Vesuvius in 79AD, they found an entire two story half-timber house which was identified as one of the masonry construction typologies described by Vitruvius as "*Craticii*" or "*Opus Craticium*" (Figure 4a). This example in Herculaneum presents the only surviving example of the form of construction that had been used in ancient Rome for the seven or eight story tenements (*insulae*) that filled that city of a million and a half people (Figure 19). Masonry bearing walls would have been too thick at the base to fit on the known footprints of these ancient buildings with space for rooms left over, so it is likely that the Romans constructed many of these tall buildings with timber frames with infill masonry.

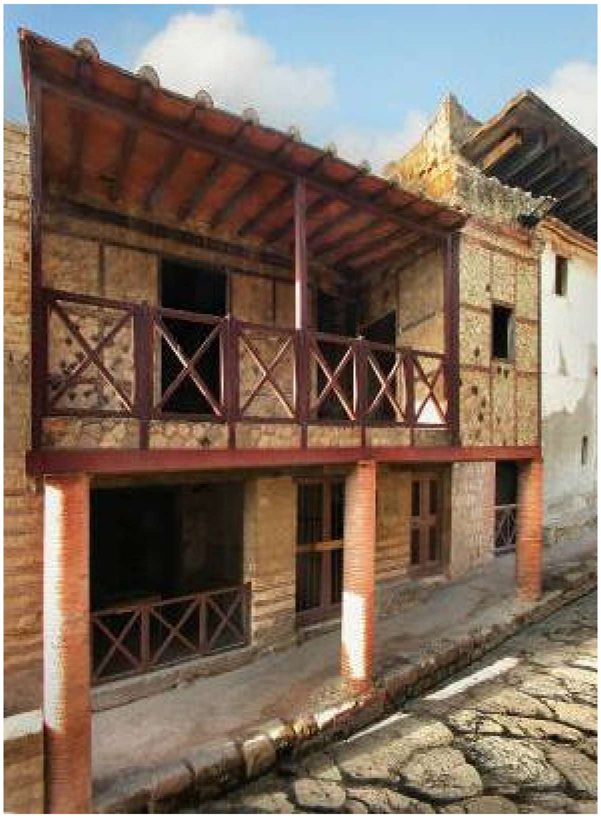


Figure 19: The *Craticii* House at Herculaneum, 2003.

After the fall of Rome, infill-frame construction became widespread throughout Europe. Timber-with-brick-infill vernacular construction is documented to have first appeared in Turkey as early as the eighth century (Gülhan and Güney, 2000). The question of whether timber-laced masonry construction evolved in response to the earthquake risk is an interesting one, but any answer is complicated by the fact that there were so many variations of timber and masonry infill construction in areas well outside of the earthquake regions of the world.

Where earthquakes do occur, the risk can be substantial, but the infrequency of the return period does temper a society's response, even in those areas where earthquakes occur more frequently than the human lifespan, as we can see from the frequency of the large death tolls from earthquakes in, for example, India, Turkey and Iran. There are so many more immediate factors that influence building construction typology that it is not easy to segregate out the influence of earthquakes, but in some cases more than others that influence can be discerned, though the adoption and continued use of timber-laced systems until the present time was more likely the successful byproduct of a technology developed as much for its economy as for its strength, rather than specifically because of earthquake risk. However, when earthquakes have occurred, it is also clear that the post-earthquake observations on what survived and what did not have had an influence on the continued use of such systems that did well. This can be seen particularly in the adoption and promulgation of the Pombalino "*Gaiola*" system in Portugal after the 1755 Lisbon earthquake, and the *Casa Baraccata* system in Italy after the Calabria earthquake of 1783.

Reinforced Concrete Infill-wall Construction: With the rapid spread of reinforced concrete construction during the middle of the last century, the traditional vernacular was displaced from all but the most remote rural regions within a single generation. This was revolutionary in more than just technology. It was a transformation of the building process – from an indigenous one to one more dependent on outside contractors, specialists, and nationally-based materials producers and suppliers of cement and extruded fired brick and hollow clay tile. The resulting problem is that even the available "specialist" builders were often inadequately trained so as to know the seismic implications of faults in the construction – with the looming catastrophe hidden beneath the layer of surface stucco troweled over the myriad numbers of rock pockets and exposed rebars that characterized the usual construction done without the necessary equipment to do it properly, such as transit mix and vibrators.

Figure 20: "Pancake" collapse in Mexico City, 1985.

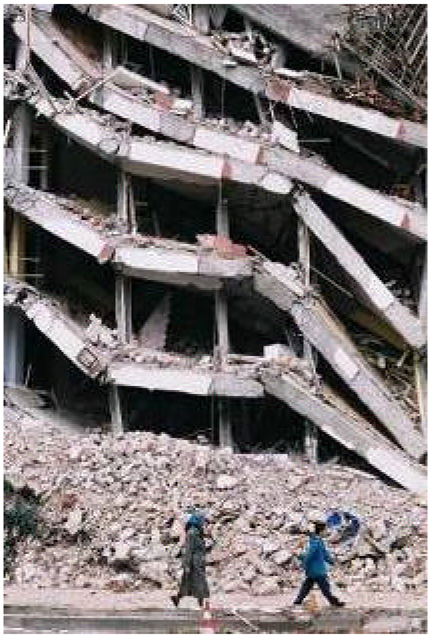


Figure 21: Partial collapse of RC Building, Gölcük , Turkey, 1999.

What occurred was that the new technology of reinforced concrete frame construction was introduced into a building delivery process that continued to exist much as in earlier times. The local, casual, rural system of local builders with a rudimentary knowledge of the science of materials had been sufficient only as long as the materials were timber and masonry; with the introduction of concrete moment frames, it has proved to woefully inadequate. And, once reinforced concrete became the default choice for almost all new residential and commercial construction, the problem has expanded exponentially. Concrete construction requires more than just good craftsmanship, it demands an understanding of the science of the material itself.

Because of the widespread absence of proper professional training in the use of the material and moment-frame system, this requirement has never communicated down to the actual building sites. The severity of this problem may be unique to concrete construction because it is a material that is widely available for use, and can be used with only a modicum of knowledge, but the difference in performance between its correct and incorrect use is profound. In fact, the celebrated robustness of reinforced concrete in earthquakes is lethally compromised even if just one of many different faults are introduced during construction – faults which remain hidden until, years or decades later, the next earthquake strikes. Further compounding the problem, concrete is most often used for high-density multi-story residential projects, where the risk of fatalities at any time, both day and night, is thus greatly amplified.

The introduction of reinforced concrete itself is not the only critical change in the building delivery process that has occurred in may places over the past century. The use of concrete itself did not mandate that it be used for moment frames rather than shear wall structures, but with a remarkably small number of exceptions, buildings in earthquake and non-earthquake areas alike have been constructed with moment frames rather than shearwalls. In some locales this may be more economical, but that may not be the reason why it is so common, especially when the track record for shearwall buildings in earthquakes is so much better. It is because of a transformation within the field of structural engineering.

Structural Engineering has gone through its own revolution over the past century. The 19th Century was an era of enormous ferment, producing engineering giants like Brunel and Eiffel, along with Jenny and the other engineers of the first skyscrapers. In the first decades of the 20th Century, buildings went from a height of 10 to 20 stories to over 100 stories. To accomplish this, engineering practice shifted from a largely empirical process to one of rigorous mathematics. Portal frame analysis based on the contraflexure methodology of isolating moments was invented and became the standard methodology for code conforming building design. This calculation method was both simple and accurate enough for it to have remained in use through the entire 20th Century, up until the present for the design of most skyscrapers (Robison, 1989). For short and tall buildings alike, the isolation of the structural frame from the rest of the building fabric has made the structural design a relatively straightforward process. The enclosure systems could then be treated simply as dead weight in the calculations, eliminating the need to deal with the complexity introduced by solid walls into the calculation of the linear elements of the frame. This also meant that the frame could be standardized into a simple system of rebar sizes and overall beam and column dimension, which in turn has served to allow for the construction of multi-story buildings that are not individually engineered.

