

## The earthquake resistant vernacular architecture in the Himalayas

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**ABSTRACT:** This paper examines the traditional construction found in the Himalayan region in Indian and Pakistan Kashmir in comparison with Nepal, which has just at the time of this writing been subjected to the devastating Gorkha earthquake on April 25, 2015. The chapter describes the widespread tradition of the use of timber reinforcement of masonry construction in Kashmir in the context of the less common use of such features in Nepal, as shown by the widespread damage and destruction of traditional masonry buildings in Kathmandu. However, some of the heritage structures in Nepal do possess earthquake resistant features – most importantly timber bands – and there is now evidence many of those buildings have survived the earthquake without collapse.

### 1 INTRODUCTION

Earthquake! When this chapter was written, the dust had not yet completely settled from the April 25, 2015 earthquake in Nepal (Fig. 1). The body count continued to increase with each day and the rescue efforts to find and free people entrapped beneath the ruins continued with more distress on the part of the survivors, as hope for those lost from sight continued to fade until rescue efforts were terminated a little over two weeks after the earthquake.

*‘Seismic Culture’?* From the evidence seen in the media images over the first weeks following the earthquake, “seismic culture” does not appear to have existed in Nepal. Considering that this has long been known as a very seismically active part of the globe, the pertinent, or perhaps impertinent, question is “*why not?*”

The Himalayan chain was created by the collision of continental plates, creating the highest mountains in the world, along with one of the world’s most active earthquake hazard areas (Fig. 2). If any region would seem to have a reason for the emergence of a “seismic culture,” one would think that Nepal would be close to the top of the list, along with neighboring Bhutan, Tibet, Indian and Pakistani Kashmir, and Afghanistan.

Historical records indicate that there was an earthquake in 1255 AD that killed a quarter to a third of the population of Kathmandu Valley (NSC, 2015). By comparison, the death toll of the 2015 earthquake is a little over 1,100 in Kathmandu city, a week and a half after the earthquake. This is but a small fraction of the city’s population of 2.5 million (New York Times, 2015).

Even in the more heavily destroyed well populated rural area to the north of Kathmandu known as the Sindhupalchok District, which suffered more than double the fatalities in Kathmandu, this death toll represents less than 1% of the population of the district.



Figure 1. View of Bhaktapur, Kathmandu area, Nepal after the Gorkha Earthquake (Credits: Xavier Romão & Esmeralda Paupério).

While this may seem like evidence that substantially greater earthquake resistance has been achieved, one still can see that the destruction in some of the mountain villages near to the epicenter has been almost total and there is little visual evidence of pre-modern earthquake resistant features in the ruins (Fig. 3). If any such features did exist in the collapsed houses, they have proven to be ineffective. However, if indeed a third of

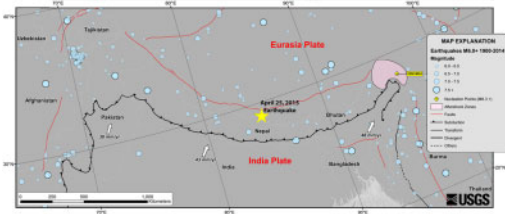


Figure 2. Himalayan and Eurasian Plate collision boundary with M6+ earthquakes since 1900 (Credits: USGS).



Figure 3. Typical view of ruins of destroyed stone masonry rural home, in Sangachowk Village, Sindhupalchowk District, Nepal (Credits: UNICEF/Chandra Shekhar Karki).

the population was killed in 1255, it is hard to argue that building safety has not somehow improved, however, at the same time, earthquakes from across almost a millennium of time are extremely hard to compare.

A similar dialectic exists in Italy, which like Nepal has frequently been subjected to damaging earthquakes throughout its multi-millennia of recorded history. Yet, certain features of traditional construction remain common in the country. These include rubble cores in the masonry walls that have long been known to make buildings vulnerable to collapse in earthquakes. However, there are many other features which have been identified by scholars as indicative of a pre-industrial era seismic culture, such as buttresses against masonry walls and corners, and arches between buildings; as well as iron ties connecting floor diaphragms and walls, and box-like building configurations.

