Chapter 9
Design for Resilience: Traditional Knowledge in Disaster Resilience in the Built Environment

K. Mitra

Abstract Design is a loaded term that encompasses diverse viewpoints. Loon (Inter-organizational design: a new approach to team design in architecture and urban planning. In Proceedings of the 5th Design & Decision Support Systems Conference in Architecture and urban Planning. Nijkerk, Netherlands. August, 2000) interprets the term 'designer' to include anyone who has an impact on design, irrespective of the individual's professional background. It follows then that optimum design is the consensual design solution that is considered optimum for the largest number of people. People will have diverse responses to what constitutes optimum. These responses are likely to be dependent on a host of factors including gender, profession, occupation, health, race, religion, age, environmental experience and attitudes, to name just a few. Thus, 'optimum' will not necessarily be the 'best looking design' or the 'most economic design' or even the 'most functional design'; it will be the solution that best balances issues considered important to the largest section of people. Such a solution should ideally ensure maximum comfort and sense of well-being for all participants. This chapter looks at design within the domain of traditional knowledge systems and shows how communities residing in some of the most disaster-prone areas in the world, such as the Himalayas, have "designed" resilient environments that have withstood the ravages of hazardous events, for example, earthquakes. Unfortunately, these traditional design skills which were handed down through generations are no longer evident in their places of origin. The easy availability and economy afforded by reinforced concrete in even the most remote parts of the country, along with the associations of permanence (of the home) and prosperity (of the family) with this material, have resulted in the hybridization of traditional masonry constructions in different seismic zones of India.

Experiences from several past earthquake.s have shown that in many cases, traditional structures have performed remarkably well, while newer, "engineered" structures have not. Traditional construction, in this discussion, does not refer to

K. Mitra (✉)
Department of Architecture, Town and Regional Planning, Indian Institute of Engineering Science and Technology, Shibpur, Howrah, West Bengal, India
e-mail: keyamitra@arch.iiests.ac.in

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historic structures—though there are many examples of good earthquake performance in this category of buildings—but rather encompasses the vernacular residential constructions made with locally available materials and using indigenous knowledge. A number of such traditional earthquake-resistant practices exist in the Himalayan region, one of the most tectonically active in the world. Some of the most effective of these are *Dhajji-diwari* and *Taq*, around the Srinagar area in Kashmir, *Ikra* construction in Assam, and *Shee-Khim*, in Sikkim. This chapter describes some of these traditional construction techniques and shows how these are effective as earthquake-resilient systems.

Keywords Earthquake resilience · Traditional knowledge · Design typologies

Introduction

Anyone who has an impact on design, irrespective of the individual's professional background, can be termed a 'designer' (Loon 2000). It may be reasonably argued then that optimum design is the consensual design solution that is considered optimum for the largest number of people. These responses are likely to be dependent on a host of factors including gender, profession, occupation, health, race, religion, age, environmental experience and attitudes, to name just a few. Thus, 'optimum' will not necessarily be the 'best looking design' or the 'most economic design' or even the 'most functional design'; it will be the solution that best balances issues considered important to the largest section of people. Such a solution should ideally ensure maximum comfort and sense of well-being for all participants. This chapter looks at design within the domain of traditional knowledge systems and shows how communities residing in some of the most disaster-prone areas in the world have 'designed' resilient environments that have withstood the ravages of hazardous events, for example, earthquakes.

Built Environment and Resilience

Earthquake-resistant construction practices are not new to India or, for that matter, to human civilization. The city of Knossos (the Minoan capital) had in-built disaster resilience mechanisms such as locating buildings away from the reach of tsunamis, avoiding valleys for construction purposes on account of their vulnerabilities to floods and tsunamis and using of timber beams and joints for improving resilience against earthquakes (Main and Williams 1994). Inca settlements in the Andes addressed issues of seismic safety through restricting size of settlements, ensuring that buildings were located well apart from each other to avoid damage due to pounding, eliminating low walls, interlocking stone blocks for better structural bonding and other measures (Main and Williams 1994, p.17). In India, as far back as 1931, S.L. Kumar, a young railway engineer, successfully built several bungalows with earthquake-resistant features. These structures performed well during the

1935 earthquake in Quetta, Balochistan, that caused widespread devastation in the built environment (Jain 2005).

