World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Dhajji Dewari

Report #	146
Report Date	10-08-2011
Country	PAKISTAN AND INDIA
Housing Type	Timber Building
Housing Sub-Type	Timber Building with Masonry/Stone Infill
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Summary

Dhajji dewari (Persian for ï¿½patch quilt wallï¿½) is a traditional building type found in the western Himalayas. Such houses are found in both the Pakistan and Indian Administered Kashmir. This form of construction is also referred to in the Indian Standard Codes as brick nogged timber frame construction. Dhajji most commonly (but not exclusively) consists of a braced timber frame. The spaces left between the bracing and/or frames is filled with a thin wall (single wythe) of stone or brick masonry traditionally laid into mud mortar. Completed walls are plastered in mud mortar. They

are typically founded on shallow foundations made from stone masonry. Dhajji buildings are typically 1-4 storeys tall and the roof may be a flat timber and mud roof, or a pitched roof with timber/metal sheeting. This building system is often used side-by-side or above timber laced masonry bearing-wall construction known as taq, bhater, unreinforced masonry and is also used extensively in combination with timber frame and board/plank construction or load bearing timber board construction. The floors of these houses are made with timber beams that span between walls. Timber floor boards, which span over the floor beams, would traditionally be overlain by a layer of clay (or mud). Dhajji buildings are typically used for housing, often of large extended families. In rural areas the lowest level may be used to shelter livestock. In urban areas they are more equivalent to town houses. With time these buildings are usually extended. This construction type was and is used extensively for commercial buildings, shops, workshops, bazaars. Because the timber framing and/or bracing is first erected the masonry does not directly carry vertical loads. Although this construction type is not formally ï¿½engineeredï¿½ and is a relatively basic construction system, well maintained ones performed reasonably well during the 8th October 2005 earthquake in both Pakistan and India. The earthquake resistance of a dhajji building is developed in the following ways. Because of the weak mortar, the masonry infill panels quickly crack in-plane thereby absorbing energy through friction against the timber framing, and between the cracks in the fill material and the infill material and the hysteretic behaviour of the many mud layers. The timber frame and closely spaced bracing, which essentially remains elastic, prevents large cracks from propagating through the infill walls and provide robust boundary conditions for the infill material to arch against and thus resist out of plane inertial loads. Because the framing and/or bracing is often extensive and close together, particularly when rubble stone is used as the infill, it is possible for keep the masonry walls relatively thin. This helps to reduce the mass of the building and therefore the inertial forces that must be resisted during an earthquake. The ï¿½softï¿½ behaviour of the system has the additional benefit of de-tuning the building from the energy rich content of earthquake excitation. Good quality timber and experienced craftsmen are the vital components to ensure the proper detailing of the buildings timber components during construction, as well as resistance against premature decay. The technology to build such a house is simple. Builders have a large degree of control over the quality of the building materials they use because the materials are sourced locally from the natural environment and are not dependant on manufacturing processes. It is often the owner who is responsible for the selection and purchase of materials and therefore often he who decides on the timber quality to be used on a project. It is rare that the ï¿½Mistrisï¿½ (term used in Kashmir to describe craftsmen such as carpenters and masons) have any significant say in the quality of the purchased materials. These structures are environmental friendly and traditionally would not have incorporated any toxic products in their construction, apart from the natural fungal and insect resistant chemicals in the timber itself.

1. General Information

Buildings of this construction type can be found in both the Pakistani and India sides of Kashmir. Similar forms of construction are found in Britain, France, Germany, Central America, South America, Turkey, Greece, Portugal and Italy and most likely other Eastern European countries. They are known as half-timber, colombage, Fachwerk, taquezal or bahareque, quincha, hımışand Gaiola respectively with some minor variations as shown in Figure 1 5 to Figure 1 10. [Note that taquezal, bahareque and quincha are somewhat different from dhajji and quincha is closer to wattle and daub. This form of construction is also known as Brick nogged timber frame construction in India. According to an article by V.K.Joshi this building type is known as Kat-Ki-Kunni in the region of Kulu and Pherols in Uttarkashi in Uttaranchal in India (see Reference 4). This type of housing construction is commonly found in rural, sub-urban and urban areas.

Typically these houses are found in the mountainous northern parts of Pakistan and India and a good example is shown in Figure 1 5 which was built in the 1930s at the time of the last great depression by a western funded research institution, for which some limited documentation was found on the web. A recent field trip by Arup engineers working in the region in August 2009 has confirmed that this particular Dhajji building is still in existence and is now being used as a museum.

Other examples of this type of construction from around the world are shown in Figure 1-5 to Figure 1-10. This report concentrates on the types of dhajji dewari buildings as typically found in the northern parts of Pakistan and Pakistani Kashmir.

This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. After the 8th October 2005 earthquake, this construction type has been adopted by many people for reconstructing their houses as they have seen how Dhajji houses have performed better than many other building types, including rubble stone construction that often had been used by those same owners prior to the earthquake. Dhajji was also selected for speed, cost and availability of materials and skills because people are in a greater hurry than normal when they are replacing a destroyed house rather than constructing a new one in normal times. However, this building type is not typically the construction type of choice for those with economic means. Reinforced concrete frame with bricks and/or blocks is often perceived to be the way to construct because it represent modern construction forms and is the construction methods widely promoted by modern engineering text books, construction codes and the training that engineering students receive. There are very large houses constructed in Dhajji and other types of timber frame construction, by rich merchants, and politicians. The current choice of construction materials are dictated most of all on by the availability of timber in the area, and cost is not the only factor. Availability of timber has been limited in several areas pre and post earthquake. For example people in Abbaspur have chosen reinforced concrete slab roofs rather than pitched timber roofs, not by choice, but due to cost and availability of construction materials. Many wealthy persons have said they would prefer to construct in timber if available. It is equally true to say that a number of people who have constructed in Dhajji may aspire to construct in masonry and or reinforced concrete, but it depends a lot on location of a building plot, and on the attitude to using stone masonry. Several households are very unhappy with their experience of the thermal performance of hollow concrete block construction and do not compare it favourably with Dhajji. Clearly there would be much value in being able to substantiate these assertions by physical measurements of the different structural types.

Figure 1 1. A Dhajji building in Simla, India without bracing elements.

Figure 1 2. Multi-storey Dhajji building in Shrinagar, India. Photo source: © Randolph Langenbach.

Figure 1 3. A two storey Dhajji building that survived the 2005 Pakistan earthquake whilst most buildings around it fell down.

Figure 1 4. A building with Dhajji in upper most storey only from Srinagar, India. Photo source: © Randolph Langenbach (see Ref. 2).

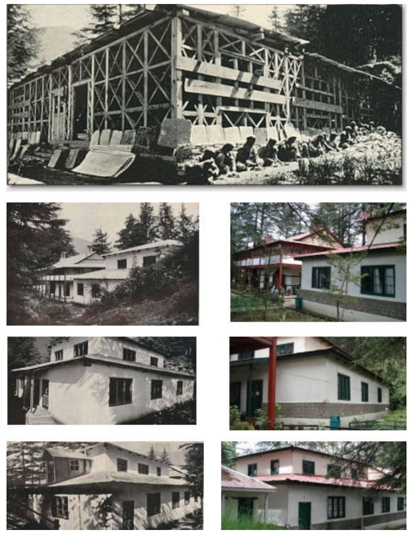

Figure 1 5. Examples from Northern India [Headquarters and Medical Research Laboratories at Naggar, Kulu, Punjab, India from article written around 1930s (See Reference 26)], Colour Photos taken in August 2009 (See Ref. 27).

Figure 1 6. Examples of similar construction types from (left) Britain (hald-timber house), (middle) France (Photo Source: www.histariege.com/le_mas_d_azil.htm), and (right) Germany (Photo Source: Hans Peter Schaefer (found on the www).

Figure 1 7. Examples of similar construction from Venezuela and South America: (left) Taquezal/Bahareque (source Wilfredo R. Rodríguez H.; Taquezal and Bahareque mean the same thing. Taquezal is the term used in Nicaragua, and Bahareque in El Salvador and other countries.), and (right) Quincha (source unknown).

Figure 1 8. Examples of Gaiola construction from Portugal (See Refs. 22 and 23).

Figure 1 9. Examples of Hımış construction from Turkey (See Ref. 24).

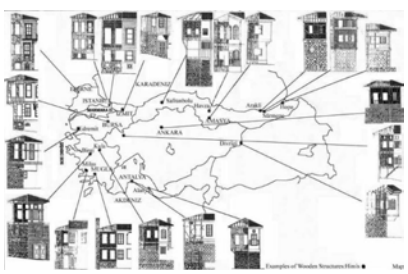

Figure 1 10. Examples of similar types of construction from Turkey (See Ref. 25).

