

**Standing Firm:
Traditional Aseismic Architecture
of the Western-Central Himalayas**

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Introduction

The Himalayan mountain range is one of the world's most active seismic regions. According to Plate Tectonics theories, the seismic activity in this region is caused by the collision of the Indian sub continental and the Eurasian plates. The relatively rapid northeasterly movement of the Indian sub continental plate at the rate of 5 cm/year causes the lifting of the Indian plate, with its consequent deformation in a wide arc, which we see as the Himalayan mountain range (Le Pinchon, 1968; Fitch, 1970). A tremendous amount of strain accumulates along this convergence zone, which is highly inelastic, meaning that instead of deforming the rock landmass, the potential of the rock to slip equals the rate of convergence. Out of 10 equally spaced regions of the Himalayas, there are six regions with a slip potential estimated at about four meters, and in some places it the strain may exceed six meters (Bilham *et al*, 2001). The 1950 Assam earthquake, which is the most powerful intracontinental earthquake ever recorded, released about four meters of strain (Bilham *et al*, 2001). Several research studies have warned of the probability of several great earthquakes in this region, and the estimates of casualties range within the hundreds of thousands, and some even estimate casualties in the millions in more densely settled regions (Bilham *et al*, 2001; Arya, 1990). The geological activity in this region has always been a menace to human settlements, which are virtually at constant risk of earthquakes, landslides and numerous other hazards.

A defining feature of indigenous rural houses around the world is that they are non-engineered structures, constructed by native artisans who primarily use locally available materials like mud, stone, and wood. These indigenous and traditional construction practices evolved in the context of local culture, environmental constraints and empirical knowledge. Over several centuries of human settlement in the Himalayas, indigenous housing throughout the region has a variety of adaptations and reinforcements which help in resisting damage during earthquakes. The western-central Himalayas have several indigenous types of construction which have earthquake-resistant or aseismic features. In Himachal Pradesh, timber, slate, stone, mud and bamboo are used in traditional architecture. The *kath-ki-kuni* style of housing in central Himachal Pradesh makes highly effective use of timber beams as binding elements, and the *pherols* of Garhwal's Uttarkashi region have similar architecture. Another type of construction found in Kashmir and Himachal Pradesh is *Dhajji-diwari*, or structures with diagonal wooden bracing in the walls, which are effective helping the building resist shear and tension during earthquakes.

However, the western-central Himalaya's native heritage of aseismic construction techniques is being rapidly lost, replaced by reinforced cement concrete (RCC) construction. This decline is due to a variety of factors, including changing cultural values, demographic and economic transitions, and rural development programmes.

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While RCC construction can be highly earthquake-resistant, the manner in which this new technology has proliferated in the western-central Himalayas has created vulnerability to earthquake disasters, and poses many questions of the sustainability and appropriate use of newer technologies. Indigenous construction techniques still have much to offer in terms of their inherent sustainability and appropriateness. The Peoples' Science Institute has documented and studied the aseismic aspects of indigenous and traditional construction techniques. This paper presents prominent examples of this architecture in Himachal Pradesh and Garhwal, along with a discussion of their aseismic qualities, and some observations on sustainability and appropriate technology aspects.

Aseismic Architecture & Challenges in Rural Housing

The impact of an earthquake on a building depends on a complex interaction of factors during an earthquake, including the depth of the epicentre, magnitude, frequency, intensity and duration of shaking and soil conditions, and the quality of construction (ISET, 1989). One of the most common fallacies of post-earthquake assessments of damage to buildings is the assumption that buildings left standing or relatively undamaged are assumed to be earthquake-resistant. It is important to understand how different forces generated during a quake affect a building, and the behaviour of building materials under the influence of these forces, and interactions between different structural elements of the building.