The more important question is “What constitutes a seismic culture?” Is it simply a rise in construction quality and technological sophistication, or does it feature certain specific details the purpose of which can best be ascribed to resistance against earthquake forces? Or is the only proof of a seismic culture to be found in documents or in generations of knowledge and folklore of a known need for certain earthquake resistant details, such as was done so deliberately after the Great 1755 Lisbon earthquake with the invention and promulgation of the gaiola system of timber and masonry frame construction (Fig. 19)?

Surya Acharya, a civil engineer at the National Society for Earthquake Technology (NSET) in Nepal

said: “All the monuments [in Nepal] were built with earthquake-safe technology 400 years ago, using timber, brick, stone or mud, and lime. Those buildings survived many big earthquakes – this one was not so big. Many of the historical structures even survived the last major earthquake here, in 1934, but materials weaken due to age and poor maintenance” (Fleeson, 2015).

The problem at this moment, just a short two weeks following the earthquake, is that the impression is that Bhaktapur and other traditional construction areas are devastated. What is missing at this early stage is an assessment of those structures which have survived without collapse. For that we will have to wait for further research. Later we will return to discuss Nepal, but first, we turn to nearby Kashmir.

## 2 INDIA AND PAKISTAN KASHMIR

The Vale of Kashmir in India is located in the western part of the Himalayan mountain range on the site of a prehistoric lake created by the uplift of the mountains between Indian and Pakistan Administered Kashmir. Over geological time, this lake gradually silted in, and the alluvium from the mountains became the fertile soil of the valley floor. This is responsible both for the area’s rich agriculture and for its earthquake vulnerability. Srinagar lies on one of the most waterlogged soft soil sites for a capital city in the world, not unlike Mexico City.

The timber-laced masonry historic construction systems found here are mentioned in texts from the 12th century (Langenbach, 2009). Unreinforced masonry is strong in compression, but suffers both from differential settlement on soft soils and in earthquakes from a lack of tensile strength which allows for brittle failure from shear forces within the walls, or from overturning of the walls from differential settlement or out-of-plane earthquake vibrations.

Timber lacing and a strong tie between the timbers in the walls and the floors serve to restrain the walls from spreading and hold the building together while still allowing the system as a whole to be flexible. In traditional environments in developing countries, strength is not always possible, so flexibility or “give” is essential. In fact, in 1875, after spending some years in Kashmir, a British geologist, Frederick Drew, wrote “*These mixed modes of construction are said to be better against earthquakes (which in this country occur with severity) than more solid masonry, which would crack*” (Drew, 1917).

At the beginning of the 19th century the systems evolved into what are now the two main traditional construction systems: taq (timber-laced masonry bearing walls) and dhajji dewari (timber frame with masonry infill – like what in Britain is called “half-timber”). Most of the traditional buildings in Srinagar and the Vale of Kashmir can be divided into these two basic systems (Fig. 4). In Pakistan, timber-laced masonry is



Figure 4. An older building in central Srinagar, Kashmir, India, that has *taq* timber-laced construction on the first two floors, and *dhajji dewari* infill frame construction above (Credits: Randolph Langenbach).



Figure 6. A three and a half story building in central Srinagar, Kashmir, India, of *taq* timber-laced construction partially demolished for a street widening (Credits: Randolph Langenbach).

