

EARTHQUAKE-RESISTANT TRADITIONAL ARCHITECTURE IN UTTARKASHI



a photo-essay

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FOREWORD

A couple of months after the Uttarkashi earthquake, in October 1991, some of PSI's staff visited the district to observe the relief and rehabilitation activities. The most noticeable feature of reconstruction was the massive intrusion of new building materials -- steel rods, cement and galvanized iron sheets -- along the roadside villages. These 'modern' materials were being equated with 'strength', i.e., earthquake-resistance. Mud and stones, the locally available traditional materials of construction were being labeled as 'weak' or destruction-prone.

In the absence of experience and knowledge, however, the new construction materials were not being used properly. The new houses were full of structural defects and hence likely to fail in a future earthquake. It was clear to us that we had to educate the people about the principles of earthquake-resistant construction, without which no combination of construction materials could guarantee safety in an earthquake.

In the course of preparing communication aids to explain the principles and techniques of earthquake-safe construction, we came across some excellent examples of earthquake-resistant traditional houses in Uttarkashi. Made of mud, stones and timber, they had withstood the earthquake very well. They incorporated the principles of quake-resistance discussed in text-books of earthquake engineering. We used them to illustrate the features of earthquake-safe construction and to restore peoples' confidence in their local construction materials.

In this little booklet, we have put together a technical paper and a photo-essay to share our observations of the earthquake-resistant traditional architecture in Uttarkashi, with people involved in similar work in other parts of India and the world. We hope it will be of use to them. We welcome comments from the readers.

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THE PHEROLS OF UTTARKASHI *

Rural houses all over the world are usually non-engineered structures. Their construction is guided by some traditional practices, without the involvement of a professional architect or engineer. In general, locally available materials of construction are used, the most common ones being stone, mud and wood. The materials of construction and the resulting structures are, however, changing. Houses with reinforced concrete roof slabs, columns, beams and floors are becoming familiar sights in rural areas.

Earthquakes are not a common phenomena in most parts of the world. Hence houses in most rural areas are not built to withstand seismic forces, resulting in heavy casualties – even in moderate quakes. In some parts of the world, however, where earthquakes are not uncommon, people have incorporated the critical elements of quake-resistance in their traditional construction methods. This is evident in parts of Garhwal and Himachal Pradesh, which lie in the seismically active Himalayan region.

In this paper, we briefly explain the basic scientific principles of quake-safety and list the important quake-proofing resistance structural features. In section III we identify the use of several such features in traditional houses in Uttarkashi district of Garhwal. In the concluding section, we discuss the present relevance of these structures.

BASIC FEATURES OF EARTHQUAKE-SAFE CONSTRUCTION

The impact of an earthquake on a building depends on several factors, including the magnitude, intensity and duration of the earthquake, the frequency of ground movement, the geological and soil conditions and the quality of construction.⁽¹⁾ All of these, except for the last, are naturally determined. Studies of the performance of buildings during an earthquake have shown that the use of a few simple but critical construction features can minimize or eliminate earthquake damage, even in non-engineered structures.

Seismic Forces

The main cause of buildings' damage in an earthquake is ground movement. A building is fixed to the ground at its base (Fig 1a). When the

ground moves to the right, the base of the building also shifts suddenly to the right. But, because of its mass, and hence inertia, the rest of the building tends to resist this movement to the right, resulting in deformation of its superstructure (Fig 1b). The effect is as if the building was pushed to the left, relative to its base, by an imaginary force that is called the 'Inertia Force' acting at the centre of gravity of the building. This causes severe deformation of the superstructure.

In reality, the seismic forces acting on the building are very complex, since the ground moves in the three orthogonal directions almost simultaneously. The net result is equivalent to a horizontal seismic force (or load) acting on the building as shown in Fig 1e. This inertial seismic load on a building is a function of its mass and

* This paper was read at the Congress on Traditional Science & Technology held at Bombay, November 28 - December 3, 1993.