The force of earthquakes is often measured as ground acceleration. During earthquakes, the ground moves in three orthogonal directions almost simultaneously, generating a combination of compression, tension and shear forces. Ground movement is the primary cause of damage to buildings, because it causes the base of the building to move while the inertia of the superstructure (a function of its mass) causes it to resist motion (Chopra *et al*, 1993). This results in the deformation of the superstructure. The action of three types of forces is equivalent to a horizontal seismic force or load acting on the building (Chopra *et al*, 1993). The inertial seismic load is a function of the mass and location of the centre of gravity. Thus lower mass and lower centres of gravity make a building less likely to topple over in an earthquake (Chopra *et al*, 1993). In structural engineering terms, most rural houses are “load-bearing” structures, which means that the weight of the roof and upper storeys rest upon the walls of the structure. Under normal conditions, the structure bears vertical or compressive loads. During an earthquake, the combination of compression, tension and shear forces act in complex and differential ways on the structure and its constituent elements, causing complex deformations and the constituent elements to behave differently and independently of each other. The risk of critical failure of the overall structure increases. Weaker elements may fail and lead to a domino effect, causing the failure of other elements. Thus it is also essential to interconnect the structural elements using tie bands and bracing, so that as far as possible the structure behaves as a single unit and does not disintegrate. The stress on component elements also tends to accumulate at corners and openings in a building, and so it is important to reinforce the corners and keep openings small and properly spaced in order to minimise the risk of failure due to the accumulation of stress. It is important to have strong bonding with mortar. There has been some discussion on the importance of rigidity in the overall structure. One of the most touted aspects of RCC construction is its rigidity and high compressive strength. However, the goal of aseismic architecture is not to design

buildings that do not fail, rather it is to allow controlled failure in order to allow the dissipation of the tremendous stresses experienced during an earthquake. One of the problems of using cement in rural construction is that if the strength of the cement mortar exceeds the strength of mud bricks, the latter may shatter, while the former resists the force (Langenbach, 1986). Many types of rural construction feature weak mortar (lime instead of cement), loose in filled walls and plaster that shatter easily during an earthquake, and thus help dissipate the stress on the building (Langenbach, 1986). The behaviour of different materials is also important to consider. Very often, the combination of traditional and modern construction materials can lead to disastrous consequences. Table 1 summarises the primary principles and features to be included for earthquake-resistance in non-engineered structures.

Table 1: Basic Principles & Construction Features for Quake-Resistance

(from Chopra *et al*, 1993)

Principle	Effect in an Earthquake	Construction Features
Structural Stability	Avoid overturning and collapse	<ul style="list-style-type: none"> ✓ Subsoil bears loads ✓ Adequate tying elements ✓ Proper aspect ratios ✓ Geometric regularity ✓ Uniform rigidity distribution ✓ Masonry courses planned
Minimise Inertia	Lessen overturning moments	<ul style="list-style-type: none"> ✓ Light building materials ✓ Thin walls
Strong & Well-Tied Frame	Transfer inertial forces to the ground	<ul style="list-style-type: none"> ✓ Tie bands ✓ Triangulation of the frame ✓ Corner reinforcement
In-Plane Stiffness In Both Directions	Resistance to earthquake inertial forces	<ul style="list-style-type: none"> ✓ Few openings, proper spacing ✓ Cross walls & buttressing
Low Center of Gravity	Lessen overturning possibility	<ul style="list-style-type: none"> ✓ Low storey heights ✓ Light building materials
Shear Centre Close to Centre of Gravity	Reduce local stress & Initiation of Collapse	<ul style="list-style-type: none"> ✓ Symmetrical & regular building forms ✓ Maintain ratios of length:breadth ✓ Simple designs (min. projections/openings/cut outs)
Increase Ductility of Structure	Absorption of inertial forces	<ul style="list-style-type: none"> ✓ Use ductile materials at points of tensile stress; e.g. steel/bamboo reinforcement at corner joints
Damage is Preferable to Collapse or Destruction	-do-	<ul style="list-style-type: none"> ✓ Increase redundancy: Provide several supports for key structural elements; multiple columns support for long portions of the building

The tremendous destructive force that can be potentially generated by earthquakes and practical constraints make it impossible to build an “earthquake-proof” structure. In a

rural context, where there are sustainability issues, limits on the availability of construction materials and inadequate knowledge about the appropriate use of newer technologies, indigenous construction techniques offer many features that help in ensuring the earthquake-resistance of housing. Many of the materials that are available in rural areas also have good qualities for aseismic architecture. Wood and bamboo have high tensile strengths and are effective in tying the structure together. Stone and mud bricks, when prepared correctly, can be highly effective in bearing compressive and shear forces. Slate has high compressive strength.