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. In rural areas building are separated by many meters. If a building is extended then extensions will share common walls with the existing half. Dhajji buildings are more commonly found in rural areas. In urban areas and settlements along transportation corridors, wherever modern materials such as cement and steel are easily available and more affordable than they used to be, Dhajji buildings are largely being displaced by modern forms of construction. In rural areas, houses probably have a larger foot print but are likely to be only one to two stories high. In urban areas, and this is mainly in Srinagar, Indian Kashmir, there are many example of Dhajji buildings up to four stories high. After the 2005 earthquake in Pakistan there has been considerable uptake of the Dhajji construction method due to evidence of their relatively good structural performance under the earthquake and the fact that they are affordable unlike the more modern and much more expensive and complicated reinforced concrete construction methods that exist these days. One of the big issues for the siting of Dhajji buildings or any other type of such building is the necessity to construct back walls as part of the building to retain the higher ground and to construct high plinths at the downward slope of the building or under the veranda. Safe site selection is an important issue. However often families do not have much choice in deciding where they live. Typical sites are at risk from avalanches, landslides and are accessed with great difficulty because most are built away from the few existing roads in their mountainous setting. A short film prepared by the Pakistani Earthquake Rehabilitation and Reconstruction Authority (ERRA), set up after the 2005 earthquake, indicates that land ownership is recorded at the revenue department where records go back for 500 years. Traditionally land boundary records were kept on a map drawn on cloth called a ladha. The ownership records would typically name the father, the grandfather and the great grandfather and the fathers son on the records. Finally a unique field number should be available for every plot of land and that in Pakistan that records are maintained at the village level in patwar circles, district and provisional levels. Recent field experience by the authors indicates that the above description of landowner ship is not a national practice. It is thought that the majority of land is held by landlords with various agreements with tenants. Pakistan administered Kashmir has a high prevalence of owner occupancy but again that this is not a national practice. Increasingly marginal land is being used for settlement, both in rural and urban areas due to rising population. Growing rural population and settlement is increasing pressure on natural resources including ground water supply, forest cover and increased pollution by sewerage disposal. This in turn increases vulnerability to hazards and decreases resilience When separated from adjacent buildings, the typical distance from a neighboring building is 0.5 meters.

2.2 Building Configuration

Dhajji buildings are usually rectangular in plan. Length to width ratios are in the order or 2:1 or 3:1. High altitude multi-storey Dhajji is usually approximately square in plan and is typically three bays wide in each direction. If constructed on sloping terrain, these buildings are usually sat into relatively narrow man made terraces which imposes the adoption of a rectangular building plan layout for the building. Usually openings are well distributed in this type of building. Openings are in the range of 20% to 30% of the gross external wall area. However, if the building is constructed in slopping ground, the uphill long side and the short sides are usually solid wall with all the openings being concentrated on the downhill face of the building. On the downhill long side the openings can make up to 50% of the total wall area. The arrangement gives an unsymmetrical provision of the walls resulting in an increased torsional response of the building under earthquake excitation. The structural walls are evenly distributed internally of the building to ensure even lateral resistance to the seismic loads.

2.3 Functional Planning

The main function of this building typology is multi-family housing. Many Dhajji houses also accommodate shelter for livestock, usually at the lowest level, in more rural areas. It is common that these buildings are used to house single as well as multiple families. It is customary in the region for extended families to live together. This makes it very possible that a significant number of people could be living in a Dhajji house. Traditionally, including in new buildings, families like to have a large and long room for social events. The room is simply called a hall and is important for extended family gatherings. This room may be constructed at the upper level in multi-storey buildings. It is commonly over 25 ft long. It may be long in one or both axes. No likely subdivisions, buttresses etc. In a typical building of this type, there are no elevators and no fire-protected exit staircases. Commonly these buildings only have one entrance/exit found at the down hill side of the building (if built on sloping terrain). In houses with more than one storey there is unlikely to be any additional exit stairs beyond the main staircase. In multi-storey houses on sloping ground there is always an exit to the rear or side on upper and lower levels. In addition the majority of timber houses have verandas and gantries on various levels which provide means of escape. These are used for access in snow, for hanging washing, etc. Large houses have two staircases, one central and one as part of the veranda front bay of the building. This is a lot better than masonry Kacha buildings which were constructed into the slope and had rooms which could only be accessed through other rooms and no escape from the rear/retaining wall.

2.4 Modification to Building

Dhajji buildings are characterized by informal and incremental construction by nature. Addition of new space is common and is driven by the need for more rooms and the availability of resources. It is common to build upwards, due to the small flat plots available to build on in mountainous settings. Where a subsequent level is added many years after the original construction it is thought that the additional floor will be built as if it were a completely separate house that happens to be placed on top of the existing house. In other words the timber columns will not be continuous through the storeys. Similar construction techniques have been found in some pagodas. Correspondence with R. Langenbach sheds the following light on to the subject: From what I have seen, commonly Dhajji frames are more often platform frames where each story is framed onto the top plate of the story below which distinguishes them from heavy timber frames or the early American balloon frames which were stud frames where the vertical timbers carried through two stories, and the floor joist plate was framed into the studs. More generally there are three common ways to extend these buildings: 1. Horizontally, extra rooms, using end wall as party wall. 2. Vertically by constructing a flat roof initially over the Dhajji, with light mud, this becomes the first floor. 3. Vertically by constructing the frame to the roof in the first place, but only filling in walls and occupying floors according to need and resources. Detailed surveys of existing multi-storey Dhajji buildings would be required to confirm how the buildings are stacked or interconnected. If these buildings are extended horizontally, the extensions will most likely share walls with the existing building.

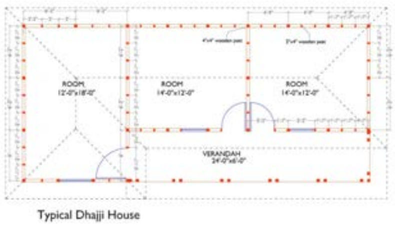

Figure 2 1. Typical plan view of an engineered Dhajji building after the 2005 Pakistan earthquake.

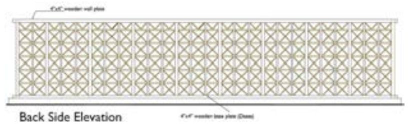

Figure 2 2. Typical rear elevation of an engineered Dhajji building after the 2005 Pakistan earthquake.

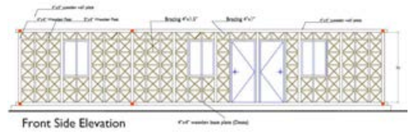

Figure 2 3. Typical front elevation of an engineered Dhajji building after the 2005 Pakistan earthquake.

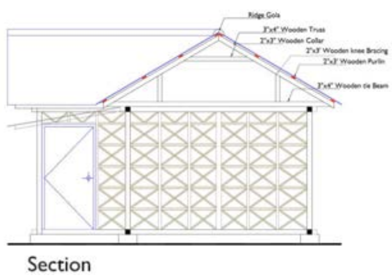

Figure 2 4. Typical side elevation of an engineered Dhajji building after the 2005 Pakistan earthquake.


Figure 2 5. Kitchen inside a rural home in Pakistan administered Kashmir.


Figure 2 6. Plastering with cement sand plaster or mud mixed with natural fibres (note that the wall is not a Dhajji wall).


Figure 2 7. Plastering with cement sand plaster or mud mixed with natural fibres.

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐

		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

In current days extensive use is made of nailing. The timber frame is extensively braced with stone/brick masonry infill traditionally laid in mud mortar. Typically after the construction of a shallow stone foundation the timber frame is built first. It is not thought that anchorage of the posts to the foundation will traditionally have been undertaken. Examples are shown in Figure 3 3, Figure 3 10, Figure 3 11, Figure 5 12, Figure 5 13 and Figure 5 16. During reconstruction efforts after the 2005 Pakistan earthquake connections between the posts and the foundation has been recommended in the ERRA guidelines (See Figure 3 7 and Figure 3 8 and Reference 3). It is most important to note ERRA and implementing partners recommended measures to make sure the plinth is stable and secure, not likely to collapse under the building. Also to make sure the building is not likely to walk off the plinth. Therefore the plinth area should have a small margin larger than the floor area of the building. The infill is added between the extensive bracing patterns adopted in building the building frames. There are no firm principles that are used to decide on the adopted bracing patterns. In other words, the location of the principle timber columns, the secondary frame members and the extent, location and configuration of the adopted bracing pattern depends entirely upon the choices of the home builder/carpenter. Examples of some idealised bracing patterns observed in the field after the 2005 Pakistan earthquake are shown in Figure 3 1 which also depend on the available timber. The infill fulfils functional (enclosure and partitioning) and structural requirements. 1. Because of the low infill panel strength and high flexibility of the timber frame, due to the generally loose timber connection, the in-plane wall panels crack in the very early stages of ground shaking. This softens the frame and has the effect of immediately decoupling the Dhajji buildings period of vibration from the likely predominant period range of an earthquake. This results in reduced inertial forces being imposed on the building. It is thought that the first phase of earthquake response is movement along the masonry-timber interfaces, before the masonry itself is stressed enough to begin to crack. In other words it is thought that there is much friction along these construction joints even before cracking of the masonry starts. 2. The cracking and sliding of masonry units along mortar joints increases the hysteretic damping levels in the building thereby reducing the earthquake loads. 3. During long duration earthquakes a few isolated infill panels may topple without jeopardizing the stability of the building as the timber frame essentially remains elastic and maintains a vertical load path and lateral stability to the building structure. 4. The closely spaced timber framing and bracing mitigates out-of-plane toppling of the infill walls by providing support point from which the masonry panels can retain their stability through arching action which ensures that the friction force is greater than the inertia force that wants to dislodge the infill pieces from the walls. It is important that long walls are regularly connected to perpendicular walls to avoid a global out-of-place failure of wall panels. Some infill failures do occur when the infill is poorly compacted because the masonry units are unable to develop proper arching action between the timber boundaries. Equally failures also seem to occur due to geometry such as inverted triangles with the long side at the top of a wall.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is timber frame. Because the stone/brick masonry infill with mud mortar is placed into the frames after the building frame has been built it is not thought that the infill carries any of the vertical loads until the building settles, the timber frame deforms under permanent gravity loads with time and the timber shrinks as it dries out. It is thought that this compression of the infill panels is in part responsible for their stability during out of plane shaking. In the case that a building is extended upwards at a later date some degree of vertical loading of the complete infill wall system will occur.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). The lateral resistance of a Dhajji building comes from a combination of the extensively braced timber frame with stone/brick masonry infill laid in mud mortar. This combination of timber framing and masonry infill resists the earthquake loads in a composite way. Because of the weak mortar, the masonry infill panels quickly crack in-plane under lateral loads and thereby absorbing energy through friction between the infill material and hysteretic behaviour of the many mud layers that form the mortar between the stones/bricks and timber framing and bracing. The timber frame and closely spaced bracing, which essentially remains elastic, prevents any large cracks from propagating through the infill walls. The framing provides robust boundary conditions for the infill material to arch against and thus resist significant out of plane inertial loads. Because the framing and bracing is so extensive it is possible to build the walls out of relatively thin masonry panels. This helps to reduce the mass of the building and therefore the inertial forces that must be resisted by the building system during an earthquake.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 20 meters, and widths between 5 and 20 meters. The building has 1 to 4 storey(s). The typical span of the roofing/flooring system is 3-4 meters. The typical distance between walls (frame + infill wall) depends on room size but is estimated to be around 3m to 5m. If a building is more than one storey the height is not likely to exceed the plan length in both directions. Multi storey timber buildings are close to cubes. Distance between columns is typically 1 meter. The typical storey height in such buildings is 2.5 to 3.5