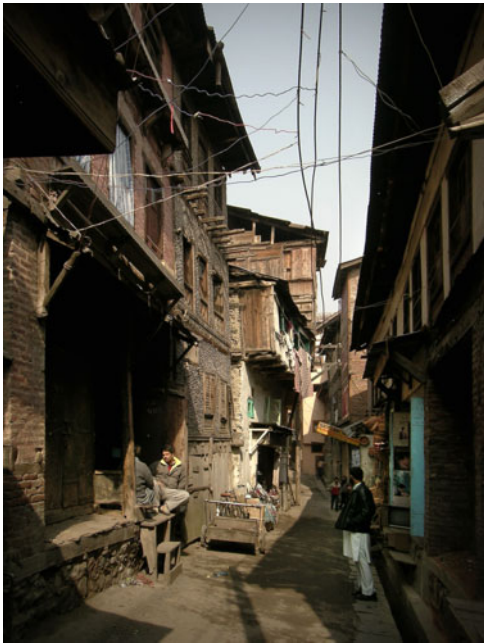


Figure 5. A small lane in central Srinagar showing typical streetscape of the historic city that is now getting rare as street widening and demolition and replacement with concrete structures have wreaked havoc with what had been one of the most remarkably well preserved historic urban environments in the world (Credits: Randolph Langenbach).

known by the Pashto word *bhatar*, and the timber frame with infill is simply called *dhajji*.

There are so many influences on the development of building construction traditions that it is not easy

to isolate any one reason for the use of timber lacing in the masonry, but its effectiveness in holding the masonry together on soft soils undoubtedly has played a major role. It has also proven to be effective in reducing damage in earthquakes, which may help explain why variations of it can be found in the mountains, where soft soils are not a problem.

**Taq (bhatar) Construction:** *Taq* (or *bhatar*), consists of load-bearing masonry walls with horizontal timbers embedded in them. These timbers are tied together like horizontal ladders that are laid into the walls at each floor level and at the window lintel level. They serve to hold the masonry walls together and tie them to the floors (Fig. 6).

There is no specific name in Kashmiri to identify this timber-laced construction method itself, but the closest name used to describe it is *taq* because this is a name for the type of buildings in which it is commonly found. *Taq* refers to the modular layout of the piers and window bays, i.e. a five-*taq* house is five bays wide. Because in Srinagar this modular pier and bay design and the timber-laced load-bearing masonry pier and wall system go together, the name has come to identify the structural system as well.

The best early account of the earthquake performance of *taq* construction maybe the one by British traveler Arthur Neve, who was present in Srinagar during the earthquake of 1885 and published his observations in 1913: “*The city of Srinagar looks tumbledown and dilapidated to a degree; very many of the houses are out of the perpendicular, and others, semi-ruinous, but 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*



Figure 7. Example of cribbage construction, The Khankah in Pampore, near Srinagar, ca. 1600. When photographed in 2007, the interior was being clad with plywood in order to, as they stated, to “modernize” the interior (Credits: Randolph Langenbach).

*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 storeys high, sways together, whereas more heavy rigid buildings would split and fall”* (Neve, 1913).

An important factor in the structural integrity of *taq* is that the full weight of the masonry is allowed to bear on the timber lacing and the ends of the floor joists penetrate the exterior walls, thus holding them in place. These timbers in turn keep the masonry from spreading. Engineers now often find themselves uneasy about the absence of any vertical reinforcement, but in my own opinion, that is part of the brilliance of this system – it does not have elements which could shift this overburden weight of the masonry off and onto columns buried in the walls. It is this weight, and the resulting compression of the mud-laid masonry, that is such an essential component of what it needs in order to resist the earthquake forces.

**Cator and Cribbage:** Several of the historic mosques in Srinagar are of “cribbage” construction, a variation of timber-laced masonry construction that can be found in the Himalayan mountains of northern India, northern Pakistan near the Chinese border, and parts of Afghanistan (Fig. 7). This has proven to be particularly robust in earthquake-prone regions, but as wood supplies became depleted it must have been found to be extravagant. This may in part explain the origins of the *taq* and *bhatar* systems, where the timber lacing is limited to a series of horizontal interlocking timber bands around the building, thus requiring significantly less wood in its construction.