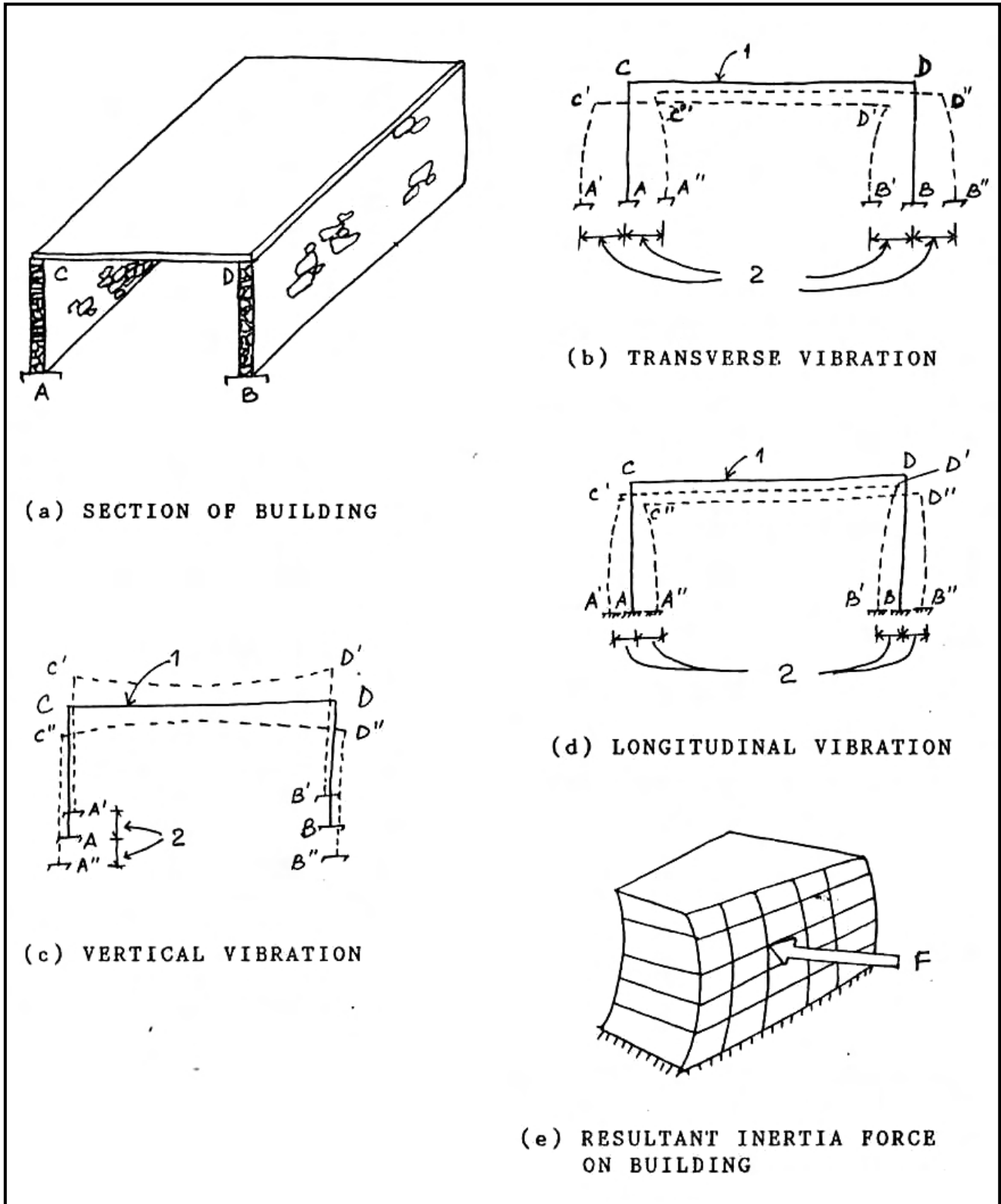


FIG 1: IMPACT OF SEISMIC VIBRATIONS

Source: ISET : A manual of Earthquake resistant Non-Engineered Construction, Roorkee, 1989

the location of its centre of gravity (CG). Hence low mass and a low position of the CG of a building are prime features of quake-proofing.

Under normal conditions, the different structural elements bear only vertical loads and are thus subjected to compressive loads. During an earthquake, there are additional horizontal, reversible seismic loads, giving rise to tensile and shear stresses in various components of the building. These stresses give rise to complex deformations in buildings (Fig. 2). Hence high tensile and shear strengths are important for quake-proofing.

During an earthquake, different structural elements of a building, e.g.,

walls, columns, beams tend to shake or vibrate differently depending on the loads encountered by each. Due to weak interconnections, these elements tend to behave somewhat independently under critical loads. The weakest element collapses first, increasing the stresses on the next weaker element and ultimately even leading to collapse of the structure. If, on the other hand, the different elements are suitably joined or interconnected, the stresses will be distributed and shared by the building as a whole. Hence interconnected elements of a building, particularly walls, are essential for quake-proofing. Tie-bands are the most important construction feature that ensure interconnectedness and tying of a building.