Figure 22: Typical Turkish RC building under construction showing the hollow block infill being installed.

Figure 23: Typical hollow clay block infill as used in reinforced concrete residential construction in Turkey.

As we have seen, the acceptance of the concrete moment frame as a standard form of construction, and of frame analysis as the basic engineering approach, fails to recognize the fact that most buildings end up as solid wall structures once the rooms and exterior enclosures are finished. If the enclosure and partition walls are of stiff and strong materials attached rigidly to the frame, as is the case with the infill masonry used in many countries of the world, the structural system can no longer be correctly defined as a frame. However, nearly all of the engineering that underlies the design of these buildings is based on it being modeled as a frame, with the infill masonry included in the calculations only as dead weight, rather than as a structural element. The collapse of so many residential structures of reinforced concrete has shown that there is a flaw with this approach: the irrefutable fact is that the infill corrupts the frame behavior under lateral forces on which the portal frame analysis method is based.

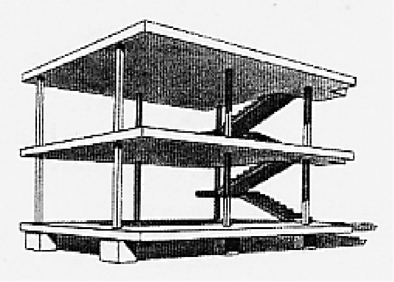


Figure 24: "Domino" frame as ideal structural form by Le Corbusier, 1915. **(Giedion, 1928)**

Figure 25: A massive RC frame in Golcuk, Turkey under construction at time of 1999 earthquake before installation of infill masonry walls. Much greater damage or collapse would have been likely had the infill walls been installed by the time of the earthquake.

The seemingly reasonable explanation for this effect was that by including only its weight, the design would be more conservative than if the infill walls were included as part of the lateral resisting system. Walls then could be moved at will, and the frame (in theory) would be strong enough to carry all of the structural loads as was proposed by Le Corbusier with his publication of his famous "Domino House" in 1915 (Figure 24) which helped to promote the use of this system around the globe. This methodology was also a product of the well-recognized fact that the infill masonry is very difficult to quantify mathematically and does not conveniently fit with portal frame analysis. While under all but the most severe wind loading, ignoring the effects of the infill rarely causes a failure because the load sharing that occurs in reality between the frame, and the infill can off-set any diminished performance of the frame resulting from the infill. In a "design level" or greater earthquake, however, the situation is very different because a building's structural system is expected to deflect into the nonlinear range. (More information on the establishment of the European "Modern Movement" and the invention of the "Chicago Frame" and the "skyscraper" on the evolution of the reinforced concrete moment frame can be found in (Langenbach, 2006a&b)

In other words, the structure of the building (that is, the skeleton frame together with the infill) will go inelastic in a design-level earthquake, which means that structural damage is expected to occur. For frames, this has been recognized in codes through the use of ductility factors which are assigned based on the individual elements that make up a structural frame. Such factors, however, are unresponsive to the conditions that exist when "non-structural" infill masonry is added to the system, as this masonry is usually a stiff and brittle membrane contained and restrained by the frame that changes the behavior of the frame, sometimes with catastrophic results. The standard analysis method for code-conforming design, which is based on linear elastic behavior, is too remote from the actual inelastic behavior of the infilled frame for the calculations to recognize the effects of the forces on it. This is true even without the problems introduced by the usual compromises in construction quality, despite the incorporation of safety factors and recognition of the variations in the ductility of the materials used.

Figure 26: Infill wall RC building in Mexico City damaged in 1985 earthquake. The infill masonry in this structure almost caused the collapse of the building. The damage to the corner column that left the building teetering on the edge of collapse can be seen on the right.

Figure 27: Typical hollow block infill wall partially fallen out of the frame of a building under construction at the time of the Izmit earthquake in Turkey in 1999. The typical infill construction has no mechanical ties other than loosely packed mortar to hold the infill masonry from falling out of the frame. The subdivisions in *himis* construction help hold the masonry together in the frame because the panels are much smaller.

The masonry infill commonly found in today's modern vulnerable buildings is weak and loosely packed into the frame, yet it is strong enough to interfere with the idealized performance of the frames by throwing stresses onto portions of buildings that are not capable of resisting, mostly because of asymmetrical loading resulting from the progressive loss of the infill masonry (Figure 21 & 27). The contraflexure methodology presumes that the column/beam flexure is free to take place throughout the full height of the building, and that the location of the points of contraflexure conforms to that defined in the methodology. The restraint on this motion caused by the insertion of the infill turns this widely accepted analysis method into a fiction. The actual forces no longer bear any relationship to those predicted in the analysis.

This phenomenon has long been identified as a problem. Research projects in the 1960s and 1970s identified what became known as the "equivalent diagonal strut" model for analyzing the structural effect of the so-called "non-structural" masonry infill walls – a name which draws attention to the profound structural role these walls have, a role that can serve at one and the same time to support an otherwise weak structure, or to precipitate its collapse by tearing apart its beam/column intersections as effectively as if they were a wrecker's ball and chain. The equivalent strut concept was first proposed by Polyakov (1960). Since then, Holmes (1961, 1963), Stafford Smith (1962, 1966, 1968) Stafford Smith and Carter (1969), Mainstone (1971 and 1974), Mainstone and Weeks (1971), and others have proposed methods and relationships to determine equivalent strut properties. Klingner & Bertero (1976) have found the method developed by Mainstone to provide reasonable approximation to observed behavior of infill panels (FEMA 1997: 7-27).

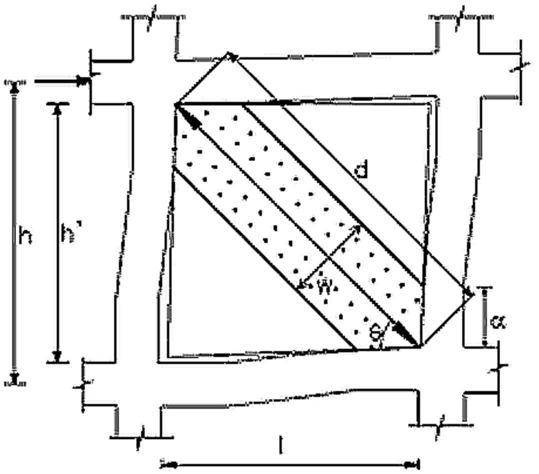


Figure 28: The "Equivalent Diagonal Strut" of a masonry infill wall in an RC frame (Erberik & Elnashai 2003).

This research has continued in various forms over the last forty years but, as remarkable as it seems, the knowledge of the existence of severe problems with this form of construction has had little effect in stemming the massive proliferation of these buildings in earthquake areas worldwide. There have been attempts to find ways to separate the infill from the frame, or find other ways to buffer the frame, but these efforts have foundered on the problems of how to finish the enclosure and ensure the out-of-plane stability of the infill, while leaving a gap between it and the frame.