meters. The typical structural wall density is up to 10 %. .

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☑	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	☐
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☑
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

In other words the timber columns are connected by primary timber beams. Secondary timber beams span between the primary beams with timber floor boards that are likely to be nailed to the secondary beams. In traditional dhajji buildings it will have been common for the timber floor to have overlain by a mud screed for levelling purposes. Important to note, that good quality timber boards are used in areas where timber is plentiful or people have money. In other conditions, scrap timber of various lengths and sections are simply laid on the beams and overlaid with a mud screed. In this version there is no fixing to the beams and therefore no diaphragm action, this built up floor simply shakes apart in an earthquake. Unfortunately this has proven to be very common in the post earthquake reconstruction. Traditional houses often had timber boards also used beneath the beams as a ceiling, new practice is likely to be plywood which is all to often actually a poor quality fibreboard rather than proper plywood. The mud screed serves the secondary purpose of fire protection to the structural timber floor. It is thought that the floors, although not rigid are sufficiently stiff to reasonable distribute lateral loads to the dhajji wall system in the case that the floor beams have been covered with wooden floor boards. The roofing system consists of wooden trusses clad in corrugated iron either zinc galvanised or with a painted finish. The roofing system typically consists of timber A-frame trusses spanning between principal timber columns, though this is not always the case. Sometimes the timber trusses are found to span between primary beams rather than columns. The timber trusses are typically configured to form a gable roof or even better in a hipped roof configuration. The hipped roof has better all round stiffness compared to roofs pitched only in two directions. Hipped roofs also avoid the unrestrained gable masonry. 95% hipped in Pakistan except in very high areas close to the line of control. Note that some of the roofs are getting very elaborate with complex floor plans, dormer openings and variations within the hipped roof. The elaboration of the roof has also been a response to ERRAs restriction of single storey for all construction types, whereby people simply planned to use the roof space more for living, but constructed as habitable roof not as second or third storey. In April 2008 ERRA started to allow multi-storey timber in areas of traditional timber frame construction. Traditionally rough cut purlins were used to span between the roofs trusses on to which shingles were placed as the weather surface. Flat boards were also used as found in the region of Neelum. Shingles were typically for richer people. More recently the roof covering has been made of various types of sheeting such as metal, asbestos, cement or plastic corrugated sheets. The authors do not know of cases where clay tiles have been used on these types of buildings in Pakistan or India.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☑
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Typically, these buildings have shallow dug foundations without any proactive drainage provisions around the timber frame base. It has been found that often people build a house first and only then do they think about the site preparation. This can only in part be explained through the need to provide safe shelter after the earthquake. Nowadays solid masonry (not concrete blocks or hollow clay tiles) or even nominally reinforced concrete may be used to form the shallow foundations. It is not thought that any positive anchorage will have been traditionally provided between the timber frame and the strip foundations. Foundations are typically most of the time stone. The plinth may be constructed up to several feet depending on site and location (slope or snow). There was some previous use of bolting to foundation prior to the earthquake. Nowadays, with the availability of long bolts it is envisaged that positive coupling between the timber frame and the strip foundations is being adopted more frequently as part of the reconstruction efforts undertaken after the 8 October 2005 earthquake.

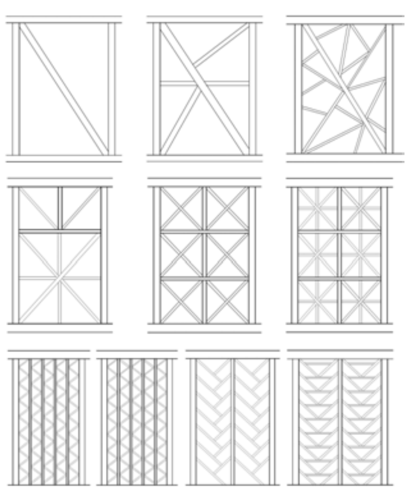

Figure 3 1. Typical bracing patterns being used post

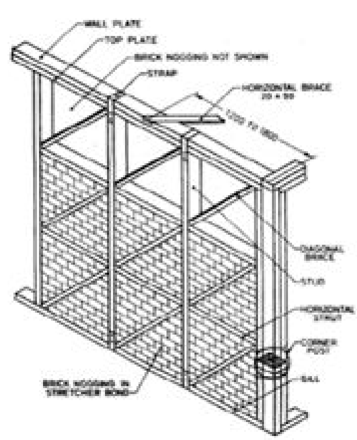

Figure 3 2. Sketch of a dhajji building from the Indian Building Code IS-4326.

Figure 3 3. Foundation below plinth beam, note no connection between plinth wall and timber beam (existing building).

2005 Pakistan earthquake: (top) braced frames with increasing levels of random subdivisions, (middle) frames with intermediate columns and regular cross bracing with increasing levels of refinement going from left to the right, (bottom) frame with intermediate columns and various regular bracing patterns.

Figure 3 4. Stone strip footing under construction to raise the timber frame off the ground (new building).

Figure 3 5. Strip footing made from stone with concrete capping and embedded steel reinforcement.

Figure 3 6. RC plinth band under construction (note poor splicing of stirrups) (Note: This was constructed for ERRA reinforced masonry. Picture was taken in Leepa in September 2006 before dhajji decision from ERRA. Picture from an area with no prior knowledge of reinforced concrete construction.)

Figure 3 7. Bolts in the foundation to tie-up plinth timber.

Figure 3 8. Bolting of plinth band with foundation. Note that a damp proof course has not been used.

Figure 3 9. Timber ground beam (or sill beam) raised above the ground to protect the timber frame from rotting. Note attempted connection of the timber beam with the foundation. Damp proof course not provided.

Figure 3 10. Corner connection detail with generous overlaps.

Figure 3 11. Post and plinth beam (called dassa locally) connection details. Note that the timber frame is founded directly on stone which will help keep the timber dry. (Note: The recommended way to fix the dassa is to use a small amount of concrete and some large stones to fix the bolt in place below ground then use dry stone above ground to drain properly. Focus should be on good stable plinth construction as much as the fixing.)

Figure 3 12. Timber frame ready to receive stone infill. Bracing has a zigzag pattern and bracing does not coincide/node-out.

Figure 3 13. Timber frame ready to receive brick or stone infill, bracing is very much in the form of x-bracing.

Figure 3 14. Construction of wall with stones and mud mortar. The planks on the other side of the wall act as formwork and will be removed after the infill placement is completed.

Figure 3 15. A wall ready to receive final coats of mud plaster (view taken from inside a building).

Figure 3 16. A completed wall, note large stones. (Note: This was built before the earthquake; it is a cheap commercial building. Mostly for houses people use smaller stones and are afraid of large stones falling on them. They may use chicken wire or timber boards to brace or line the upper few feet of the internal wall to restrain stones from falling.)

Figure 3 17. A completed wall. Note that the entire building has been raised above the ground level by a stone masonry foundation.

Figure 3 18. Inverted A-bracing pattern.


Figure 3 19. Herringbone bracing pattern.


Figure 3 20. A dhajji building with gable wall with planks.


Figure 3 21. Collapsed timber floor structure of an abandoned house in Simla, India. (Note: Layer of mud laid on floor structure).


Figure 3 22. Close-up view of photograph in Figure 3 21, note post at mid room to support floor structure (Simla, India).


Figure 3 23. Connection of first storey post with second storey post with a cylindrical wood member passing through floor beam (Simla, India).


Figure 3 24. Tie-up of roof with wall structure.