A combination of cribbage at the corners with timber bands, known as “*cator* and cribbage”, can be found in the Hunza region of Northern Areas of Pakistan. Examples can also be found in the Himalayan regions of northern India. This is a heavier, more timber-intensive version of timber-laced masonry than *taq* and *bhatar* that dates back some 1,000 years (Hughes, 2000). The corners consist of a cribbage of timber filled with masonry. These are connected with



Figure 8. Example of dhajji dewari construction in Srinagar. This is an example with only rectangular panels. There is often in the present a belief that diagonals are necessary, just as they were in Lisbon in the *gaiola* that was invented after the 1755 earthquake, but there is increasing evidence that they are not necessary, and may even be counter-productive (Credits: Randolph Langenbach).

timber belts (*cators*) that extend across the walls just as they do in *taq* and *bhatar* construction.

There is evidence that many of these construction traditions have followed patterns of migration and cultural influence over centuries, such as the spread of Islamic culture from the Middle East across Central Asia, including Kashmir and other parts of India. In Turkey, timber ring beams in masonry, known singly as *hatıl* and plural *hatıllar*, are part of a construction tradition that is believed to date back 9,000 years (Hughes, 2000). The Turkish word *hatıl* has the same meaning as *cator* does in Balti language. Also in Turkey, another common traditional construction type, *humuş*, is similar structurally to *dhajji* construction in Kashmir.

British conservator Richard Hughes has noted that “*The use of timber lacing is perhaps first described by Emperor Julius Caesar as a technique used by the Celts in the walls of their fortifications. Examples, with a lot of variations, are to be noted from archaeological excavations of Bronze and Iron Age hill forts throughout Europe.*” Hughes also cites examples in the Middle East, North Africa and Central Asia (Hughes, 2000). Different variations on all of these construction types are also likely to be found in the areas outside of the regions discussed in this volume, including Nepal, Bhutan and parts of China, including Tibet.

**Dhajji dewari Construction:** *Dhajji dewari* is a variation of a mixed timber and masonry construction type found in earthquake and non-earthquake areas around the world in different forms. While earthquakes may have contributed to its continued use in earthquake areas, timber and masonry infill frame construction probably evolved primarily because of its economic and efficient use of materials. However, its continued common use up until the present in Srinagar and elsewhere in the Vale of Kashmir most likely has been in response to the soft soils, and perhaps also to its observed good performance in past earthquakes (Fig. 8–9).



Figure 9. A cross-section of dhajji dewari construction revealed by a demolition for a road widening. Notice how thin the walls are in this form of construction. Despite this, it has proved to be remarkably resilient in earthquakes. (Credits: Randolph Langenbach).

The term *dhajji dewari* comes from the Persian and literally means “patchwork quilt wall”, which is an appropriate description for the construction to which it refers. The Persian name may provide a clue to Persian influence in the origins of this system of construction. It is also very similar to Turkish *hımış* construction, which was also common beyond the boundaries of Turkey, perhaps in part because of the widespread influence of the Ottoman Empire. *Dhajji dewari* consists of a complete timber frame that is integral with the masonry, which fills in the openings in the frame to form walls. The wall is commonly one-half brick in thickness, so that the timber and the masonry are flush on both sides. In the Vale of Kashmir, the infill is usually of brick made from fired or unfired clay. In the mountainous regions of Kashmir extending into Pakistan, the infill is commonly rubble stone.

*Dhajji dewari* construction has proven to be very effective in holding the walls of buildings together even when buildings have settled unevenly so as to become dramatically out of plumb. In the mountain areas, where soft soils and related settlements of buildings are not a problem, its use continued probably because timber was available locally and the judicious use of timber reduced the amount of masonry work needed, making for an economical way of building. The panel sizes and configuration of *dhajji* frames vary considerably, yet the earthquake resistance of the system is reasonably consistent unless the panel sizes are unusually large and lack overburden weight.