The research that one sees in university engineering labs around the world most often is focused on the how to strengthen this infill, to enable it to perform more like shear walls, but this aggravates the kind of problems that the equivalent strut model addresses. As many of these experiments have shown, improvements in performance by reinforcing the infill comes at a cost. Because the infill is stiff to begin with, strengthening schemes almost always further increase its stiffness, which in turn increases the forces. In addition, the stronger infill can increase the potentially destructive effects of the diagonal strut on the beam/column intersections of the frame, which can lead to the sudden catastrophic collapse of the building. This, of course, is especially true if the frame suffers from any of the construction flaws so commonly found in reinforced concrete construction.

Figure 29 & 30: Five story building damaged in the 1999 Düzce earthquake in Turkey, being retrofitted with reinforced concrete shearwalls. No.30 shows the existing hollow clay block walls removed and steel being inserted for the construction of a reinforced concrete shearwall. These images illustrate the extent of the work, and disruption needed for earthquake strengthening using shearwalls. The occupants had to move out for the duration of this work as many existing walls were removed.

An alternative to this approach is to convert the buildings from moment frames to shear wall structures (Figure 29 & 30). Shear wall buildings have a significantly better record of survival in earthquakes than moment frames, but the cost of retrofitting existing buildings with shear walls is prohibitive and involves the added costs of relocating the occupants for the duration of the project. Thus, the financial cost of this and other strengthening procedures is too high for widespread adoption in the economies where the vulnerability is greatest. In Istanbul, for example, mitigation schemes have recently been drawn up and promulgated with World Bank assistance, but retrofit of the vast numbers of reinforced concrete residential structures has been dropped from consideration despite the overwhelming need, simply because nothing other than demolishing and replacing the buildings has yet been identified as a way to solve this problem, and because the cost of the standard retrofit usually exceeds the value of the buildings.

A Lessons from Traditional *himis* Construction - Armature Crosswalls: Returning to the aftermath of the 1999 Kocaeli earthquake in Golcuk, an answer to this problem may lie hidden behind the heaps of rubble from the collapsed concrete apartment houses. As different as they are from their concrete cousins, the *himis* houses that remained standing amongst the ruins also have masonry infill confined within a frame (Figures 4, 10 & 31). It is their survival that has provided a source for an idea on how to keep reinforced concrete buildings from collapsing – “Armature Crosswalls.”

Figure 31: Three story RC building next to a 2½ story *himis* house near Düzce after the 1999 Düzce earthquake showing the repair of severe damage to the RC building (notice the size of the ground floor columns). The *himis* 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.

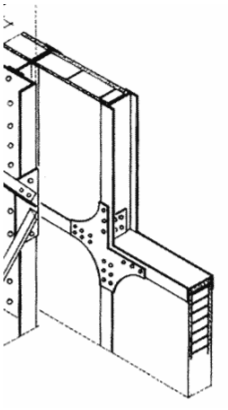
The name *“Armature Crosswalls”* is based on the use of the term “crosswall” in the *Uniform Code for Building Conservation* Appendix Chapter 1, which uses that term for walls that are not shear walls but nonetheless provide structural support and damping to unreinforced masonry buildings. Instead of the existing method of constructing infill walls in reinforced concrete buildings totally out of hollow clay tile or brick, the Armature Crosswall concept is that they are constructed with a timber, steel, or concrete sub-frame of studs and cross-pieces. These studs and cross-pieces (the ‘armature’) would be securely attached to the primary frame of concrete, and the bricks would be tightly packed into the ‘armature.’ The mortar to be used for this construction is intended to be a high-lime mix that is less strong, stiff, and brittle than ordinary cement mortar. When finished, the wall would be plastered as it would normally. The intention is that these walls would have less initial stiffness than standard infill masonry walls, and the studs would also serve to reduce the development of a single equivalent diagonal strut.

Thus, ‘Armature Crosswalls’ are intended to address the initial stiffness, diagonal strut formation, out of plane collapse, and energy dissipation issues that exist for RC infill buildings. The purpose is to make the infill walls into a productive part of the overall structural system, in a way that transforms what is now a problem into an advantage. This approach to mitigation is based on the assumption that low to mid-rise buildings will continue to be constructed with the same materials as are currently used, and that the RC frames themselves are most likely to continue to be unreliable. The benefits of the subdivision of the infill walls into panels by a sub-frame can already be seen in the examples in figures 32, 33 & 35 where the damage was reduced or prevented by the resistance provided by these armature-supported infill walls. In the case of Figure 33, the upper floors were prevented from collapsing by the infill walls despite it having suffered the soft-story collapse of its ground floor which was devoid of infill walls.

Figure 32: Infill RC building in Mexico City after the 1986 earthquake collapsed many buildings nearby, including the one in Figure 20. Each infill wall is subdivided vertically and horizontally into 4 panels.

Figure 33: A subdivided internal brick infill wall in San Salvador after the 1986 earthquake.

The Armature Crosswall system is based on an approach where all parts of a building's fabric are regarded as "structure," so that the ductile behaviour that cannot be assumed to exist in the underlying concrete frame can be achieved through the energy dissipation provided by the controlled degradation of the infill walls. The danger of a soft story collapse can be reduced or avoided using the Armature Crosswall system because (1) the crosswalls can be extended to the ground more conveniently than shearwalls because they do not have to follow such a rigid system of lining up with foundations below and the walls above, and (2) the reduction in the initial stiffness of the walls at all floor levels allows frame action to occur in the superstructure frame because it can sway within its elastic range before the crosswalls begin to bind. This sway is then restrained when the crosswalls begin to shift and crack along the interface with the 'armature,' which serves to dampen the building's response and dissipates energy. As they begin to yield they shed load to other crosswalls, so that all parts of the building function to support and supplement the frame.



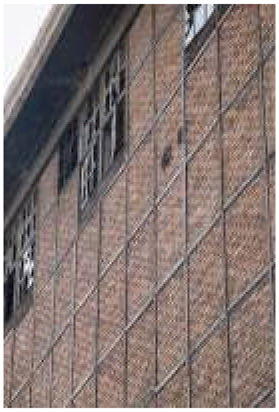


Figure 34: Detail of masonry wall in Istanbul's Silahtaraga Powerplant showing brick infill with horizontal and vertical light-frame steel "I" sections. (Kiraç et al, 2003) This construction is similar to that shown in Figure 35 below.

Figure 35: Detail of exterior wall of Mexico City power plant in the heart of the damaged district photographed after the earthquake in 1985 showing light steel frame and infill wall construction. The building had no visible damage, yet was next to reinforced concrete buildings that collapsed. It had a floorless open interior space that was approximately 20 meters high. This photograph provides an idea of how a building could be retrofitted with Armature Crosswalls by inserting steel channels or angles into existing hollow clay block infill walls to subdivide them.

Because the initial elastic strength is substantially lower than the ultimate strength of the walls (which is based on the crushing of the masonry units, rather than the initial cracking of the mortar between the units) the building should increase in stiffness as its deflection increases until its overall ultimate strength is reached. Even then, as the trajectory of the strength/deflection curve begins to descend, its descent should be gradual, with continued large amounts of damping which continues to serve to resist collapse. (Langenbach, 2003, 2006b)

There are two fundamental questions that are raised by this proposal: (1) why traditional buildings, with their seemingly weak and fragile construction, survive earthquakes that felled their newer counterparts, and (2) is it reasonable to expect that such a technology could be exported for use in multi-story concrete buildings, which are much heavier and larger than their traditional counterparts? In other words, if the infill masonry can damage modern reinforced concrete frames, then why does it not crush the much weaker timber frames?

