KEYNOTE ADDRESS

Intuition from the Past: What We Can Learn from Traditional Construction in Seismic Areas

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Introduction

Earthquakes have affected buildings since people began constructing them. They are infrequent enough to make it difficult to plan for their occurrence, but potentially devastating enough to lead to catastrophe. For years engineers and scientists have traveled to the sites of earthquake disasters to observe and study the effects of the earth's sudden movement on structures. Just as often they have returned with reports of damage and collapse of different types of buildings constructed with time-honored materials such as stone or brick, and more modern materials such as reinforced concrete. More often than not, the masonry structures are shown only for their failures. The masonry buildings that did well are rarely looked at carefully to identify their advantages, or to explain why they have survived.

In the December 7, 1988, devastating earthquake in Armenia, collapsed crude rubble stone masonry buildings were shown in some engineer's reports, while the many older nineteenth and early twentieth century masonry structures in the central city were often ignored, despite the fact that they survived better than did most of the more modern reinforced concrete structures. This should not be a surprise, as conventional wisdom has long held that masonry buildings are dangerous in earthquakes. They are rarely examined for their intrinsic seismic capacity. Instead, engineers almost always focus on how to strengthen them using steel and reinforced concrete.

In this paper, I will explore a different set of questions from those usually asked by the engineers. I will not deal with how weak structures can be strengthened. Instead, I wish to explore what historical features actually have allowed the older and seemingly weak buildings to survive, while newer ones of reinforced concrete collapsed. In other words, are there things that we can actually learn from these buildings that can be used to improve both building conservation practice and new building construction?

Background

Most people are probably not aware that, even in the United States, the structural codes for new buildings, much less older ones, are not written to ensure that buildings are strong enough to survive a large earthquake without major damage. The objective of the code requirements is to avoid collapse. Codes are intended primarily for life safety, not property protection. Even for new structures, extensive damage may be unavoidable in a large earthquake. The reason for this is plain enough: earthquake forces are potentially so sudden and large that to design against them for all but nuclear power plants is considered to be uneconomic.

Two developments have occurred over the last 75 years of engineering and construction evolution that effect our understanding of the behavior of traditional construction. First, engineering instruction has come to rely on a mathematical construct for engineering design – with mathematical models which get impossibly complex if used to measure damage and loss of capacity in systems with combinations of brittle materials. Second, the empirical understanding and acceptance of the characteristic behavior of masonry under different loads has for the most part disappeared as skilled crafts people and engineers have focused their attention on more modern materials.

For most things in life, however, knowledge is power, and where there is a lack of knowledge, there is often a fear of the unknown. This is especially true when it comes to earthquakes – which come without warning and which shake the very bedrock of our sense of well being within the structures in which we live and work. Thus, as I have seen when I have visited earthquake-damaged areas, people often emerge afraid of their own houses -- and continue to be so even when inspection of them reveals that they have withstood the tremors intact. Because of the lack of knowledge about traditional building practices, the fear of older buildings can be greater than that for newer buildings, despite the fact that the more severe life-threatening damage has often occurred in the newer and larger structures.

So why study traditional construction? The vernacular buildings I am going to discuss have little to do with monument preservation. These were common buildings in their time, and where they do survive today, they rarely garner the kind of attention that is directed towards historical monuments. In burgeoning modern cities like Istanbul -- which as recently as 50 years ago was filled with wooden houses – almost all have been ruthlessly swept away, often within the space of a single generation. Their loss is generally not seen as equivalent to what the loss of great monuments such as the Haghia Sofia would be.

The reason for studying vernacular buildings is two-fold. One, they form the cultural context of our civilization – helping to provide us with an understanding about past lives in ways that individual monuments cannot. Two, of greatest interest to this conference, they can tell us how people in the past confronted the problem of creating structures in which to live and work under the influence of adversities such as shortages of wood, stone, or clay, and threats such as wind, water, and, of course, the most extreme threat of all – large earthquakes. From these lessons from the past, we can even learn some things that could help address the severe problems that have manifested themselves in the more modern reinforced concrete buildings – buildings that have performed so poorly in the recent great earthquakes here in Turkey last August. Thus, by examining earthquakes and traditional buildings, we are looking at how human beings have dealt with overwhelming forces on structures in the past with technology and materials that were considerably more limited then now.

Construction is the unsung area of architectural history research. However, when studying vernacular buildings it is not only an essential part of such study, it forms a large part of the essence of the cultural record. It is where the hand of man is represented in the artifact. As I have traveled around the world, I have often found the similarities that exist in the way that people have designed and built buildings in different parts of the world to be remarkable. With vernacular buildings, this phenomenon is most evident because they often lack the layer of formal architectural expression that characterizes most monuments. These shared traditions may provide evidence of cross territorial communication and also of the commonality in the human invention of methods to cope with common threats. When we look at buildings in earthquake areas, we can explore both of these phenomena. We can also learn much from the differences that are to be found between buildings and between regions.

There have been many masonry buildings in history that have collapsed on their occupants. What is more interesting to examine, however, are those that survived even when conventional wisdom had predicted that they would not. These are those seemingly unpretentious, weak, insubstantial, but characteristically common buildings that have been renewed for generations. They are most often constructed of masonry and timber – rubble, mud and lightweight pieces of wood – without even money for stucco or fancy finishes.

They can be found here in Turkey as well as across the whole seismically active belt that extends around the globe from Africa and Europe across Asia, and also in Central America.

To get a perspective on these important issues, let me first describe my own personal experience here in Turkey when I had the timely coincidence of being in the country in June of this year, when an earthquake struck a region in Anatolia just north of Ankara in and around the town of Orta. The damage from this earthquake was immediately reported in the newspapers, so I headed off to the area within a day of the event.

The Orta, Turkey, Earthquake of June 6, 2000

The earthquake, which struck Orta, measured only 5.9[1] on the Richter Scale. It was thus considerably smaller than the great earthquakes, the Kocaeli Earthquake at 7.4, and the Düzce Earthquake at 7.2, which struck the industrial belt of cities around the Sea of Marmara to the west the year before. Nonetheless, it was large enough to cause damage to some traditional and some modern structures.

What first caught my attention in the newspapers were the early accounts of extensive damage to traditional masonry barns and houses. Photographs showed piles of collapsed stone building walls. Unlike the 1999 earthquakes, here was an earthquake that appeared by all accounts to have caused considerably more damage to traditional structures than to modern concrete buildings.

Why did this point catch my attention in particular? It certainly is not unusual to have masonry buildings – particularly those of rubble stone[2] - collapse in earthquakes of moderate to large magnitude. At least collapsing walls did not cause any loss of human life, although some farm animals were crushed inside the stone barns. In spite of this fact, the earthquake caught my attention because I had expected that the style of traditional construction in this area of Turkey was similar to the traditional construction I had seen in the Kocaeli Earthquake damage district around the Sea of Marmara the preceding October, and which could also be seen in the historic World Heritage site of Safranbolu, which was not far from Orta. After the much larger Kocaeli Earthquake, I had found that a significant number of buildings of traditional construction of timber and brick masonry had done remarkably well, while neighboring more modern reinforced buildings had collapsed onto their occupants. How is it possible, I asked myself, that such buildings could survive a great earthquake, while others of similar construction had succumbed to a temblor measuring a mere 5.1?