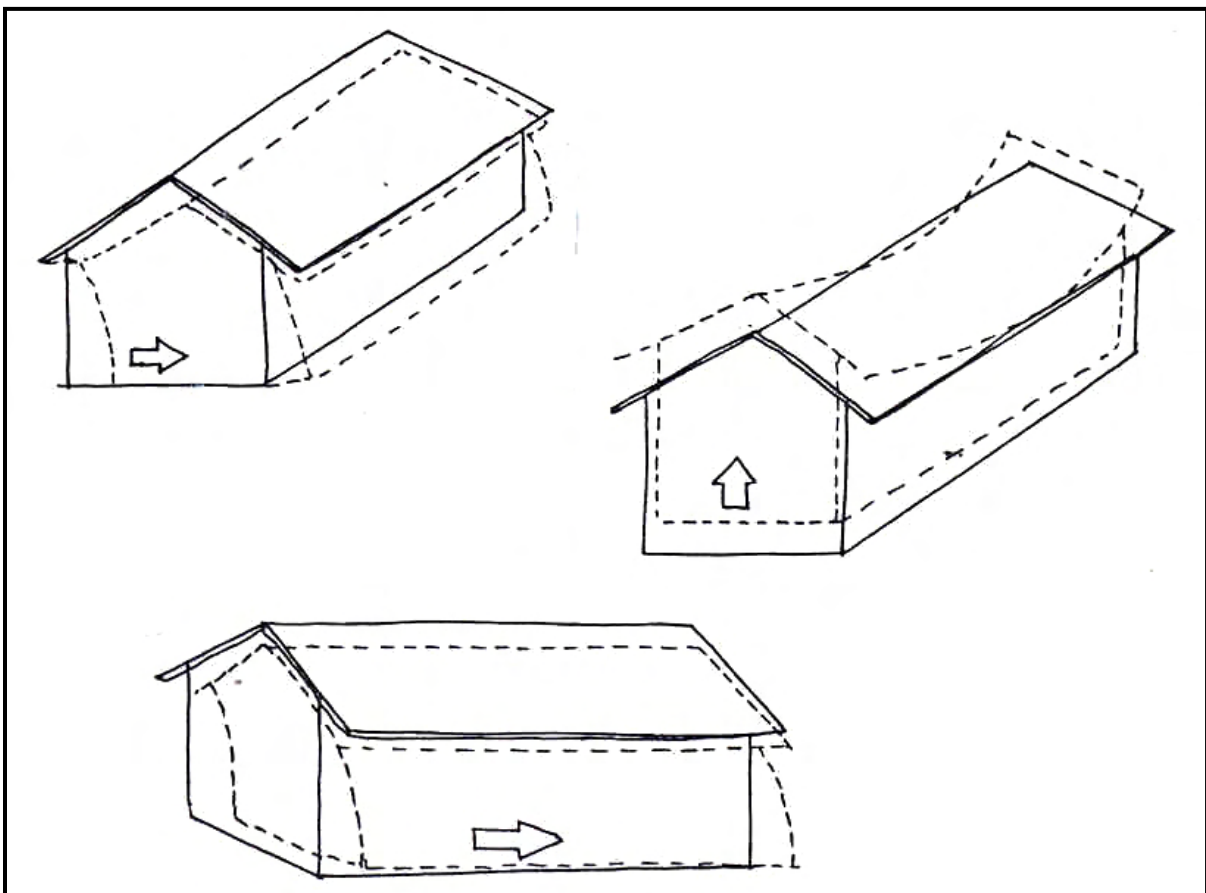


FIG 2: DEFORMATIONS PRODUCED BY SEISMIC VIBRATIONS

Source : Garhwal Chetra Mein Bhukamprodhi Paramparik Ghar : Kahan Aur Kaise, TARU

Each unit of a building, e.g., a brick or a stone, tries to distribute the stresses on it over the adjacent units. The maximum build-up of stresses thus occurs at the corners of the building or at corners of openings (Fig 3). Hence corners need to be reinforced.

The stones or building blocks need a **strong mortar** in order to share/distribute their forces and behave as a single disciplined wall. The walls must have strong interconnections to make use of each

others' rigidity. The roof must be properly joined to the wall structure supporting it.

To sum up, the building design must ensure that it has adequate strength, high ductility and will remain as one unit, even when subjected to large deformations. The incorporation of a few critical features during the construction of a building can enhance its ability to resist damage or collapse in an earthquake. Table 1 lists the main structural features that are required to enhance the stability of non-engineered structures during an earthquake.