The answer to these questions lies in the fact that the subdivision of the walls into many smaller panels with studs and horizontal members, and the use of low-strength mortar, combine to prevent the formation of large cracks that can lead to the collapse of an entire infill wall. As stresses on the individual masonry panels increase, shifting and cracking first begins along the interface between the panels and the sub-frame members, and then in the panels themselves (Figure 36). When the mortar is weaker than the masonry units, cracking occurs in the mortar joints, allowing the masonry units in the panel to remain intact and stable. Because the bricks themselves remain intact and held in place by the armature, the ultimate strength of the wall is determined by the crushing strength of the masonry after substantial deformation of the wall. This strength is well above its initial elastic strength. The resulting mesh of hairline cracking produces many working interfaces, all of which allow the building to dissipate energy without experiencing a sudden drop-off in resistance. By comparison, standard brittle masonry infill walls without an "armature" lose their strength soon after the initial development of the diagonal tension "X" cracks. With fully developed "X" cracks, the walls are unstable, as the top triangular section can easily fall from out-of-plane forces. (Figure 37)

Figure 36: *Himis* interior wall in house in Düzce earthquake damage district showing "working" of wall that caused loss of plaster.

Figure 37: Collapse of a brittle interior hollow clay block wall illustrating typical failure pattern for such walls lacking subdivisions.

By comparing the hypothetical strength and deformation curves in Figure 38, it can be seen that the improved performance of the Armature Crosswall is in the extended range between its elastic limit, and the ultimate strength that is established by the crushing of the masonry. It is expected that the computed elastic strength would be slightly lower than that of the standard wall because of the initial slippage between the panels and the armature - which is considered to be a benefit as it allows the overall structure to be more flexible, allowing the frame-action to occur on which the portal frame analysis is based. This kind of initial slippage can be seen in the *himis* house in figures 39 & 40, where the mud plaster cracks can be seen to be along the frame.

This energy dissipation from the "working" of the materials against each other also serves to dampen the excitation of the building by the earthquake. This working of the composite structure during an earthquake can continue for a long period before the degradation advances to a destructive level, as demonstrated by the behavior of the *himis* buildings in the epicentral region of the 1999 earthquakes in Turkey when compared with the surrounding RC buildings. While these structures do not have much lateral strength, they possess lateral capacity

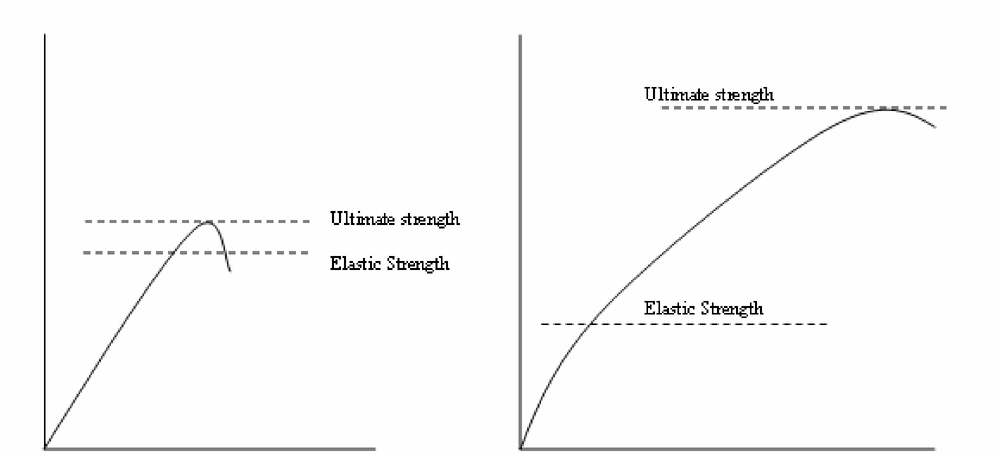


Figure 38: Strength and Deformation Curves for standard infill walls (Left) and Armature Crosswalls (Right).

This explains why traditional infill-frame buildings are capable of surviving repeated major earthquakes that have felled modern reinforced-concrete buildings. The basic structural principle behind why this weak but flexible construction survives is that there are no strong stiff elements to attract the full lateral force of the earthquake. The buildings thus survive the earthquake by not fully engaging with it, in much the same way that a palm tree can survive a hurricane.

In other words, although the masonry and mortar is brittle, the system behaves as if it were ductile. Ductility is not a quality normally used to describe the structural behavior of unfired brick masonry, but in the 1981 published paper "Earthen Buildings in Seismic Areas of Turkey," Alkut Aytun credited the bond beams in Turkey with *"incorporating ductility [in]to the adobe walls, substantially increasing their earthquake resistant qualities."* (Aytun, 1981) While the scale of reinforced concrete buildings may be different, their performance with Armature Crosswalls is predicated on the same phenomenon. The scale issue is reasonably addressed by the fact that the larger residential buildings have more walls in each direction in direct proportion to their size, as the room sizes are very similar. Since the Armature Crosswall system is based on flexibility and on a reduction in initial stiffness when compared to standard infill walls, the building's deflection in an earthquake is likely to engage all of the crosswalls parallel to its deflection in rapid succession. Because the initial cracking of each wall does not represent any loss of the ultimate strength of any given wall, the load shedding is interactive, with loads passed along from one wall to another and back again as the overall deflection increases until all of the walls have been engaged relatively uniformly.

Figure 39: Exterior of 1955 *himis* house in Gocuk damage district one month after 1999 earthquake. Do damage is visible.

Figure 40: Same wall as Fig.10 showing earthquake caused cracks in interior mud plaster.

While this concept may seem relatively easy to comprehend as written, few disaster recovery engineers and other personnel have understood its significance when evaluating the performance of traditional construction – with sad consequences in terms of the loss of cultural heritage. This failure, as I will demonstrate in the examples below, has even also seriously harmed relief efforts to provide safe and livable housing after earthquake disasters.

Figure 41: Partially demolished house in Golcuk showing the single brick wythe thickness of typical *himis* wall. On the LEFT is the exterior and on the RIGHT is the interior face of the same wall.

Figure 42: 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.

One of the reasons why engineers have failed to recognize the benefits of this inelastic behavior is that for most standard engineering analysis, linear elastic models have been used to represent the relative strength and progressive loss of strength of the elements of a building's structural system under earthquake loading. If the masonry is eliminated from the structural seismic analysis once it reaches its elastic limit (for example, at the onset of cracking along the mortar joints, which is far short of collapse), then this post-elastic strength and energy dissipation behavior will remain unrecognized and unaccounted for in the analysis, with the result that their report will show an unrealistically high level of vulnerability. This then serves to put the building at risk of being "red tagged," requiring immediate evacuation, which so often results in eventual condemnation, leading to demolition or a disruptive and costly retrofit.

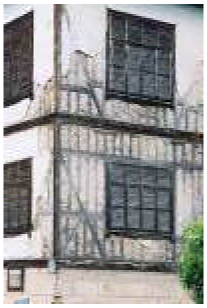


Figure 43: Large 3 story house in *himis* construction, Safranbolu, Turkey, 2000. Safranbolu is now on the World Heritage List because of its unique collection of intact Turkish vernacular houses.

Figure 44: *Himis* construction on 3 story house in Safranbolu, Turkey, 2000.

All too often, the post-earthquake inspection process is where cultural heritage takes an unnecessary hit, especially with unlisted and unofficially recognized cultural properties – namely vernacular buildings like the ones in figures 43 & 44. Because of the unrecognized lateral resistance provided by archaic structural elements, some historical buildings are often forced to meet a level of lateral resistance in excess of that required of fully code-conforming newly constructed buildings. The inspectors who are sent into areas after a disaster often have no training and even less sympathy for vernacular buildings and archaic construction, especially when buildings such as those with thin walls of light frame with masonry infill construction like that in Figures 41 & 42 are encountered, simply because they have no reference point in their training to understand how such buildings can competently resist earthquakes.