Figure 3 25. A view showing roof and braced timber frame.


Figure 3 26. Mixed bracing pattern making uses of salvaged timber and window frames.


Figure 3 27. Internal view of completed wall. Note that the timber frame is not protected from getting wet as it is built straight in to the ground.

Figure 3 28. Timber, stone laid in concrete. This is not traditional dhajji construction. There is a risk that the entire panel may fall out as a rigid object during an earthquake.

Figure 3 29. An internal view of a hipped roof. Apart from the CGI sheets there is no bracing to stiffen the roof structure. (Note: This roof is likely for storage/use. There will be a floor and ceiling of some kind added at a later date depending on the budget available.)

Figure 3 30. Timber connection details. Unless nails have been used this connection will not have very limited tension capacity to poor joint interlock.

Figure 3 31. Simple strapping of nailed scarf joint will provide confinement to the joint and help increase its capacity. The nailing increases the scarf joints tensile capacity.

Figure 3 32. Strapping around the timber will help confine the scarf joint; long straps will help with tension as will the nails.

Figure 3 33. Poorly built scarf connection. The joint is a poor fit and the wooden peg that should pre-stress the joint appears loose. Note that the joint has been crudely reinforced with nails.

Figure 3 34. Common random bracing in small panels.

Figure 3 35. X-bracing pattern using partially cut stone.

Figure 3 36. Bracing using large timber braces as timber resources are less constrained in the higher altitude. Note the more layered infill effect due to the type of locally available rock.

Figure 3 37. Large panel that appears to be in poor contact with the timber frame. Lack of tight fit may result in the entire panel falling out-of-plane. Again note the layering of the infill due to local rock characteristics.

Figure 3 38. Mixed reinforced concrete and timber framing in dhajji style using X-bracing pattern.

Figure 3 39. Reasonably cut stone laid with a lot of mud mortar. Note that the timber has been soaked in old engine oil as a way to give it some better protection against rotting.

Figure 3 40. Wall built before the 2005 earthquake.

Figure 3 41. Wall built after the 2005 earthquake.

Figure 3 42. Zigzag bracing that nodes out. Note that the roof is erected early as it helps to stabilise the walls before their completion and helps keep the work dry. Also note the hipped roof giving stiffness in both principle building directions. Note 1: anchor rods in the foreground and that a damp proof course is not used. Note 2: The whole building is over 1 ft off the ground. The veranda is protection for the building. The dassa is treated. There is a curious issue that the concrete band is referred to as damp proof course. It is usually not reinforced, but perceived as having another function. In some areas they are using flat galvanised sheeting wrapped around the timber, but there is not a perceived need to protect from ground water.


Figure 3 43. Engineered dhajji building frame under construction.


Figure 3 44. Inside view of a 1 storey house under construction. Note that the timber frame is in direct contact with the ground.


Figure 3 45. Preferred roof framing for those who can afford more


Figure 3 46. Anchor bolt in stone masonry wall laid in sand and cement mortar. Note that the mortar is only used locally around the anchor. Also note that the bolt is already rusting and is unlikely to receive any rust treatment prior to connecting to the frame base plate apart from being maybe treated with old engine oil which is very commonly done.


Figure 3 47. Base plate corner detail and bolt anchorage holes. Note that orthogonal walls are already planed and interconnected with the perimeter timber ring beam.


Figure 3 48. Mixed construction form. Dry stone wall with dhajji timber frame on top but without traditional infill material. Note: This is only a stage in construction. This is always infilled later. The corrugated galvanised iron sheets will be used as permanent shuttering / weather protection.


Figure 3 49. Internal view of large room with partially completed infill walls. Note the lack of bracing in any direction from the roof and apparently large distances between orthogonal walls. The system may be too flexible without enough support to the walls. There was Some buttressing by walls of external rooms. This room is a hall for social occasions and shared use in winter, most families will not subdivide this room.


Figure 3 50. Double storey hipped roof built in to the slope on one side.


Figure 3 51. Simple frame at the start of the process of converting the posts into dhajji walls with hipped roof. Note that gutters are not provided to any of the roofs. (Note: This is an early stage construction photo. There are now many houses with gutters either for water or to control splash, and a big programme to increase rainwater harvesting.)

Figure 3 52. Dhajji frame under construction. Note that the front sits on top of a retaining wall and the back is partially a retaining wall. (Note: Front retaining walls are usually constructed too steep without the required inclines.)

Figure 3 53. Full height built in wardrobe with reasonable thick solid timber back possibly it acts in part as a timber shear wall but it is not a detail that the engineering solution should depend upon. Note: The wardrobe back wall is usually solid ½ inch timber.

Figure 3 54. Dhajji frame built on a poor quality dry stone wall.

Figure 3 55. Mixed wall construction. Dry stone wall on the left hand side and dhajji construction on the right hand side. Note: The stone wall looks like it is against the slope; these are not strictly built as retaining walls, but as stone walls with loose fill behind.

Figure 3 56. Single storey house with dhajji walls. It was not clear if the roof damage was due to the 2005 earthquake or if this was post earthquake construction. The exposed timber looked like post earthquake construction with fresh cut timber along the long facade.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). With the passing of time these houses can become home to a relatively large number of people from an extended family. Typically extensions are built with the growth of the family or the house is divided in two when the male offspring of the owners each inherit a part. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10. One family is likely to have on average 7 people per family as quoted in Pakistan after the 2005 earthquake.

4.2 Patterns of Occupancy

During the day/business hours these houses will typically be home to babies, very small children, most women of the household from teenage girls upwards, sick people and grandparents. Children of school age and working men will typically be at school or work. School children will return earlier in the day than working adults. In the evenings and night time these buildings will have the largest number of inhabitants. As these buildings are mainly family homes they will likely have their highest occupancy level during school holidays, weekends and in particular during the cold and wet and dark winter months.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

Most of the dhajji buildings belong to subsistence farmers and small business owners. Their economy is based on subsistence farming, labour work, or remittance (money sent back to home by family members working in other parts of the country. Construction of dhajji also depends on geography and the locally available construction materials. In some locations wealth household also build in dhajji albeit in a more elaborate manner.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☐
3:1	☐
1:1 or better	☐

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☑
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

The ratio of the housing unit price to their annual income is typically not available. The typical source for financing the purchase of these buildings is owner financed through personal savings and loans from a network of friends and relatives. Often the extended family will provide assistance in the form of labour to construct such houses. Dowries may include furniture to help set up homes For example a person on a low income is earning ~3000 PKR per month. Middle income is ~30 000 PKR per month. A house will cost from 150-500,000 PKR current costs (year 2006/7 prices). A lot depends on the cost to the owner of timber, he may have his own trees, or good relations with the forestry dept. In effect these houses are built by the building owners with the help of friends and extended family. The only source of technical input will come from local craftsmen who are known as Mistris (a term used in Pakistan and India to describe a craftsman or master craftsman in Urdu/Hindi). These Mistris play a pivotal role in the overall construction process of dhajji houses. The house owner will typically collect the construction material over a number of years. Cash will be required for procurement of materials such as some wood (traditionally locally available); iron sheets, nails, metal straps etc that needs to be brought from larger towns, transportation of these items to the construction site and for the payment of the Mistris as recognised skilled craftsmen. A local set up of band sawing is usually set up at site to cut timber to size and helps the Mistri .in his work Traditionally, many of the people who built dhajji will not have had bank accounts. However, after the 8th October 2005 earthquake this was being changed as the government of Pakistan only provided financial assistance to those who achieved compliance with the reconstruction guidelines provided by ERRA and who had bank accounts for the money to be placed into. This resulted in an increased uptake of formal banking in the region. All affected households were required to and supported to open bank accounts in order to manage the direct and efficient disbursement of funds. Financial assistance was in 4 tranches, 25,000PKR initial, 75,000 mobilisation, 25,000 at plinth inspection, 50,000 at lintel inspection. Tranche 3 and 4 were contingent on compliance with ERRA standards. Currently it is not known if this will lead to banks providing financial services to anybody who wants to build in dhajji or any other type of building in the future in Pakistan. One issue with dhajji is that there are no codes in Pakistan according to which a dhajji house should be built or assessed. However, the ERRA guidance has provided basic guidance for dhajji construction as part of their compliance catalogue. In each housing unit, there are no bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) including toilet(s).

Older houses had a series of rooms in a line and bathroom adjoining at the end. Often the bathroom will have been separate from the main building. Sometimes it was planned to be accessed off a veranda. In new houses the bathroom may be more integrated into the building but it is still generally planned to be on the end. The main difference is that the bathroom or toilet can probably now be accessed directly from the inside of the house. This will be of particular benefit to the inhabitants during the wet and cold times of the year. Larger and multi-storey timber houses with square plans have the bathroom located at the external corner, accessed from the inside or from an external balcony/veranda. .

4.4 Ownership

The type of ownership or occupancy is outright ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	☐
outright ownership	☑
Ownership with debt (mortgage or other)	☐
Individual ownership	☐
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

It in not thought that mortgages or even micro loans have typically been made available to people who have built their houses in dhajji. In the North West Frontier Province the land may be owned by a landlord, the house may be owned by the landlord or by a tenant who constructs it.