Traditional Knowledge Systems

Traditional knowledge systems (TKS) have been a part of the mainstream narrative in the fields of medicine, ecology and social sciences. The research literature acknowledges the importance of the conservation of this knowledge (eg., Gadgil et al. 1993; Folke 2004). It has been established that, on the one hand, traditional knowledge and related institutions increase capacity to cope with change, while on the other, traditional knowledge and beliefs tend to erode with adoption of modern technology. Drawing a parallel with the built environment, traditional knowledge systems in the design and construction of the built environment have received some attention globally, as it has been proven time and again that these are often the most optimum for the societies where they have evolved. For example, traditional practices in seismic areas, which have evolved over time, using locally available materials have offered increased seismic resistance along with good climate control. Some international examples of earthquake-resistant architecture include the *Himis style* of construction in Turkey (Gülkan and Langenbach 2004; Güçhan 2007), *Bahareque* construction in El Salvador (Bommer et al. 2002; López et al. 2004), timber houses in Nepal (Dixit 2004; Shakyaa et al. 2012), adobe houses in Yugoslavia and other parts of Eastern Europe (Dutu et al. 2012; Hrasnica 2009), confined masonry construction in Latin America and Central Europe (Brzev 2007; Langenbach 2007; Wood et al. 1987; Audefroy 2011) and *Dhajji-diwari*, *Taq*, *Shee-Khim* and *Ikra* in different parts of the earthquake-prone Himalayan Belt in India (Jigyasu 2002; Alkazi 2014).

Traditional Earthquake-Resistant Construction in the Himalayan Belt

The Himalayan Belt represents the boundary between two major tectonic plates (Indo-Australian Plate and Eurasian Plate), with the Main Boundary Thrust (MBT) and Main Central Thrust (MCT) coinciding with the Himalayan arc that forms the northern border of the Indian subcontinent spanning a distance of approximately 3200 km, stretching from Kashmir in the north-west to Arunachal Pradesh in the north-eastern tip of India. This tectonic plate boundary is a convergent boundary where the Indian Plate (at the north-western tip of the Indo-Australian Plate) is actively subducting into the Tibetan Plate (part of the Eurasian Plate). This belt has witnessed some of the largest earthquakes throughout geological time, 1897 Assam (M8.7), 1905 Kangra (M8.0), 1934 Bihar-Nepal (M8.3) and 1950 Assam-Tibet

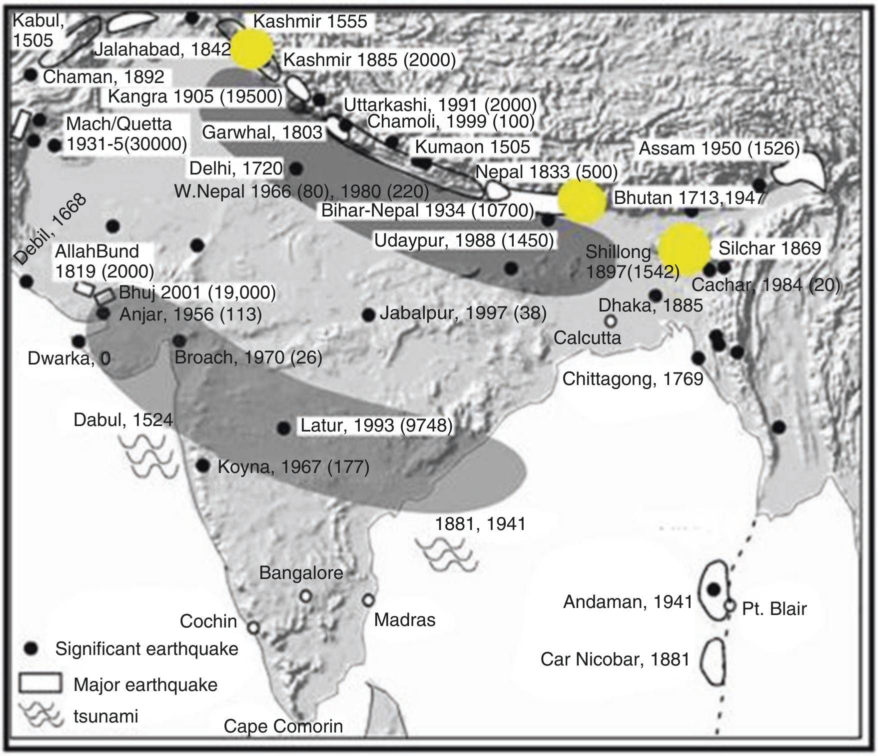


Fig. 9.1 Historical record of earthquakes in the Indian subcontinent showing the locations of three traditional earthquake-resistant systems. (Adapted from Bilham 2004)

