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# 'Earthquake Resistant Traditional Construction' is Not an Oxymoron*:

## The Resilience of Timber and Masonry Structures in the Himalayan Region and Beyond, and its Relevance to Heritage Preservation in Bhutan

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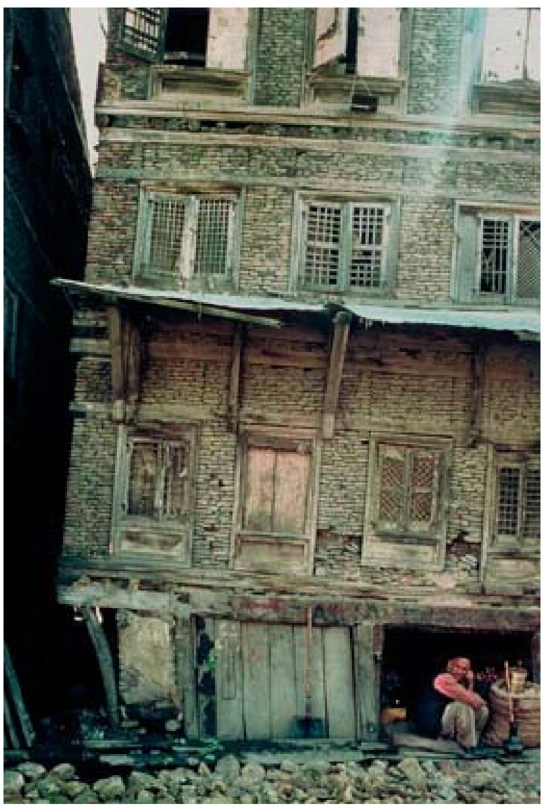

**Fig. 1:. How is it possible to consider this building as "earthquake-resistant construction"? This photograph was first published by the author in 1989, and has since become symbolic of what is counter-intuitive about the findings that such timber-laced masonry construction is earthquake resistant.**

The earthquake that struck an area of Bhutan on 21 September 2009 was not a large earthquake, compared to other destructive events in recent years, but it has raised concerns over the safety of the built environment in Bhutan – particularly that of its traditional stone and timber houses, some of which were badly affected by the earthquake. In addition to the actual damage, there is another risk to the cultural heritage of the country. One of the most profound risks to the vernacular architecture that come from earthquakes is not so much the actual vibrations, but people's understandable fear of them. Once people perceive their buildings as potentially hazardous – a perception often reinforced by engineers and government officials untrained in traditional masonry construction – the structures are at risk of being modified out of recognition or replaced with ones that look similar, but are only newly-created traditional-looking facades on modern frames of concrete or steel (Figure 52).

The recent history of construction techniques is illustrative of this concern. Throughout the Middle East and Asia, and also in much of Europe and Central and South America, common construction of buildings has shifted from traditional systems to reinforced

*An "oxymoron" is defined as a figure of speech that combines normally-contradictory terms.

concrete (RC) all at once within a single generation (Langenbach, 2009). This represents a profound change in more than simply the nature or existence of hidden structural members, but also a revolution in the entire building delivery process. It is also a change in the way that buildings are perceived and understood, including the perception of what is considered to be strong and permanent.

**Fig. 2: A model showing the timber-lacing in Kashmiri *taq* construction. Only horizontal timbers are placed, and timbers on the inside and outside faces of the wall are tied together like ladders. The joists are secured to the wall by the weight of the masonry above.**

**Fig. 3: A model showing the timber elements in traditional Kashmiri *dhajji dewari* construction. To form the exterior and interior walls, a single layer of stone or brick (fired or unfired) masonry is laid into the walls within the timber frame.**
*Illustrations from Langenbach, 2009.*

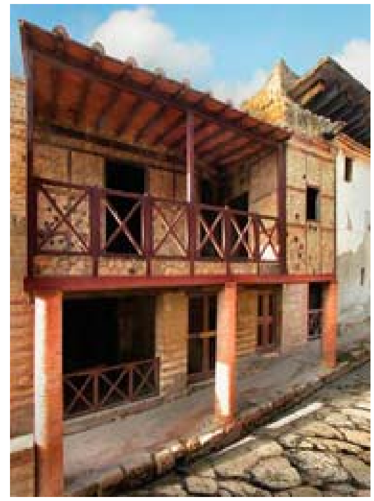

**Fig. 4: 2,000 year old Roman house in Herculaneum, Italy with timber frame and infill wall construction revealed after having been buried by the ancient eruption of Vesuvius.**

The consequences of these changes can lead to the rapid undermining of what sustains the domestic architecture of a society, region or country, even where the traditional architecture is as unique and recognizable as it is in Bhutan. Over time, timber floors are replaced and additions are constructed of reinforced concrete (figure 49 & 50) (Jigyasu, 2009). New buildings are designed with concrete frames, and the stone and timber used for the facades becomes nothing more than a veneer. For example, the battered masonry walls are one of the most identifiable characteristics of Bhutanese and Tibetan architecture, yet they lose their meaning if constructed with the exterior surface tapered towards the top without the original rational purpose, which is to support the structure with load-bearing masonry or rammed earth that is attenuated as it rises from the ground, so as to avoid excessive overburden weight at the base of the walls.

Frequently in Europe and North America buildings made of pre-modern construction of masonry have had their internal structural systems rebuilt with strong modern materials, saving only the facades and architectural features. Vernacular buildings, where the architecture and the structure are one, are effectively destroyed when this happens. For example, the ripping out of a wooden floor and its replacement with concrete, and the insertion of a concrete frame into a stone building is so radical that the heritage completely loses its integrity and thus most of its cultural significance (Figure 50).

Lessons learned from parallel environments in the Indian and Pakistan parts of Kashmir, as well as in Afghanistan, Iran, and Turkey, and even as in Italy, Portugal, and Central America, all help explain some of the hazards identified in Bhutan in a culturally compatible and sensitive way. In these places examples exist of pre-modern construction systems that have proven to resist collapse in earthquakes that may possess attributes that also exist also in some historic buildings in Bhutan, or if not, may embody ideas which could be usefully applied in Bhutan as ways to maintain and protect the historic masonry construction while avoiding the more radical transformations that are required if reinforced concrete or steel are used for seismic upgrade work.

**Earthquakes and modern national building codes**

Unlike other natural threats, earthquakes come without any warning. This leads to a fear of buildings that the comparative rarity of earthquakes cannot completely assuage. Getting out of harms way must take place during the event, and that act may even place the individual at greater risk than standing in place or lying down. This "Hobson's Choice" places a greater burden on designers and stewards of buildings than for other natural hazards.

Earthquakes are also the one natural force for which even the present day building code in many countries including Europe and the United States presumes a level of inelastic behavior in a code level earthquake, and thus an expectation and acceptance of structural damage (Langenbach, 2006) When following the codes for winds from hurricanes and typhoons, the expected maximum wind forces are used. However, this is not done for earthquakes. Earthquake forces are deliberately discounted because the forces are both so rare and potentially so large, as to make designing for them uneconomic and unrealistic for all except nuclear power plants and other critical buildings. Thus, engineering research has been used to establish force-reduction factors into the code. These factors are tuned to the expected ductility and robustness of the materials used in the structural system of each building to be constructed.

While this situation provides a reasonable basis for codes for new buildings, problems arise with the use of such codes for analyzing existing buildings constructed of materials that are no longer allowed by code. After an earthquake most buildings in an area need to be examined and evaluated, so the risk to historic structures is particularly profound. Rarely do the inspectors who are doing safety evaluations of damaged structures fully comprehend the underlying philosophy of the building code which presumes damage in an earthquake over a certain size.