Traditions of Aseismic Architecture in the Western-Central Himalayas

Kath-ki-kuni

Kath-ki-kuni literally means “timber-cornered.” This type of architecture is found predominantly in central Himachal Pradesh in the Kullu and Mandi districts, and parts of Shimla and Solan districts. This type of architecture is very common in the Kullu valley, and Picture 1 shows an example from old Manali town. Several of the buildings are about 100 years old, and some of the more massive structures, like temples or palaces, are several centuries old. This type of architecture was noticed by officers from the Geological Survey of India after the 1905 Kangra earthquake, who were impressed by the remarkable lack of damage to these buildings.

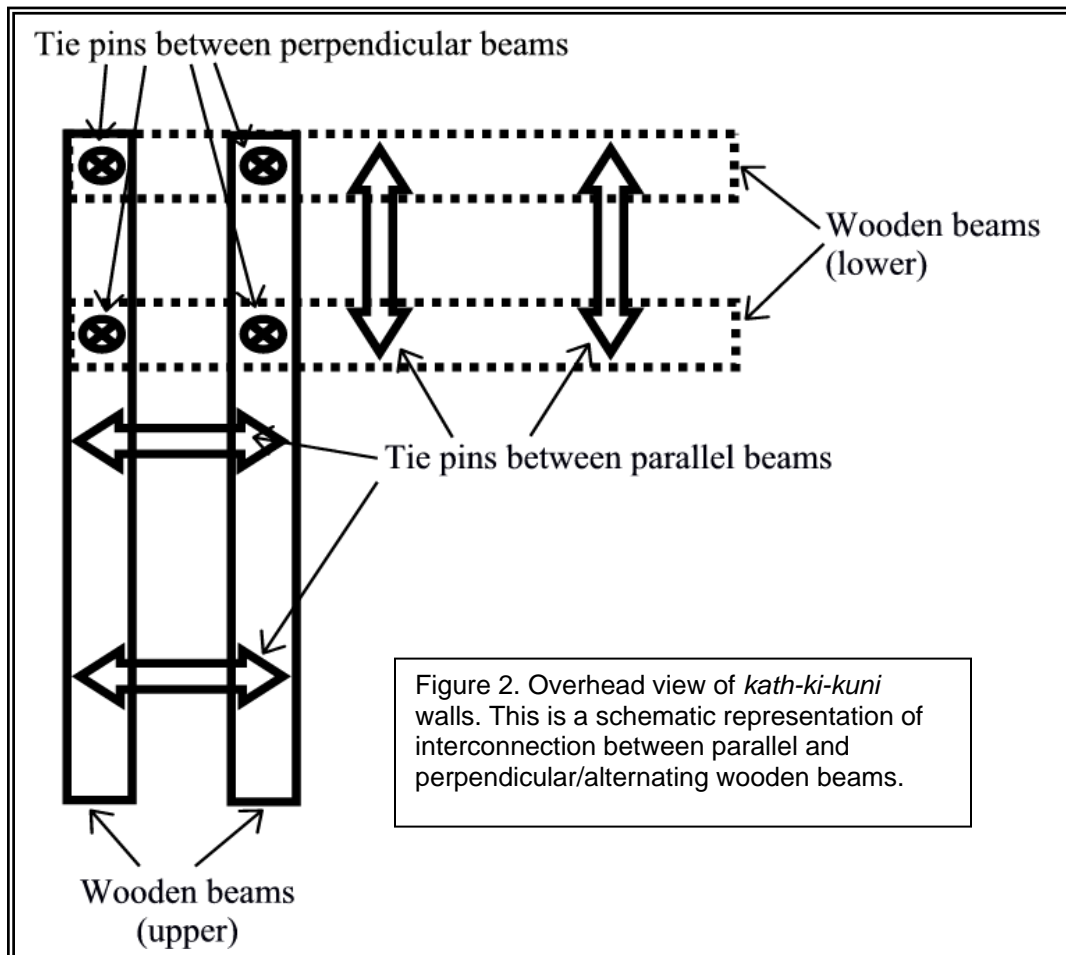
“The long gentle slope from the Beas river up to the pass, a total ascent of about 4,000 feet, was not remarkable for much damage to the village and hamlets situated thereon. This at first sight appeared unnatural on account of the apparently rather top-heavy construction of the houses – all of the hill type – until one came to realise the natural resisting power of their timber-bonded walls...which, whether intentional or not, seems a suitable form of hill architecture for earthquake countries.”
(Middlemiss, 1910)