As I drove to the area, I kept an eye out for damage. On the way I passed one unscathed sleepy town after another, with their houses peacefully nestled together around a mosque, each with its strikingly slender minaret marking the towns with a dignified presence. Just when it seemed that the earthquake must have been a non-event, blown up by the press in typical fashion all out of proportion by using file photos from earlier earthquakes, the town of Orta came into view. Here the scene changed dramatically. Partially collapsed buildings were spotted here and there. On other houses, there were walls that showed the signature damage from earthquakes – diagonal cracks, and missing triangular pieces of stucco.

As I traveled through this town, and the nearby villages of Üzlü and Yuva, it became clear that the damage was concentrated on traditional buildings, with collapsed stone barn walls,

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[1] As reported in the Turkish daily papers the day after the earthquake. The USGS web site reported 6.1.

[2] Rubble stone masonry, as opposed to ashlar masonry (horizontally bedded masonry of hewn stone) consists of irregular natural stone set into mud or lime-based mortar in an irregular pattern. Lacking horizontal bedding planes, rubble stonework is considerably more vulnerable to being dislodged in earthquakes.

and sometimes, although rarely, collapsed brick and timber upper story house walls. While it was rare to find an entire house collapsed, it did happen.

Of the few modern reinforced concrete buildings in Orta, most appeared undamaged. Some damage could be found in a cluster of five story apartment blocks, but even this damage was limited to hairline "X" cracks on the exterior walls. (The interiors were not inspected.)

When I first encountered this scene I thought that perhaps my confidence in the Turkish traditional construction might be over estimated, and that I would have to revise my conclusions about its performance in earthquakes. Maybe its behavior in the Marmara Earthquake was an anomaly explained by some differences in the characteristics of the shaking and the relative difference in the sizes of the collapsed reinforced concrete buildings from that of the surviving traditional ones. As it turned out, the answer was not so simple. I will return to the lessons of Orta later in this talk, but first let me describe the kind of traditional construction that I have found to be of particular interest in terms of earthquake performance, and why, when I arrived in Orta, I was initially surprised to see the damage that I did.

From textile factories in New England, to brick buildings in California, USA

I first became interested in this subject when I moved to California to teach at the University of California, Berkeley in 1984. I had moved there from the New England region of the United States, an area of some of the nation's oldest settlements, and an area full of masonry buildings. It was also the area in the nation where the Industrial Revolution first took root with the textile machine technology imported from England. Large brick and stone factories dot the region to this day. When these mammoth buildings were in full industrial use, they literally rocked, with the floors taking on a rhythmic bounce from the reciprocating motion of the thousands of power looms.

When I first arrived in California, I found that the conventional wisdom viewed "unreinforced masonry" buildings as of the "highest risk" in a seismic event. The devastating earthquakes in Mexico City, El Salvador and Armenia brought new attention to the subject of earthquake awareness, and new legislation directed at mitigating the risk from masonry buildings was passed. Because the cost of code-conforming retrofit work can be so enormous, this legislation had put many historical buildings, including churches and other cultural monuments at risk of demolition.

My interest in the debate over masonry buildings stemmed from my earlier experience of documenting the historic New England textile mills, and thus experiencing the extraordinary shaking that they endured every day when still actively used. This experience gave me pause to wonder if all that was being said to condemn masonry buildings in California was true. What I came to realize was that there was much to be learned about the intrinsic characteristics of some of these ancient masonry buildings that could be still valid in the modern world – both for the protection of cultural artifacts which would be destroyed by conventional strengthening, and for the continuation and economical improvement of local building traditions in areas of the world where traditional construction is still prevalent.

Mexico City Earthquake in 1985, and the San Salvador Earthquake in 1986

Both the Mexico and El Salvador earthquakes brought new evidence to bear. The Mexico earthquake, which killed about 25,000 people, was particularly devastating to modern high-rise buildings, while relatively benign to historic unreinforced masonry buildings. Even the towers of the Cathedral, which rose to the height of the high-rise buildings that had been devastated, survived unscathed. Many modern buildings of steel and reinforced concrete construction had crumbled to the ground leaving us with the unforgettable images of the babies being rescued from the collapsed Juarez Hospital, and the steel frame skyscraper draped over a freeway like a big dead caterpillar.

All around the collapsed modern buildings in Mexico City, there were masonry buildings of varying sizes and construction types. Some showed a little damage, others were not damaged at all. The earthquake's epicenter was a considerable distance away, which caused a longer period to the waves, which exactly resonated with the Mexico City's substrata. This in turn affected taller buildings particularly severely because of their longer periods. As it turned out, the lower and stiffer masonry buildings were not as vulnerable as the more recent high-rise buildings.

In El Salvador the earthquake was not of such a long period as in Mexico City. Thus, the shorter buildings were subject to the extreme shaking. Here, there were many rudimentary timber and mud masonry buildings in the damage district and many of these were damaged. However, again the largest concentration of loss of life was in a single modern reinforced concrete building that collapsed killing over 600 people.

The traditional construction in San Salvador, called *bahareque*, consists of timber studs of small dimension (approximately 50mm x 100mm) set vertically, approximately 600mm on center, with wood or bamboo lath nailed to each side to form a pocket in the wall. Unlike with timber frame buildings in the United States, where the pocket is left open and the wall is covered completely with wood, in the Central American construction, the pocket is filled with stones in mud mortar or adobe. The wall is then plastered with mud or lime plaster directly over the filling and the lath. In this fashion, irregular stones or lumps of clay can be used as infill between the timbers as they are held in by the lath and stucco.

Many, but not all, of these *Bahareque* buildings were heavily damaged in the earthquake. Others were only slightly damaged or completely unscathed. On closer examination, almost all of the observed damage originated in areas where the timbers were rotted or had been permeated with insect holes. This, of course brings up the issue of whether earthquake failures in traditional buildings which are enhanced by previous deterioration, are a failure of the system or a maintenance problem.

In nearby Nicaragua, where the same construction type is called *"taquezal"* or "pockets of mud", this issue was raised again and given some historical meaning. When researching the earthquake effects on Managua, I discovered an interesting discrepancy between a 1931 earthquake reconnaissance report and a second reconnaissance report done after the devastating earthquake of 1971. While the later report identified the collapse of the *taquezal* buildings as the cause of the high death toll, the 1931 report extolled their virtues as seismically resistant construction. This discrepancy becomes clear and poignant when it is realized that, in this span of time, lumber from locally grown tropical hardwoods ceased to be available, and was replaced by the more vulnerable northern softwood. It is interesting to note that the engineer, J.R. Freemen, who in 1931 reported on the earthquake damage, anticipated the problem of wood decay in 1932. He stated: *"In the Managua climate, this type of structure in course of time may become weakened by decay of the wood posts and by the eating out of the interior of the posts by termites or white ants."* This comment turned out to be a correct forecast.

By 1972, the time of the next large earthquake, the average age of the existing *taquezal* buildings in Managua was substantially older than in 1931. Therefore, their condition had probably deteriorated.[3] In addition, the rot resistance of the available wood was reduced as the quality of wood supplies had declined. The evidence, therefore, is that the primary cause of failure of this class of buildings was not the result of a defect in the system itself, but rather a problem in the long-term stability of the structures affected by environmental factors other than the earthquake.

If we can explain the failures of this system by rotten wood, what can we learn from those buildings that did not suffer heavy damage? Looking more closely at the exterior plastered walls of those standing after the San Salvador Earthquake is revealing. In the 1931 earthquake in Managua, Freeman had commented that practically all of the plaster was shaken off. In San Salvador in October 1986, there were many *bahareque* buildings where the plaster had fallen off, but there was little or no evidence of damage in the structure of the walls themselves. This phenomenon of the shedding of plaster or stucco during an earthquake was also found also to have occurred on some buildings in Mexico City that were of a more substantial brick construction.