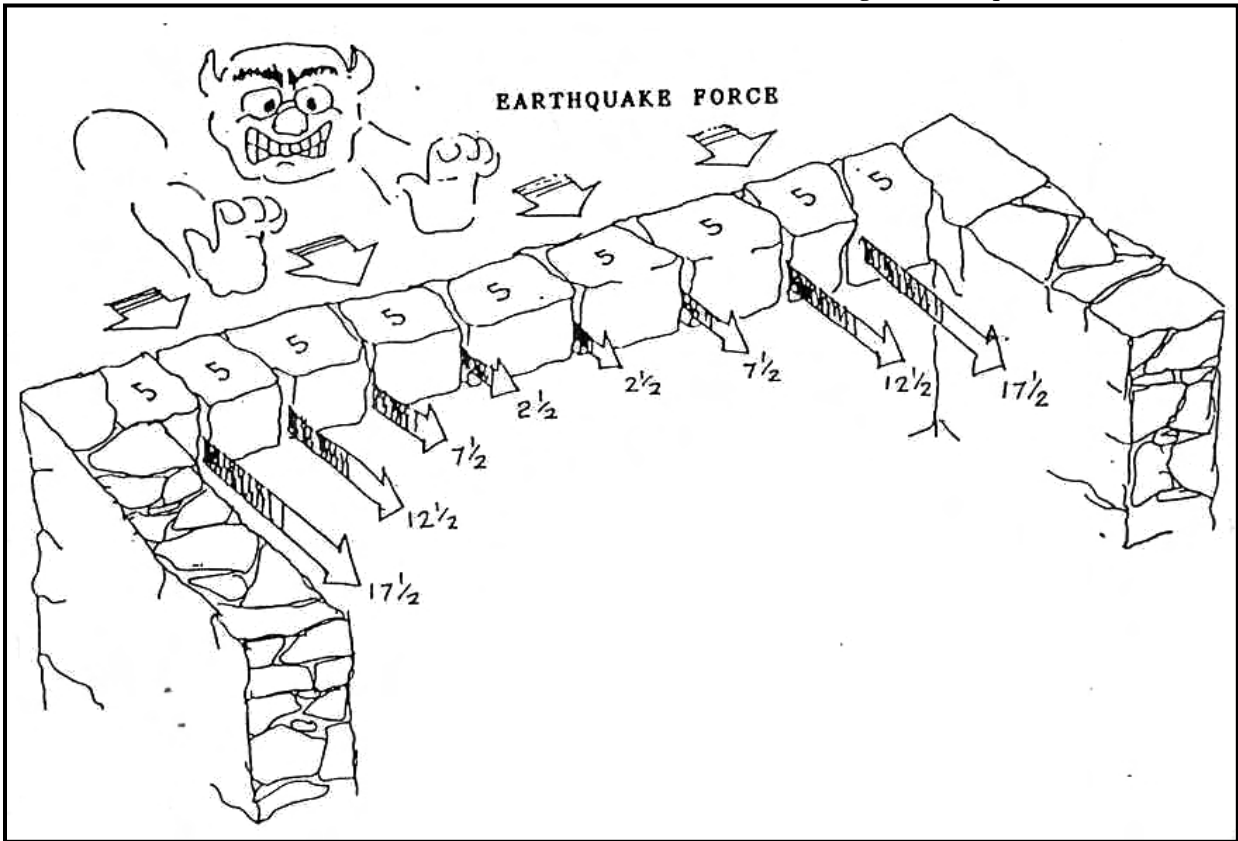


FIG 3: CORNERS EXPERIENCE LARGER FORCES

Table 1: BASIC PRINCIPLES & CONSTRUCTION FEATURES FOR QUAKE-RESISTANCE

SNo	PRINCIPLE	EFFECT IN AN EQ	CONSTRUCTION FEATURES
1.	Structural Stability	Avoid Overturning & collapse	<ul style="list-style-type: none">- Subsoil bears loads.- Adequate tying elements.- Proper aspect ratios.- Geometrical regularity.- Uniform rigidity distribution.- Masonry courses planed.
2.	Minimize Bldg Inertia	Lessen Overturning moments	<ul style="list-style-type: none">- Light building materials- Thin walls
3.	Strong & Well-Tied Framework	Transfer of Inertial Forces To Ground	<ul style="list-style-type: none">- Tie-bands- Triangulation of frame- Corner reinforcement
4.	In-Plane Stiffness In Both directions	Resistance To Eq. Inertial Forces	<ul style="list-style-type: none">- Few openings, suitably placed- Crosswalls & Buttresses
5.	Low C-G	Lessen Overturning probability	<ul style="list-style-type: none">- Low storey heights- Light building materials
6.	Shear Centre Close To CG	Reduce Local Stress & Initiation of Collapse	<ul style="list-style-type: none">- Symmetrical & regular building forms- Avoid long lengths- Simple designs (min. projections/ openings/cut outs).
7.	Increase Ductility of Structure	Absorption of Inertial Forces	<ul style="list-style-type: none">- Use ductile materials at points of tensile stresses, e.g., steel/bamboo reinforcement at corner joints
8.	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 a building.

QUAKE-SAFETY FEATURES IN PHEROLS

The entire Himalayan region is an earthquake-prone belt. According to available records, the Central Himalayan region suffered two devastating earthquakes before the one in 1991. These were:

1. In 1803, affecting Garhwal and Nepal
2. In 1905, affecting the Kangra and Doon Valleys.

In our visits to various parts of Uttarkashi district, after the earthquake in

1991, we came across several settlements with old traditionally built houses incorporating several of the basic features of quake-proof construction cited above. Locally, these houses are called 'pherols'. They were typically built around 100 years ago or more. A characteristic housing plan is shown in Figure 4. Pherols are multi-storied structures and the main materials of construction are stone and wood with mud mortar. The construction is essentially coursed-rubble masonry type.