This phenomenon alone has been, and will continue to be, a serious problem for the preservation of historic resources that have suffered damage in earthquakes. There are many examples of where this has been the case in the United States and other countries, but one particularly graphic example from Turkey after the June 6, 2000 Orta earthquake in Central Anatolia, illustrates this problem from a Disaster Management perspective.

The 2000 Orta Earthquake and the Meaning of Damage: At 5.9 on the Richter scale, the earthquake that struck near the rural town of Orta (100 km north of Ankara) on June 6 of the year following the great 1999 earthquakes did not seem particularly large. Indeed, the reinforced concrete buildings showed little damage, with cracks appearing through their stucco walls, but otherwise intact (Figure 51). By contrast, many of the houses of traditional *himis* construction showed damage, with much plaster fallen off, and with some partial collapses here and there (Figure 45 & 46). What was interesting to note was that the *himis* damage appeared to be similar to that seen in Gölcük and around Düzce after the significantly larger 1999 earthquakes. Could this be evidence that the qualities of earthquake resistance attributed to this type of construction could not be relied upon?

Figure 45: LEFT: House in Orta, Turkey one day after the 2000 Orta earthquake – showing plaster cracking that reveals the timber frame. There was no evidence of damage beyond that of the cracked plaster.

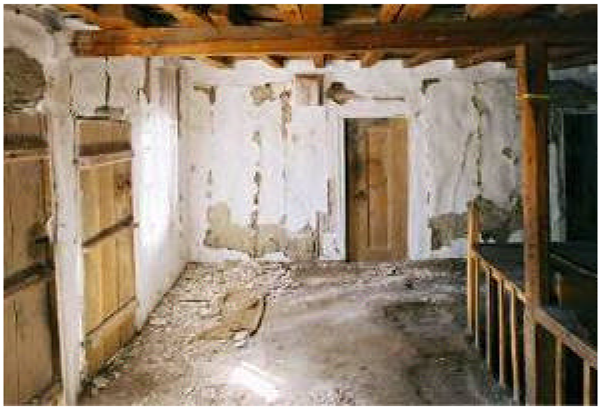


Figure 46: RIGHT**:** Interior of *himis* house after the Orta earthquake showing the "working" of the masonry panels. This view shows the inherent flexibility of the structures, but the inevitable disruption of the mud and lime plaster leads people, including both the owners and the government inspectors to assume that the buildings has lost strength when it has not.

On further study, it became clear that most of those buildings that suffered collapses had been abandoned years before and were in a heavily decayed condition. Wood, particularly the young sapwood that was often used for farm area construction, is vulnerable to fungal and insect decay, and this can advance rapidly when the buildings cease to be maintained. But this did not explain the pervasive damage to the finishes, which left piles of plaster on the floors and along the outside walls of most of the houses, together with some loose bricks and missing wall panels in a small number of places.

Following the earthquake, teams of government inspectors descended on the villages, and pronounced many of the houses "*destroyed*." The residents of one village, Elden, reported that *"95% of the houses were destroyed by the earthquake"* even as I looked about and could not see evidence of that level of damage. What I realized on inspecting several of these villages is that "*damage*" was not objectively defined. A "*destroyed*" house to the post-earthquake inspectors was one that merely had experienced the onset of damage, as demonstrated by the evidence after the 1999 earthquakes (Figures 47 & 48). It became increasingly clear that the government inspectors were already convinced that the traditional buildings were inherently weak and dangerous and not worth repairing or improving. They then easily convinced the owners that they would be better off in new houses of reinforced concrete and brick, a process made easier by the fact that the Turkish government subsidized the new construction by providing a much larger grant for replacement than for repair.

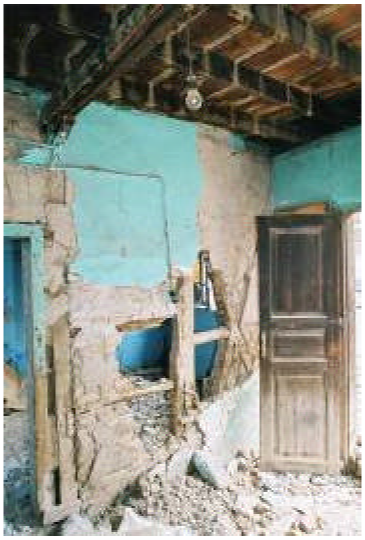


Figure 47: Interior vestibule of house in Adapazari after the 1999 Izmit earthquake.

Figure 48: Interior vestibule of house in Orta after the 2000 Orta earthquake.

A comparison of these views help illustrate that the damage in *himis* buildings in the two earthquakes is similar despite the fact that the 1999 earthquakes were very much larger than the Orta earthquake. (The house in 42 was abandoned and in poor condition prior to the earthquake, while that in 42 was occupied and in good condition – so the difference seen would have been less if both had been the same.)

Once again, part of the problem is that standards appropriate for damage in reinforced concrete buildings were applied without modification to traditional *himis* construction, ignoring the fact that one of the fundamental differences between *himis* houses and concrete buildings is their flexibility. Thus, the onset of damage – particularly to the plaster and stucco finishes – is at much lower levels of shaking than in stiffer structures (Figures 45 & 46). Looked at superficially, it appeared that *himis* 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. Had a similar amount of plaster damage been found in a reinforced concrete building, the frame itself could no longer be safely relied on without substantial reconstruction, as for example in the example damaged in the Molise earthquake in Italy in 2002 see in figures 49 & 50. With *himis* this is simply not the case. The level of damage observed is of a nature that can be repaired with no net loss of capacity in future earthquake events. The plaster, stucco and even the mortar is stiff, weak, and brittle, and so is easily shed from the walls in an earthquake, but it is also repairable to a pre-earthquake condition. When a reinforced concrete frame is broken in an earthquake, it is far more difficult to repair it to a pre-earthquake level of safety without an extensive amount of structural replacement of the damaged beams and columns.

Figure 49 & 50: Interior and exterior of a damage reinforced concrete building in San Giuliano di Puglia after the Molise earthquake illustrating that the frame is on the verge of collapse. While this building will be difficult or impossible to repair to an earthquake-safe condition, the traditional house in Orta in Figure 46, with a similar amount of debris on the floor has lost a negligible amount of its total capacity, and can be easily repaired.