The shedding of the plaster, therefore, draws attention to the fact that the earthquake stress is spread evenly throughout the wall, with the small movement of each of the masonry units so that no one major destructive crack occurs. The buildings that did survive showed that the walls were thus able to dissipate a significant amount of energy through the working of the material, rather than by rigid strength. This characteristic – the ability of the disparate materials, each of relatively low strength, to work together as a single <u>system</u> to resist catastrophic damage from the overwhelming forces of earthquakes – is what makes these buildings so important.

While the buildings in Central America were usually of only one or two stories, and constructed with complete timber frames, what about the effects of earthquakes on buildings in areas where wood is even less available and where the predominant material is masonry, rather than wood. For this we move half way around the world to Kashmir.

Srinagar, Kashmir

Because of the on-going civil strife in this remote region of India, the architecture and building technology in Kashmir is not widely known. I first visited Kashmir in 1981 when I was in India to study and photograph the textile industry. Arriving in the City of Srinagar was like being catapulted back in time – not a century, but half a millennium. Srinagar is (or maybe was) a magical place a long side Dahl Lake, one of the most fabled lakes in the world.

When I last visited it in 1988, Srinagar had, for the most part, escaped the rampant modernization that had erased similarly unprotected historic city centers in other parts of the world. Where modernization had occurred, the results were certainly unsatisfactory, but enough buildings of the older style survived to form a complete image like that of a city in medieval Europe. More over, the building construction tradition was still being used, although rapidly being displaced by reinforced concrete. Kashmir is poor and has been removed from the mainstream of industrialized society, with construction methods remaining virtually unchanged for generations. In addition, earthquakes in Kashmir have

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[3] 32. R. Wright and S. Kramer, <u>Building Performance in the 1972 Managua Earthquake</u> (N.B.S. Technical Note 807, 1973). This report documents that the timber framing in 1972 was frequently found to have been weakened by termites.

occurred with a degree of regularity over the centuries, and the Kashmiri people have had to learn to live with them.[4]

Many of the older buildings are of four or five stories in height. All are constructed on soft moisture-laden clay, not unlike the ground under Mexico City. Most of the traditional buildings in Srinagar can be divided into two basic systems of construction. The first system, sometimes referred to as *taq*, [5] consists of load-bearing masonry piers and infill walls, with wood "runners" at each floor level used to tie the walls together with the floors. The second system, known as *dhajji-dewari*, [6] consists of a timber braced frame with masonry infill. The *taq* system is of particular interest in contrast with the *bahareque* because it consists of heavy thick walls of masonry bonded together with large horizontal timbers embedded in the walls. There are no vertical timbers except around the doors and windows, and thus no timber frame. Instead of frames with infill masonry, the large horizontal timbers or "runners" are embedded on either side of the load-bearing masonry walls, with the core of the masonry wall between them. The floor beams and the "runners" for the cross walls are lapped over them. The wood serves to tie the walls together with the floors. The overburden weight of the masonry serves to "prestress" the underlying walls, contributing to the building's resistance to lateral forces.[7]

Turning to the *dhajji-dewari* we find a different style of timber and masonry construction. The *dhajji-dewari* exists side by side with the *taq* system in Kashmir. It can be described as a half-timber, brick-nogged type of construction. It is this type of construction that most resembles the traditional Ottoman style found in Turkey. Buildings of this type have much thinner walls and are therefore much lighter. *Dhajji-dewari* construction provides an efficient and economical use of materials. It is this type that I found continued in use for new construction on my last visit to Kashmir in 1988. In it, the use of wood is kept to a minimum, but the wood still enables the 1/2-brick-thick walls to resist out-of-plane collapse, while at the same time restraining the in-plane movement and cracking of the infill masonry. This type has also shown a marked resistance to earthquakes when compared to conventional unreinforced solid-wall masonry construction.

The construction practices used for these Kashmiri buildings that are in the greatest contrast to today's codes and commonly-accepted practices, include (1) the use of mortar of negligible strength, (2) the division of the masonry in both systems into a series of discrete

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[4] Seismicity of 8-9 on the Modified Mercalli Scale (Anand Arya. interview, August 1988).

[5] This system, sometimes incorrectly identified as *dhajji-dewari*, actually has no specific name in Kashmiri to identify the construction method. The closest name identified by local experts to describe it is *taq*. *Taq* refers to the modular layout of the piers and window bays, i.e., a 5-taq house is 5 bays wide. The piers are almost always 50 to 60 cm square, and the bays are approximately 100 cm in width. This traditional system with the piers and horizontal wooden runner beams was in common usage before the *dhajji-dewari* came into use. The bricks were usually small in size, rough-surfaced, and hard-fired. They are known, as "Maharaji bricks." The reason for the name is unknown. Bricks of this type can be found in Mogul period buildings as early as the sixteenth century, but the houses that survive today for the most part date from the eighteenth and nineteenth centuries. This construction can be found in Afghanistan and Kashmir, but not in Nepal (Anand Arya, 1988 interview).

[6] *Dhajji-dewari* comes from Persian and literally means "*patch-quilt wall*." This method of construction appears to have emerged into common usage alongside of the *taq* system during the late nineteenth century when bricks of a more standard large size became available. This larger-sized brick (2 1/4 x 4 1/2" X 9") set into the timber frame enabled the construction of one-wythe-thick brick walls. *Dhajji-dewari* buildings constructed with unfired mud bricks were also common, especially in the villages.

[7] N. Gosain and A.S. Arya, *"A Report on Anantnag Earthquake of February 20, 1967,"* Bulletin Of the Indian Society of Earthquake Tecbnology (fn4), No. 3 (September 1967).

piers with little or no bond between, except that provided by the timbers, (3) the weakness of the bond between the wythes of the masonry in the walls, and (4) the frequent use of heavy sod roofs (a practice which has now disappeared).[8] These same buildings were observed almost a century earlier by Arthur Neve, a British visitor to Kashmir, when he witnessed the 1885 Kashmir earthquake, who reported in 1913:

> *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."*[9]

More recently, two Indian engineers, N.Gosain and A.S.Arya ascribed the damage from a 1967 earthquake to the different types of traditional and modern construction in Kashmir:

> *The timber runners ... tie the short wall to the long wall and also bind the pier and the infill to some extent. Perhaps the greatest advantage gained from such runners is that they impart ductility to an otherwise very brittle structure. An increase in ductility augments the energy absorbing capacity of the structure, thereby increasing its chances of survival during the course of an earthquake shock. This was substantiated by the observation that* dhajji-dewaris *in which a larger volume of timber was used were comparatively safer*.[10]

Gosain and Arya note that during the 1967 Kashmir earthquake, buildings of three to five stories survived relatively undamaged. Prof. Anand Arya confirmed that his research shows that one of the most important reasons for this is the damping from the friction induced in the masonry of the *taq* and *dhajji-dewari* walls. Internal damping *"may be in the order of twenty percent, compared to four percent in uncracked modern masonry (brick with Portland cement mortar) and six to seven percent after the [modern] masonry has cracked."* His explanation for this is that *"there are many more planes of cracking in the dhajji-dewari compared to the modem masonry."*

Contrary to the conventional wisdom of present-day earthquake resistant design, weak mortar (meaning lime or mud mortar with little or no Portland cement) is essential for this phenomenon to work. The weak mortar allows the wall to begin to yield under a much smaller load than strong cement-based mortar. The onset of yielding in the masonry allows the shifting of the loads through the timbers to other stiffer sections of the wall until the yielding extends across the whole wall. This allows the distribution of stresses throughout the wall rather than the concentration of them in one area. This serves two functions that are important to consider in all forms of construction in seismically active areas. First, it prevents cracking to a destructive level in one area, and, second, it leads to a much greater level of energy dissipation than would otherwise be possible. The timber runner beams and floor diaphragms keep the individual piers from separating, thus preventing their collapse,

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[8] Intertect, Vernacular Housing in seismic zones of India (Albuquerque: University of New Mexico, 1984).