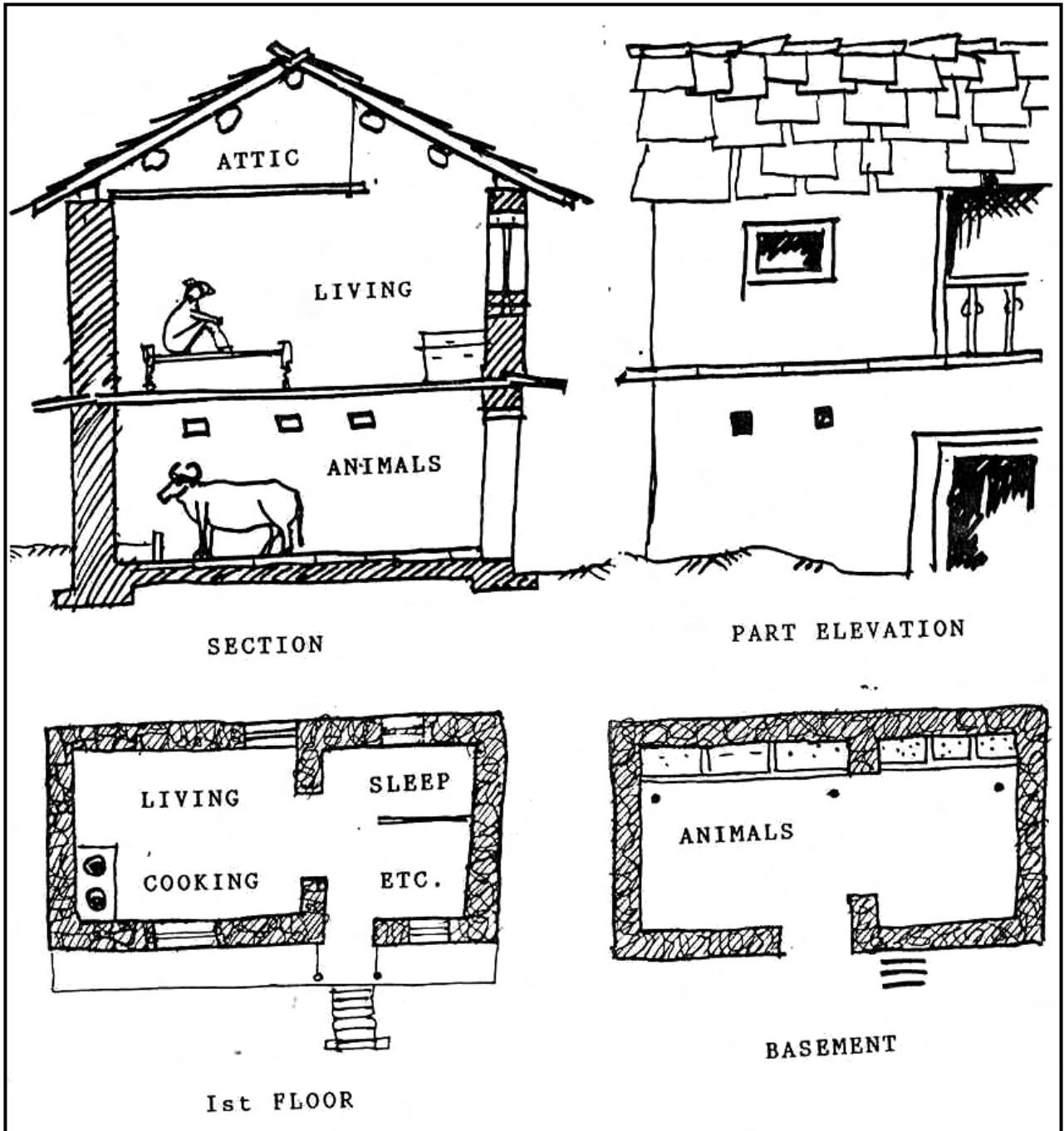


FIG 4: TYPICAL HOUSING PLAN IN THE HILLS

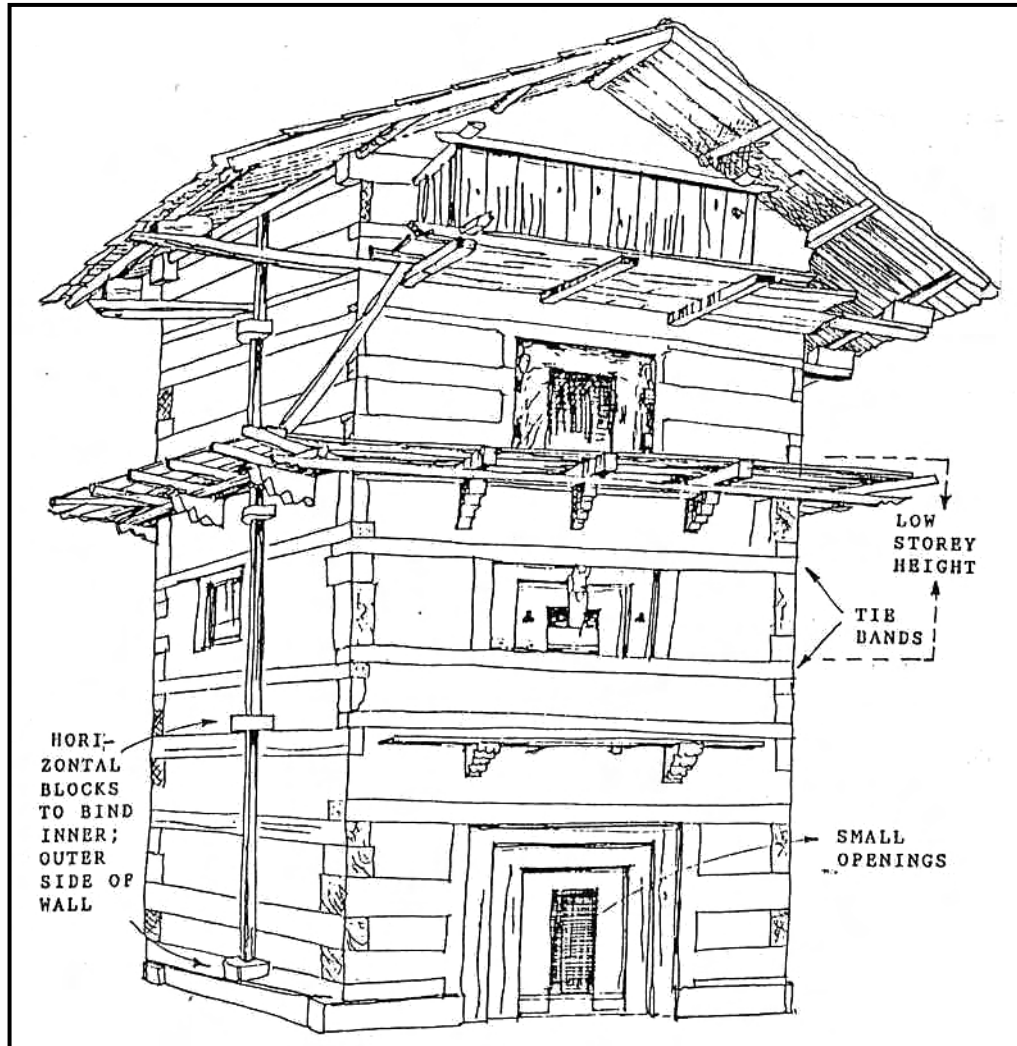


FIG 5: QUAKE-PROOFING FEATURES OF A TRADITIONAL HOUSE IN THE YAMUNOTRI VALLEY

Figure 5 is a sketch of a traditional earthquake-safe house in the Yamunotri Valley of Uttarkashi. The main features of quake-proofing that can be identified in these type of houses are:

1. **Tie-bands:** The use of wooden beams as tie-bands are the most prominent feature. The wooden

beams also serve to course the rubble masonry.