As the account mentions, these buildings are particularly noticeable for their top-heavy appearance, which is especially accentuated by the external balconies on upper storeys and the use of the upper stories as granaries. As the name of the architectural style suggests, the extensive use of timber as a bonding element in the structure is the signature style of these houses. A variety of structures fall within this architectural style – ranging from the ornate palace of the Maharaja of Kullu to some of the massive towering temples of Mandi district, to simpler houses in old Manali. This style of architecture bears close resemblance to the *pherols* of Uttarkashi, and the geographical proximity and similar nature of the terrain and environments of these regions would suggest a large number of indigenous artisans in the region who used common principles and techniques in constructing houses, granaries, livestock shelters, temples, palaces and other buildings.

The prominent aseismic features of this type of construction are as follows:

1. *Timber tie-bands*: A pair of parallel wooden beams traverse the entire length of the walls at regular intervals. The pairs of wooden beams alternate in direction; the alternating pairs are placed perpendicular to each other (Picture 2). The space between the beams in the pair is usually filled with dry stone masonry, although there are variations depending upon locally available materials. These also serve to course the stone masonry in the walls. These beams act as tie bands and connect the superstructure, helping the building resist tension and lateral forces.

2. *Interconnection & Corner Reinforcement*: The pair of timber beams are interconnected at regular intervals along the length of the wall with wooden pegs, and at the corners, the perpendicular pairs of beams are interconnected vertically at four points at the corners (Figure 2). This provides vertical as well as lateral tying of the structural elements in the building. This helps in the strengthening of corners and distributing the load vertically, and also in preventing the wall from splitting under high compressive force. The joinery reflects the skilled craftsmanship of indigenous masons.
3. *Well-dressed stone masonry*: Although the composition of the walls varies by location, usually they are composed of dry stone masonry, and the stones used are long and flat stones, which are well laid in order to evenly distribute compressive strain vertically and prevent outward movement of stones in the wall (Picture 5 and 6). Many of the older *kath-ki-kuni* buildings have massive, almost monolithic stone blocks which have been well dressed. The massive construction stands testament to the technological capacity of the indigenous masons. The walls range in thickness from 40 cm. to over 100cm. in some cases, and the thickness of the walls give much-needed insulation from the cold and also distribute compression in these load-bearing structures.
4. *Small Openings & Low Storeys*: Doors and windows are kept small and have heavy wooden reinforced frames, which help bear the accumulated stress on the openings during an earthquake (Picture 3). The placement of openings is also staggered so as to avoid vertical alignment of the openings, which would weaken the wall (Picture 4). The frames and doors have diagonal bracing elements also, which are exquisitely carved. The heights of storeys are also kept low, which



keeps the centre of gravity low.

5. *Stable Geometry*: The floor plans of *kath-ki-kuni* houses reveal that structures are very nearly square, and the ratio of the sides usually lies within a 3:2 ratio. This reduces excessive strain on longer walls, and maintains a shear centre close to the centre of gravity. Taller structures have wide bases and a tapering construction, to reduce overturning moments. Thus even massive structures like the temples of Jungi village in Mandi district (Cover Picture and picture 4) are very stable.
6. *Roofs*: The roof frames in *kath-ki-kuni* houses are most commonly made of bamboo, which is generally available in this region. In some areas, the construction is of wood, or of both materials. Bamboo is an excellent material for roof frames, since it is flexible and has high tensile strength, which are essential qualities to negotiate the compression and tension of vibrations in the roof during earthquakes. The roof tiles in *kath-ki-kuni* architecture are thick slabs of slate, which are very heavy, and a very sturdy roof frame is needed to support the weight of the roof.