[9] Neve, Thirty Years, p. 38.

[10] Gosain and Arya, "Anantnag," p. 29 (italics added). In this case the authors are referring to the taq system.

while the forces are distributed throughout the whole wall.[11] As a result, even though the mortar is weak, the masonry is held together during earthquake shaking.

In summary, in Kashmir, as in all earthquake areas with traditional construction, rigidity carries the potential for destruction. The more rigid a building is, the stronger it must be in order to avoid fracture. Because of the primitive materials and means of construction in Kashmir, strength was not possible, so flexibility was necessary. To compare the traditional systems found in Kashmir with those of a seismically active area with a different pre-modern building tradition, one need only go to the neighboring country of Nepal.

The traditional construction in Nepal

Related to the question of historical influences, it is interesting to notice what has occurred in the Himalayan Kingdom of Nepal, a place that has largely remained an independent kingdom isolated and protected by the ring of the world's highest mountains. As it turns out, the historical differences in the traditional construction between Nepal, which is Hindu, and the nearby Himalayan state of Kashmir, which is Muslim, are significant, especially in light of the common threat of earthquakes in both areas.

It was not until spring of 2000 that I had my first opportunity to visit the Himalayan Kingdom of Nepal. After having studied the traditional construction in Kashmir, In Nepal I was surprised more by the differences I found, than by the similarities. Despite its proximity and its exposure to the risk of earthquakes, Nepal does not possess the same construction tradition. While the domestic architecture is architecturally similar to that found in Kashmir, the multi story masonry houses in Nepal lack both the complete timber frame of the *dhajji-dewari* or the timber runner beams found in the *taq*. What exists instead is a series of oversize headers and sills above and below each window, and sometimes a plate at each floor level on which the joists, which penetrate the wall, rest. As a result, the masonry at the corners of the buildings is not tied together with timber, as in the Kashmiri construction. The problems with this became abundantly apparent when, in 1934, a devastating earthquake struck the Kathmandu Valley. Many of the houses, palaces and temples were leveled by the temblor.

Following that devastation, the Rana King reconstructed the historic temples and palaces with surprising speed and completeness. Although some reinforced bond beams were added, on the whole, few modifications were made to improve the seismic performance of these reconstructed buildings.

There is now a substantial increase in awareness and interest in seismic hazard mitigation in Nepal, as the number of attendees at this conference attest. Nepal is also in a unique and enviable position because, although most general construction is now in reinforced concrete, it still possesses the handcraft tradition to fuel a growing revival of interest in traditional building methods and indigenous architectural styles.

[11] The division of the wall into piers and infill panels, without an interlocking masonry bond between them is one of the most perplexing anomalies in this system. it would seem to violate all of the other provisions to hold the wall together while allowing it to deform. This aspect needs to be investigated further, but it may have been intended as a relief joint between areas of different thickness, and therefore, stiffness. if the separation were not there, severe shear cracks would likely develop in the spandrels, even at low levels of shaking.

The Ottoman style of construction in Turkey

Returning to Turkey, we can find elements of both of the Kashmiri styles of construction. There are large differences as well, but Turkey shares many similarities with the construction across the entire region, including most of Europe and a good part of Central Asia. The timber with brick infill vernacular construction is documented to have originated as early as the 8th Century AD.[12] There is much to support a hypothesis that this building tradition traveled from Europe into Asia as a result of the reach and influence of the Ottoman Empire, which at one time extended almost from Vienna to the Caspian Sea, including the fact that it did not exist in the Kingdom of Nepal, as described below, which was never part of the Ottoman empire and isolated from its cultural influence. The Islamic Religion, which extended farther, may also have provided a cultural connection helping to further extend the construction method. The infill frame style of construction may have followed these same lines of cultural influence. Its absence in Nepal, which remained more isolated from these currents of influence, lends credibility to this theory.

One thing is clear. The style can be found in almost every part of Europe, including England and Spain, as well as Asia. In addition to finding it in Central America, it can even be found in the United States in New Orleans, a city of French origins, in some other historic French settlements on the Mississippi, and in parts of Pennsylvania, where it has been derived from the German *fachwork*. In final assessment, it may be impossible to attribute the similarities of all of these traditional construction types to cultural communication. There is enough basic logic to the construction method itself, based on the limited materials at hand, to indicate that the ideas could have emerged independently in several areas.

In Turkey, as in Kashmir, the construction type and the architectural expression are closely intertwined. The Ottoman style house, with its tiled roof, extended bays clad with timber and brick, or covered with stucco, all surmounting a stone base, has almost become an icon. It is a distinctive vernacular that is known the worldwide. However, the defining elements, which have contributed to its character, are not always fully understood by people in modern Turkey. This loss of understanding can be seen, painfully, by looking at the hotels and guesthouses in the Sultanahmet historical district in Istanbul that try, but fail, to resemble the genuine historical timber buildings they replaced. Genuine Turkish traditional architecture is intertwined with the traditional way of building. The overhanging jetties actually serve to strengthen the buildings because the joists, which extend well beyond the walls below, hold the walls firmly in place with the weight of the overburden. This compressive force gives the walls below added strength against lateral forces.

In those many houses which have the first story of stone bearing walls and the upper floors of infill construction, the stone in the first floor is often laced with horizontal timbers, (*"hatıl (s) hatıllar(pl)"*), as it is in the Kashmiri *taq*.[13] The division of the stone into piers found in Kashmiri architecture is not to be found in Turkey, but the "runner beams" can be found. Frequently these runner beams consist of very thin timber boards. Thus they serve to bind the stone layers together without interrupting the continuity of the masonry construction.

On the upper floors (or all floors in some buildings) the timber frame and masonry infill style of construction (*"hımış"*) is most prevalent. By not continuing the heavy masonry up

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[12] Rena Günay, The Tradition of the Turkish House and Safranbolu Houses, Endüstri Merkezi Yayınları, 1998, p32.

[13] Houses found in parts of Greece affected by earthquakes also have horizontal wood members. The brick-nogged type of construction is also found in Greece, where it is sometimes used for the upper part of the houses where the stability of the wall is not assisted by the weight of the overburden.

to the roof, but substituting the timber frame and single layer of brick, the walls are lighter, and thus may be supported on the cantilevered joists and brackets. This allowed for the characteristically Turkish bays and jetties that overhang the streets. It is these streets and lanes that give so much visual vitality to historic Turkish towns.

There are a number of fine studies of the Turkish traditional house published in English, including that by Prof. Doğan Kuban, with Prof. Zeynep Ahunbay, but little attention has been focused on the question of how earthquakes may have influenced the evolution of the construction style and thus the architectural form. Earthquakes have always been a part of Turkish history, and have undoubtedly been a factor, but it is likely impossible to isolate such infrequent events as a dominant influence when similar forms of construction can be found as far away as England and Germany, in areas with no record of seismic activity.