What many people fail to grasp is that the timber frame and the masonry are structurally integral with each other. In fact, such structures are best not considered as frames, but rather as membranes. In an earthquake, the house is dependent on the interaction of the timber and masonry together to resist collapse in the tremors. Historically, the amount of wood used,



Figure 10. The debris left from the total collapse of almost all of the concrete slab and stone walled houses in Balakot, Pakistan in the 2005 earthquake (Credits: Randolph Langenbach).

and therefore the sizes of the masonry panels, varied considerably. There is evidence that walls with many smaller panels have performed better in earthquakes than those with fewer and larger panels.

There is no research that demonstrates that one *dhajji* pattern is better than another. Some patterns even lack diagonal bracing elements, relying on the masonry to provide all of the lateral resistance. The ones with random patterns probably result from the economics of using available random lengths of wood in the most efficient way possible. In fact, the quilting from which it gets the name ‘*dhajji*’ is itself produced from the reuse of scraps and small pieces of cloth.

*Dhajji dewari* construction was frequently used for the upper stories of buildings, with *taq* or unreinforced masonry construction on the lower floors (Fig. 4). Its use on the upper-floors is suitable for earthquakes because it is light, and it does provide an overburden weight that helps to hold the bearing wall masonry underneath it together.

### 3 THE 2005 KASHMIR EARTHQUAKE

The Kashmir earthquake was one of the most destructive earthquakes in world history. The death toll from this magnitude 7.6 earthquake was approximately 80,000 and over 3 million were left homeless. In a region known to be so vulnerable to earthquakes, it is reasonable to ask: Why did both the masonry and reinforced concrete buildings in the area prove so vulnerable to collapse? Why did over 80,000 people lose their lives in what is a largely rural mountainous region? Why did 6,200 schools collapse onto the children at the time of morning roll call in Pakistan alone? (Fig. 10)

This kind of scenario has played out repeatedly over recent decades in other earthquakes around the world, in cities and rural areas alike, as it has again in Nepal.

Ironically, even as the knowledge of earthquake engineering has grown and become more sophisticated, earthquakes have an increasing toll in places where steel and reinforced concrete construction have displaced traditional construction.

After the 2005 earthquake, international teams of engineers and earthquake specialists fanned out over the damage districts on both sides of the Line of Control and returned with reports on the damage to different types of structures. Most of these reports focused on the Pakistan side of the Line of Control because the epicenter of the earthquake was northwest of Muzaffarabad. In that area, which has a high population density, the death and destruction was far more extensive than on the Indian side.

None of these reports covered timber-laced traditional construction of any type. The reason for this is superficially explained by the following exchange between Marjorie Greene of the Earthquake Engineering Research Institute (EERI), an international NGO, and various local officials and technical experts in Pakistan three months after the earthquake. She asked if they were aware of any examples of traditional timber-laced construction of any type in the earthquake-affected area. The officials answered that they were “unaware of any, but in years past there may have been” (Langenbach, 2009).

In some ways, this lack of knowledge of the vernacular building systems in the earthquake area is not a surprise. It parallels a widespread lack of interest in such systems that exists in many countries which have recently experienced the rapid transformation from traditional materials and methods of construction to reinforced concrete. In most universities in the Middle East and South Asia, reinforced concrete frame construction remains the only system that most local engineers are trained to design.

As a consequence, after the earthquake the Government of Pakistan began to withhold reconstruction assistance funds from those people who proceeded to rebuild with *dhajji* or other timber-laced systems rather than with the government approved reinforced concrete block and slab system. For over a year after the earthquake, only those who followed the government’s approved plans for reinforced concrete block and slab houses were allowed to obtain government assistance. This belief in the efficacy of reinforced concrete and concrete block continued despite its abysmal performance in that very same earthquake in Muzaffarabad, Balakot (Figure 10), and even including one middle class apartment complex in Islamabad.