2. **Tying of Inner & Outer Walls:** The walls are made of coursed rubble masonry, using wooden beams. They are thick – usually 45 to 50 cm across – to provide insulation during the bitterly cold winters. Since the width of the masonry stones is much less than the width of the wall, there is a need to tie the

- inside wyeth and the outside wyeth of the wall. This is done by using horizontal wooden blocks with vertical timber columns acting as pins to tie the inside and the outside wyeths of a wall.
3. **Use of long flat stones:** Long stones with flat surfaces are well-distributed in the walls. The flat surfaces help to make the loads vertical in the wall units and minimize the tendency of the wall stones to push or run outward.
 4. **Corner reinforcements:** The corners of a building are reinforced by the use of wooden blocks in the outside walls. They help distribute some of the seismic loads vertically. The use of long flat stones, at 90° to each other, at the corners also enhances their strength. Inside too, diagonal braces are used to maintain their perpendicularity and strengthen corners.
 5. **Low storey heights:** Though most pherols are four or five storeys high, the heights of the floors are low, thus keeping the centre of gravity of the entire building low.
 6. **Small Openings:** Doors and windows are kept to a minimum and so are their sizes. Though this is done most likely for insulating purposes, it also serves to improve the earthquake-resistance characteristics of the building.
 7. **Quality of Construction:** This is particularly evident in the carefully crafted joints. Wooden dowels and cotter pins are used to connect wooden beams. Beams of roofs are held down in slide off. The careful joinery also helps to enhance the interconnectedness of the entire structure.

CONTEMPORARY RELEVANCE

Most professional engineers and architects in discussing quake-proofing principles of structures, emphasize the importance of minimizing the mass of the structure.⁽²⁾ But in areas subject to extreme temperatures, hot or cold, people prefer to have wide stone walls for better insulation. This can also be seen in the pherols of Garhwal. The pherols, however, clearly demonstrate that such "heavy" or massive houses can withstand earthquakes, provided the necessary design and construction precautions are taken. This viewpoint has been recently supported in the context of the Marathwada earthquake by Laurie Baker.⁽³⁾

A question that often arises about traditional technologies is whether they can be revived. In the context of the pherols of Garhwal, the answer depends on

two major factors : (1) materials and (2) the prevailing culture.

Materials: From the materials point of view, it appears that while it may be unlikely that pherols identical to the ones described here can be built, pherols with minor variations are still possible.

Pherols are constructed with stones, mud and timber, mainly deodhar. The quantity of timber used, by today's standards, is enormous. Given the diminishing access to timber in the hills, it is doubtful whether one can build identical structures. Mud and stone, however, continue to be major materials of construction. The amount of wood used can be reduced, by using battens or other means of coursing. Several alternatives to timber tie-bands have also been highlighted by People's Science Institute, as part of its activities during the post-

earthquake reconstruction period in Uttarkashi.⁽⁴⁾

Culture: Technology is as much the product of a society's culture as its knowledge or resource base. Pherols were the product of a society where a cooperative or communitarian mode of living was the dominant paradigm. Discussions with villagers all over Uttarkashi revealed that agricultural operations, maintenance of forests, construction and maintenance of irrigation channels and construction of houses were done on a community basis. Villagers would thus assist each other in the construction of pherols. (The sheer massiveness of pherols suggests that it is not the work of a few individuals and that their construction is spread over time.)

In the last three or four decades, there has been a massive out-migration of able-bodied and skilled people from the Garhwal hills, as part of a society's strategy to cope with the denudation of its resource base.⁽⁵⁾ Simultaneously, modern civilization has made significant inroads in the hilly areas through the spreading

administration, new technologies (e.g., major dams, roads, etc.), tourism and visiting migrants. Both these phenomena have transformed the society of the hill villages.