The question of whether earthquakes have had a shaping influence on traditional construction is an interesting one and one for which further research could be rewarding, because it can tell us how people have addressed this risk in the past. People must have responded to it, but before the emergence of steel and concrete they did so in ways that were different from what we are familiar with today. Now there is a professional community of scientists and engineers who specialize in the subject, whereas in the past, the science of building was not so defined as a separate professional activity. Earthquake risk must have been a factor in the evolution of building design and construction, but it may not have been a defining one. The economy and availability of building materials and craftsmanship is likely to have had a stronger influence than earthquake risk. Timber with brick infill allowed for the construction of comparatively thin lightweight walls, thus using available materials economically.

However, as we look to solutions for the problems that have been so profoundly thrust on Turkey by the tragic earthquakes of last year, it is important to look at what the wisdom of the ages may have infused into traditional structures, to see if there is indeed some lessons in this over confident age of high technology that we have been missing. In the end, it may be something so obvious, simple and non-high tech that we may not have seen it until we stare it in the face.

The Kocaeli Earthquake of August 17, 2000, and the Düzce Earthquake of November 12, 2000

This is the question that I wanted to answer as I returned to Turkey last October after the devastating Kocaeli Earthquake, an earthquake which caused the death of approximately 30,000 people[14] just 200 km east of Istanbul. In some areas of Gölcük and Adapazari, the earthquake destroyed more than a third of all housing units.[15] While I had studied traditional construction, and had read reports of earthquakes in the past, I had not had any experience except in El Salvador of seeing the effects of an earthquake on this type of construction. When the earthquake occurred in Turkey, I was immediately aware that it was highly likely that somewhere within the affected region, there must have been some traditional dwellings, yet there was no commentary about them in any of the first dismal reports of the collapsed apartment buildings and the human suffering that it had brought about.

[14] Totals of confirmed deaths and missing combined. Source: Kandilli Earthquake Research Institute Web Site, accessed 11/2/00, Boğaziçi Üniversitesi.

[15] ibid

The first indication that there would be something worth studying was a aerial photograph in the New York Times newspaper showing a stone Mosque in Gölcük, with its minarets looking completely unscathed, completely surrounded with collapsed multi-story apartment buildings. The tall thin minarets seemed to defy common sense with all of the recently constructed buildings around them collapsed to the ground. The photograph was clear enough to see that the stone walls of the mosque itself were also unblemished.

As for traditional houses, rather than mosques and minarets, I had little expectation that any of the multitude of engineers who made a pilgrimage to the devastated region would include such structures in their documentation. In fact, one engineer from a government funded national research center did say to me *"oh yes, I saw some traditional timber and brick houses and they didn't seem to be damaged."* Photographs them? *"No, I did not because they did not seem to be significant."* It was at that point that I knew I would have to come to Turkey myself to see what could be found – not to look at ruins, but to look for what had survived.

I arrived in Turkey about six weeks after the earthquake. The earthquake was a rare event of great magnitude, and thus almost any building of whatever age was severely tested by it. It was for that reason that I wanted to see how the traditional construction in the damage district fared during the earthquake. However, I expected that it would be difficult to find examples, as most of the affected area had been developed recently. When I entered the heart of the area, it was clear that the damage to modern buildings was widespread. In some apartment complexes near Gölcük, every single building had been reduced in height by one story because of collapsed columns. Looking out over this one of many scenes of twisted multi-story apartment houses all leaning at cockeyed angles, it was as if the buildings had turned to putty.

It was near one of these complexes that we turned toward the Sea of Marmara to look further. Almost immediately, we stumbled on our first cluster of older brick and timber, or *hımış*, buildings. These houses were not of great age, mostly dating from the early part of the twentieth century, but they all pre-dated the destroyed reinforced concrete blocks which were nearby. It was also there that we saw the surface trace of the fault where the land had dropped 2.5 meters dragging buildings and people under the sea. Some of the *hımış* houses near there were damaged, but many of these seemingly crude and weak vernacular buildings had survived nearly untouched next to collapsed apartment buildings, where people were still digging through the rubble to recover their belongings.

It was as scene that was repeated in Adapazari. There, because of the softer soils, many buildings either collapsed or literally sank into the ground. What the news media did not show was that many of the older houses remained intact. It was here in one cluster that, with the help of some residents, I was shown around and could see a full range of damage to the timber and brick infill buildings from one that had totally collapsed to the others which had survived. What was important about this cluster, was that it was evident that the shaking in that location had been severe. Thus, one had the opportunity to see the characteristics of the damage that such traditional buildings would sustain in a large earthquake.

In the case of the one collapsed house, which was the only time that I had learned of a death inside a house of traditional construction, there was little to be learned from the indefinable ruins. It was the partially damaged buildings here, and also in Gölcük, that provided the story. As each building was inspected, and the damaged area in each building was identified, a pattern began to emerge. In many cases, the damage originated at areas of rotted timbers. Those with the most timber rot frequently turned out to have been unoccupied for years prior to the earthquake. It was not difficult to see or understand that the decay of the timber armature in the timber and brick infill house will significantly degrade its performance in an earthquake.

In addition to this observation, many of the fully occupied houses had been altered and modernized in ways that had corrupted the integrity of their original construction. In one case, the only seriously damaged parts of the building were the walls surrounding large horizontal picture windows that had been installed. The installation had required the severing of the timber diagonal braces and many of the studs. The house remained standing, but two walls with these new windows were blown out and the remaining walls on the ground floor level were damaged. In another, a new bathroom had been installed, with walls of heavy concrete to support the tile. This room had, in its entirety, punched through the side of the house and crashed to the ground. The rest of the house remained intact and almost unblemished.

This range of damage was actually instructive because it showed that the houses had not escaped the effects of the earthquake because of some local geological anomaly (the nearby collapse of modern buildings also appeared to counter that possibility). It also enabled one to study the progression of damage to this type of construction, and thus begin to understand how the traditional construction responded to large scale earthquake shaking.

My observations from the Kocaeli Earthquake included the following:

(1) The "working" of the house along the joints between the infilling and the timbers was manifested as cracks in plaster along the walls and at the corners in every house examined on the interior. On the exteriors of houses without a layer of stucco, such damage was impossible to see. The bricks themselves were only infrequently displaced sufficiently to make for visible cracks. The movement was primarily along the interface between the timbers and the brick panels, thus leaving no trace.

(2) The next level of damage was the falling of small sections of the infilling out of the enframing timbers. In other words, the construction method included little or no mechanical ties between the two elements to hold the infill masonry in place. It was also evident that the loss of some of the panels did not progress to a rapid degradation of the remaining panels in the same horizontal plane.

(3) Further degradation was most often manifested as separation of vertical timbers from the sill plate at the base of the structure, where timber decay was likely to be most prevalent. In one observed instance, this lead to the "sloughing off" of a wall, but, even then, the rest of the structure remained standing.

(4) Significant degradation of the masonry in the form of large shear cracks (that is the kind of cracks manifested in the infill walls within concrete buildings) within the masonry panels themselves was not observed.

(5) The subdivision of each structural bay with a progression of timbers diagonal, vertical and horizontal timbers, rather than simply with a row of studs, clearly helped hold the walls in place even if some panels of masonry had fallen out.