Apart from the aseismic qualities of *kath-ki-kuni* architecture, this type of construction shows great adaptation to traditional livelihoods, environmental conditions and cultural norms. Firstly, in terms of materials, the use of stone, slate, wood, mud and bamboo reflected primary use of local resources, and an intimate knowledge of the qualities and manner of using these materials with each other. The typical plan of a *kath-ki-kuni* house provides space for livestock on the bottom storey, a granary on the first storey and the living quarters are on the uppermost storey. There is usually an attic above the living space. The living space usually has an external verandah, which adds floor space without making the structure top-heavy. This general layout is adapted to the agrarian lifestyle of the region. The placement of the living quarters on the upper storeys makes this space warmer, both by allowing in more sunlight and capturing the body heat of the livestock rising from below. There was also some danger of wild animals entering houses, and so the grain and people stayed on the upper storeys, and the access to these spaces was from the top instead of the ground. The heavy slate roofs and thick walls are adaptations to the extreme cold in these regions. Sloping, thick roofs were needed to bear the weight of heavy snowfall, and the thick walls provided good insulation against the cold. Amongst the cultural aspects of this type of construction, the ornamentation of the heavy door frames usually includes a carving of the household or ancestral deity. As one woman in old Manali explained, “My grandfather used to tell us that in the old days, men knew respect for the Gods, and so every time you entered their houses, you had to bow your head to enter (because of the small openings) and show reverence for the household deity.” Furthermore, *kath-ki-kuni* houses reflect a communitarian style of living, with the clustered layout of houses, and families living together and often sharing storage space or livestock. “Technology is as much a product of a society’s culture as its knowledge or resource base” (Chopra *et al*, 1993).

Dhajji-diwari

The distinguishing feature of this type of architecture is the presence of diagonal wooden bracing in the walls. In Himachal Pradesh, this type of architecture is found in different

regions, and shows a great deal of variability in form and application. Two regions where *dhajji-diwari* was observed in the present study are in Dharamsala and Karsog area of Mandi district. Pictures 8 and 9 show examples of the buildings in Dharamsala. The buildings found here are mostly government buildings which were built after the 1905 Kangra earthquake devastated the region, and the district headquarters were moved to Dharamsala (Arya, 1990). It is unlikely that the colonial administration used local artisans and masons' technologies for this construction, since it is not seen elsewhere in the region. Thus, this example is not indigenous to the region, but similar architecture is found in other parts of Himachal, like Mandi district and also further north, in Kashmir (Langenbach, 1986). Thus, the general principles of using wooden diagonal bracing must have been encountered by the British. The examples in Dharamsala show very sturdy bracing and other design elements which make these buildings resistant to earthquakes.

1. *Diagonal bracing*: The use of wooden diagonal bracing in the walls adds a high degree of resistance to shear forces, which cause great damage to longer walls, and at the corners of openings. By using diagonal bracing, triangular stability is added to the walls, which means that deforming forces of compression, tension and shear are distributed and dissipated by the frame. Picture 8 shows the well-reinforced bracing. At the intersection of the bracing, triangular blocks of wood are used to stabilise the brace and iron pins are used to tie these elements, and add further tensile strength.
2. *Light structure*: The roofs of these buildings are made of corrugated iron sheets, or wooden frames with tiles, which reduces the mass of the structure and lowers the centre of gravity. The walls are also generally thinner, since they do not have to bear the weight of a heavy roof.

The *dhajji-diwari* encountered in Mandi (Pictures 9, 10) district bears some interesting parallels to the *dhajji-diwari* of Kashmir, described by Langenbach (1986). The aseismic quality of this type of *dhajji-diwari* is different than that of the Dharamsala examples. Here, the diagonal bracing is achieved by using a different pattern of bracing, with smaller pieces of wood, with loosely coursed masonry. While the basic principle of diagonal bracing is the same, the frame does not have the same bracing as the Dharamsala examples. As in the Kashmir examples, this type of construction has the added advantage of flexibility in the structure, and the weak masonry absorbs much of the stress and may shatter during an earthquake, but the structure will not fail. These houses in Mandi district are about 60-70 years old.

Pherols

After the 1991 Uttarkashi earthquake, some engineers with the Peoples' Science Institute visited the affected regions and conducted a study of how the rural housing stock had fared in the earthquake. They encountered Uttarkashi's *pherols*, some of which were over a century old and had survived (yet another) earthquake, and they conducted a detailed study on how these remarkable structures were resistant to earthquakes. The study was published in 1993, and is referred to in this paper. *Pherols* bear strong resemblance to *kath-ki-kuni* architecture in Himachal Pradesh, especially in the use of heavy slate roofs, thick walls, wooden tie-bands and corner bracing, multi-storied construction and the geometry and functions of different portions of the building. As mentioned above, the

parallels suggest that these indigenous construction techniques were closely tied to the cultural and social conditions of these regions, and they also have in common the use of locally available materials. For a detailed description of *pherols*, see Chopra *et al*, 1993.