This problem is particularly acute for masonry and timber buildings, because, in many countries, unreinforced masonry is often not even allowed for new construction, or it is treated as having little or no ductility, and thus is not given any meaningful force reduction factor. While this may seem reasonable for rubble masonry lacking any of the mitigating factors described below, it is not true for all types of traditional timber and masonry building systems. In earthquake after earthquake, there have been many examples of traditional forms of masonry construction that have survived in good enough condition to have met the intent of current earthquake codes (which, remember, are predicated on the expectation of damage). Many of the different forms of traditional construction found in India, Pakistan, Turkey, Greece, (Langenbach, 2007) and now, most recently, in Haiti, have proven in recent earthquakes to be more robust and considerably safer than many of the much more recent buildings made of reinforced concrete.

**Kashmir, India**

Srinagar is the capital of the India administered part of Kashmir, and it has for the most part escaped the rampant modernization that had erased similarly unprotected historic city centers in other parts of the world.

**Fig. 5:. Srinagar, Kashmir was fabled in the 19th century as a water-borne wonderland of canals and shallow lakes. Only one of these famed canals still exists – the Rainawari Canal, shown here in 2005. Many of the buildings tilt and lean seen here on the left because of the soft water-laden soils making the evolution of the timber-laced construction necessary for structural survival. It is this timber lacing of the masonry that has proven also to provide earthquake resistance.**

Most of the traditional buildings in Srinagar can be divided into two basic systems of construction. The first system, sometimes referred to as *taq*, 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, all of which is locked together by the weight of the masonry overburden (Figure 1,2 & 6). The second system, known as *dhajji-dewari*, consists of a braced timber frame with masonry infill. With its thin, one-wythe thick walls, it provides an efficient and economical use of materials, which helps to account for its use even for new construction until about two decades ago (Figure 3,7 & 9) (Langenbach, 2009)

These buildings were observed by Arthur Neve, a British visitor to Kashmir, when he witnessed the 1885 Kashmir earthquake, who reported: "*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…the whole house, even if three or four stories high, sways together, whereas more heavy rigid buildings would split and fall.*" (Langenbach, 2009)

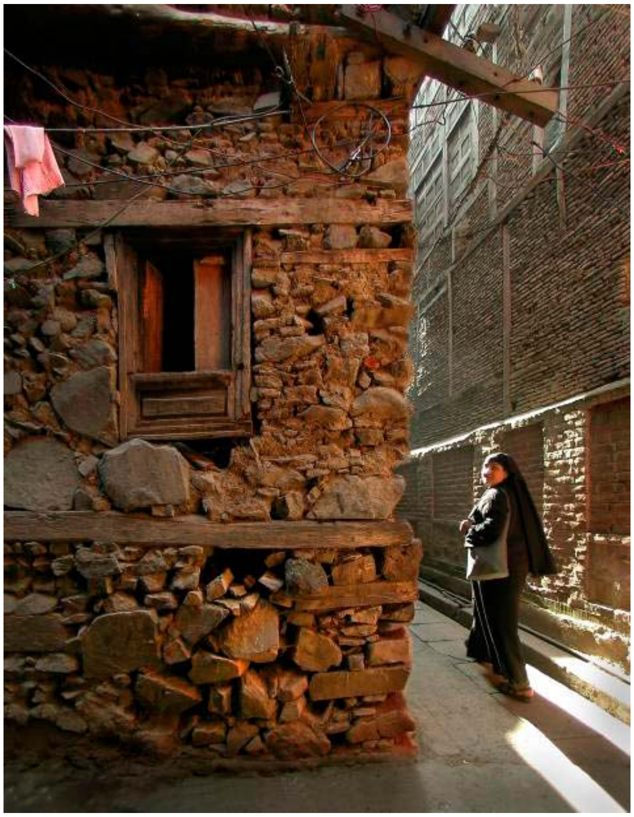

**Fig. 6:. Timber laced masonry in Srinagar, Kashmir, India. This is referred to as *taq* construction in Srinagar, and *bhatar* in Pakistan.**

More recently, two Indian engineers, N.Gosain and A.S.Arya ascribed the level of damage from a 1967 earthquake to the different types of traditional and modern construction in Kashmir: *"Perhaps the greatest advantage gained from [timber] runners is that they impart ductility to an otherwise very brittle structure. …This was substantiated by the observation that* dhajji dewaris *in which a larger volume of timber was used were comparatively safer."* Gosain and Arya note that during the 1967 Kashmir earthquake, buildings of three to five stories survived relatively undamaged. The research of Prof. Anand Arya 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."* (Langenbach, 2009)

On the 8th of October, 2005, an earthquake devastated the mountainous area of the Pakistan section of Kashmir, killing over 80,000 and rendering most of the remaining people homeless. On the Indian side of the border the damage was much less, but another difference was noticeable – the traditional construction as described above was rare on the Pakistan side of the border, where the massive death toll occurred. On the Indian side, the performance of the timber-laced traditional construction confirmed earlier findings. Professors Durgesh Rai and C.V.R. Murty reported: *"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)

The Kashmiri examples illustrate the division of timber-laced masonry into two sub-categories: timber-frame with infill masonry (infill-frame) known as *dhajji dewari*, and horizontal timber-laced bearing wall masonry, known locally at *taq*. In some locales these two types were used in the same building, with the timber-laced bearing wall system used for the ground floor and the infill-frame for the upper floors. Variations on these types of construction can be found across the seismically active belt that extends around the globe from Africa and Europe across Asia to Central America.

## Timber and masonry infill-frame construction

In addition to Kashmir's *dhajji dewari*, regional manifestations are called "*colombage*" in France, "*fachwerk*" in Germany, "*hımış*" in Turkey, and "half-timber" in Britain. Variations that used earthen plaster and sticks or reeds (wattle and daub) include Turkish *bağdadi* 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. A type that is best described as halfway between the masonry version and the wattle and daub version can also be found in Central America, where it is known as *bahareque* or *taquezal*. 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* (For more details, see Langenbach, 2007).

**Fig. 7: *Hımış* construction in Srinagar, Kashmir, India.**

**Fig. 8: Partially demolished dhajji dewari house in Srinagar showing the timber frame with the single thickness brick walls.**

**Fig. 9: In the 2005 Kashmir earthquake the unreinforced masonry front wall of this 4 story building collapsed, while the *hımış* wall above bridged over the collapse holding the side walls together, and thus prevent the complete collapse of the building.**

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 he identified as one of the masonry construction typologies described by Vitruvius as "*Opus Craticium*" (Figure 4). This example in Herculaneum may provide us with 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. 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 and infill masonry.

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 adoption and continued use of this system until the present time was most likely the successful byproduct of a technology developed as much for its economy as for its strength, rather than specifically because of earthquake risk.