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☑	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☐	☐	☑
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☑	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☑	☐	☐

Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☐	☐	☑
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☐	☑
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☑	☐	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☑	☐	☐
Additional Comments	The dhajji structural system generally contains a complete load path for seismic forces in any horizontal direction that transfers inertial forces from the upper portions of the building to its foundation. These buildings are generally regular with regards plan and elevation unless it has been built on a steep slope. On sloping ground the downhill wall will typically have more openings than the uphill wall(s). The roof diaphragm is not considered to be rigid. Usually there is no in-plane bracing at the bottom chord level of the roof trusses or bracing in the vertical plane joining adjacent trusses or in the inclined plane of the roof as shown in Figure 5 1. The simplest roof construction method that gives stiffness in both orthogonal directions is by the adoption of a hipped roof. It is thought that improvements to the roof diaphragm could be made by the introduction of roof bracing as shown in Figure 5 2, Figure 5 4 and Figure 5 5. Traditionally dhajji buildings will have been clad in timber shingles which would not offer any additional in-plane roof stiffness. The use of plastic, asbestos or metal roof sheeting more recently will offer some roof stiffness depending on how frequently the sheets are connected to the roof purlins, the degree of overlap between the sheets, the gauge of the roof sheeting and probably most importantly the general level of craftsmanship. Sometimes there will be a ceiling made of various board type materials and in certain instances the ceiling will be made from timber boards which will be able to contribute towards the diaphragm capacity. The floor diaphragm(s) are generally not considered to be rigid unless the floor boards have been extensively nailed to the floor beams. As dhajji buildings have a good distribution of walls in both orthogonal directions it is not thought that the flexibility of the floor(s) or the roof will have a negative impact on the seismic performance of the building. This does assume that walls are regularly supported by orthogonal walls that are structurally interconnected. However the roof often slides off, as it is not adequately fixed to the walls if at all. A second issue is that the roof and ceiling could help retrain the walls, especially the longer walls, but may not be able to do so if it is not well connected to the walls. Generally there is no evidence of excessive foundation movement (e.g., settlement) that would affect the integrity or performance of the building in an earthquake where such buildings have been built on safe ground. dhajji buildings are relatively light and are not expected to impart significant inertial forces that would need to be resisted by the ground under the building. However a number of buildings have had their built up plinth collapse causing damage to the buildings. At least two walls or frames are available in each principal orthogonal direction of the building structure. In dhajji typically all walls have the dual function of resisting vertical and lateral loads. Traditionally it is not thought that the vertical load-bearing timber columns that make up the walls will have been anchored into the foundation. From our experience the lowest timbers have always been raised off the ground and have been built with a continuous base plate. More recently, especially after the 2005 Pakistan earthquake the use of anchor bolts has been widely promoted. A few examples of foundation connection details are shown in Figure 3 5, Figure 3 7, Figure 3 8, Figure 3 9, Figure 3 10, Figure 3 11 and Figure 5 5. Exterior and interior walls should be anchored into the roof and at every floor level by the way the timber frame is built. In reality the degree of connectivity is very much dependant on the ability of the carpenter to build such joints. Traditionally metal anchors or straps to help resist seismic forces will not have been provided. More recently the use of metal strapping to strengthen connections is gaining more widespread usage. Unfortunately the use of nails and metal strapping is also being used as a substitute for proper carpentry. Examples of the walls and their connectivity are shown in Figure 3 11, Figure 3 12, Figure 3 13, Figure 3 14, Figure 3 15, Figure 3 16, Figure 3 17 and Figure 3 18. Equally the reconstruction rush following the earthquake has meant that nailing is seen to be a quick form of making connections as labour costs are high and nailing is fast. The quality of modern workmanship (based on visual inspection of some typical buildings) is very variable but it can be said to be generally of poor quality. It is clear that buildings such as those shown in Figure 1 1, Figure 1 2 are the exception in that they will have been built by highly skilled craftsmen who would have ensured a good fit and detailing of the timber frame with careful placement of the masonry infill between the timbers Since the earthquake many houses have been constructed by people who were not previously carpenters which will account for some of the post disaster construction quality issues. It is hoped that when the market slows down again, real carpenters will prevail. Traditionally dhajji houses were built without codes and standards. Even today there are only a few written guidelines available for people to follow. Even with the few available guidelines most of the people who build these houses are not formally trained and many have a very limited amount of schooling making written training material of little direct value as many cant read the material that is available. However, Rules of thumb do exist and these are typically passed on in the form of oral instructions. The technical support provided through the earthquake reconstruction programme included collecting and promoting good practice and training principles as well as improving joints and workmanship. Most information materials are based on photographs and physical models and out of necessity did not rely on literacy. In addition there is an issue for the clients to also appreciate the value and importance of joints and workmanship, and be willing to pay for it. Buildings of this type are generally maintained but there are often visible signs of deterioration of the timber framing. (Figure 3 3, Figure 3 11, Figure 3 19, Figure 3 20, Figure 3 25, Figure 3 29, Figure 3 30, Figure 3 33, Figure 5 1, Figure 5 2, Figure 5 2, Figure 5 3, Figure 5 4, Figure 5 5. Typically the timber is not well maintained, protected or treated enough. One of the main problems is the exposure to the rear of the building. There are many examples of deterioration. People also plan for a short life span so there are often many buildings in an advanced stage of decay. This is a wasteful use of valuable natural resources. It is important to extend the lifespan of the building, by increasing the durability and thereby reducing vulnerability. It is not expected that the floors or roof will maintain their shape due to their flexible nature. However the building is thought to maintain its integrity due to the many walls that support one another. In other words the various timber walls work together to give the building a box like characteristic. However very poor people may only be able to afford one large room which lacks the supporting walls to buttress their only room making them more vulnerable. The location of opening is not thought to be too important because the basic structural system is braced walls that also brace one another. However a concentration of the openings on one side of the house, as found on houses built on sloping ground, leads to an increased torsional response. The low mass of the building and the many walls mean that the torsion force are low and well distributed throughout the building walls. Clearly a systematic approach for locating the openings will help contribute toward better seismic performance of dhajji buildings. Metal straps are not seen in old dhajji buildings. Floors and roofs have been well tied with the walls through good quality timber joinery. However the use of metal straps and in particular the use of nails is a frequent modern occurrence in building dhajji houses. It is not uncommon to use cut strips of galvanised iron for such applications. It is also noted that where the galvanised sheets have been cut the bare steel will be exposed and it is unlikely that these cut			

	locations will be sealed with an appropriate corrosion barrier. The maintenance of a dhajji building depends on the value and importance each occupier / building owner places on the long term value of good building maintenance. Likewise it must not be forgotten that good structural and architectural detailing will ensure that the base building design is inherently of good quality making sure that water is prevented from getting to the timber as much as possible and therefore compromising the longevity of the building frame.