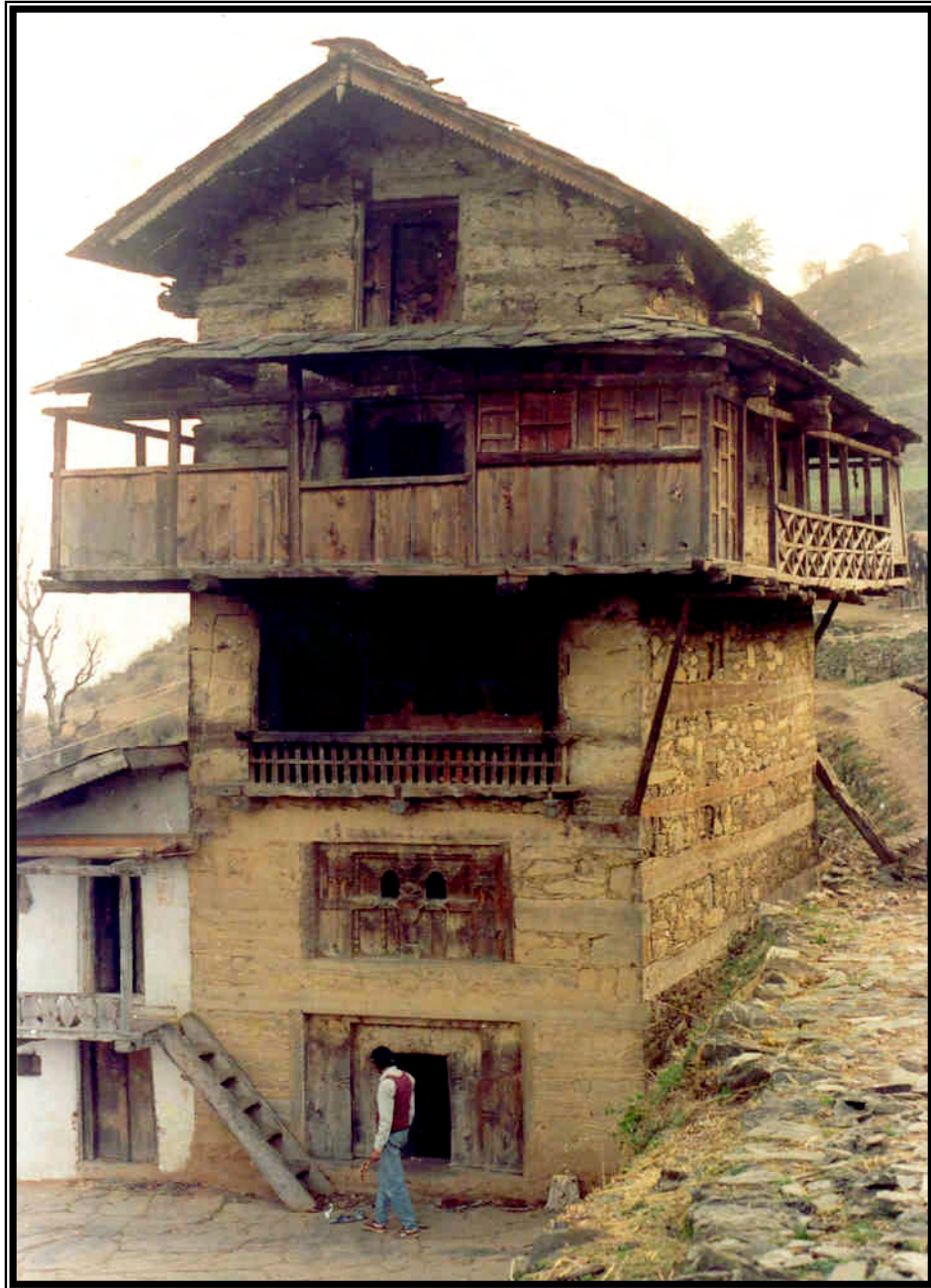
The out-migration has eroded the human and knowledge resources of the hills. During our tours in the post-earthquake period, masons in the hills – particularly in the roadside villages – freely admitted that they had neither the skills nor the knowledge to build pherol-type structures, even if wood were made available to them. Also few villagers wanted to invest the time that would be required to have pherols built. And finally, the status symbol in the hills is to have a strong (pucca) cement-concrete columns-and-beams type of structure, like the ones in the cities, with their smooth, painted exteriors. The emphasis is on competition among neighbours rather than cooperation.

The rapid cultural transformations taking place in Garhwal, more than the materials, make the revival of pherol-type structures unlikely.

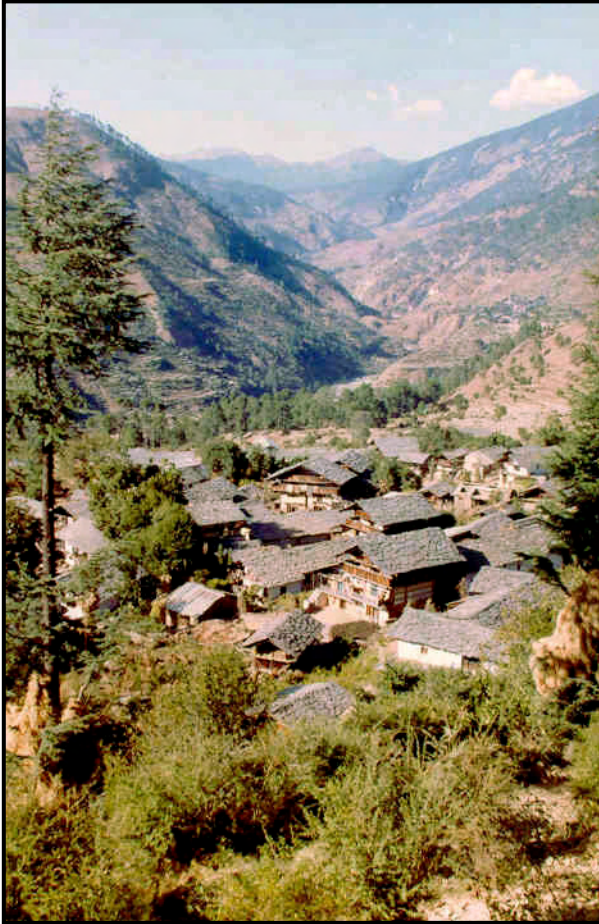
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EARTHQUAKE-RESISTANT TRADITIONAL ARCHITECTURE
IN UTTARKASHI
a photo-essay



A five storeyed house, about 125 years old in Raithal village, Uttarkashi, that withstood the earthquake in 1991. Most of the other houses in the vicinity were partially or fully damaged.



Traditional earthquake-resistant houses in Nandgaon village, Yamnotri valley. These houses are more than 100 years old. The main construction materials are mud, stones and timber.

One of the four storeyed earthquake resistant structures in Nandgaon. This 125 year old structure is still in use.





Timber beams are used as tie-bands. Long flat stones at the corners provide extra reinforcement.