(M8.6), and more recently, 1988 Bihar-Nepal (M6.6), 1991 Uttarkashi (M 6.4), 1999 Chamoli (M6.6), 2005 Kashmir (M 7.6), 2011 Sikkim (M6.9) and 2015 Gorkha Earthquake (M) and its aftershocks. The communities inhabiting these regions have, over time, developed resilient systems against earthquakes and other natural hazards (Fig. 9.1).

Dhajji-Diwari *and* Taq

The *Dhajji-diwari* style of construction is typically found in the Srinagar area of Jammu and Kashmir, in seismic zone V of the seismic zone map of India (IS1893:Part 2 2016), representing exposure to the most severe seismic hazard. The building typology uses three locally available materials, namely, stone, timber and clay bricks, in different combinations along the height of the building. Thus, stonemasonry is used in the plinth level, and also sometimes in the lower storeys, while a combination of brick masonry confined with timber members is used in the upper storeys.

Construction at the foundation and sometimes up to the plinth and even ground floor levels is with local stones, usually rounded in profile, as they are sourced from the river beds. The brick masonry in the upper storeys uses a lime-based mortar (locally known as *lime surki*), which uses lime and *surki*, which is an aggregate made of crushed bricks. These brick masonry panels are confined with timber members, placed vertically, horizontally and diagonally. *Taq* construction techniques are also seen wherein the vertical and diagonal wooden framing members are not used and the walls are made of brick with horizontal wooden bands placed at regular intervals along the entire height of the structure. The sloped roofs are constructed by putting panels of corrugated galvanized iron (CGI) sheets on a timber framework of trusses that rest on the confined brick masonry walls. In rural areas, the timber framework is often topped with thatch, finished with an application of a wet clay paste. In houses with more than one storey, the intermediate floors are made of timber planks above a timber floor grid that rests on the walls. Seismic safety can be achieved in a building through proper conformance to some well-known architectural and structural concepts that have proved to be beneficial in improving the seismic performance of structures.

The wood frame houses in the Srinagar region are typically two to four storeys tall. Plan configurations are compact and centralized. Floor plans are typically rectangular. The main entrance doorway leads into a small, square space which has a narrow dog-legged staircase opposite to the entrance. In the upper floor, the staircase leads to the lobby space with two rooms on either side of it like in the ground floor.

The foundation is strip foundation with stonemasonry. Often, the plinth masonry is 900 mm thick and made with locally available large-sized stones, coursed or uncoursed irrespective of the material used for the walls in the upper storeys (Fig. 9.2). Sometimes the ground floor walls are also of random rubble stonemasonry with a thickness of 600 mm, but usually brick masonry is used above plinth level where the brickwork is framed within a set of wooden members in the traditional *Dhajji-diwari* style.

The plinth masonry is laid in a shallow trench marginally wider than the wall width and about 600–750 mm deep. The plinth stops at about 600 mm from the natural ground level. A plinth beam made of timber is placed on the plinth masonry at plinth level. The plinth beams in two orthogonal directions are secured by nails or metal plates for better connections (Fig. 9.3).

Walls in the ground floor including plinth masonry are often made of stone-masonry, both, random rubble and dressed and coursed/uncoursed. In the upper floors, thin bricks are laid in horizontal courses with horizontal, vertical and diagonal ties that reduce the area of unreinforced masonry panels and help to confine the infills (Fig. 9.4) and prevent out of plane collapse during earthquakes.