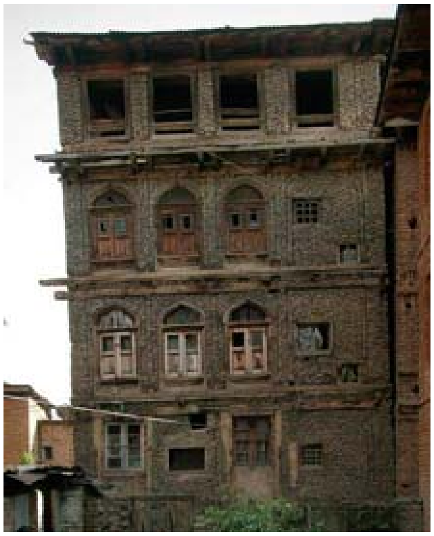

**Fig. 10: Four story house of *taq* construction in Srinagar on soft soils showing foundation settlement. The timber lacing has served to hold the building together.**

**Fig. 11: The resilience of *taq* construction is demonstrated by this building here held up with widely spaced timbers even though it is of brick in mud mortar bearing-wall construction.**

**Fig. 12: Partially demolished taq house in Srinagar showing the timber framing members which encircle the building at the floors and above the windows.**

## Timber-laced bearing wall construction

The historic origins of timber-laced-bearing wall construction can be found in the 5th Century AD Theodosian city walls of Istanbul, where the belts of red brick are an integral part of the architecture. Modern restorers, who reconstructed a portion of the walls mistakenly treated this only as an architectural element by applying a brick band as thin layer on the surface, rather than as a structural layer extending through the masonry (Figure 14). When the 1999 earthquake struck, this newly constructed section collapsed, while the surviving 1600-year-old heavily deteriorated portions of the wall were little affected by the earthquake (Figure 13). This system evolved into the timber-laced construction found in historic Turkish towns and villages today described below (Figure 15).

## The 1999 Marmara earthquakes and 2000 Orta earthquake in Turkey

Before the advent of reinforced concrete, houses in Turkey (as well as in Greece and parts of Eastern Europe) were often designed with the timber-laced bearing wall construction on the ground floor level, and the infill-frame (called *hımış*, pronounced "humush" in Turkish) used for the upper stories. The multi-wythe masonry bearing walls of the first story are often laced with horizontal timbers, serving a purpose similar but more effective than the brick bands in the ancient construction. In Turkish, the timbers are called *hatıl* (s) *hatıllar* (pl). In contrast to those used in Kashmir, these are often very thin timber boards laid into the wall at approximately one-meter intervals, placed so that they overlap at the corners. They thus serve to bind the stone layers together without interrupting the continuity of the masonry construction.

The Turkish Ottoman-style house, with its tiled roof and overhanging timber-and-brick bays above a heavy stone first floor wall, has become an icon known worldwide. The jetties provided more than extra space and light; they strengthen the buildings because the joists that cantilever over the walls below hold those lower-story walls firmly in place with the help of the weight of the infill masonry overhanging upper story. This upper story is almost always of *hımış* construction. This construction utilizes a weak mortar of mud or lime holding a single wythe of masonry into a timber framework of studs and horizontal dividers rarely more than 60cm apart. Because the masonry is only one wythe in thickness, the walls are light enough to be supported on the cantilevered timbers.

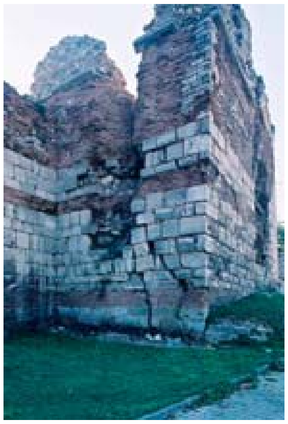

**Fig. 13: Original section of Theodosian City Wall, Istanbul after 1999 earthquake. The visible damage to these walls is from well before the earthquake.**

**Fig. 14: This tower is a modern reconstruction that collapsed in 1999 earthquake. The bands were one-brick thick for architectural appearance only.**

**Fig. 15: Abandoned earthen house near Yazıköy, Turkey showing timber hatillar. Notice that the timber bond beams are on the inside as well as the outside of the walls.** *Photo by Jacqueline Homan (Homan, nd)*

In those regions most affected by the 1999 Kocaeli and Düzce earthquakes, most of the settlements were industrial towns developed mainly in the 20th century. The Kocaeli earthquake of August 17, 1999 killed approximately thirty thousand people (Kandilli, 2000). The epicenter was just 200 kilometers east of Istanbul. In some areas of Gölcük and Adapazari, the earthquake destroyed more than a third of all housing units, almost all of them in reinforced concrete buildings (Kandilli, 2000). While the timber-laced bearing wall type was rare, there were clusters of *hımış* buildings in the heart of these districts (Figure 16). The houses were constructed of *hımış* from the ground up. These houses, mostly dating from the early part of the twentieth century, were nevertheless much older than the ruined reinforced-concrete apartment blocks nearby (Figure 17). Many of the older *hımış* houses remained intact with little damage except loss of interior plaster in spite of the fact that they were old. Indeed, some had been abandoned well before the earthquake and were in poor condition.

This finding was confirmed by researchers who conducted a detailed statistical study in several areas of the damage district. They found a wide difference in the percentage of modern reinforced concrete buildings that collapsed, compared to those of traditional construction (Gülhan and Güney 2000). Gülhan and Güney documented that in one district in the hills above Gölcük, of the 814 reinforced-concrete four-to-seven-story structures, 60 collapsed or were heavily damaged, while only 4 of the 789 two-to-three-story traditional structures collapsed or were heavily damaged. The reinforced-concrete buildings accounted for 287 deaths compared to only 3 in the traditional structures. In the heart of the damage district in Adapazari, where the soil was poorer, this research shows that of the 930 reinforced concrete structures, 257 collapsed or were heavily damaged and 558 were moderately damaged, while none of the 400 traditional structures collapsed or were heavily damaged and 95 were moderately damaged.

**Fig. 16: *Hımış* house in Gölcük, Turkey after the 1999 Kocaeli earthquake. This house, although old and abandoned, suffered almost no damage while many reinforced concrete buildings nearby collapsed.**

**Fig. 17: View of collapsed multi-story modern reinforced concrete residential buildings in Gölcük after the 1999 earthquake.** *Photo credit: UN ISDR.*

A smaller earthquake (6.1 magnitude) that struck the rural town of Orta on 6 June 2000 provided a comparison with the damage caused by the Kocaeli and Düzce earthquakes the previous year. In this smaller earthquake, the damage to the *hımış* structures was similar to those affected in the larger earthquakes (Figure 18 & 19), whereas the damage to RC structures was much less. This may explain why locally there is a widespread perception that RC buildings are safer.

**Fig. 18: Interior of *hımış* house in heart of damage district in Adapazari after 1999. This building was abandoned and in poor condition when the earthquake struck.**

**Fig. 19: Interior of *hımış* house in Orta after 2000 Orta earthquake. This building has been occupied both before, during and after the earthquake.**

**Fig. 20: Interior of partially collapsed multi-story apartment building in Golcuk after the 1999 earthquake showing how the hollow block unreinforced masonry infill walls have suffered a brittle failure contributing to the collapse of the building. This can be compared to the resilience shown in Fig's 17 and 18 of *hımış* construction.**

A comparison of the RC buildings affected by this earthquake with those in the 1999 earthquakes has revealed that the common RC buildings in Turkey have very little reserve capacity. While in the Orta earthquake, they exhibited little damage, both of the more severe 1999 earthquakes caused widespread collapses. This observation contrasts with the performance of the traditional *hımış* buildings shaken by the same earthquakes. The small difference in the damage caused by the smaller and larger earthquakes demonstrates their ability to absorb the much increased shaking with little increase in damage (figure17 & 18).