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Ground, Foundations, and Timber frame base beam	Land on which the building is built is unsafe (see Section 9). Foundations may not have been provided (or not raised enough) placing the timber frame in direct contact with the ground. On hilly sites slopes are sometimes retained by the back wall of the house. General deficiency: drainage not provided to the foundations away from the building Built directly on to the ground leading to rapid rotting of the timber frame Timber base ring beam anchored to the foundations Traditionally anchorage will not have been provided between the timber frame and the foundation Base beam not connected perpendicular to the wall direction	Proper strip footing provides solid foundation for the timber framing. Build well detailed retaining wall away from the house (also ensures water seepage through the retaining wall does not entre the house directly Stone foundation extends away from the building ensuring that timber stays as dry as possible Timber base built on top of a stone base or where reinforced concrete is used for the foundations a damp proof course should be used to prevent water making the timber frame wet through capillary action in the end grain. Fixity to the foundations ensures building does not fall of its base, especially if the house has been built on a slope where the downhill side of the building is raised much more than the back of the house Lack of anchorage may have provided some form of natural base isolation to the building. This needs detailed engineering investigation. Provision of timber ties for internal cross walls help tie the walls together if done at the outset	Complete destruction of any building Rotten timber frame leading to rapid collapse of the building Retaining wall failure during earthquake leads to partial or full collapse of the house. Rotting of the timber frame base leading to failure at the base of the building and then subsequent collapse. Leads to collapse of the building do to loss of strength in the timber frame House falls off the foundations leading to local damage or in the case of more severe drops complete collapse of the building. Lack of tying of the timber frame base in both principle directions allows walls to move independently leading to differential movement and thus damage.
Walls, Wall bracing, and Infill	Wall principle posts do not align with roof trusses or second floor principal beams Walls posts are not properly connected to the timber base plate When more than 1 storey it is not clear if the columns are continuous between the floors Perpendicular walls are not properly interconnected Bracing too few resulting in large infill panels Extensive use of nailing in more recent dhajji constructions will stiffen the timber frame up considerably. it is not clear if this is a good development as a stiffer frame will attract larger seismic forces. There are very many bracing patterns there is no real engineering evidence that quantifies the performance between various wall bracing patterns adopted. The extensive cross bracing feels like a formal engineering solution but is more likely to be stiff and thus attract larger seismic forces. The random looking bracing patterns with many odd sized brace sections looks looser and may provide better energy absorption and period elongation opportunities to the building. Detailed Engineering analysis required to evaluate this scientifically. Poorly built infill large stones that have limited planes over which energy can be lost. Limited opportunity to absorb energy by yielding the mortar material Round stones used for the infill material which will pop out when squeezed. Infill made from mass concrete which will fail as a rigid body Infill poorly built with lots of gaps masonry will not be able to arch properly	Alignment of principle structural members ensure a simple load path and direct load distribution Proper use of timber to timber connections ensures reversible load paths. Use of proper strapping keeps the wall posts connected to the same ring beam which reduces differential demands on the walls Continuity of main timber columns ensures load path continuity but having discontinuous columns may provide a form of limited seismic isolation as long as the upper columns cannot get dislodged - Engineering study required to gain a better understanding of this. Proper connection of orthogonal wall lines from the start High level of bracing ensures small masonry panels giving the masonry many lines to arch against and the bracing helps prevent crack propagation in the infill Tightly build Use of bricks or well prepared stones laid tightly to ensure good bond between each stone/brick and one another, the timber frame and the timber bracing	Local torsion effects are introduced and timber members and their connections perform poorly in torsion leading to failure of the building frame Separation of framing from one another. Separation of wall panels and loss of mutual support leading to out-of-plane failure of walls. Out-of-plane failure of the masonry infill. Larger panels also suffer from greater amounts of shrinkage in both the mud mortar and the timber framing which may both work to loosen the support to the bracing Out-of-plane failure of the masonry infill
Roof level ring beam, Roof, Floors (when more than 1 storey high)	Roof trusses do not align with principle posts introducing significant torsion in to the roof level ring beam Ring beam too small Ring beam splices in the wrong locations and or of poor quality Roof trusses not aligned with timber posts Roof truss not braced vertically between trusses Roof truss not braced horizontally to provide good horizontal roof level diaphragm Roof truss poorly connected to roof ring beam Truss bottom chord has poor quality splice Pitched roof have stiffness and strength in one direction only Floor beams only rest on top of first floor ring beams providing limited support to the walls Loosely laid floor boards that do not help distribute loads between walls If floors are not well tied together but the timber framing has very generous overlaps then it might be possible that there is a degree of natural isolation between the floors more engineering analysis is required to gain a better understanding of this construction type	Ring beam helps distribute lateral forces evenly between all the columns and walls. Ring beam provides the point at which lateral support is provided to walls preventing them from failing out-of-plane Roof trusses aligned with wall posts. Hipped roof provided rather than roof with gable end. Horizontal bracing provided to connect walls. Good quality connections (that can handle load reversals) between the roof trusses and the roof ring beam Continuous bottom chord preferably made from one member alone Hipped roofs have stiffness in both orthogonal directions Floor beams detailed with sufficient overlap and locking with main beams to be able to take reversible loads Well connected floor boards providing a strong and stiff floor diaphragm	Failure of the roof ring beam and thus prop to the walls. This will then lead to failure of the walls Failure of the roof ring beam and thus prop to the walls. This will then lead to failure of the walls Ring beam falls apart due to high force demand and/or inadequate connection capacity Loss of support to walls leading to wall collapse Tension failure of roof truss bottom chord splice Gabel wall infill fails out of plane.

Other	Introduction of mixed systems (reinforced concrete columns with timber roof) Bracing between columns is made from timber and panels are filled with stone and mud. In principle there is no reason why this should not work. Needs more engineering research but could significantly help with the affordability and sustainability of construction. There are similarities between confined masonry construction and dhajji. It is felt that the current practices of mixed system construction are generally of poor quality with minimal understanding of what is important. Clearly proper engineering assessment is required to understand the typical issues with mixed system construction where one part is dhajji.		

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance)*, the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is *E: LOW VULNERABILITY (i.e., very good seismic performance)*.

Vulnerability	**high**	**medium-high**	**medium**	**medium-low**	**low**	**very low**
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☐	☐	☐	☑	☐

5.4 History of Past Earthquakes

Date	**Epicenter, region**	**Magnitude**	**Max. Intensity**
1555	Kashmir	>7.0 Mw	
1842	Kunnar	7.5 Mw	
1855	Shrinigar, Kashmir	6.3 Mw	
1878	Abbottabad, Pakistan	6.7 Mw	
1905	Kangra, Himachal Pradesh	7.8 Mw	IX
1974	Pattan	6.2 Mw	
1981	Karakoram, Darel, Tangir, Khanbari valleys	6.2	
1991	Uttarkashi, Uttarakhand	6.8 Mw	IX
1999	Chamoli, Uttarakhand	6.4 Mw	VIII
2005	Bagh, Muzzafarabad, Poonch (Kashmir), Abottabad, Battagram, Kohistan, Mansehra, Shangla (NWFP)	7.6 Mw	X to XII

From the available literature it is not known to the authors on when and how dhajji construction was introduced to northern Pakistan and India. Was it a construction method developed locally, in isolation from outside influences, as a direct response to observations by the local population that well built dhajji buildings performed well in past earthquakes or was it simply a construction method that was developed due to local economic conditions where timber and other construction materials were in relative short supply? Alternatively was dhajji introduced from another region? If dhajji was a local response to a past earthquake event what event was the triggering event that led its construction form? Dhajji may have evolved from economy and in response to optimising the characteristics of stone and mud as well as timber. If one looks at Leepa Valley, the east end has 100% timber houses; the west end has 100% dhajji, within few kilometres of each other within the same community. In between there are combinations, the explanation we found is that more timber is available in the east, and less timber and better stone in the west. It also seems to depend on a number of local conditions, height of snow, quality of stone, etc... Fully timber houses are considered locally the best for earthquakes with interlocked corners. In areas of stone construction people know timber bracing makes it stronger and less liable to damage. It is an economical way to use stone also as the wall thickness is smaller, the technique allows all materials to be used sparingly and in small and random pieces.

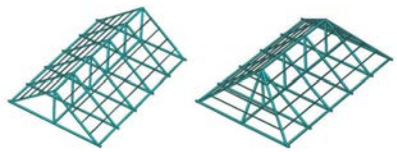

Figure 5 1. (left) Typical A-frame and hipped roof without any in-plane bracing. (right) The hipped roof is inherently better braced in both directions.

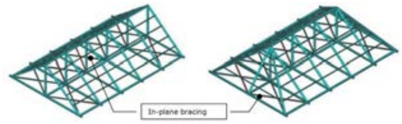

Figure 5 2. In-plane bracing between trusses at the truss bottom chord level shown in red. Note: It is difficult to cross over two diagonals of timber. It is not usual practice. Even in the dhajji square frames, one will see that they make one diagonal and two short cross diagonals. Rather than overlap two longer pieces. The long timber shown parallel with the ridge along the bottom of the tie beams does not exist in most roofs. Realistically most roofs are stiffened only by ceilings and bracing is not used.

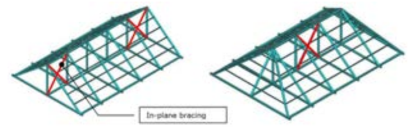

Figure 5 3. Vertical bracing between roof trusses shown in red. Note: Most roofs are occupied so cross bracing as shown here is not favoured and is rarely implemented.

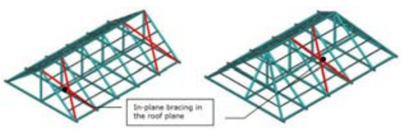

Figure 5 4. In-plane bracing in the plane of the roof incline. Note: If such bracing is used one brace will be continuous the other will be made of two half length braces.

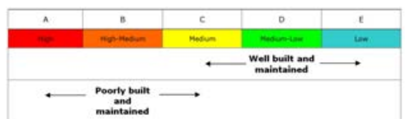

Figure 5 5. dhajji seismic vulnerability rating.

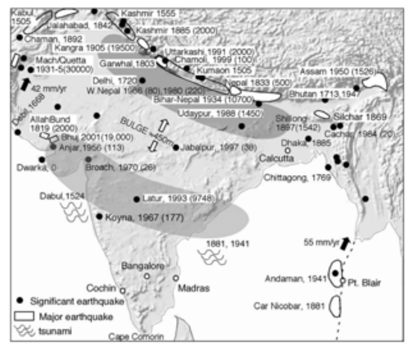

Figure 5 6. Map indicating significant earthquakes (Refs. 9 and 10) along the general Himalayan fault region.

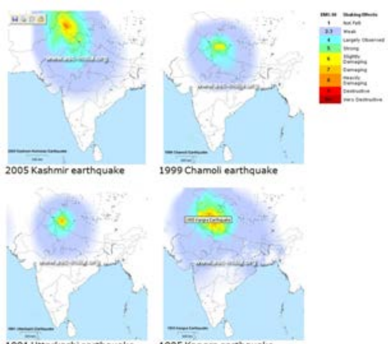

Figure 5 7. Historical intensity maps (source: www.asc-india.org).

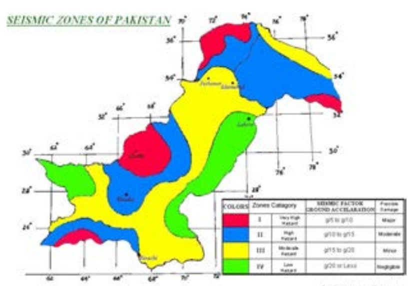

Figure 5 8. Seismic zonation map for Pakistan before 2005. (Note: This map has since been replaced by the 2008 Pakistan seismic code.)