The 2000 Orta earthquake thus provides an excellent point of comparison with the much larger 1999 earthquakes. The survival of *himis* buildings in the much larger and longer 1999 earthquakes illustrate that *himis* is capable of maintaining stability over many cycles of shaking, regardless of the fact that the plaster and some of the infill masonry is disrupted right from the start. In fact, it is *because* of this damage and the friction damping that it produces, that the buildings as a whole are so much more resistant to collapse. The inelastic behavior which produces friction damping begins at the onset of shaking and can continue without much further degradation for many cycles. Thus the shedding of the plaster and stucco in both the large and small earthquakes was often found to be similar despite the vast difference in intensity and duration between the earthquakes. Although only lightly damaged in this smaller Orta earthquake, in the larger 1999 earthquakes the concrete buildings by comparison often suffered a rapid and catastrophic degradation of strength because of their lack of the kind of a reserve capacity of strength and energy dissipation found in the *himis* structures. Their stiffness also served to attract increased loads in comparison to the comparative flexibility of the *himis* structures. The brittle hollow tile block infill walls in the concrete frame buildings are initially very stiff, but, once cracked, they tend to collapse as can be seen in figure 37 and figure 52. (Langenbach, 2003)

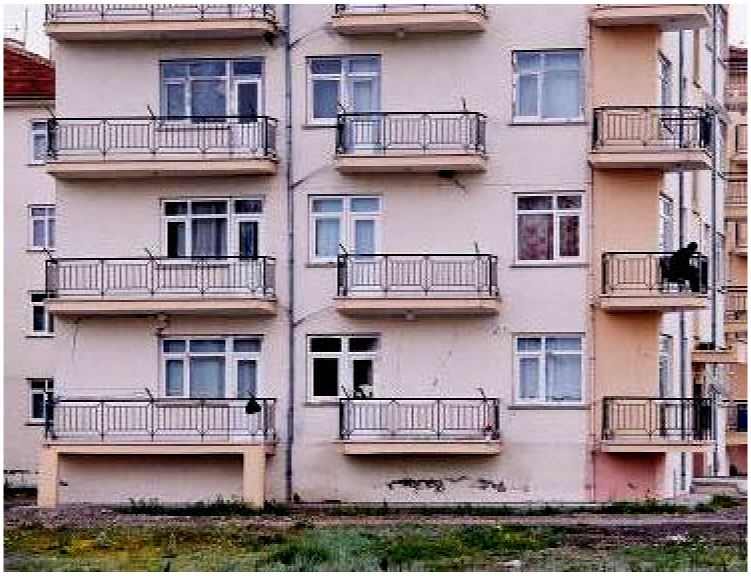


Figure 51 LEFT: RC apartment building in Orta after 2000 earthquake shows cracking in the infill walls.

Figure 52 RIGHT: Apartment building in Golcuk after 1999 earthquake shows extensive collapse of infill walls and damage to the RC frame.

Thus, the comparison between the performances of these two types of construction in the smaller and larger earthquakes has significant public policy implications. Viewed in isolation, the comparatively good performance of reinforced concrete in the smaller earthquake has served to falsely assure people that such buildings are safer. Each time this has happened, it covers up the consequences of poorly built reinforced concrete construction, which tragically are revealed only in the stronger earthquakes such as those in 1999, and subsequently in Bingöl in 2003 where 85 school children (out of about 150) were killed in a single concrete dormitory, when it suffered a complete pancake collapse. Had the earthquake happened during the day, the death toll among the children would have been higher, as many school buildings collapsed.

An Un-learned Lesson in Disaster Management: The Story of Elden Village: There is one final story that serves to underscore the harmful consequences of disrespecting traditional methods of construction and rural ways of life during the recovery process. While this example throws the importance of traditional knowledge systems into high relief, it is not at all unique to Turkey. Similar experiences have been repeated in other countries with increasing frequency, as the vast size of the populations now living in modern buildings and the differences between traditional cultures and the modern urban way of life have become more acute, leading to less understanding between the two worlds. Disasters, which tend to thrust people together from the divergent backgrounds, also serve to shine a spotlight on such differences, as well-intentioned people from the government relief agencies and from non-governmental organizations are thrust into unfamiliar environments where their efforts to help can end up compounding the destruction.

Figure 53: View of Buguören from road to Elden.

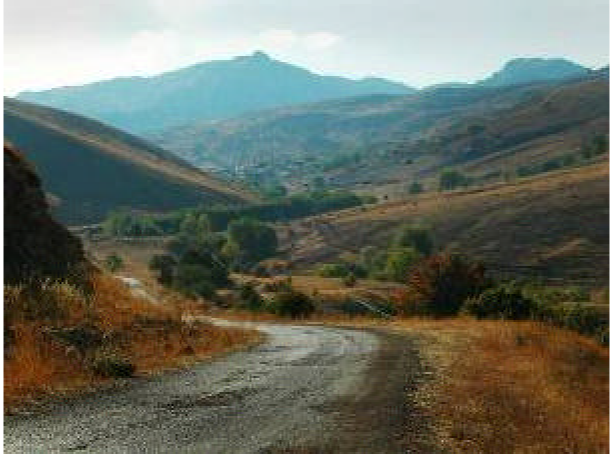


Figure 54: Road into the valley to Elden Old Village, with the village in the distance at the base of the valley.

While surveying Yuva, one of the villages damaged in the Orta earthquake, we were told of another village, Elden, where the government had condemned the houses and had undertaken the relocate the village to what was determined by geologists to be a site safer from landslides and earthquakes. When we set out to Elden to see the results, it was already four years after the earthquake. For several kilometers there was little evidence of settlement, but then we climbed a hill and passed through a sleepy small village consisting of a mixture of old and new houses alongside the road. The older homes were mainly constructed of timber and masonry in the local traditional vernacular, and the newer ones were of reinforced concrete, sometimes painted with gaudy colors, but the view from the distance was that of a characteristic Turkish rural settlement of rectangular tile roofed houses punctuated in the middle by the tall minaret of the mosque. We learned that this village was named Buguören, and that Elden was further along the road. We then descended the hill and curved around almost in the opposite direction as we ascended another hill along the road that was now cut into the steeper hillside at an angle to allow a navigable grade. This hill was much higher than the one on which Buguören sat, which afforded a picturesque view of it off to our left, with the characteristically Turkish tight cluster of boxy houses punctuated by the tall thin minaret of the mosque – and iconic view for this part of the world (Figure 53).


Figure 55: Elden New Village, a government constructed re-location settlement of 87 houses.

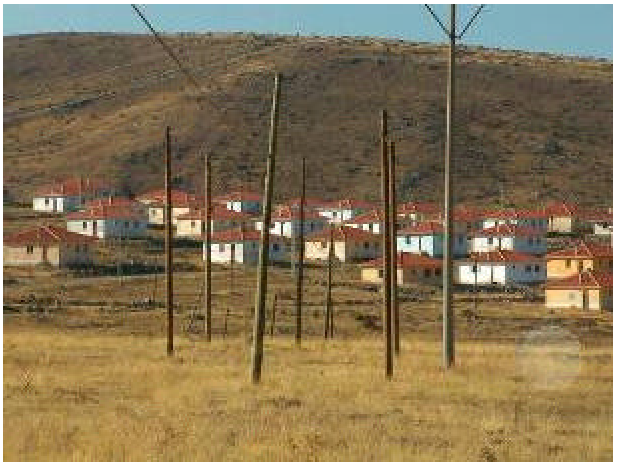


Figure 56: Almost all of the houses are identical. There is no mosque or community services, and no provision for the construction of barns or water and fertile land for gardens or grazing.

Gradually the road began to turn away from the view of Buguören as we reached the crest of the hill, opening up a view in front of us across a wide but barren plateau of dry grassland that extended as far as one could see. This view was punctuated only by wooden telephone and electric utility poles that crisscrossed the view in front of us with no apparent order or direction, but it was not these that caught our attention – it was the distant view of another settlement. This view shared little with the one of Buguören we had just seen only seconds earlier. This was not the characteristic view of a rural Turkish settlement that I had come to know and love. There was no minaret that in more time-honored settlements marked both the physical and cultural center; there was not even any evidence of a town center of any kind. The little one-story brick and concrete houses were lined up on the sloping hillside like the identical tombstones of a military cemetery. There was also no evidence of ordinary human life – no stone walls, no barns or sheds, no unique shutters or painted doorways, not even any hanging laundry. Surely this was not the "new" Elden, we thought – but that is exactly what it was (Figures 55-57).

Our initial destination was not this stark cluster, but the original Elden. The route to Elden first bisected this new cluster. As we drove slowly through the new subdivision, we could see evidence of human activity in only a handful of the 87 identical houses. Only one person, a woman, could be seen outside her home as we passed (Figure 57).