**The 2001 Bhuj earthquake in Gujarat, India**

After the large earthquake that struck western Gujarat on Republic Day, January 26, 2001, the scene of devastation was as appalling as that after the Turkish earthquakes in 1999 (Figure 21). Whole towns were completely leveled. In Bhuj, Anjar, and Bachau, the building stock consisted of an almost equal variety of older stone masonry and reinforced concrete structures, some with later additions in RC on top of the earlier unreinforced masonry.

**Fig. 21: Widespread collapsed of URM and RC buildings in Bhuj in 2001 Gujarat earthquake.**

**Fig. 22: Typical URM building in Bhuj in 2001.**

The masonry consisted mainly of rubble stone laid in mud or weak lime-mud mortar. The newer construction was of reinforced concrete, with infill masonry walls (Figure 22).

There was no evidence of shear-walls in any of the reinforced concrete buildings, all of which had weak masonry infill walls. The earthquake shook most of the rubble stone buildings to the ground; buildings with horizontally bedded ashlar performed better, but sections of their walls were often missing. Many of the RC structures appeared to have collapsed just as readily (Figure 21). Timber-reinforced construction, either the bearing wall type with horizontal timbers, or the infill-frame type, was extremely rare in Kutch. The only example found in this survey was a large building within the Swaminarayan Temple complex in Bhuj This building, which dates from the early 19th Century, was unscathed by the earthquake, while a modern reinforced concrete building right in front of it collapsed (Figure 23).

**Fig. 23: Swaminarayan Temple in Bhuj after 2001 earthquake with collapsed RC structure in front.**

**Fig. 24: Timber laced building in Ahmedabad.**

Interestingly, this temple was a branch of a Hindu sect based in the historic walled city area in Ahmedabad, and thus it shared with the Ahmedabad mother temple the same kind of structural system. This construction system demon-strated good performance in the earthquake even while a number of major reinforced concrete apartment complexes in Ahmedabad collapsed, the historic "walled city" section survived virtually intact. Many of the RC buildings had open parking areas underneath and other poor details. Of the tens of thousands of buildings in the walled city, only one was reported to have collapsed, and it had been previously abandoned. The difference between the masonry buildings in the historic walled city part of Ahmedabad and the walled city area in Bhuj, is the presence of timber lacing (Figure 24). The Ahmedabad buildings, including the Swaminarayan Temple, shared some of the building construction tradition found in Turkey and Kashmir, while Bhuj did not.

**The 1931 and 1971 earthquakes in Nicaragua, and 1986 earthquake in El Salvador**

A different variation on the infilled timber-frame system is common in several countries in Central America. This system, which most likely evolved from a merging of Spanish construction infill-frame practice with local Native American construction traditions, is known in Nicaragua as *taquezal*, or "pocket" system, and in neighboring El Salvador as *bahareque*. In these structures, a post-and-beam timber frame is constructed, and the walls set within the frame consist of a row of 5cm x 10 cm studs, approximately 60 cm on center. The timber frame consists of hardwood posts placed at the corners and at points in the walls about every 2 meters. Wood lath or bamboo is then nailed across the studs to form a kind of basket, and the resulting pockets are filled with layers of small stones (*taquezal con piedra*), or adobe (*taquezal con barro terra*). The wall is then usually plastered with a final layer of mud or lime plaster.

Buildings of this type at one time filled the Nicaraguan capital, Managua. In 1932 about 85 percent of the buildings in the city were of this type. American engineer J.R. Freeman reported after the 1931 earthquake that *"In the newer buildings of this type, the only serious damage was the shaking off of roof tiles and practically all of the plaster…*Tarquezal *[sic] construction bears resemblance in its timber frame work and in its safety from collapse and killing people within, to the* baraccata *type developed in Southern Italy a hundred years ago* (see below)*."* In 1971, however, the results were quite different. In a report by the Earthquake Engineering Research Institute, engineers observed that *"approximately 70 percent of the* taquezal *buildings in the central area of the city collapsed or were seriously damaged. This mode of construction was the major cause of the high death toll."* This same report recommends that *taquezal* should be banned in earthquake-prone areas such as Managua.

The October 10, 1986 earthquake in El Salvador provided the chance to study this apparent discrepancy. Examination of the damage to *bahareque* buildings revealed that almost every case of structural failure originated where the wood armature was rotted or eaten by insects. Those structures with a greatest level of damage were invariably those which were the most rotted or consumed.

It is interesting to note that Freeman anticipated the problem of wood decay in 1932: "*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*." By 1972, the existing *taquezal* buildings in Managua were, on average, older than they were in 1931. More significantly, less resistant North American softwoods had replaced the depleted supply of tropical hardwoods. These observations thus support a conclusion that that the primary cause of failures in this class of buildings was not the result of a defect in the structural system itself, but from environmental factors and lack of maintenance preceding the earthquake.

**Fig. 25: San Salvador *bahareque* building after 1986 earthquake. The shedding of the plaster is evidence of the flexibility of the building. The infill masonry still in place shows its resilience.**

In 1931, Freeman observed that *"the only serious damage was the shaking off of…practically all of the plaster."* Likewise, in San Salvador in 1986 there were many *bahareque* buildings where the plaster had fallen off with no evidence of damage to the underlying walls (Figure 25). The dislodging of the plaster from nearly the entire surface of the walls is evidence of the distribution of the earthquake stress throughout the wall, which is indicative of good behavior because the earthquake stress is dissipated throughout the wall with small movements between the masonry and wood of what is inherently a flexible structure. As a result, there is no single major destructive crack, and the energy of the earthquake is dissipated by the friction from the micro-cracking of the substrate which is confined between the studs.

**2010, a big year for earthquakes: Haiti and Chile**

In the 2010 7.0 magnitude earthquake in Haiti, it was remarkable how many of the late 19th century timber and masonry houses, even those with rubble stone walls, remained standing, while close to half of the reinforced concrete buildings in the city center collapsed or destroyed (figure 26 & 27). Most of the surviving houses were over 100 years of age, and many were of unreinforced masonry or timber frame with masonry infill construction, in French called *colombage* (Langenbach, *et al* 2010). Over a quarter of a million people died in this earthquake, overtopping the huge death toll of the 1976 Tangshan earthquake in China, thus making it the largest loss of life in an earthquake in 554 years (USGS). Most of those who died were crushed by buildings of reinforced concrete or concrete block.

**Fig. 26: Late 19th century "Gingerbread" house with a brick masonry ground floor and *colombage* upper floor in Port-au-Prince after the 2010 Haiti earthquake. Less than 5% of the 100 or more year old Gingerbread Houses suffered collapse.**

**Fig. 27: One of many of the Modern reinforced concrete office buildings in Port-au-Prince that collapsed in the 2010 Haiti earthquake. Approximately 40% of the buildings in the downtown area were partially or totally collapsed – most of which were reinforced concrete.**

**Fig. 28: A timber and masonry infill wall on a three story late 19th century building in Chile after the 2010 earthquake. At magnitude 8.8, the Chile earthquake was much larger than the 7.0 in Haiti, with strong shaking lasting over a minute.** *Photo by Luigi Sorrentino*

A little over a month after the earthquake in Haiti, an 8.0 in Chile managed to topple some very large modern high-rise buildings, yet much older buildings with timber and masonry infill construction survived, with their structural system revealed by the loss of their stucco veneer (Figure 28).