Corners bear maximum stresses. In this case, timber corner braces have been used for reinforcement. The extra space created becomes a cupboard





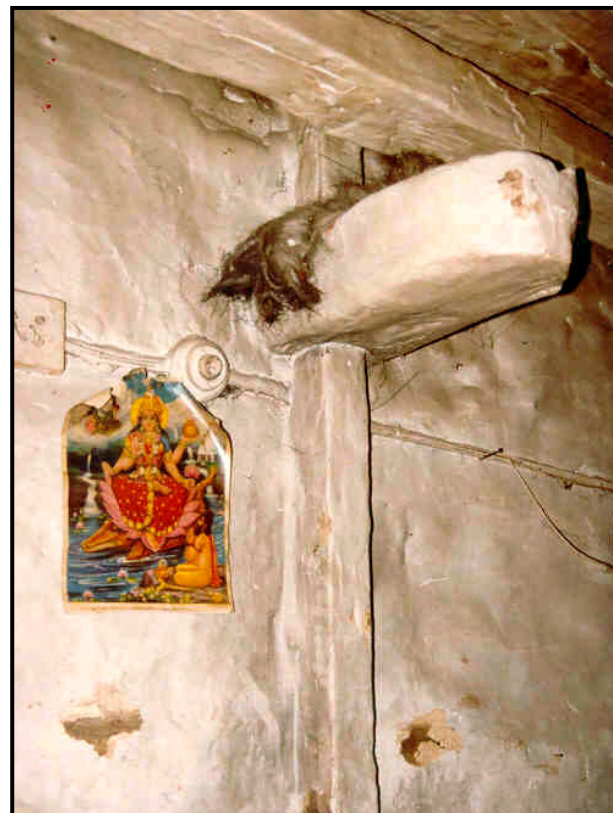
Aesthetics are an important feature of the traditional architecture in the mountain districts of the Central Himalayas. The diagonal braces provide support to wooden columns and intricate carvings provide an artistic touch.





Traditional houses in Garhwal have thick walls, which provide insulation against the winter cold. These walls are often built in two separate layers, since long stones are not readily available.

The photograph above shows the use of horizontal wooden blocks and vertical blocks and vertical columns to tie the inside and the outside.



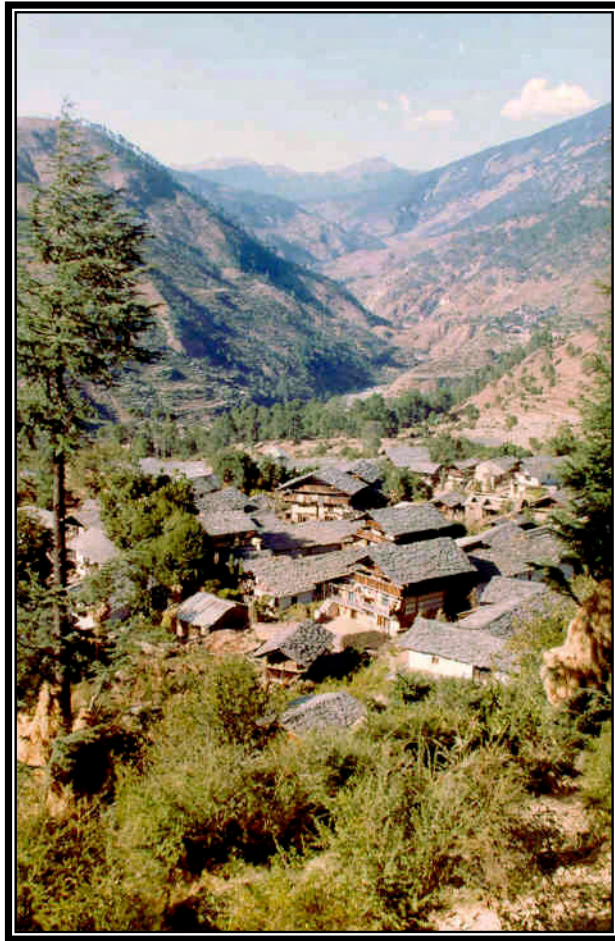


Small openings are an important quake-resistant feature

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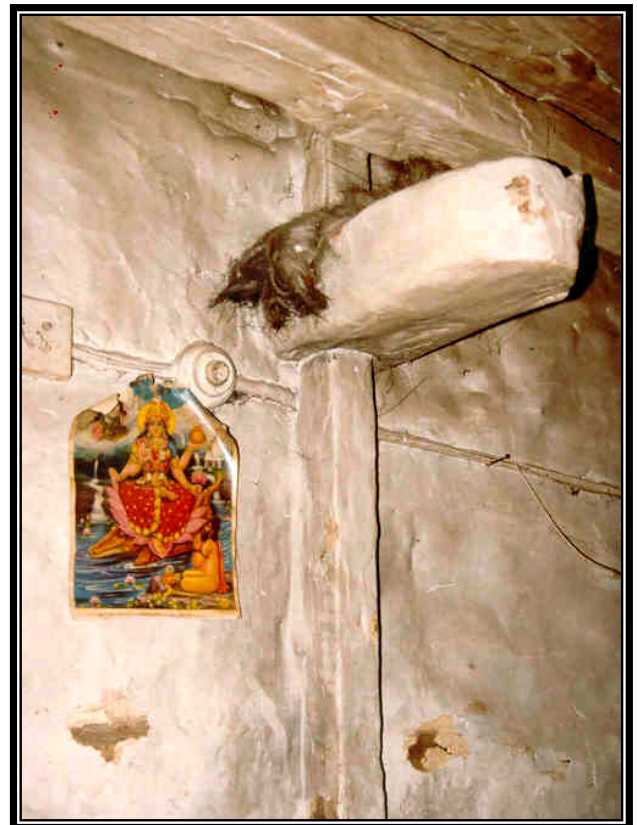
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