However, what the experts failed to see was painfully evident to the rural villagers themselves, who, after they had climbed out of the ruins of their rubble stone houses, saw that the nearby concrete buildings were also destroyed. They could not help but notice that the only buildings still standing were of traditional *dhajji* and *bhatar* construction (Figure 11). Then on their own initiative, they revived the use of these historic technologies in the reconstruction of their own houses.



Figure 11. Country store of dhajji construction in Pakistan Kashmir near the epicenter of the 2005 earthquake. This and other buildings like it are what the local residents saw that inspired them to rebuild dhajji houses (Credits: Randolph Langenbach).

Eventually, after the architects in the disaster response and recovery NGOs could see this and brought it to the attention of the government’s consulting engineers, both systems were approved by the Government of Pakistan as “compliant” for government assistance. As a result, there may be as many as a quarter of a million new houses using one of these two traditional systems, which before the earthquake had largely fallen out of use.

Returning to the Indian side of Kashmir, one of the most important of the post-earthquake reconnaissance reports was published by EERI. This report was written by Professors Durgesh C. Rai and C. V. R. Murty of the Indian Institute of Technology, Kanpur and published in December 2005 as part of the EERI “Learning from Earthquakes” report on the Kashmir earthquake. The quotations below from the authors were based on observations made during the first several weeks after the earthquake. Describing *taq* construction, which they observed in the damage district on the Indian side of the Line of Control, Professors Rai and Murty observed:

*“In older construction, [a] form of timber-laced masonry, known as Taq has been practiced. In this construction large pieces of wood are used as horizontal runners embedded in the heavy masonry walls, adding to the lateral load-resisting ability of the structure... Masonry laced with timber performed satisfactorily as expected, as it arrests destructive cracking, evenly distributes the deformation which adds to the energy dissipation capacity of the system, without jeopardizing its structural integrity and vertical load-carrying capacity” (Rai and Murty, 2005).*

It is interesting to compare their observation with that of Professors N. Gosain and A.S. Arya, after an inspection of the damage from the Anantnag Earthquake of 20 February 1967, where they found buildings of similar construction to Kashmiri *taq*: *The*



Figure 12. The owner and carpenter building a new dhajji house in Topi, near Bhag, Pakistan, to replace one of rubble stone on the right, which collapsed after seeing the survival of the building in Figure 11 and others like it (Credits: Randolph Langenbach).



Figure 13. Villager standing near his house in a remote village between Batagram and Besham, in NWFP, Pakistan with bhatar construction which survived the earthquake. This inspired the new construction in bhatar seen on right (Credits: Randolph Langenbach).

*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* (Gosain and Arya, 1967).

The concept of ascribing ductility to a system composed of a brittle material – masonry – is difficult for many modern engineers to comprehend. It can be readily observed that a steel coat hanger is ductile, as demonstrated when it is bent beyond its elastic limit, but by contrast, a ceramic dinner plate is brittle. So how can masonry, which on its own is inarguably made up of brittle materials, be shown to be ductile? Rai and Murty in 2005 avoided the use of the term “ductile” probably because the materials in *taq* are not ductile and do not manifest plastic behavior. However, what makes timber-laced masonry work well in earthquakes is its ductile-like behavior as a system. This behavior

results from the energy dissipation because of the friction between the masonry and the timbers and between the masonry units themselves.

This friction is only possible when the mortar used in the masonry is of low-strength mud or lime, rather than the high-strength cement-based mortar that is now considered by most engineers to be mandatory for construction in earthquake areas. Strong cement-based mortars force the cracks to pass through the bricks themselves, resulting in substantially less frictional damping and also rapidly leading to the collapse of the masonry. Arya made this difference clear when he said: “*Internal damping may be in the order of 20%, compared to 4% in uncracked modern masonry (brick with Portland cement mortar) and 6%–7% after the masonry has cracked.*” His explanation for this is that “*there are many more planes of cracking... compared to the modern masonry.*” (Gosain and Arya, 1967).