**An earthquake hazard mitigation "invention": the *Gaiola* after the 1755 Lisbon, Portugal and *Casa Baraccata* after the 1783 Calabria Italy earthquakes.**

One of the largest earthquakes ever to hit Europe struck Lisbon in 1755, which also unleashed a destructive tsunami and fire. In planning for the rebuilding of the central area, Chief Minister Sabastiao Jose de Carvalho e Melo (who later became the Marquis of Pombal), gathered a group of military engineers led by Manuel da Maia to determine the best manner of earthquake-resistant construction to use for the rebuilding. For this, they developed the *gaiola* ("cage"), which has become known as *Pombalino* construction. The *gaiola* essentially is a well-braced form of half-timber construction. After testing a prototype, they made its incorporation into the reconstructed buildings a requirement (Penn, et al, 1995). Many of the new buildings with the *gaiola* were five and six stories in height, and most of these remain standing today (Figure 29 & 30). At the time of the earthquake, timber infill-frame construction was common throughout the Iberian Peninsula, including Lisbon. The inspiration to use this system most likely came from the observation of half-timbered structures that survived the earthquake. Consistent with this, one eyewitness, Reverend Charles Davy, observed: *"With regard to the buildings, it was observed that the solidest in general fell first."* (Tappan 1914)

**Fig. 29: Lisbon area rebuilt with *Gaiola* walls after 1755.**

**Fig. 30: Typical *gaiola* wall exposed in remodeling project.**

**Fig. 31: Lab test of *gaiola* wall.**

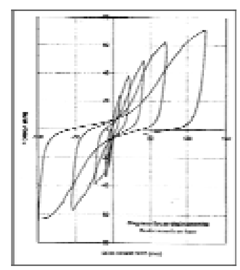

**Fig. 32: Hysteresis loop of *gaiola* wall.**

The seismic capacity of the Pombalino walls was recently tested in the Portuguese Government's lab by subjecting actual wall sections removed from a building to cyclical tests. The wide hysteresis loops (one of which is shown in Figure 32) from these tests show that the walls were able to dissipate energy over many cycles without losing their structural integrity. The sample remained largely intact despite having been pushed cyclically beyond what would be expected from a large earthquake (Cóias e Silva, 2002 & Santos 1997). The loss of plaster shows, just as it did in Nicaragua and El Salvador, that the forces were distributed across the wall section (Figure 31 & 32).

The only other known example where a similar anti-seismic system was developed is in Calabria and Sicily, where there had been frequent devastating earthquakes, including one in Calabria in 1783, 28 years after the Lisbon earthquake. This Italian system, known as "*Casa Baraccata*," was likely influenced by the Portuguese "*Gaiola*." In Italy, the *Casa Baraccata* became the underlying basis for an extensive series of manuals of practice, and even of patent applications for seismic resistive construction techniques up until the beginning of the 20th Century (Barucci, 1990 & Tobriner, 2000). Both the *Pombalino* and *Baraccata* systems are significant because they were deliberately developed and selected as earthquake-resistant construction. While it is hard to firmly establish whether the earthquake risk influenced the adoption or proliferation of other infill-frame examples of traditional construction, the gaiola and baraccata provide definitive instances where the infill-frame was promulgated and even required by law because of its earthquake-resistant qualities.

**Why did these forms of earthquake-resistant construction emerge?**

While the choices made in the "invention" of the *Gaiola* and the *Casa Baraccata* are reasonably well documented, one may ask whether the other systems described above emerged because of earthquakes. This is a question that remains debated, and for which there are no clear answers. British geographer Jacqueline Homan explains the basis for what is called a "seismic culture" with the example in Turkey of the *hatıl* used in the areas of Turkish Anatolia where earthquakes have occurred periodically. She documents its use from its early origins, through its use as brick bands within the Theodesian Walls around Istanbul, to the beginning of the modern era where it is wood bands on the inside and outside surface of earthen and masonry buildings (figure 13 & 14). She quotes a number of scholars who have observed its effectiveness in earthquakes, and she goes on to say that it forms a precursor to ring beams which are now found in the building codes for masonry construction.

A contrasting example to the argument that a "seismic culture" is generated by comparatively frequent earthquakes, however, is the 2001 Gujarat earthquake cited above where the absence of such features in the masonry buildings in Bhuj contrast with the presence of such features in Ahmedabad. Two or three large and often devastating earthquakes a century have struck Kutch – a frequency that one would think would have encouraged the kind of "seismic culture" of which Dr. Homan writes, but the masonry construction (and now also the RC construction) in that area has repeatedly proved to be unusually vulnerable despite the repeated widespread damage and deaths from prior earthquakes.

In fact, it is significant to find that the one building with timber lacing in Bhuj was constructed by an Ahmedabad-based religious organization. Interestingly, Ahmedabad was a Mogul city, while Bhuj was a Hindu princely city-state, and it is possible that the construction technology manifest in Ahmedabad and absent in Bhuj resulted from the cultural and technological influences that extended through the Islamic world from Turkey to Mogul India. The construction in 1822 of the first Swaminarayan Temple by a Hindu sect in Ahmedabad, and later in Bhuj, with the timber lacing helps to demonstrate that such influences were part of a secular culture that may have come into India along the trade routes, rather than having a religious connection. This shows how construction typologies are often defined by inter-regional cultural influences as much as by local environmental factors, with differences that are sometimes manifested from one city to the next even within a small geographic area, which may explain in part why in Bhutan there is not more evidence of the use of timber to mitigate risks to rubble masonry walls.

Another example is the difference between Kashmir and Nepal. Many masonry buildings in Kathmandu, including the Palaces, temples and houses were severely damaged in a large earthquake that struck the cities and towns in the Kathmandu Valley in 1934 (Figure 33–35). Comparing the photos and accounts of this with the descriptions of the 1885 earthquake in Srinagar, Kashmir does reveal a difference, a difference born out by the author's inspection of traditional building construction in Kathmandu in 2000 and 2005. (Compare figure 10 to figure 36).

**Fig. 33: The Patan Durbar Square with the Keshav Narayan Chowk *left* and the Degutale Temple *right* after the 1934 earthquake. The temple is totally collapsed, and the rear wing of the Palace collapsed.** *Photo credit: www.asianart.com*

**Fig. 34: Similar view of Patan Durbar Square after the 1934 reconstructions. The palace was again in such bad repair by 1980, that it was rebuilt in its entirety as a museum between 1983 and 1992.** *Photo Credit: (Hagmueuller,2001).*

**Fig. 35: Patan Durbar Square in 2000, showing the cluster of monuments, temples, palaces and shrines that give character to this extraordinary space. A large stone plaque at the entrance to the square with a lengthy 260-word paragraph history of the buildings on the square describing their construction in the 17th and 18th centuries, which says absolutely nothing about the 1934 earthquake, and the fact that the present structures on the right have been entirely reconstructed. What is important from a cultural heritage perspective, though, is the fact that all of the reconstruction has been done with traditional materials and methods using the original pieces or new materials made in the traditional way, even though in the later restorations, some earthquake hazard mitigation work has been added. Interestingly, the column in the center was not toppled by the earthquake, as can be seen in Fig 33.**

Why the difference? Interestingly, like with Ahmedabad and Bhuj, Kashmir is predominantly Islamic while Nepal is Hindu. Again, this difference only speaks to the possible cultural influences rather than religious differences, as Srinagar was much more culturally tied to Iran, Turkey and the rest of the Middle East than was Nepal. However, there is a much more compelling reason why Srinagar, even when compared to Turkey, exhibits one of the most well developed systems of timber lacing in masonry – soft soils.

Fig. 36: Lacking timber lacing found in Kashmiri houses, the unrestrained brick walls of this house in Kathmandu are visible coming apart from differential settlement and perhaps some minor earthquake tremors.