Technology Transitions & Sustainability

The aseismic construction techniques described above are all in a state of decline in the western-central Himalayas. With the advent of new economies, social and demographic changes and perhaps most importantly, cultural changes, the people of this region are increasingly moving away from traditional architecture. The common perception of old rural houses of stone, wood and mud construction as *kuccha*, and the new RCC construction as *pucca* or stronger is ubiquitous among villagers in the region. In Kullu and Manali, old *kath-ki-kuni* houses are surrounded by new multistoried RCC construction, fueled by the tourism industry and immigration from Delhi, Punjab and other parts of the country. In Dharamsala a massive new RCC building will replace the old *dhajji-diwari* buildings as the headquarters for the district administration. In villages all over the region, people want houses with concrete slab roofs, and cement and steel continue to penetrate deeper into the heart of the hills, backed by aggressive advertising by cement companies, government programmes and even voluntary organisations. The advertising of cement with images of once backward villages beginning to prosper and develop with the use of cement presents a commentary on the perception of old versus new. The woman in Manali who related her grandfather's story about showing reverence while entering traditional houses explained that in modern times, men do not want to bow their heads to anyone, and so their houses also have high doorframes which show this change in attitude. It may not be so far-fetched to draw a parallel between this arrogance and the transition to cement construction. One of the highly-touted values of cement construction is its high compressive strength and the rigidity it adds to a structure (Langenbach, 1986). While the correct use of cement with the correct complement of materials and building architecture do make for a strong, earthquake-resistant structure, the very same qualities in rural, non-engineered structures may lead to increased damage to the structure instead. For example, in the *dhajji-diwari* construction, where weak mud bricks are used in the walls, the compressive strength of cement exceeds that of the bricks, and during an earthquake, these bricks may shatter instead of the cement mortar giving way first, and as a result, the wall may even collapse. As opposed to the rigidity of engineered cement concrete structures, the strength of rural aseismic housing is flexibility and capacity to yield and release strain while reducing the risk of critical failure. While the use of new materials is warranted and beneficial in many ways, it is important to remember the context of their use. These are new materials that indigenous masons do not have any experience working with, and this leads either to inappropriate techniques of use, or reliance on outside masons, who do not have much sensitivity to the particular needs of hill architecture.

The maligning and systematic abandonment of traditional and indigenous construction techniques is a great loss. In a conversation with a mason of the Thavin caste, whose traditional craft was constructing *kath-ki-kuni* houses, we learned that a major reason this knowledge is being lost is the lack of access to local resources which are essential for such construction. Timber and slate are particularly difficult to procure due to

government restrictions and there is little effort to keep these construction practices alive and evolving along with newer technology.

There have been some efforts to revive and adapt these traditional construction practices and aesthetics. Didi Contractor, an architect in Sidhbari village near Dharamsala has been working to preserve and adapt many of the principles of traditional construction in some 18 houses and a clinic that she has designed and built in the village (Picture 12, 13). She has trained local masons in these construction techniques by combining their knowledge and working to improve several techniques of construction. For example, in the roofs and storeys of some of these houses, she has combined bamboo and ferrocement (Picture 14). She has also worked on techniques to improve the durability of this construction, using new materials like epoxy resins with old ones like cow dung and mud in the plastering, and also on methods of treating bamboo to increase its life in the construction. These houses offer many more wonderful innovations such as the use of passive solar elements, solar heaters, aseismic elements using bamboo, wood and steel in reinforcements. Her work with local materials and artisans means that the local economy and society capture over 80% of the economic activity in the construction. This contrasts RCC construction, where the majority of economic activity is captured by external agents. Ms. Contractor's work in Sidhbari is an inspiring example of how traditional practices still have so much to offer for modern housing, and its inherent adaptability to include new materials.

