Seismic Performance of the Rural Habitat on the Main Boundary Thrust

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Earthquake disasters and their accompanying human casualties are almost synonymous with destruction of the rural habitat. More than one million people were killed the world over, in the twentieth century alone, mostly due to collapse of stone houses. This is a particular problem within the seismo-tectonically active Alpine Himalayan belt. The Main Boundary Thrust (MBT) within the Himalayan collision zone has been repeatedly and frequently visited by disastrous earthquakes. Due to the known adverse seismic hazards on and around the MBT, the human habitat is vulnerable and large populations are at risk within the Himalayan arc. This situation intensifies in the western and in the eastern syntaxis. These syntaxes witness more frequent and larger earthquakes compared to the rest of the Himalayan arc. This exhibits an extreme seismic condition; in fact, it is the worst-case earthquake disaster scenario.

People who live in such adverse seismic conditions gradually learnt to live with earthquakes. After repeated disasters in stone houses, several practical methods were implemented to rectify the known deficiencies in stonewalls. The design of stone houses evolved over centuries, and used locally available material, expertise and masons. One such technology is known as *dhajji diwari*. It means "patch-work quilt wall". This kind of a house has a simple square plan. The super-structure of such a house consists of a judicious use of timber. This introduces several advantages, which become obvious in an earthquake. Timber is light, it is easy to work with, it is easily available in rural areas, and at affordable prices. It can be well seasoned, so that it does not shrink in dry weather and does not expand in wet weather. Each timber member is long and is continuous at corners, at junctions of walls and is also used as beams and columns. A very elaborate timber framework is used for the dhajji diwari kind of house.

The seismic advantage of this flexible and ductile inter-connected timber frame is manifold. The timber frame can sustain relatively large displacements without failure of individual timber members. As all timber members are meticulously interlinked, the frame behaves as one single unit during the strong ground shaking to resist the earthquake force. After the strong shaking is over, the entire frame comes back to rest in almost its original position, barring a few peripheral frayed timber joints. The most important aspect of introducing vertical timber members in walls is that these take the load off stiff, brittle and vulnerable stonewalls and become load-bearing elements in the house. It also introduces flexibility and strength to the stone walls. In addition, they restrain horizontal slip of stone. So the collapse of stonewalls is minimized in strong ground shaking.

In addition to the robust and larger timber frame a smaller timber frame work is embedded within the wall. These provide an additional framework that helps in minimizing the propagation of earthquake-induced diagonal shear cracks in stonewalls within the smaller panels. Thus, progressive destruction of interior walls is minimized. This propagation of cracks is what eventually leads to collapse of most stone houses. The large and small timber frame works are filled with partly dressed stone in the interior walls, and random rubble stone in the outer walls, in rural areas. In urban areas adobe, i.e. sun-dried clay bricks, or burnt bricks were used instead of random rubble. In addition to these earthquake resistant features in a dhajji diwari house, doors and windows are few and small, well-spaced out in the wall, are placed away from cross walls, and away from edges of walls. The space occupied by the wooden staircase is negligible in comparison with the overall size of the house. Therefore a dhajji diwari house can be three to four stories high and is still able to resist earthquake forces creditably.

The dhajji diwari style of construction has been observed to exhibit a desirable seismic response, and was ably implemented in the older houses of Kashmir, both in the rural and urban setting. It emerged as a time-tested earthquake resistant technique, indigenously developed through repeated earthquake disasters and several generations, that too in the rural setting. One such example is shown in Figure 1.

Today very few buildings exist in Kashmir whose construction is based on this system entirely. Long dormant periods between disastrous earthquakes probably led to abandoning robust and appropriate construction practices, in favor of newer construction technology, without any earthquake resistance, often with tragic consequences (Sinvhal, 2010). 86,000 people were killed in stone houses in the Kashmir earthquake of 2005.

In other parts of the world too, where destructive earthquakes are frequent, people have incorporated these critical elements of earthquake-resistant design in their traditional construction methods. These are include the Circum-Pacific belt (Peru and Chile) and the Alpine-Himalayan seismic belt (the Himalayan parts of India, Afghanistan, Iran, Pakistan and Turkey). The dhajji diwari style of construction has lived up to the lofty objectives of earthquake resistant design, mentioned in most earthquake codes, (ISI: 13828-1993). The principles on which dhajji diwari is based, are now being popularized as desirable measures of earthquake resistant design. There is an urgent need to revive this traditional form of construction practice.

(a) (b)

Figure 1. Seismic response of a *dhajji diwari* house in the Kashmir earthquake of October 8, 2006, magnitude, 7.6, epicentral distance 30 km. It survived the most adverse seismic conditions within the western syntaxis: on the MBT, perched on a steep slope near the mountain top, that was covered with weathered, jointed, fractured, sheared and faulted material. (a) The elaborate timber frame around the entire house, and (b) the smaller timber frame in the interior walls of this three-storey stone masonry house received extensive damage but saved all its occupants in the earthquake, unlike other houses in its neighborhood. Location: Sarai Bandi village, District Baramulla.

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