Srinagar is located on a prehistoric lakebed that is far softer and more water laden than is the alluvial plane at Kathmandu. This extreme condition mandated utilization of the timber lacing for basic structural integrity concerns, the absence of which would result in the buildings breaking apart even before an earthquake.

Historical innovations in construction technology most often are found to resolve problems that are immediate and continuous, while earthquakes may come only once or twice a century, or even less frequently. Thus, it is valuable to look for other factors that have contributed historically to the evolution of earthquake resistant traditional construction practices – but thanks to modern communication and media one can now benefit from a knowledge of such systems worldwide. Hopefully some of this knowledge can help offset the headlong universal rush to remake the cities and towns of the world in reinforced concrete – a phenomenon from which not even Bhutan has been able to escape.

**Non-engineered Traditional Construction and the establishment of Building Codes**

The development of building codes for traditional construction has evolved later than for the modern reinforced concrete and steel construction, and with greater difficulty. Traditional masonry and rammed earth are solid wall systems for which the frame analysis procedures common to steel and concrete frame design cannot be used.

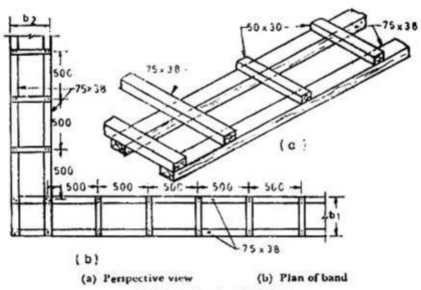


Fig. 37: Illustration from Indian Standard 13828, the Govt. of India code for *Low Strength Masonry Buildings* published in 1993. These ladder-like timber frames are exactly what is hidden in the walls of traditional *taq* construction in Kashmir, as seen in Figure 1,2 & 6.

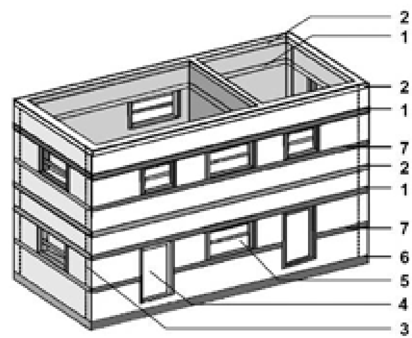

Fig. 38: Illustration from the Govt. of India Ministry of Home Affairs *Guidelines for Earthquake Resistant...Masonry Buildings in Jammu & Kashmir State,* which advocates "seismic bands" for new construction not unlike those found in traditional *taq* houses in Srinagar.

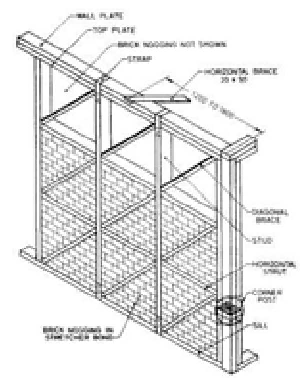

Fig. 39: Illustration from same document as Fig 42 showing the codification of traditional *dhajji dewari* construction as code-conforming construction in India for new buildings.

Another problem is that masonry and rammed earth walls are expected in earthquakes to exhibit non-linear behavior (that is to begin to crack) almost from the onset of shaking. This makes it very hard to establish a scientifically valid methodology for calculating the behavior of masonry or rammed earth in all of its infinite variety of different bonds, materials, and sizes of walls in the same way that linear elastic equations drawn from the building code are used to proxy for both elastic and inelastic behavior of steel and concrete frame structures to be subjected to future earthquakes.

However, in India a different approach has been taken towards the drafting of codes which has also been adopted in Nepal and by other countries as well. The government of India recognized the need to partition the codes between those for "engineered" buildings and those that are smaller and built of traditional materials, including "low strength" masonry and unfired clay. Recognizing that these buildings will be built regardless of applicable codes, "rules of thumb" and guidelines have been promulgated in these codes rather than strict formulas and complex equations.

Prior to the adoption in 1993 of the current Indian national codes, one of the principle authors of these codes, Anand Arya, Professor of Engineering at the Indian Institute of Technology in Roorkee chaired an international committee of experts of the International Association for Earthquake Engineering (IAEE), in producing the first edition of the *Guidelines for Earthquake Resistant Non-Engineered Construction* in 1986. This helped to further this process along by providing international recognition of traditional "non-engineered" construction which is so ubiquitous and important in many parts of the world, particularly in rural areas. The committee of experts who produced this book had representatives on it from China, Indonesia, Japan, USA, Mexico, Peru, and the USSR.

**Fig. 40:** *(left):* **A rural Pakistan family whose rubble stone house collapsed in the 2005 Kashmir earthquake are rebuilding their house using *dhajji* construction after witnessing that the one building in the village that did not fall down was of *dhajji* construction. The others of both rubble stone and reinforced concrete were collapsed.** *Photo by Maggie Stephenson, Un_HABITAT. (right)* **A new *bhatar* building under construction in the northern Pakistan to show government-approved detailing for *bhatar* after this system was approved for earthquake reconstruction.** *Photograph taken in 2007 by Tom Schacher for the Swiss Agency for Development and Cooperation (SDC).*

In Pakistan, where codes were less developed than in India at the time of the 2005 earthquake, the need for regulation of the rebuilding was met first with the issuance of requirements that made post-earthquake grants for reconstruction contingent on the use of government's approved earthquake-resistant construction. This was initially limited by the Government only to reinforced concrete frame or concrete block with concrete slabs for floors and roof. One year later, with influence from international NGO's working in the disaster areas, the government's Earthquake Reconstruction and Rehabilitation Authority (ERRA) approved the use of *dhajji dewari,* and, during the following year, a *bhatar* (Pashtun for timber-laced bearing wall construction). Five years after the earthquake, UN-HABITAT has reported that over 250,000 *dhajji* new houses have been constructed in the damage district.

**Mitigation after the 2009 Bhutan Earthquake**

The typologies of construction from around the world described above can provide important points of reference when examining earthquake damage to Bhutanese traditional construction. It is important to identify the weaknesses and strengths that are related to the traditional ways of building and separate them from faults introduced as a result of inappropriate recent changes.*

There are also other areas in the Himalayan region with variations of both frame and bearing wall timber and masonry construction that have not been described here, including Afghanistan, the Northern areas of Pakistan, Northern India and Tibet which could also provide source material for understanding the context in which Bhutanese vernacular architecture and building construction practice has evolved. The following observations touch on some of the issues involved in mitigating earthquake hazards in traditional buildings.

**Fig. 41: Earthquake-collapsed adobe (in Farsi known as *khesht*) building in Bam, Iran with roof of steel and fired brick. The buildings with mixed traditional unfired clay brick with steel and fired brick floors and roofs proved particularly vulnerable in the 2003 Bam earthquake.**

**Fig. 42: Interior of a traditional unfired clay brick vaulted building in Bam after the 2003 earthquake showing earthquake damage, but no collapse.**

The 2009 earthquake damage reports (Jigyasu, 2009 & Sethna, 2008) suggest that buildings in Bhutan of more recent vintage suffered greater levels of damage than some of the older ones, particularly if the older ones had been well maintained. This may illustrate the loss in recent years of the essential knowledge and skills necessary for good craftsmanship. It may also be explained by and inappropriate juxtaposition of old and new technologies. If this proves to be the explanation, it would be consistent with observations made in Turkey and Iran after much larger recent earthquakes.