In an environment fraught with constant threats of earthquakes, landslides and extreme climates, indigenous and traditional construction technologies remain valuable even today. The myth of the infallibility of RCC construction has been shattered with earthquakes all over the world showing that these buildings suffer as much damage and can also fail. At the same time, local materials and local knowledge can be developed to incorporate new materials and adapt to new social, economic and cultural conditions. Losing the rich traditions of indigenous architecture would be not just be an unfortunate loss, but a potentially devastating mistake.

Acknowledgements

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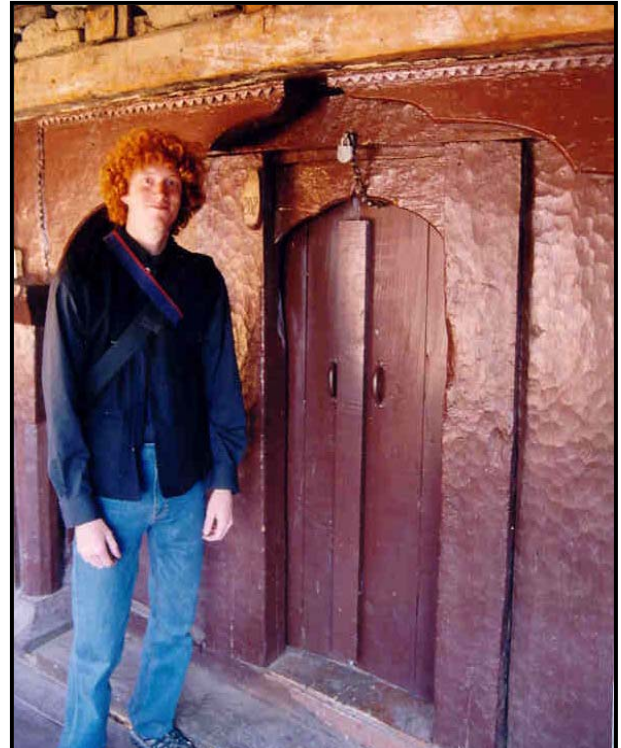
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Picture 1. A typical *kath-ki-kuni* house in Old Manali, Himachal Pradesh. The lower storey is for housing livestock, the middle is a granary and the upper storey is the living quarters.



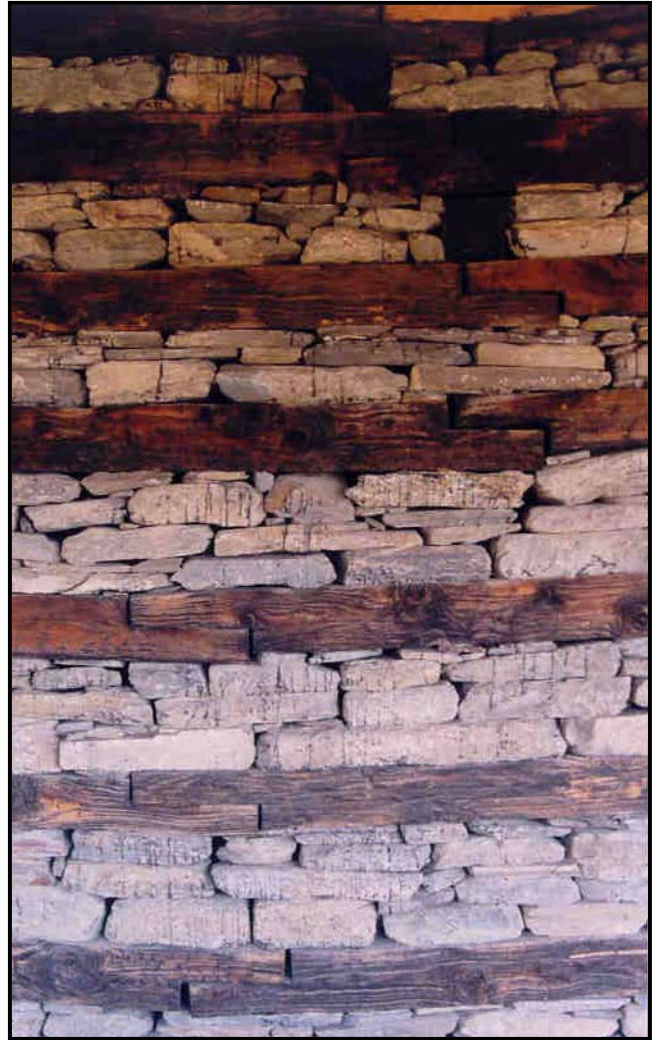
Picture 2. Corner construction detail of *kath-ki-kuni* style housing. The timber bands run along both sides of the wall and are connected by pins along their length, and at the corners.