In areas subject to earthquakes, engineers have often sought to specify strong cement-based mortar. However, in the larger earthquakes, the strength of the



Figure 14. Four and five story residential buildings in the Indian Kashmir city of Baramulla showing how the unreinforced masonry collapsed, leaving the dhajji dewari bridging over the gap, while a tall rubble stone building reinforced with taq timber beams survived the 2005 earthquake undamaged (Credits: Randolph Langenbach).



Figure 15. A grand four story bearing wall brick masonry house on the Rainawari Canal in Srinagar of timber-laced taq construction (Credits: Randolph Langenbach).

mortar ceases to be helpful once the walls begin cracking, as they inevitably do in a strong earthquake. It is then that the “plastic cushion” and other attributes described by Harley McKee become more important. More important is that the masonry units – the stones or bricks – be stronger than the mortar, so that the onset of shifting and cracking is through the mortar joints, and not through the bricks. Only then can the wall shift in response to the earthquake’s overwhelming forces without losing its integrity and vertical bearing capacity. With timber-laced masonry, it is important to understand that the mortar is not designed to hold the bricks together, but rather to hold them apart. The timbers are what tie them together. The friction and

cracking in the masonry walls dissipate the earthquake’s energy, while the timber bands are designed to confine the masonry, and thus prevent its spreading, which would lead to collapse.

#### 4 NEPAL AFTER TWO EARTHQUAKES

After a little more than two weeks after the April 25th Gorkha earthquake in Nepal, on the 12th of May, a second earthquake or large aftershock struck Nepal, testing the surviving buildings still further. Reports indicated that some have failed the test.

Just before that second earthquake, a colleague sent me a paper he had found on the internet by a Nepalese scholar, Dipendra Gautam, who claimed that *“The historic urban nucleus of Bhaktapur city Nepal has ... unreinforced masonry buildings which have many features particularly contributing [to] better [performance] during earthquake events.”* This finding, he said was *“based on detailed survey of forty two buildings.”* His conclusion in light of the two recent earthquakes seemed in sharp contrast to the cascade of photographs of partially and totally collapsed brick buildings in the Kathmandu Valley city of Bhaktapur which he said is the *“culturally most preserved city of Nepal”* (Gautam, 2014).

With only the news photos to go on, in the first weeks after the earthquake, the many collapses of masonry buildings in Bhaktapur would seem to undermine his conclusions (Fig. 17). However, his observations came with the authority of thorough building-specific research. His findings also contrasted with my own more brief observations from visits to Nepal a decade earlier, on which I had written about in several papers, and in the UNESCO book *Don’t Tear It Down!* in which I had said timber bands were less common

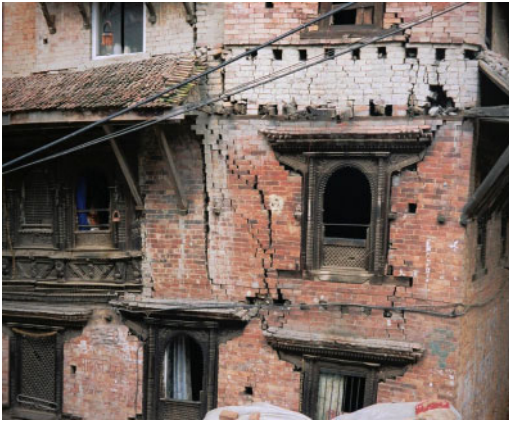


Figure 16. A photo taken in Nepal fifteen years before the 2015 earthquake showing the progressive structural deterioration of a masonry bearing wall building which lacks the timber bands of *taq* and *bhatar* (Credits: Randolph Langenbach).



Figure 17. Unreinforced brick building collapses in Sankhu, near Kathmandu, Nepal showing the collapsed end of a row of dwellings, which lacked timber bands (Credits: Xavier Romão & Esmeralda Paupério).

than in Kashmir “*except in some of the palaces and temples*” (as, for example, in Figure 16).”