The thicker walls in the ground storey often do not use diagonal members, while these are quite common in the thinner walls in the upper storeys, as the drift due to earthquake shaking increases along the height of a structure (Fig. 9.5). Buildings have CGI roofs on wooden trusses though in earlier times roofs were made of timber planks. Many variations in geometry are evident for roof design including (a) gable,

Fig. 9.2 Use of large stones and continuous wooden plinth bands. (Photos: Author)

Fig. 9.3 A metal plate connecting the timber plinth beam in two orthogonal directions. (Photos: Author)

Fig. 9.4 Two-storeyed house, rectangular in plan in the ground floor with diagonally placed room projections on the upper floor. (Photo: C.V.R Murty)

Fig. 9.5 Vertical and horizontal wooden frame members on the upper floor with diagonal framing at the corners of both faces of the building. (Photo: Author)

Fig. 9.6 Horizontal, vertical and diagonal bracing members in the upper section of the gable wall for improving out of plane performance

(b) split roof and (c) roof with dormer windows (Fig. 9.6). The roof structure is a truss with closed triangles that are desirable for best performance. Roof bands are used, and a variant of this is the use of the crossbeam with the roof band.

The suitability of the *Dhajji-diwari* system for earthquake resistance lies in the structural integrity that is achieved through the use of timber horizontal, vertical and diagonal bracing members that can deform without losing their strength and that do not allow the infill panels to fail out of plane. The strength of the system therefore lies in the adequacy of the bracing members and their appropriate placement in the most vulnerable sections of a structure, namely, corners, overhangs, gable ends, around openings, etc. However, not all *Dhajji-diwari* buildings have performed well in past earthquakes. Some common deficiencies of poorly constructed *Dhajji-diwari* structures include use of low-quality materials, inadequacy of wooden bracing members in all vulnerable locations, use of incomplete trusses on the roof and lack of connections between the structural elements such as foundations, walls and roofs. Need for adequate insulation necessitates the use of double walls, which, in *Dhajji-diwari*, are typically brick walls, where baked bricks are used for the external *wythe*, while the interior panels are made of unbaked bricks. Lack of connections between the two *wythes* contributes to the vulnerability of the system as the walls behave as independent panels with low out of plane strength and are liable to collapse or get severely damaged during strong earthquake shaking.

Ikra and the Assam-Type Construction

The typical housing in the hills of the Guwahati Region in northeast India is built both on flat lands and hill slopes. These single-or, at most, two-storeyed structures are built on raised plinth as a safeguard against surface runoff.

'Ikra' structures are built mainly for the residential purposes of the common people. The so-called Assam-type structures owe their origin to *Ikra* construction. *Ikra* typology makes use of a range of materials used for structures ranging from non-permanent (*kachcha*) to semi-permanent to permanent (*pucca*) structures. Basic features of the *Ikra* house are thatched roof, bamboo walls plastered with a mixture of mud and cow dung and bamboo splints woven together and fitted inside the wooden frame plastered with mud mortar. The bamboo adds stiffness to the mud, and being a flexible material, it also brings ductility to the system.

Ikra houses are usually low-rise structures, not more than two storeys in height (Figs. 9.7 and 9.8). In two-storeyed structures, the ground storey is made of conventional load-bearing construction, while the upper storey has lighter construction using wooden members. Simple rectangular plans are used for smaller structures, while L-and C-shaped structures are used for multifamily houses or larger structures. The sloped roofs with tall gable walls are needed to allow quick runoff during heavy rainfall. Roofs are usually sloped with a high gable to drain off the heavy rainfall.

Fig. 9.7 Single-storeyed *Ikra* structure. (Photo: Author)

Fig. 9.8 Double-storeyed *Ikra* house. (Photo: Hemant Kaushik)

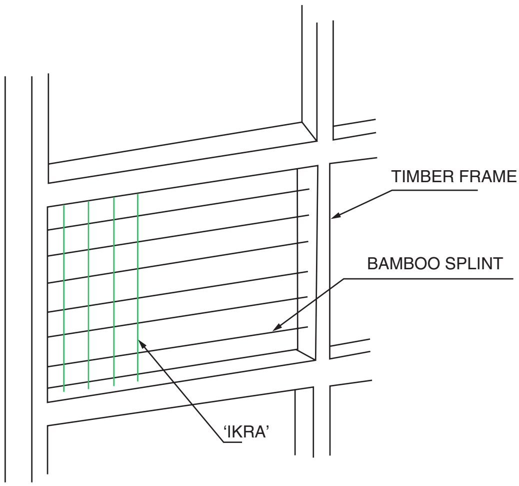
Ikra structures are made largely using wood-based materials. A weed, called 'Ikra', grows wildly in river plains and adjoining lakes across the state of Assam, and this material is extensively used in the walls and roof (Fig. 9.9). The wall panels are made of bamboo with infill panels made of vertically oriented, mud-plastered shoots of the *Ikra* reed (Fig. 9.10). The covering on the roof truss is a thick stack of *Ikra* reed or, for the more affluent, metal sheets.