Strength versus capacity

Here from the same observation we encounter two possible ways to describe the damage, one positive and one negative. To use the term "working" to describe the behavior of the masonry infill when it sheds its stucco surface during an earthquake is in contrast to describing it as cracking, deteriorating or failing. The use of the term "working" describes the behavior as a positive one, emphasizing that it could continue safely over time. The use of the term "failure" focuses on the notion that the masonry is breaking and is progressing towards collapse. The problem with the use of the concept of "working" to describe an allowed-for behavior in existing masonry is that to allow for it, one must depart from the mathematically reliable logic of strength, and replace it with something that cannot be easily calculated – energy dissipation. This is inherently messy from an engineering point of view. The behavior of these buildings relies on a disorganized combination of materials being stressed in tension, compression, shear and bending all at once. If the earthquake forces were to become focused on one element in this interlocking puzzle, that element would be shattered. However, because of the role of the soft mortar and the internal damping it provides, this does not happen.

The basic principle in weak frame and infill construction is that there are no strong and stiff elements to attract forces. Strength can be used to describe the vertical load carrying capacity of the traditional structures, but these structures do not have much lateral strength. They commonly do, however, have sufficient lateral capacity. The difference in the meaning of these two words becomes particularly apparent when one deals with the question of why the traditional buildings stay up, when today's conventional wisdom may expect them to fall down. These buildings give into the earthquake forces by allowing incremental low-level damage in the form of the "working" of the disparate assembly of brittle materials. Although the masonry and mortar is brittle, and the individual timbers remain elastic, the system behaves as if it were "ductile."[16] If this process works properly during an earthquake, it is a process that can be carried on for a long period before the degradation advances to a destructive level. Thus the buildings overcome the earthquake simply by not fully engaging with it. In addition, the high level of damping takes out the danger of the building resonating with the ground, which is a principle factor in the cause of earthquake damage to buildings. That is the difference between strength and capacity.

While one could see a range of damage across different structures, it was hard to discern how the damage might be different in an earthquake of a significantly lower level. A chance to examine this awaited my return the following summer, and the trip to Orta just one day following the June 6, 2000, earthquake there.

A return to the Orta earthquake

Returning to what I began to describe of my observations in and around Orta at the beginning of this paper, I will try to explain some of the contradictions and questions that I raised when I described my survey of the damage in the rural villages. As I mentioned at first, it seemed to me that the level of damage to traditional structures was high when compared to the effects of the much larger Kocaeli earthquake the previous summer, especially when one considers how much smaller the earthquake was. It is one thing to find examples of traditional structures that had survived a great earthquake, but another if one finds the same level of damage from a much smaller earthquake. While the chance of loss in a great earthquake is hard to protect against, the same level of risk and vulnerability in a much smaller one would not be so tolerable.

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

Further investigation did reveal two features that modified my first impression. The first was that traditional construction in the Orta area was of divided into two types – one vulnerable, and the other, less so. Second, the higher level of damage and collapse to the less vulnerable type, the timber frame with brick infill, turned out to be limited to those buildings where the wood was heavily deteriorated prior to the earthquake. In those buildings that I was able to examine, the collapsed structures had long been unoccupied. This fact also helps to explain the complete absence of people being killed by collapsing walls.

Only the houses were constructed in timber frame with brick infill method. The barns, which were sometimes physically attached to the houses, were constructed of heavy wall rubble stone with some timber *hatıls* and vertical columns imbedded into the walls. Despite these elements – and as it turned out – sometimes because of them, the barn walls proved to be more vulnerable than the *hımış* construction. The vulnerability resulted from a number of factors: (1) The rubble stone construction, with rounded natural stones, is itself more vulnerable than horizontally bedded fired brick. (2) Many walls lacked any timber *hatıls* at all, or had few that were incomplete. (3) Imbedded vertical posts, where they did exist, extended only part way down the wall, and served to prevent the roof weight from bearing on the stone at the top of the walls. As it appeared from the brief survey, it was these imbedded wood posts that seemed to be responsible for the most damage. While they may have been inserted in the construction to help hold the building together in case stones came loose at the top of the walls, the effect in an earthquake is the opposite because they served to transfer of the weight of the roof off of the wall. A loss of overburden weight during an earthquake is devastating to an unreinforced masonry wall.

Turning to the houses constructed with timber frames with brick infill, it was clear that those where the critical timbers were not rotted fared quite well. All, however, manifested evidence of the earthquake's shaking. This damage consisted mainly of that described in number (1) level of damage observed in the Kocaeli Earthquake described above. There were a few examples of number (2), but it was rare. Almost all of the collapsed walls involved the rubble stone masonry described above, not the timber frame with brick infill.

What became evident was that the level of damage was similar to that observed for similar types of structures damaged by both the Kocaeli and the Düzce Earthquakes – both of which were far larger. To make the comparison, nearby modern reinforced concrete structures were examined in all three areas. While some of those near Orta showed evidence of damage, the damage appeared to be limited to "X" cracks in the exterior infill walls and the occasional falling away of some of the infill.

What lessons did I learn from seeing this? There are two observations that can be reported on here. The first is technical, and the second has to do with the human response.

The technical observation

From the technical level, the conclusion that can be drawn from seeing a similar level of damage to the traditional buildings in both the large and the smaller earthquakes, when the modern buildings show a progression from minor damage to destruction, is that the most important protective characteristic of the traditional construction may indeed be its ability to dissipate the earthquake's energy over a long period without undergoing a rapid structural degradation. This is true, regardless of the level of shaking. In effect, such buildings are able to take a lot of abuse because of the "energy absorption" provided by the "ductility" of the system.

This is the same reason that Gusain and Arya attributed the good performance of the buildings in Srinagar, Kashmir, but it in sharp contrast to the performance of the modern reinforced concrete buildings.[17] In fact, if one turns to the different reconnaissance reports that visiting engineers wrote after visiting the Kocaeli Earthquake damage district in 1999, almost all describe the many instances where collapsed buildings stood next to architecturally identical ones, which by all appearances looked minimally damaged.

While these same engineers may be searching for local ground motion differences and other scientific data for an explanation, the key to this puzzle may in fact be revealed more by observing both the traditional *and* modern reinforced concrete construction in the Kocaeli area, and comparing it to both types of construction in Orta. To do this may reveal as much about the reinforced concrete structures as it does about the traditional structures themselves. By comparing the damage to modern structures in both the Orta and Kocaeli Earthquakes, one can see that in general, the damage to the reinforced concrete buildings progressed from minor cracking of the walls, to complete destruction and collapse within a narrow range. In other words, while the reinforced concrete buildings appeared to be more than strong enough to come through the Orta Earthquake with little damage, they proved to have far less reserve capacity than did the traditional buildings. This was demonstrated by their comparative behavior in the much larger earthquake.

There, at the edge of the Sea of Marmara, the traditional *hımış* houses were found in condition that was very similar to those in Orta. However, in Gölcük, they were surrounded by concrete buildings, which were not just cracked, but which instead were shattered like dropped china pots. Even those concrete buildings which did survive were probably at risk of the same fate, but for some stroke of luck – better batches of concrete? – cooler weather during curing? – more partitions on the ground floor? – different orientation to their critical columns? – or any number of a myriad of things. One thing is certain, though. The difference between remaining standing and collapse fell within a very small range – a range that could be seen by comparing the two earthquakes, and then going to Gölcük or Adapazari and seeing what stood and what fell. This, again, is a demonstration of the difference between <u>strength</u> and <u>capacity</u>.

The human response

The second observation about the Orta Earthquake flows from the first – but stands in sharp contrast to the conclusions described above. It has to do with the human response to the earthquake more than an objective analysis of the damaged structures. However, as it turns out, the two are interrelated.