In Bam, Iran the earthen construction was commonly blamed for collapses, but the most lethal buildings ironically turned out to be those with modern steel and fired brick

* To gain valuable data on the performance of traditional buildings, a useful project could be to assemble a full database on the performance of buildings in the 2009 earthquake within each affected village in the damage district. There is always a tendency after an earthquake for people to photograph damage far more often than to photograph those buildings of similar construction that have come through the event with little visible damage. However, the best information for mitigation of risks may lie in those buildings which have manifested less damage when subjected to similar levels of shaking.

masonry roofs on adobe walls, rather than those adobe buildings with the older system of adobe masonry vaults. These and other examples of the earthquake failure of buildings where pre-modern and contemporary construction technologies have been combined can serve as a warning of the potential perils of intermingling modern construction in reinforced concrete with existing traditional construction in heritage buildings undergoing repair and seismic strengthening work.

***Stone masonry construction in Bhutan***

The Bhutanese traditional buildings in the central and eastern part of the country are most often made of unreinforced masonry bearing walls with timber floors, sometimes with roughly shaped stones set in a mud mortar. The conventional wisdom is that such construction is particularly vulnerable to damage in earthquakes, and some indeed were damaged in the 2009 earthquake (Figure 43 & 44).

**Fig. 43: Damage to a masonry with clay mortar house from the 21 Sept. Earthquake.** *Photo by Mark LaPrairie for the World Bank*

**Fig. 44: Damage to a masonry house from the 21 Sept. Earthquake.** *Photo by Mark LaPrairie for the World Bank*

There does not appear to be the tradition of timber lacing in Bhutan that is found in Kashmir or Turkey; however, the extensive use of wood and the thick battered masonry or rammed earth walls found principally in some of the more monumental buildings, including the *dzongs, goembas and lhakangs,* may provide a greater level of resistance than initially assumed. Almost all traditional houses have timber floors and roof systems, as well as internal columns and framing members. In addition, one of the signature elements of traditional Bhutanese, as well as Tibetan and Nepali, architecture are the heavy window frames – elements which often extend from floor to the cornice below the roof on the upper floors of the houses. In the lower stories, they are more often recessed into large openings in the masonry walls. For environmental reasons in rural architecture, these window-walls primarily face south, with the north wall having fewer, if any, penetrations.

Many of the domestic and religious structures are constructed with a timber frame infilled with woven wood slats covered on both sides with plaster, a system which is both light and robust. Not only is it earthquake resistant in and of itself, but its common use for all or most of the upper story walls in many houses as a projecting element known as a *rabsel* helps hold the underlying unreinforced masonry walls in place by imparting an overburden load onto the walls – which makes them more resistant to lateral forces than if they were only overtopped with a roof. The *rabsel* is perhaps the most iconic element in Bhutanese vernacular architecture. A continuation of this type of timber framed with wattle and daub panels used in the *rabsel* is consistent with good earthquake-resistant practice, however the smaller segments of stone walls or earthen that extend up above the first floor level may be unusually vulnerable unless securely tied to the supporting structural elements.

Future studies in this region should divide the building typologies by different features, such as those which have masonry walls that extend to the roof, compared to those which have a full story of timber frame with wattle and daub construction, which is described below, with unreinforced masonry walls below. This could give an indication of what level of protective effect this type of top-floor timber frame construction has had on the masonry walls below during the earthquake.

In the masonry buildings the characteristics of the masonry itself must be addressed. While there may be little visual difference on the exterior, some buildings may have better bonding through the wall with longer stones, and more consistently horizontally bedded masonry with less rubble stonework either in the core or the interior and exterior faces of the wall. Also, some may have lime mortar while other have only mud mortar. The better bonding and use of lime mortars is likely to improve earthquake resilience, which may explain discrepancies in the performance observed with traditional buildings in the recent earthquake.

***Rammed earth construction***

In the western part of Bhutan, the typical historic construction is with 80-100cm walls of rammed earth instead of stone (Figure 47). Earthen construction is one of the most common building systems in the world, but, as the earthquakes in Bam, Iran and in Chile have shown, earthen construction presents significant mitigation challenges to deal with the earthquake risk. However, as seen in Bam after the 2003 earthquake that devastated that city, not all unfired clay structures collapsed. Most revealing was the discovery that many unrestored and unmaintained structures which were even of ancient origin, survived the earthquake in the heart of a damage district that saw the collapse of modern steel frame buildings as well as the earthen structures within the ancient Arg-e Bam that had been restored in the 20th century! (Figure 45 & 46)

**Fig. 45: The *Arg-eBam*, or Bam Citadel, which includes the walled city that surrounded the governor's palace, almost entirely collapsed in the 2003 earthquake. The parts that collapsed had all been reconstructed or restored from 1950 onwards. Ironically, those parts that had not been restored suffered less damage or remained undamaged.**

**Fig. 46: The *Ghal-e-Dokhtar* (Castle) in Bam. This earthen structure (*chinneh* in Farsi for built up, but not rammed, earth) survived the earthquake with very little damage. It has not been altered or maintained in over 150 years, providing a remarkable example of earthquake resilience in an ancient earthen structure. (**See Langenbach, 2004 for more information**)**

In recent decades, a number of scholars, engineers and architects in different parts of the world, including Turkey, Peru, and India, as well as Europe and the United States have researched the seismic risk and behavior of rammed earth and other forms of earthen construction, including cob and adobe. Some of this has led to the further development of codes that are more detailed and specific to unfired clay construction than those adopted in India in the 1990's.

**Fig. 47: Historic Rammed earth building in Thimphu now becoming surrounded by the expanding city of concrete multi-family housing.** *Photo by the author while in Bhutan for the "Living in Harmony with the Four Elements" Conference.*

This work can be a resource for research and code development in Bhutan specific to the kind of rammed earth tradition that exists there, and as reported by Cambridge University student Zareen Sethna, in a research paper on Bhutanese rammed earth construction, there is a need for it in Bhutan. In her paper, she made the observation that "*the lack of a code is acting as a barrier to rammed earth construction*" (Sethna, 2008). Her paper was based on interviews with Bhutanese architects and engineers, and one of her interviewees, an engineer is quoted as having told her: *"We can't offer mud rammed structures to clients since there is no code."*

This comment highlights the intersection between time-honored traditional ways of constructing buildings and the modern world, with its segmentation of the building process into the distinct disciplines of engineering, architecture, and governmental regulation. Earthen construction is rarely a part of a modern engineering curriculum, and for practicing engineers the absence of codes or other accepted professional methodologies for rammed earth leaves them without accepted professional standards with which to undertake the design of such a project in a seismic zone. For example, an architect, also quoted by Zareen Sethna, said that the Thimphu City Corporation *"wanted to make this two-story rammed building "earthquake safe" by following standards and codes applied for masonry construction. For instance, they insisted that we use galvanized iron pipe or steel rods as vertical reinforcement, which... is incompatible for carrying out proper ramming."*

**Traditional is Modern: The Preservation of Cultural Heritage in the context of earthquake safety**

Both pre-modern and modern building systems call for hazard mitigation strategies particular to each individual building, as well specific to each particular building type. For the Bhutanese buildings with both rammed earth and stone masonry walls, the strengthening and stiffening of the floors and roof structures to make them into functioning diaphragms could be the most important step to take, yet, there are risks if this is done in ways that are unresponsive and unsympathetic to the nature of the older building materials and systems. In Italy, up until relatively recently, wooden floors have frequently been ripped out of buildings and replaced by reinforced concrete slabs. Earlier earthquake engineering theory viewed this as beneficial, as the diaphragms were strong and rigid, but now, with the evidence provided by recent earthquakes, there have been numerous conspicuous examples where this treatment has proved to be counterproductive, even to the point of causing collapse. Instead of damping the vibrations and dissipating energy, the heavy floors tended to increase the earthquake forces and transmit destructive vibrations into the masonry walls at high frequencies. As a result, the masonry was often found to have fallen away from the concrete portions of the buildings leading to collapse or the ejection of the concrete element with extensive damage.