The wooden framework for the *Ikra* panels is made of either bamboo or wood. The wooden frames are plastered on both the sides with mud mortar. Three layers of plaster are applied one after another, waiting for a coat to dry before application of the next coat. After all the layers of plasters are fixed and firm, a final finishing is given with a coating of a liquid mixture of mud and cow dung (Fig. 9.11).

These structures have no formal foundations, as such. The main wooden verticals of the superstructure continue below the ground to depths of about 600–900 mm. In more formal constructions (so-called Assam-type structures), the main wooden posts of the house are supported on masonry or plain concrete pillars constructed over the ground up to plinth or sill level (Fig. 9.12). The connections between wooden posts and the pillars are achieved using steel bolts and U-clamps. Later foundations were made of plain concrete mats (generally in plain cement concrete (PCC) of grade 1:3:6) over which pedestals of same grade were raised up to plinth level of buildings. Wooden posts were fixed to these pedestals with the help of iron clamps (Fig. 9.13).

Fig. 9.9 Bundles of 'ikra'

Fig. 9.10 Schematic sketch of *Ikra* panel



An important aspect of this typology is the joinery between the various elements – the posts, wall panels, roof truss and roofing elements. In Assam-type structures, connections were achieved with nails and bolts. In the informal construction, coir ropes are used to connect the various elements. The latter raises concerns on durability of the connection materials and thereby on the safety of the house. One of the most important connections is at the plinth level between the vertical main posts and the supporting pedestal. The connection is achieved by U-clamps and bolts.

Fig. 9.11 *Ikra* wall panels with mud plaster

Due to unavailability of the sufficient length of vertical posts, it is sometimes necessary to join two elements together (splicing), using bolts (Fig. 9.14a). In some cases, the main or intermediate vertical posts are embedded inside the plain concrete pedestals discussed earlier and shown in Fig. 9.11. The vertical intermediate posts are connected with the horizontal wooden members at floor level, sill level, lintel level and eaves level using nails, steel clamps and bolts. The main vertical posts are continued till the roof level and connected to the horizontal rafters and other truss members of the roof using nails, bolts and steel clamps (Fig. 9.14b–g).

The wooden planks used for slabs are supported on intermediate rafters, which in turn are supported on main wooden beams at ends that transfer the load to the main vertical posts. The empty space between the slab and the roof truss is generally used as storage. The truss is made of wooden members that support the tin or asbestos roofing.

Ikra structures are known to have a number of strengths that influence earthquake safety of the house. These include:

(a) Architectural aspects: good plan shape, small openings, appropriate location of openings, e.g. away from corners, and small projections and overhangs
(b) Structural features: light mass of walls and roofs, good wall-to-wall connection (in case of formal construction), good quality and strength of materials used
(c) Flexible connections (bolting, nails, grooves, etc.) between various wooden elements at different levels

Fig. 9.12 Brick masonry pedestals supporting the vertical timber posts

Moreover, in *Ikra,* bamboo is used as the main structural element. Bamboo imparts ductility in the system leading to good earthquake performance. The lightweight material, owing to lower seismic weight, helps to reduce the earthquake-induced inertia forces in the structure leading to better seismic performance.

The system does, however, have a number of shortcomings. The choice of wood as the basic construction material and thatch (in rural areas) as roofing material of the house draws high maintenance and is vulnerable to fire. To a large extent, the fire hazard to the house is mitigated, when the kitchen is separated from the main house but placed within the courtyard of the house. But the use of electricity in such houses leaves possibilities of fire due to short-circuit during earthquake shaking. In urban areas, the roof has long been converted to metal roofing; hence this is not an area of concern.