While I traveled about the damage district, I was often kindly shown the interiors of the houses and barns. While I was lead around, despite the language barrier, I noticed that there

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

was much concern and even fear for the condition of the houses. Some people had even set up tents in their front yard, and were sleeping in them. While this is a normal reaction to a concern over after-shocks, it became clear that many of these people were concerned that the plaster cracks were evidence the buildings were unsafe. What the first observation above shows is that it was not. However, how can the people know this? They could see the cracks, and the plaster dust and chips lying on the floor and it made them feel vulnerable.

This observation leads us to confront the central question in the conservation of buildings of archaic construction in the modern world. The issues described above may be discussed in technical terms, but ultimately they are human issues. Objective technical research and understanding can only go so far in helping to answer the concerns over risk and safety that living in earthquake areas inevitably raise. While it was evident in Gölcük and Adapazari that the modern buildings had failed to perform, as people believed they would, it was not entirely evident to the occupants in and around Orta that the older structures had performed well enough to be relied on. They had not seen, and therefore could not be expected to understand, that the traditional buildings in Gölcük had survived when so many modern buildings had collapsed. What they could see is that the damage in their own houses was more widespread than it was in the nearby modern concrete structures. The fact that it was largely plaster damage did not matter. By contrast, people in the Kocaeli and Düzce area could see that the traditional houses rode out the earthquake, while the larger concrete buildings did not. One 92 year old resident, Mehmet Bayındır, in the town of Handanoğlu, near Düzce, said: "*These earthquakes are tests from God, We should build houses the old way – from Chestnut wood. They don't collapse.*"[18]

It seemed evident to me that many of the people I encountered near Orta already wanted the Government to condemn their older houses and give them new homes of reinforced concrete. This was driven home to me when, as I was leaving one village where I had been led to almost every house, and where one family even insisted that I eat a meal with them, in their tent – one woman, grabbed me by the arm and literally tried to drag me to see the damage in her house. Despite the language barrier, they identified me as in some way connected with Government's decision on whether to help them get new houses. It was only a day after the earthquake, and thus way too early to see what the future would bring. Despite this, I gained the impression that the trend would be in the direction of building new homes. If that was so, those new houses will be reinforced concrete.

This then begs the question of what would have happened after a similar event in an earlier age – before both government assistance and reinforced concrete were available? What would the people have done then?

I suspect that the people would have set about repairing and rebuilding their own houses as they had over the centuries before. In fact, they may have benefited by observing what worked best, and what did not. To benefit from such observations, one must be disposed to ask the right questions. What has changed between the past and the present is that people have lost the kind of knowledge and familiarity with the construction of their own houses in the traditional way that they once had. This is true over much of the world. The importation of reinforced concrete building technology has often been so effective in displacing the native ways of building that the memory and understanding of those ways has effectively disappeared.

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[18] National Geographic Magazine, Washington D.C., Vol. 198, No.1, July 2000, P50.

Reinforced concrete depends on a vastly different building delivery system – a professional and external one. Construction is now undertaken by companies from outside the area who have access to the material and the equipment necessary to transport the concrete. The construction workers who know how to handle the material are also usually from outside the area. As mentioned earlier, a lack of knowledge can lead to fear, and therefore, it is quite possible that the kind of fear the Orta inhabitants had of their houses after the quake is shaped not just by the earthquake they felt, or the damage that they saw, but also by the times in which they live.

The message in all of this is an educational one – and this conference is one of the first steps in that direction. It is not that we should return to an age that has ended. The changes that have occurred in building construction are profound, but reversing them wholesale is neither a possible, nor a worthwhile objective. There are, however, some useful lessons that the study of these traditional buildings can bring.

(1) First, building conservation of historic vernacular structures can benefit immeasurably from better knowledge of the reliability and safety of traditional building construction in earthquakes. A great deal of the repair and reconstruction that takes place in historic towns in earthquake areas is highly destructive of the original fabric. The integrity of the original construction is as much a part of the historical record as is the architectural image.

(2) Second, contemporary construction can benefit from an understanding of the structural performance of the traditional structural systems. The principle lesson is that strength and rigidity are less effective in ordinary and unregulated construction than is flexibility, ductile behavior, and cumulative non-destructive damping. This is described in more detail below.

(3) Third. humility and respect for the work of past generations is an essential ingredient to full understanding of the contribution that this work can continue to make to the future. So much of the world's pursuit of modernization and the holy grail of "progress" has been fueled by a belief that we alive today know more and do things better than those who passed before us. To arrive in a scene of such devastation as I witnessed here in Turkey after the great earthquakes of 1999 and see these unsung, unnoticed indigenous brick and timber buildings standing among the ruins of the modern (and imported) world around was enough to give anyone pause. These were not sophisticated buildings, and they certainly were not engineered. None-the-less they had withstood an earthquake that brought down many of the more sophisticated buildings around them.

Lesson 1: Using the technology of the past in historic conservation: During the summer of 2000, I visited the historical village of Cumalıkızık, near Bursa, and discovered that this was an example of the kind of place that could benefit from the kind of knowledge and respect for the older construction that is being discussed here. What stood out was the number of the buildings that were undergoing radical restoration by replacing the lower story masonry walls with reinforced concrete faced with stone. The justification was that the concrete is stronger, but as we know, it is not necessarily longer lasting. Architecturally, the effects of this change were subtle, but significant – giving the buildings a kind of frozen and artificial look by erasing the effects of time that had manifested itself in the gradual movement of the original stonework. Stone veneer cannot have the same character as a genuine stonewall laid in mortar. In addition, the *hatıls* within the original wall were represented in the new wall by using thin strips of wood recessed into the surface only couple of centimeters. Ostensibly, these were intended to give the same visual effect as the *hatıls*, which they did not.

Lesson 2: Borrowing from the past for present-construction:

As strange as it may seem, considering the extreme difference between the old and new style of construction, there are a number of specific ideas that I believe might be derived from the traditional timber and brick infill style of construction. One is the introduction of smaller panels of masonry surrounded by studs (which, if not wood, may be pre-cast concrete, galvanized steel, or some other material) into reinforced concrete infill wall construction. These walls could be constructed instead of the large infill walls of hollow clay tile now almost universally used in reinforced concrete construction in Turkey and other parts of the world. If this were to be done, the infill walls will be able to take on the role of a secondary structural element, giving the buildings the kind of redundancy that many existing or future substandard concrete buildings will need in a large earthquake. This is similar in concept to the energy dissipating "cross walls" which are included in the new codes for the seismic mitigation of existing unreinforced masonry buildings in the United States.

2.1 "Cross-walls"

I shall use the term "cross-walls" to refer to the use of infill walls in new and retrofitted construction as proposed here, so as to distinguish them from "shear-walls." These "cross-walls" are not designed to be shear walls – in other words, they are not intended to act as the building's primary lateral reinforcing system. They simply are not strong enough for this alone. As a result, they do not have to be calculated mathematically into the primary structural design. What they become is a secondary line of defense against collapse, However, this is not a secondary defense that comes into play only after the primary system is broken, but one that is beneficial from the very onset of the earthquake (remember those cracks inside the Orta houses.) By beginning to crack – but also being able to remain stable and in place over the whole course of the earthquake – these walls will act collectively as massive energy dissipaters and sway dampers. Thus, they will serve the valuable function of taking the earthquake's energy out of the building, and also radically reducing the building's ability to resonate with the earthquake's motions.