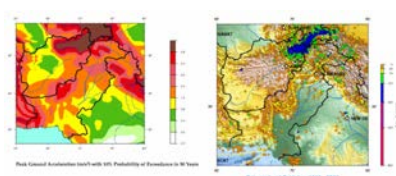

Figure 5 9. GHSAP and seismicity maps for Pakistan.

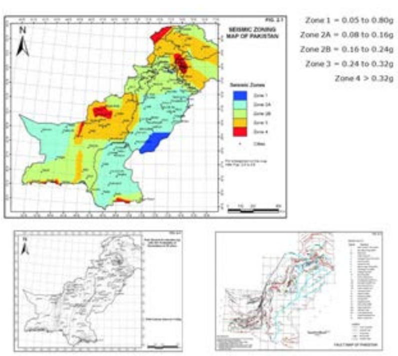

Figure 5 10. 2008 Seismic hazard maps for Pakistan and map of known major faults (Building Code of Pakistan; Seismic Provisions 2007). Note: This Code is dedicated to the memory of thousands of children, women and men lost in the earthquake of October 2005.

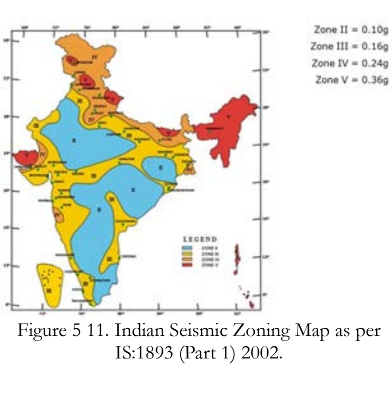

Figure 5 11. Indian Seismic Zoning Map as per IS:1893 (Part 1) 2002.

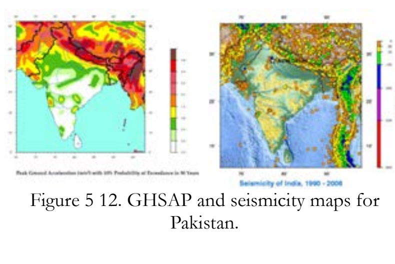

Figure 5 12. GHSAP and seismicity maps for Pakistan.

Figure 5 13. Timber frame that is not protected from moisture a major cause of timber rotting due to direct contact with the soil.

Figure 5 14. Timber sill beams and columns in direct contact with the ground exposing the timber to moisture. Note that the infill looks more like a dry stone wall.

Figure 5 15. Mix of concrete columns with timber dhajji. Note poor quality compaction of the concrete and large cracks in the concrete column.

Figure 5 16. Mix of RC columns, dhajji infill construction (note the large panels of stone infill and limited amounts of timber bracing).

Figure 5 17. Dhajji in one direction and unreinforced stone masonry in other. Back wall of the house also acts as a retaining wall. It is not known if the wall perpendicular to the back wall of the house has buttresses to give it additional strength

Figure 5 18. Dhajji house built into the hill side making the building act as a retaining wall. There is likely to be a stone wall at the back called a breast wall locally.

Figure 5 19. Isolated collapse of infill panel in dhajji house.

Figure 5 20. A building with dhajji in one direction, and stone URM wall in orthogonal direction

Figure 5 21. A building with dhajji in upper storey surviving although brick URM walls of lower storey toppled (Ref.: R. Langenbach, www.traditional-is-modern.net).

Figure 5 22. Dhajji wall intact apart from mud plaster that has fallen off. Plain stone masonry walls have partially failed, near Bagh, Pakistani Kashmir.

Figure 5 23. Example of effort to provide foundation to a timber post to reduce the immediate settlements under the post and provide limited protection to the timber end grain from moisture.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Timber posts with timber braces (nailing has been found in older buildings). Rubble or cut stone dressed in mud mortar. Mud mortar may be strengthened by the addition of lime and/or the addition of natural fibres (pine needles, goats/horse hairs) to avoid shrinkage of the mortar but more likely the render.	Properties of the mud infill are not known. The level of hysteretic behaviour of the mortar during seismic actions is not known but unlike sand cement mortar it is expected that the mud mortar will retain some degree of ductility, a bit like malleable clay, and therefore be able to continuously keep creating new bonds and its energy absorption capabilities. Clearly research is required to scientifically quantify the value of the mortar in absorbing energy.		Brick/stone in mud mortar. Failure occurs along infill material pieces through the weak mortar therefore the strength of the infill material is largely irrelevant (though it should not just crumble). Energy is absorbed by breaking the bond between the mud mortar and the infill material. Further energy is lost in the friction between all the infill components. Geometric shape of the infill is thought to influence the performance of the infill wall as shown in Figure 6 3. Wedge shaped fill may pop out when under compression cycle.
Foundation	Stone masonry			Semi dressed or rubble stone masonry (dry or mud mortar). More recently with uses of sand cement mortar and or reinforced concrete bands and anchor bolts are becoming more prevalent. Foundation failure thought to be rarely a controlling factor. Foundation adequacy is more determined by foundation depth and quality of stone wall construction. Where failures occur it is never due to the failure of the stone strength or mortar strength. Regular use of bonding stones, adequate wall height to thickness proportions are controlling factors.
Frames (beams & columns)	Timber beams overlain with wooden planks Timber framing, with joinery and timber dowels and wedges		The size of the timber sections is an issue as they are only 5 x 5, 4 x 4, 4 x 2 inches, not like large European or American timber sections with dowel and peg joints.	Principle frame of beams, columns and braces are mostly made from softwood. Timber connections do not appear to make any use of timber dowels or pegs apart from the Kashmiri joint which uses a locking peg. The most readily available timber in the region is shown in Table 6 3 (See Reference 31). Deodar is a species of Cedar and shares has properties of being rot resistant, fine grained and of reasonable strength. It is native to the Himalayan Region - and of cultural significance in Kashmir. The Wikipedia entry explains that "Deodar" is a "Sanskrit word, (Sanskrit: devdar), which means, "divine wood". Clearly the longevity of dhajji buildings will in some part depend on the effort that has been made during the construction to ensure that timber members remain dry. Using timber sections with good quality rot and fungal decay are to be preferentially selected for use on those members that are in contact with the ground or part of an external wall, in other words to members that are going to be exposed to moisture. The quality of Cedar is also illustrated by the observation that in North America, cedar is used for wooden roof shingles. It is also used for cedar closets and cedar chests for wool clothing storage because of its bug (moth) repellant qualities. How timber is handled until it is dry is not known to the authors at present. However, construction of dhajji houses using green wood will no doubt have its own problems, especially in cases where significant levels of shrinkage occurs as a relatively wet timber frame dries and becomes accustomed to the environment (principally temperature and moisture levels) it eventually finds its self in. It is important to stress that the selection of timber is a skilled art and must take into account the following principles: Visual strength grading (a function of the presence of knot area ratio and their disposition along a piece of timber). Slope of grain relative to the longitudinal axis of the piece Rate of growth (As an average width of the annual rings) Fissures Wanes Degree of distortion (bow spring, twist and cup) Resin and bark pockets Insect damage In an ideal work the visual grading of timber will be supplemented by machine grading of timber which does require testing equipment. Another aspect of dhajji construction is how the sapwood and heartwood are used. Sapwood which is found on the outside of trees is where the tree movement of sap and storage of sap occurs. In other words it is sugar rich and is the trees food. Because of this simple fact, sapwood is attractive to many decay organisms. On the other hand the heart wood is the older part of the tree and is known to be generally rot resistant. Typically sapwood will take days or weeks to dry after being exposed to rain, whereas heartwood may dry within an hour or two after being exposed to sun light. Many bugs and insects will bore in the sapwood and lay their eggs in this outer timber layer which is another reason why care needs to be taken when selecting timber for construction purposes. Sapwood also does not hold paint well. In fact it holds any moisture

				that may have entered a painted timber section through cracks and it is because of this reason that even apparently painted sections are found to be completely rotten after a few years of being exposed to the elements, typically as found in window frames. Anecdotal evidence indicates that heart wood can outlast sapwoods by 10 to 20 times. This is a sound argument to make use of Sapwood strategically, concentrating on the wood that will be most exposed to the moisture. This also emphasise the need to use mature trees in a responsible manner. Whilst the purpose of this report is not to be a report on timber grading but the importance of this craft to the construction of dhajji buildings cannot be over emphasised. Without proper selection of timber many houses will simply not last for any length of time and will require expensive rebuilding in an unreasonably short time. This will impose further pressure on already dwindling forest resources in the region and can safely be considered to be false economy. It is likely that the poor will not rebuild, they will simply live in buildings that have lost their strength and are in poor condition, therefore at high risk from future earthquakes.
Roof and floor(s)	Floor compacted and levelled earth screed Shingle (i.e. wood roof tiles) connected to timber purlins often made from full timber boards or planks In more recent times extensive use of corrugated galvanised iron (CGI) sheets are being made. Gauge of the metal decking is thought to be very thin, making the longevity of many of the recently constructed roofs highly questionable.		Available CGI sheets are generally available in 8 or 10feet lengths. 12ft long sheets are rarely available. Available sheets widths are 32, 36 and 42 wide Typical dimensions of available CGI sheets are shown in Table 6 4. CGI sheets used for roofs have a gauge of around 26 (0.476mm) giving a weight of 3.662kg/m2. Range of available sheet thickness is Typically 3 rows of purlins are used for 8feet long CGI sheets and 4 rows for the 10 and 12 feet long sheets. CGI sheets may typically extend approximately for 4inches beyond the eve boarding. Purlins are typically around 2.5 inches x 2 inches CGI sheets are typically connected to the purlins with 2 to 3 inch long nails every 2 to 3 corrugations. These nails are in the order of 4-5mm thick. Overlap between CGI sheets is typically 1.5 to 2 corrugations	

6.2 Builder

The builders usually live in the house they build. There is no concept of a builder in the general sense. House owners are involved in the construction right from the beginning until the completion and occupation of a house. This construction system is mostly an informal construction process whereby the building owner manages the project and procures the materials. The skilled craftsman (Mistri), who may be employed by the home owner for more specialist aspects of construction, plays a pivotal role in the building development process. The Mistri help the building owner in various ways such as: Architectural advice Informal quantity estimation Time estimates General procurement advice Quality control Execution of the works Informal building training to the home owners who will typically be doing significant amounts of the construction will also be provided by the Mistri. In Kashmir trades are carried out generally by distinct families. Masons, carpenters, metal workers. House owners may salvage or procure timber, but they do not carry out the main tasks of construction themselves. Even the poor consult and hire the designated mistris. House owner members may assist the mistri, but he is responsible on site. Even skilled mistris are not high in social status. In North West Frontier Province there is less social stratification and more owner building.