The mud-dung plaster on walls requires a lot of maintenance and frequent application. During summers, it becomes brittle and then falls off easily during the rainy season. In rural areas, the thatch on the roof is vulnerable to suction under strong winds.

When the wooden vertical posts are directly plugged into the ground without any foundations, structures have sunk up to 300 mm. Sometimes, differential sinking of

Fig. 9.13 Connection details between vertical wooden posts and plain concrete plinths

the vertical posts can lead to lateral sway of the house and tearing. The problem is aggravated in sites with high water table but can be mitigated by providing the vertical posts with stone piers or plain cement concrete as a foundation.

Use of *Ikra*-type construction in hill slopes has some inherent problems. On hill slopes, the unequal lengths of the vertical posts lead to unsymmetrical shaking.

Shee-Khim Construction of Sikkim

Shee-Khim is the traditional style of construction, practiced in Sikkim, and most prevalent in Upper Sikkim. *Shee-Khim* houses are of single-storeyed wooden plank construction. These are made of wooden frames and planks, supported on wooden posts. Random rubble masonry is used in foundation. The floors and double-pitched roofs were of timber construction, using single post beam system.

Traditional structure in Sikkim can be classified based on the type of material used. The two predominant categories are (1) wood houses, e.g. *Ikra* and *Shee-Khim* (Fig. 9.15), and (2) masonry houses.

Shee-Khim structures have four types of plinths according to the slope profile. These are (1) random rubble masonry (RRM) with and without mud mortar; (2) dry

Fig. 9.14 (**a**) Splicing; (**b**) connection between vertical posts and horizontal rafters at verandah; (**c**) connection between vertical posts and horizontal rafters at eaves level; (**d**) connection between vertical post and wooden slab; (**e**) connection between vertical post, horizontal rafters and inclined roof member at eaves level from inside; (**f**) connection between vertical post, horizontal rafters and inclined roof member at eaves level from outside; and (**g**) connection between vertical post, horizontal rafters and asbestos sheet used for roofing

Fig. 9.15 *Shee-Khim* house. (Photo: Sutapa Joti)

dressed stonemasonry; (3) dressed stonemasonry; and (4) dressed stonemasonry with pointing. In the hilly slopes, tapered stone plinth is preferred, while uniform masonry made of stone and mud mortar is used in flat ground. Both mud and lime-based mortar are used for bonding. Mud with fine river sand plaster is used in interiors, while the exterior has exposed stone finish without plaster.

Traditional *Shee-Khim* structures performed excellently in both the earthquakes of 2006 and 2011 (Kaushik and Dasgupta 2012) due to a number of factors. Symmetrical and simple geometric configuration in plan is excellent for earthquake resistance. The horizontal bands help to increase lateral strength capacity, while the closely packed wooden frames prevent the spread of diagonal crack, while the closely spaced vertical members also restrict the diagonal shear and out of plane collapse. The reduction of mass in the upper storey results in lower earthquake-induced inertia forces at roof level.

Concluding Remarks

The traditional earthquake-resistant systems discussed in the preceding sections fall within a rich sample of such typologies that have evolved over centuries in some of the most earthquake-prone regions of the world. These can all be said to belong within the broad umbrella of confined masonry systems with excellent connections, flexibility and ductility, stability, strength and structural integrity. Earthquake resistance is achieved through damping and shock absorption, horizontal tying actions, reduction of span between supports, enhancing out of plane stability and consequent containment of masonry. Well-constructed samples of these traditional systems are amongst the best examples of vernacular earthquake-resistant construction and may be taken up as models for new vernacular constructions in earthquake-prone areas. Rural housing programmes such as the Pradhan Mantri Awas Yojana (PMAY) initiative, for example, add huge numbers to the housing stock, involving enormous fiscal allocations. Aspiring house builders in this owner-driven programme should be encouraged to construct their houses in these earthquake-resistant technologies, using locally available materials through the construction of model PMAY houses in these technologies in district headquarters and by conducting masons' training programmes. Traditional housing construction techniques should be brought back in a significant way. Appropriate research is required to be undertaken to develop better understanding on critical aspects of the said traditional housing, especially the quantitative understanding of the earthquake resistance of such housing. These practices need to be given wider publicity amongst the various stakeholders – homeowners, NGOs, governments, artisans, financial institutions and contractors.

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