Picture 3. Small reinforced openings are a key feature of *kath-ki-kuni* architecture. This beautifully hand-crafted door in the maharaja of Kullu's palace has elements hewn from solid blocks of wood.



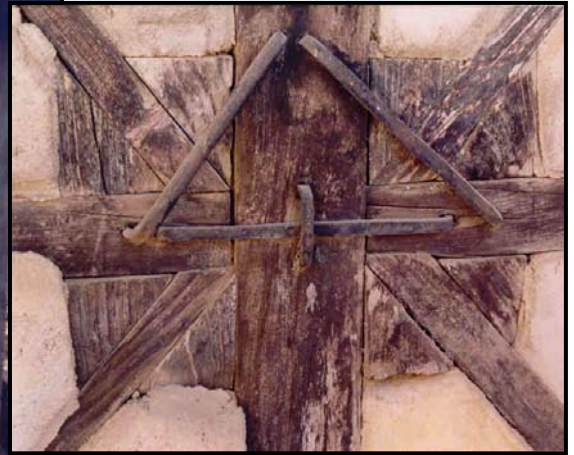
Picture 4. Shiva temple in Jungi village, Mandi district, H.P. Locals say this massive 50 foot tall temple is over 200 years old.



Picture 5. Detail of dressed stone masonry in *kath-ki-kuni* architecture. The use of long, flat stones distributes compressive loads evenly. Note the drv masonrv.



Picture 6. A temple in Karsog area of Mandi district, H.P.



Picture 10. Detail of *dhajji-diwari* in Dharamsala. Notice the use of iron pins and wooden blocks to tie the bracing together firmly

Picture 9: *Dhajji-diwari* building in Dharamsala. This was built after the 1905 Kangra earthquake by the British colonial administration. The diagonal bracing is effective in absorbing shear and tension forces.



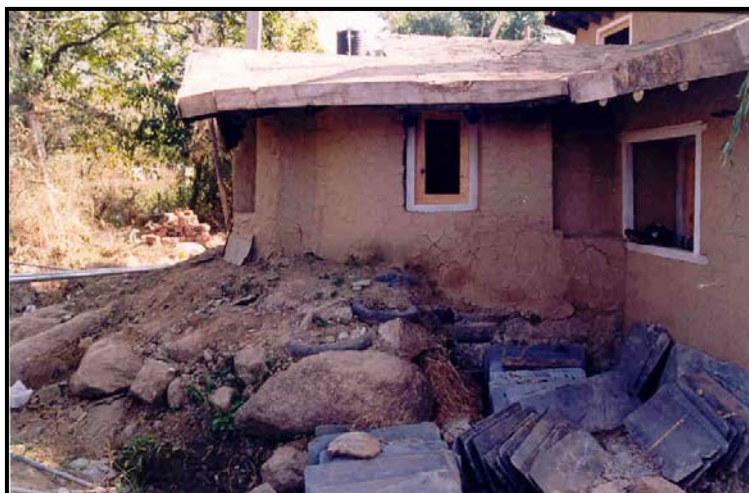
Picture 11. Detail of *dhajji-diwari* in Mandi district. Notice the loose mud masonry and plaster, which will absorb shocks during an earthquake.

Picture 10. *Dhajji-diwari* construction in Mandi district of Himachal Pradesh. The pattern of diagonal bracing here parallels traditional architecture in Kashmir.



Picture 12. A house by Didi contractor in Rakkad village (Sidhbari), near Dharamsala. This house is built both with traditional materials like mud, bamboo, stone and also new materials like reinforced cement and ferrocement.

Picture 13. Another house by Didi Contractor. These houses have earthquake-resistant elements, as well as passive solar and environmentally appropriate designs, such as the use of natural cooling and heating elements in the structure.



Picture 14. This house, under construction, shows the use of ferrocement and bamboo in the roof, over which slate tiles will be placed. This house was also built so as to be accessible for handicapped persons. This picture also shows the use of old tyres in the foundation, as a protection for the wall and a shock-absorber in earthquakes.