A compelling source for evidence was a book of photographs of the heavy damage inflicted by the 1934 earthquake, which had devastated large parts of Kathmandu, including some of the palaces and temples. In those photographs, there was no evidence of timber lacing that could be seen in the ruins.

Based upon a conversation with Mr. Gautam about how the 42 buildings in his study fared in the earthquake, there appeared to be evidence that those with timber lacing survived the earthquake intact. His study sample consisted of houses, rather than palaces or temples. His reply to this question – based on his initial reconnaissance in Bhaktapur after the both the first and second earthquake was “*I re-inspected [the 42 buildings and] I am really excited with their performance...The timber bands, double boxing of openings, struts, subsequent load reduction mechanism are*



Figure 18. Hanuman Dhoka Palace, Kathmandu after the earthquake showing a section with timber bands – visible as horizontal lines on the brick façades (Credits: Kai Weise, Kathmandu, Nepal).

*genius. The smaller openings, building symmetry and others are also excellent... Inside many of the houses ...there were only minor diagonal cracks... Till date, I haven't found any collapsed house [with] timber bands.”*

His prior research and publication, together with his post-earthquake findings, ultimately leads to an important contribution towards the preservation of the historic structures that make of the context for the World Heritage Site in Bhaktapur. If the effectiveness of these aseismic features – particularly timber bands – can be shown to have kept the buildings from collapsing, the survival of particular masonry buildings thus would be determined no longer to be a matter of chance. This knowledge can then help both (1) lead to a program of reinforcement of masonry buildings, and (2) help give confidence in such systems, so as to counteract the present belief that all masonry construction is at risk of collapse in the future.

In the months following the completion of this chapter, more information will likely become available to help to answer the question of why some houses and not others were timber reinforced. However, the earthquake and its aftermath in the media have already proved that such aseismic construction was far from universal. It will be interesting to learn from further research why timber bands were not included in the construction of so many masonry buildings. Was it a result of a rise in price of timber, or some other factor, or simply that the technology was not widely known?

These are important questions to raise at a time when concrete construction, which has already displaced most of timber and masonry construction in the rest of Kathmandu outside of Bhaktapur, stands poised to be used after these earthquakes to replace the masonry buildings in the heritage areas. It is easy to see that for many people the immediate impression is that the concrete structures proved to be safer, despite the collapse of many of them spread out through the city. One Nepali heritage professional, Kai Weise, reported



Figure 19. Interior of post-1755 Lisbon, Portugal, earthquake building in Baixa, Lisbon with interior walls of *gaiola* exposed during a remodeling (Credits: Randolph Langenbach).

his experience in a Kathmandu coffee shop “*my waiter, who brought me my latte... explained that all the load-bearing houses cracked open horizontally and vertically, while the “pillar system”* [the local name for reinforced concrete frame structures] *withstood the earthquake.*

This then raises the question of what now might become evidence of a ‘Seismic Culture’ in Nepal after these two earthquakes. Will the collapsed masonry buildings get reconstructed with timber bands? Or will people look around and see that in these particular earthquakes that the reinforced concrete buildings for the most part remained standing and proceed to rebuild in concrete, despite the increasingly disappointing record of reinforced concrete in other earthquakes including massive collapses in Ahmedabad in 2001 and in nearby Sikkim in 2011.

In a sense, this could be reminiscent of what happened in Lisbon, after the 1755 earthquake with the ‘invention’ of the *Gaiola*. This was a technology that was not new – but which was derived from the traditional form of construction which could be seen to have survived the earthquake – a form of construction that can be found around the world from Elizabethan

England, medieval Germany, Eastern Europe, Spain, Turkey, Kashmir, and in Lisbon itself – where medieval half-timber buildings were found to be still standing amidst the devastation of the earthquake. Their resilience was proven by their survival, and so they inspired the design and mandatory use of the *Gaiola* – a technology that became such a compelling part of Lisbon’s subsequent rebirth.

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