Figure 57: The only occupant visible in Elden New Village at the time of this visit can be seen in this frame of a video.

Figure 58: Old Elden Village showing the loose intertwined arrangement of barns and houses centered on the mosque and village store.

After passing between the new houses, the narrow road hooked to the left around the side of the hill behind the new houses and began to descend from the plateau into a deep valley. As we turned this corner, the view changed dramatically from the barren plateau to a sylvan scene of rolling hills, with a higher peak in the distance that closed the view (Figure 54). Nestled in the middle of this view was a village marked by a minaret, the view of which was almost lost amongst the abundant green of the many trees that lined the road all the way down to the village. Moving from the dry open landscape of the plateau towards the sylvan valley was a study in contrasts – a contrast that was all the more remarkable because of the fact that it was the *new* village – a settlement deliberately established ostensibly to improve the life of the inhabitants – that stood on the exposed barren plateau, a site never before settled in this ancient land.

After proceeding down into the valley, we came into the original village of Elden, which consisted of a cluster of farm houses interwoven with connected barns and paddocks. From the vantage point of the small grass-covered yard to the left of the mosque that stood in the center of the village, one could look out over the houses that descended the hillside to a tree-lined creek-bed, beyond which was a steep incline of pastureland, which served as common lands for the whole village Figure 59). More houses climbed the hillside on the other side of the mosque.

Figure 59: Panorama view of Elden from the mosque. A creek runs through the valley at the base of the hill.

As had been observed in the other villages in the district, the houses were a mixture of older timber and masonry structures, and newer dwellings of reinforced concrete. We were first greeted by the Imam and assistant Imam, and a number of the village elders. Some of these residents described for us the earthquake and its aftermath. A wizened bearded villager said as he gesticulated by moving his hands up and down that the earthquake *"came as a really big rumble."* The up-and-down motion he made with his hands helped to confirm the government's finding that this village was close to the epicenter, which tends to increase the vertical component of the shaking. He reported that his house developed "X" cracks and "some tiles fell." The earthquake managed to cause the death of some farm animals, but in this village no residents lost their lives.

We learned that in recent years Elden's population of approximately 100 families had reduced to about 35 families because of out-migration, which, more than the fact of the earthquake, explained why some of the houses were in such poor repair. This loss of population was not because of the earthquake, but had been part of a general trend in many of the villages resulting from a decline in farming in this region of Turkey and the infertility of the soil. Despite having left, however, the former villagers retained their properties, and, after the earthquake, they applied to the government for new houses along with their former neighbors who still lived there, which served to explain the construction of the 87 new houses in the new village (Dikmen, 2005).

The conversation then turned to the question: *"why build the new village?"* The villagers described how, after the earthquake, government inspectors surveyed the damage and made the determination that *"95% of the houses had been destroyed,"* a figure that was not easy to believe based on what could be seen in the village in our visit. Albeit, some things could have changed over the course of four years, but there was little evidence in this case that much did.

The government then proposed to provide new houses on a new site, justifying the relocation based on their geologists' determination that the existing village was subject to risk of landslides, as well as the fact that the epicenter of the 2000 earthquake was right under it with other active faults nearby. The site chosen for the new village was on the top of the plateau, away from any landslide risk, and presumably subject to less earthquake vibrations because it does not lie on the alluvium one finds in the valley. The government provided the house plans for the new houses and hired the contractor. Most of the houses they said (and we could see from the exterior) were identical, and they were lined up in regular rows.

From our conversations with the residents it became clear that, while they had initially endorsed the relocation, they did not find it appealing now. At first it was an abstract concept backed up by the government's assertion that the existing site was unsafe and thus the new houses would be offered to the residents at a new location, whereas now that the new site was identified and the houses were constructed, they could see that there was no place for their animals, no gardens, and no mosque, nor community facilities of any kind. There was not even a reliable source of water, and the soil was not suitable for farming – not even for the grazing. At the time of our visit four years after the earthquake, they explained that only ten of the eighty-seven houses had been occupied. In fact, one of them had already been abandoned by a single older man who returned to the old village because, as they described, "there was no mosque" and he was lonely up there on the wind-swept ridge. He then simply constructed a shack for himself in the old village.

A year later, only seven houses were occupied in the new village, with some of the others used by former village residents who had moved to jobs in Turkey's cities, including Istanbul, for summertime visits. The others remained essentially abandoned, and the government had embarked on a new program of getting the residents of the old village to sign a statement taking responsibility for their own losses should there be another earthquake if they did not move. (Dikmen, 2005)

Figure 60: Assistant Imam and community leaders of Elden Village

Figure 61: Elden Village elders sitting after services at the gate to the Mosque

In summary, it appears that the government's well intended disaster relief efforts were a failure, and that the large sum of money spent on the new village had for the most part been wasted. In fact, over the long term there was evidence already that this failed plan may end up seriously harming what otherwise could have continued as relatively healthy village. Indeed, in spite of the general rural agrarian decline in this part of Anatolia, this village could have continued on with its small and increasingly elderly population with the ability to sustain itself in its remote valley setting with an intact core community. With the new village the community has been torn apart, with some people eking out a living on the windswept plateau, while the rest remained in the valley. The massive government investment in housing has flowed into the hands of an outside contractor (who was described by the residents as having done low quality work), while the local reinvestment in repairing and maintaining the houses in the village has all but ceased. The local store has closed, and community activities are on a decline. While it is too early to tell, the population of the village could reach a tipping point where neither the old nor the new village are socially or physically viable, and both may become abandoned or reduced to hamlets sustained only by family members who make their livings in Ankara or Istanbul.

While it is important to examine what led to the decision to relocate rather than rebuild in place, it is even more important to examine what first led to the consideration of such a decision – the flawed assessment of the damage to the houses themselves. Had the government *not* condemned the traditional houses, but had instead provided both technical and economic assistance to help the occupants to proceed with repairing them, then the government's largess would have been expended in the village itself, the earthquake recovery would have been much more rapid, and the social fabric of the village would not have been disrupted and divided. Equally important is the fact that the pre-existing local traditional building skills would have been sustained and enhanced.

A Repeat of Past Mistakes: The 1971 Bingöl Earthquake: Unfortunately, the experience in Elden is neither unique nor even new but stands as a classic verification of George Santayana's famous quotation: *"Those who cannot remember the past are condemned to repeat it."* It is one more example across decades of earthquake recovery efforts with similar results in Turkey and in other countries, such as Italy, with the reconstruction of San Giuliano di Puglia after the 2002 Molise earthquake. So many disaster recovery failures could have been avoided if people had simply made the effort to look at the compelling evidence in the historical record, but disasters are infrequent and disaster managers are rarely tutored or even sympathetic to cultural heritage values or traditional ways of life.

Whether one focuses on the prevention of harm or the responses to past earthquakes, the product of this ignorance is monumental, and has served to substantially reduce what could otherwise have helped people in need. It also precluded any attempt to empower residents to restore their own cultural heritage. For this to be avoided after future earthquakes, the government inspectors must be taught to understand that most traditional houses – despite all of the fallen plaster and loose infill masonry – are of a type of construction that, in contrast to reinforced concrete, is repairable, and that their ability to resist future earthquake shaking can be the same or better after such repairs.

A draft report dating from 1982 serves best to illustrate this point. This report was prepared by the Turkish National Committee on Earthquake Engineering and the Cambridge University Department of Architecture on the recovery operations after the Bingöl earthquake of 1971. The field staff included individuals from Middle East Technical University Departments of Architecture and Engineering, members of the Earthquake Research Institute, as well as from Cambridge University Department of Architecture. Called the Bingöl Province Field Study, Preliminary Report, this report covered the reconstruction of 25 villages. Three villages were studied in detail.