Now in Italy and other countries the approach is more often to strengthen and slightly stiffen the existing timber floor and roof diaphragms, rather than replace them with rigid concrete slabs. In addition, of critical importance, is the securing of the existing masonry walls around the entire perimeter of the buildings. Seismic hazard mitigation for masonry and earthen-walled traditional structures that respects and utilizes the existing strengths and qualities of these traditional structures while improving their performance with modifications that are consistent with their historic structural integrity and cultural significance, not only preserves their cultural heritage, but can also often lead to demonstrably safer results.

If Bhutan's masonry, rammed earth, and timber building traditions are replaced with reinforced concrete construction that is alien to the culture of the region and the nation, and especially if constructed with a disregard of the sophisticated requirements necessary for safe construction in concrete, the nation's earthquake hazard will actually be increased, rather than reduced. In addition, the sustaining effects of the learning of skills that are indigenous and imbedded in the culture of the country will be gradually lost, as the business of building construction is shifted to large corporations that make and deliver cement and steel and to contractors who have little knowledge or respect for the traditional crafts.

**Fig. 48: This building in Thimphu is an example of the use of iconic elements from Bhutanese vernacular architecture on an outsized modern steel and concrete building. The absence of traditional construction materials and methods leads to a conspicuous departure from the essential character that makes traditional Bhutanese architecture so distinctive and of high artistic quality.**

**Fig. 49: A Bhutanese traditional masonry and timber house in Rongthong Ngat-shang with modern RC additions attached to it. In the event of a significant earth-quake, these additions, which lack shearwalls, are at risk of collapse. Their weight also increases the risk of damage or collapse of the historic house.** *Photo credit: UNESCO Report by Jigyasu & Karanath.*

**Fig. 50: Interior of traditional house where the timber structure of the first floor has been demolished and replaced with reinforced concrete resting on its own reinforced concrete frame. Notice that the columns do not line up with the beams, which is usually a poor structural detail.** *Photo credit: UNESCO Report by Jigyasu & Karanath.*

Cultural heritage in Bhutan is so valued that it is the subject of Article 4 of *The Constitution of the Kingdom of Bhutan*, ahead of all but three of a total of thirty-five articles. In addition, the "*Preservation of Traditional Art and Culture*" is one of "*nine guiding principles"* of Bhutan's modern development goals (Royal Govt.,n.d). Timber and masonry construction in Bhutan has evolved over the centuries in ways that the builders and occupants learn through the direct handing down of knowledge, rather than from foreign interpretations of what is "modern." It is within the prerogative of the Government of Bhutan to develop codes which are consistent and supportive of the very advanced work already done to preserve the nation's iconic stylistic traditions with the publication and dissemination of the government's "*Traditional Architecture Guidelines*." (Royal Govt., n.d.)

Modern construction materials and methods have provided extraordinary opportunities for new spaces, forms, and ways of building.. But in many parts of the world they have also been disruptive of local culture, resulting in building forms that are alien to the local society, even where perceived and promoted as safe and modern. Earthquakes have proven to be particularly unforgiving when the new ways of building are not well enough understood locally to be carried out to an acceptably safe level of quality. By learning from indigenous pre-modern examples of earthquake resistant technologies we can also help preserve the surviving examples of these now seemingly ancient ways of building in ways that respect what these buildings are, not just how they appear.

As the world moves from an era of profligate energy use to one where fossil fuels are gradually depleted, sustainability and "green" have become the catchwords in building design and construction. In this respect, wood is nature's most versatile renewable building material, and stone and unfired earth, together with wood, represent the most energy efficient materials available. To this can be added fired brick and lime mortar, which require far less energy to manufacture than Portland cement and steel. Thus, honoring traditional vernacular construction practices that have performed well against one of nature's strongest forces can provide a lens through which one can see that preservation of vernacular buildings represents far more than the saving of frozen artifacts. It is an opportunity for cultural regeneration — a reconnection with a way of building by people who traditionally had learned how to build successfully for themselves with materials readily at hand.

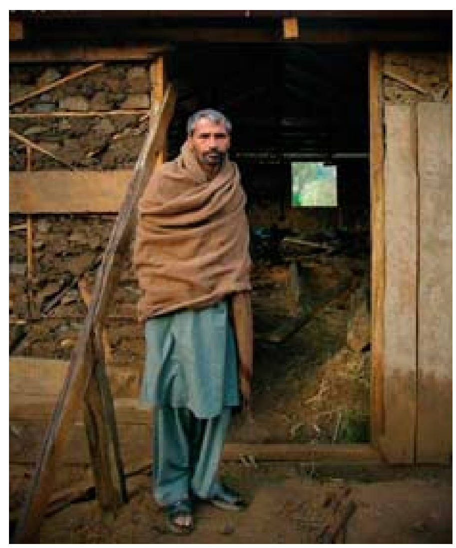

**Fig. 51: These rural farmers in remote parts of Pakistan Administered Kashmir lost their rubble stone houses in the 2005 earthquake. They were photographed in 2007 standing in front of the houses they were rebuilding with their own hands using *dhajji dewari* construction. They and many others in these same villages began to reconstruct their houses using this traditional technology well before the Pakistan Government agreed to provide financial assistance for reconstructions in other than the government-approved designs in reinforced concrete. *Dhajji* construction was approved a year after the earthquake, and within about four years after that, UN-HABITAT reported that approximately 250,000 new *dhajji dewari* houses had been constructed within the earthquake damage district.**

 

**Fig. 52: The juxtaposition of houses which are genuinely of traditional timber and masonry construction and ones of reinforced concrete with concrete block can be seen in Thimphu** *(left)* **and a village** *(right).* **In Thimphu, this genuine traditional farmhouse, also shown in Figure 47, serves to show how the mere use of Bhutanese style windows fails to reduce the alien quality of its outsized neighbor. Had these same accommodations been contained in a cluster of sections of smaller bulk on the same property to form a group, the visual interest and compatibility would have been both more interesting and more respectful of its neighbor – and of Bhutanese cultural heritage in general. The Government's *Traditional Architecture Guidelines* does not address this issue.**

**In the village on the** *right* **the two on the left are clearly of concrete construction, despite their use of traditional features such as the window frames and the articulated cornices. Instead of the projecting *rabsels* seen in the stone houses on the right, the cement block walls step out with recessed windows. This violates one of the basic structural principles of traditional masonry construction. This stepping out is only possible because of the concrete floor slabs. The design guidelines are not sufficient to deal with these anomalies.**

**Vernacular architecture is closely predicated on both the materials and methods of craftsmanship common to timber and load-bearing masonry. Absent this discipline the traditional construction imposes on the architecture of the buildings, the details drawn from design guidelines simply become appliqué. Like these, the results are often buildings that try to fit in, but ultimately can seem more alien than if they were of a different style all together.**
*Photo on left by the author, and on the right by Stephen Kelley.*

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