In addition, should the reinforced concrete frame of the building nevertheless begin to degrade, the "cross-walls," as they distort, will begin to load the masonry infill in compression. Because these walls are restrained from falling out of the frame by their internal armature of studs, and because the masonry is strong in compression, they can provide a secondary support against collapse.

There are several caveats to make this idea work:

(1) The present use of thin-wall hollow clay tile blocks must be changed to stronger and smaller bricks. The hollow clay tiles used at present are like building with dinner plates. They have the advantage of being lightweight, but they are of insufficient strength, when compared to stronger and smaller bricks, to serve for energy dissipating cross-walls. The extra weight of the cross-walls should be offset by a considerable improvement in performance.[19]

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[19] For tall buildings, or other situations where the weight becomes an insurmountable issue, the use of hollow clay tile in the smaller panels proposed here instead of the bricks, can be considered. The performance of such walls will still be better than the present system of large wall panels, but not as high as if bricks are used. To be most effective for this, the hollow clay tile blocks should be produced to a smaller external dimension than the standard size used today.

(2) The mortar used for the infill masonry in cross-walls must be weaker than the masonry units. Such mortars are best if rich in lime, but lean in cement. The use of cement in mortar results in a strong, but brittle, mortar. This serves only to aggravate the possibility of concentrated cracking, rather than the distributed micro-cracking necessary for the "working" of the wall.

(3) The panels of masonry should be designed and constructed to ensure that they are held in place even if they become degraded during shaking.

(4) For exterior facades, the use of cross-walls as proposed here would be a vast improvement over the present-day use of hollow clay tile infill walls – as the hollow clay tile is so easily broken and thrown out of the frame, with the resulting cascade of lethal debris. However, to further protect from falling debris potential, cross-walls used on the exterior are best if covered by a cladding that can catch any loosened debris from falling outward.

(5) The subdivision of the infill walls into panels in much the same way as found in traditional construction is essential. This diminishes the likelihood that the surrounding frame will be damaged by the "equivalent diagonal strut,"[20] or that the infill will suddenly lose its effectiveness from diagonal cracking leading to collapse.

(6) Cross walls must be installed in both directions on all levels of the building. Mixing cross walls with the present-day standard hollow clay tile infill walls is unwise because the infill walls, being stiffer, will rapidly be knocked out of their frames causing hazards.

(7) Cross-walls do not necessarily need to be lined up one above the other as is best for shear walls because they are being relied on primarily to dissipate energy, not direct it towards the ground. However, it is important to have approximately an equal number of them in each direction on every floor.

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[20] In engineering terms, research has shown that the behavior of the standard modern infill walls is often equivalent to that of a "diagonal compression strut." When the frame deflects, it bears upon the infill wall on its upper corner. The stresses in the wall thus become concentrated along a narrow zone diagonally across the face of the panel. Until the infill wall itself collapses, all of the resisting pressure is delivered to the top of the column just below the intersection with the beam. This can be sufficient to cause the reinforced concrete column be sheared off, leading to the collapse of the structure. As a result of the danger of the equivalent diagonal strut, and of the shear failure of the infill walls, many engineers around the world have developed methods to provide a gap between the infill from the structural frame. Then the structure can be engineered to resist the code-defined earthquake forces within the more easily calculated strength and ductility of the moment resisting frame itself. While this can prevent much nonstructural damage in a minor earthquake, in a major earthquake, the frame can collide with the infill, causing a more dangerous condition than if there had been no gap.

The "cross-wall" proposed here, if designed as suggested and constructed with weak mortar, have the advantage of contributing to the overall capacity of the buildings without the pronounced diagonal strut effect. If the diagonal strut behavior were a characteristic of *hımış*, *dhajji-dwari*, or *bahareque* construction, the weak and insubstantial timber frames would have come apart at the very onset of earthquakes, which they have not.

For more information on the Equivalent Strut, see: R.E. Klingner and V.V. Bertero, Infilled Frames in Earthquake-Resistant Construction (Berkeley, CA: EERC, 1976); and N.J.N. Priestley, "Masonry," in Design of Earthquake Resistant Structures ed. E. Rosenblueth (New York: John Wiley & Sons, 1980), p. 216.

2.2 Building Codes

Another lesson that can be learned is to introduce the best aspects of what is learned from traditional building performance into the current building codes. This will be especially helpful and pertinent to countries where a traditional building tradition continues, or where traditional techniques must be permitted and encouraged to undertake the kind of conservation work advocated in Lesson 1 above.

There is often a tendency in areas where the adoption of a building code is being considered for the first time to default towards the kind of professional engineering-based code as is used in the United States, Europe or Japan. In many parts of the world, this is inappropriate, and will only serve to restrict the adoption of good practices of a traditional intuitive nature while the engineered approach may be simply unattainable.

In some of these areas, earthen or brick building continues to be built in a traditional way and local building codes have already been adapted to be inclusive of it.[21] Prof. Anand Arya in the University of Roorkee reports that good traditional practices have formed the basis for the Indian Standard Building Code #4326.[22] In Nepal, a new building code is in the process of being adopted. This code provides two sections for non-engineered buildings, including mud buildings. In this new code are provisions specifying that timber runner beams be laid into mud walls, and used in masonry construction. This is especially important because it improves on the traditional construction methods mentioned above that have proved to be deficient in earthquakes.

Lesson 3: Humility and respect for past construction practice:

It is so easy in our time of images and superficial effects, to believe that the cultural value of indiginous national styles of architecture is dependent only on the visual image. As I mentioned before, the comparison of the new hotels around the Haghia Sofia with their genuine stylistic predecessors shows a failure to qualitatively understand the Turkish vernacular style that they are trying to reproduce. Part of this is simply poor design training, but another part is the fact that these new buildings are totally divorced from the building tradition that their designers wished to reference. Imagine how Safranbolu would appear if all of its buildings were to be rebuilt in concrete, with the Turkish architectural elements simply fastened onto the exteriors as a veneer. Would the place be of interest? unlikely. Would it be culturally meaningful for its aesthetic value? No.

For some places where the architecture of which we speak does still exist, whether it be in Safranbolu or Cumalıkızık in Turkey, in Baktapur, Nepal, in Srinagar, Kashmir, or in the many other extant settlements with traditional buildings around the world, the effort directed towards public knowledge and awareness that we are undertaking in this conference is no less than an effort towards reclaiming important elements of each country's national heritage. It is not enough to preserve isolated examples of historic vernacular buildings traditions as if they are animals in a petting zoo, or, worse, to paste cute details borrowed from such traditions onto the facades of buildings constructed using alien technologies. As I have tried to demonstrate from the few examples above, there is more to the traditional

[21] For example see: Panayotis Carydis, "The Extent of the Problem of Earthen Buildings it Greece," International Workshop on Earthen Buildings (Albuquerque: University of New Mexico, 1981), p. 120. (The buildings constructed "have withstood the various earthquakes quite well.")

[22] Anand Arya, interview. (Arya participated in the preparation of this code.)

buildings than veneer. Understanding their structural characteristics is like getting to know someone in person, not just from a reflection in a mirror.

In the final analysis, it can give us a chance to step back for a moment to evaluate where we are now, based, not on a narrow view from the commonly accepted standards of our time, but in comparison with all time. In so doing, we can have the chance to notice the loss along with the gain, and, in so doing, re-capture some of the quality of inventiveness that is manifest in the traditional buildings of all national cultures. Only then, perhaps, it will be possible again to have new buildings reflect the identities of their local cultures, rather than add to the dead uniformity that so often characterizes modern buildings that are now so often interchangeable the world over.

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