This report provides a detailed assessment of the failures and successes of recovery and reconstruction efforts after the 1971 Bingöl earthquake. As a combined effort by British and Turkish scholars and experts, it provides a good objective view of the situation. What makes this report remarkable is the strategies in the Bingol recovery effort that they describe as having failed were exactly what was repeated after the 2000 Orta earthquake, more than a quarter of a century later. Just as with the "new villages" of Yuva and Elden, the Field Study described how the decisions to relocate villages and the *"appraisal of the…possible alternative sites had [been] carried out with great speed and sometimes by inexperienced people…[consisting] of a geologist and a district surveyor."* They *"were required to collect certain information and present it on a protocol form for ratification by the Ministry of their decision on the location of the relief housing. This information is mainly concerned with the assessment of the geological situation, the cost of rebuilding in terms of accessibility of materials and contractors, acquisition of the required land and the cost of the provision of water both for the building process and for householders…and improve[ing] the accessibility of remote villages."*

What was missing in the skill set of the personnel and in their analysis was *"regard for the orientation or layout of the original settlement or its relation to crops and natural resources."*

Ten years after the disaster when the report was prepared, the results were unambiguous. Of the four relocated villages studied, three were largely abandoned, with many of the new houses fallen to ruin or dismantled by their occupants and used for reconstruction at the old village sites.

The report goes on to make an even more radical observation. It states that had traditional timber and masonry construction been used (with some low-tech and low-cost anti-seismic modifications), the resulting reconstructed houses would have been *safer* than the government-designed and contractor-constructed concrete houses, primarily because this new construction was alien to the region and outside of the knowledge and skill set of the indigenous people who lived there. This then required that it be undertaken by contractors from outside of the area, which resulted in construction of particularly low quality. The authors of the report concluded that:

> *Instead of trying to re-house most of the population using reinforced concrete and other very expensive, and unfamiliar methods of building, which at the moment result in substandard construction, some attempt could be made to make the traditional methods become the basis of an improved building stock which is also earthquake resistant. The traditional building is well adapted to the lifestyle of its occupants, it is climatically sited to its environment, relatively cheap to construct and can be built extremely quickly (in some cases a number of weeks). With some technical modifications using the materials available and the building processes and skills already in use in the villages, it may be possible to make the traditional house form as strong against earthquakes, if not stronger than the concrete block and reinforced concrete houses at present under construction and at a fraction of the cost.*

They also observed that the "*provision of the prefabricated houses has…threatened the continuity of the building tradition in the area. The adoption of the buildings as semi-permanent means that fewer buildings are being built and renewed, making a gap of many years before the building practice in each village resumes its former level, and a gap in the experience and training of many village craftsmen.*" While this report did not directly address the issue of cultural heritage in the context of rural settlements where building crafts are based on a pre-industrial local itinerant craftsman tradition, this observation gets to the very core of what cultural heritage preservation requires in the context of a living vernacular architecture tradition. It also embraces how the traditional knowledge must be understood and embraced for government assisted disaster recovery to be successful. To do otherwise will serve only to destroy the traditional knowledge system, slow down the recovery, and permanently harm the communities that are meant to be helped.

Figure 62: Asagi Kayi farm family in a tent the day after the earthquake.

Figure 63: Interior of house of family in tent in Fig. above the day after the earthquake in 2000.

Figure 64: Same room six months later after they had repaired the house and moved back in. *Himis* construction can be easily repaired, and, in contrast to damaged RC, when repaired, it retains its capacity.

The avoidance of Past Mistakes, the Village of Asagi Kayi, after 2000: The relevance of the 1981 report’s recommendations were affirmed after the 2000 Orta earthquake in another village,. In this village, most of the still active farmers and their families rejected the government assistance which would have required them to tear down and replace their houses. After the earthquake, they immediately set about to repair their houses while living in tents in their yards until finished. They used mostly traditional methods to repair them, and when finished, they moved back in, and went on with their lives, as seen by the example of the family whose tent and house is shown in Figures 62-64. Within a year, there was little evidence of the earthquake remaining, and life was back to normal. This record must be compared with the fact that the villages with relocation plans were neither repaired nor resettled when re-visited four years after the earthquake.

Conclusion: One of the problems that plagues the assessment of existing buildings and the 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 a viable objective. 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 even for new buildings, except for the most vital installations, because it is economically infeasible because the forces are so great, while the incidence is so infrequent. 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?

Figure 65: This house in Elden had been abandoned for years before the earthquake. Despite its deteriorated condition, the earthquake damage was limited to the collapse of some of its walls. The basic rough construction characteristic of a rural area without a saw mill or access to a kiln can be seen with the undressed logs used for the structure, and unfired adobe blocks used for the infill.

This problem is not just academic; it is integrally connected to the longer-term issues of post-disaster recovery and regional development. 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, and in the Orta earthquake case it has led not only to the unnecessary destruction of traditional houses, but also spawned the relocation of entire villages – most of which have failed at tremendous social costs. This can have profound consequences for the owners and for the economic and social dislocation of the disaster as a whole, and it can also result in the unnecessary loss of buildings of historical and cultural value. 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 often wrongly applied to archaic systems where even large cracks may not represent the same degree of degradation or even any loss of strength. This can result in the unnecessary condemnation of buildings.

Modern construction materials and methods have brought with them extraordinary opportunities for new spaces, forms, and ways of building, and for lower-cost housing of great numbers of residents. But in many parts of the world they have also been disruptive of local culture, resulting in building forms and ways of building that are alien to the local society. The earthquake risk is just one way in which we can observe what this disruption represents in terms of a loss of cultural and technical knowledge and memory. Earthquakes have proven to be particularly unforgiving when the new ways of building are not sufficiently well enough understood or respected to be carried out to an acceptable level of safety. Moreover, by opening up to learning from indigenous pre-modern examples of earthquake resistant technologies, we can learn to preserve the surviving examples of these now seemingly ancient ways of building in a way that respects what these buildings are, not just how they look.

Recent catastrophes, with their sizeable death tolls, show there is much to learn about how to build in a safe and durable manner. Just as many have begun to rediscover the value of ancient Indian ayurvedic medicine or Chinese acupuncture, earthquakes can serve to reveal the value of forgotten indigenous knowledge as well as shortcomings in the modern methods. Well engineered and constructed modern buildings have fared well in earthquakes, but the effort to improve public policy challenges us to meet the needs of a broader range of rural and urban populations lacking access to well-trained engineers and builders. It is in this realm that the construction methods developed before the introduction of modern materials and modern computational tools have much to teach us, both before and after the inevitable earthquakes. Old ways of building that are based on an empirical wisdom passed down through the ages will probably defy most attempts to be rationalized into systems that can be fully calculated, but the evidence remains that some of these systems nevertheless have worked well. This was true despite the extreme and unpredictable forces experienced in earthquakes - forces that have continued to confound modern-day efforts protect the plethora of buildings that make up the contemporary city.

Figure 66 & 67: After witnessing the destruction of RC buildings in Duzce while his father's *himis* house survived undamaged, this resident of Düzce decided to stop construction of a new RC house and change it to *himis* construction.

FOOTNOTES

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[1] The reinforced concrete building visible on the left remained standing consistent with the general observation that those reinforced concrete buildings that were under construction at the time of the earthquake, as this one was, were less likely to collapse than buildings completed with all of the infill masonry in place.

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