6.3 Construction Process, Problems and Phasing

It is basically owner built construction. Locally known labour contractor cum mason (Mistri) are invited and entrusted with the labour contract or wage contract. Construction is carried out under the advice and consultation of the Mistri. Construction material is procured by the building owner with help from the Mistri. Small tools such as saw, hammers and chisels are used for the entire construction process. The entire construction process is labour intensive and is usually carried out as per the availability of resources and funding. Plinth first, basic frame, roof, cover, then infill, it can take weeks or years. For example in some cases a temporary light mud flat roof is constructed until the owner can afford a pitched one. The design is typically worked out during the construction. There is no history of planning buildings by the preparation of construction drawings and specifications. Provisions in the design to be able to readily accept future changes and additions will rarely be considered during the initial construction process.   The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. To ensure a proper foundation to a dhajji building it is important that proper foundations are built using one of the methods below: Stone masonry with regular through stones Brick masonry with proper bonding pattern Reinforced concrete strip footing with proper placement of reinforcement by ensuring proper cover is maintained to the rebar during the concreting, adequate concrete strength, placement and compaction of the concrete is required. Profile of reinforced concrete plinth to throw off water, Height of all options above are to be built above ground level by at least one foot. Commonly recent the advice given to people is that the building should be anchored to the foundation. This is sensible advice for resisting wind loads and is in line with most modern earthquake codes for buildings. However, it is not clear if creating a solid connection with the foundations is beneficial during seismic actions as long as the building has a sufficiently large and stable base to sit on (i.e. prevented from falling of a ledge or similar). It could be argued that the ability for the building to move about on its foundations is a form of natural base isolation thereby reducing the level of seismic forces that are seen by the building. To allow this to happen the timber walls would need to be robustly interconnected at their lowest level to minimise differential movement across the building. Clearly this merits detailed research. Where possible the core wood should be used for members that connect to the foundation or are exposed to the outside. Sap wood should not be used for important locations of the timber frames. The base plate is required to be sufficiently large to be able to receive all vertical posts. It is important to make the base plate from high quality timber as it is close to the ground. Interconnection of the perpendicular wall and base plates is important to ensure the building acts like a box. Doing so ensures that the walls do not just separate during an earthquake. Do not place the base plate directly on to the ground, concrete, or bricks. If placed onto concrete or bricks it is important to use a damp course layer to stop moisture travelling into the timber frame. At corners, using overlapping connections will enhance the general robustness of the frame and reduces the exposure of vulnerable end grain. The principle members of the walls consist of timber posts and ring beams at floor/roof level. Figure 6 15 to Figure 6 18 show a range of timber carpentry details that should be used to help built robust frames. The quality of these joints is dependant on the carpenter knowing when to choose a certain type of joint over another. It is believed that poorly prepared timber to timber connections will result in premature failure of the timber frames. Key to preparing these connections is having a clean and proper work area, a feature that is seldom given any consideration. Looking at Figure 6 4 to Figure 6 7 and Figure 6 10 it is clear that much work is done on the ground, a weak position from which to build. Equally important as a good work surface is the availability of good quality tools. Typically a carpenter will need a saw, hammer, chisel, set square and a drill to prepare good quality timber connections. The use of blunt tools results in poor quality finishes to any joinery making it harder for the joints to function as they might have been envisaged. The importance of building good quality connections is even obvious in that the skilled people who make these connections are called Joiners in English, a skill that society has long recognised as being important and thus given appropriate linguistic recognition. Figure 6 17 shows a series of sketches on various connections, principally how to splice timber pieces together. There is a general issue about complex joint connections as compared to simple nailed connections, or splice pieces. Joints are reductive making small pieces of timber which may break, and also making the frame potentially very stiff as compared to the ductility of nailed connections which can loosen if done the way they are here. Japanese evaluation of timber frame construction recommends it is not preferable to develop timber joints. Dhajji construction would benefit from a holistic review of suitable timber connections in seismic applications Whilst many might see installing the infill material as a step in the construction process that can be executed without too much attention to detail the authors believe that this is not the case. The following points are thought to be important to ensure the reliable behaviour of the infill frames during seismic actions: It is important that infill material is packed tightly against the main timber frame and the bracing in order to ensure that arching action can be developed in order for the infill material to be able to resist out of plane forces. Do not use round stones or wedge shaped stones as these will pop out when the infill panels are squeezed during the compression cycles of the seismic loading (See Section 6.2.3). Do not use too much mortar as it is likely to be soft and thus not provide the support to develop arching action between the infill and the timber frame and bracing. Research is required to determine optimum mud mortar thickness to be used as a function of panel size. Avoid shrinkage of mud, test in advance and add other materials or prepare better. Also leave to shrink before plastering, and plaster in a few rounds to catch all small holes to be filled. Where a dhajji building is two storeys or more it is important that the floor framing is built in such away that it has either enough room to move about without loosing bearing contact or that the connections are strong enough to resist the seismic forces at the connections. The assumption is that the joints are the weakest parts of timber frames with failures always occurring at the joints simply because it is at these locations that the gross timber sections have been cut down to enable the connections to be made in the first place (unless metal inserts have been used skilfully). Probably because of timber supply and manual work, timber posts are never more than one storey. From field surveys, all timber frame construction is platform frame type, with each floor constructed as a box and the boxes separate and stacked. Each storey has a separate base plate and wall plate, with close spaced timbers in between. The roof keeps the house dry and therefore plays an important part in ensuring that the frame is protected from moisture increasing the durability of a house. A few simple connections are shown in Figure 6 19 and Figure 6 20. As ever it is important that these connections are carried out with great care. Especially for single storey dhajji building the roof is the only thing that holds the various walls stitched together. Therefore, it is important that connections between the roof trusses and the walls are able to withstand significant levels of load reversal. Unfortunately when people construct a ceiling they dont fix it on top of the walls / posts to contribute to the diaphragm action. Instead they simply fix it in between the posts. Clearly this is an area where strategic strengthening could significantly help improve the performance of dhajji buildings. The use of pegs and proper joinery will go a long way to ensuring good the appropriate load paths are an inherent feature of the dhajji building. Strategic use of metal strapping or similar is also thought to contribute towards the strength of the connections.

6.4 Design and Construction Expertise

Generally design and construction expertise exists in the local communities to some degree. However their skill level is low and fundamental issues such as timber selection, curing, joinery are not much appreciated or understood. It could be said that the craft of the master carpenter or joiner in the sense of the master builder from a European perspective is not commonly found in the regions where dhajji buildings are still being built. Dhajji construction would benefit from a better understanding of the merits of traditional joinered connections vs. the performance of nailed connections. After the 2005 earthquake necessity has dictated that a large degree of people have taken on the roles of carpenter and builder to rebuild their homes. Unfortunately many of these builders will not possess a natural aptitude to the building profession and this is reflected in some of the construction practices being observed. A rush time is never good for quality control, even the good carpenters take short cuts, to maximise profit, or under pressure from house owners, costs are far higher due to timber supply, labour supply and transport costs. It should stabilise again. Also note the very lowest income households used dhajji and recycled less than optimum quality timber. Unfortunately the engineering, architectural and technical community will have very limited knowledge of the construction type simply because education courses around the world do not teach traditional construction methods as a rule. Basically as a generalisation engineers/technicians do not have knowledge of this type of construction. The construction method will not feature in any conventional engineering courses which tend to focus on reinforced concrete, steel and masonry construction, even when those modern forms of construction are not afforded by local people. This is changing, and some progress has been made in mainstreaming dhajji, for engineers, sub engineers and architects since the 2005 earthquake.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Pakistan does not have any formal engineering codes/standard on this building type as up to the year 2009. However, the ERRA guidelines do provide basic guidance on dhajji construction (See Reference 3). We understand that there are efforts to incorporate dhajji in the code. The main problem is the lobby who do not want timber standards endorsed as they see it as timber construction promoted and deforestation. Indian standard cover this building type but with name brick nogged timber framed construction as can be found in Reference 5.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules.

Traditionally this form of construction was not formally recognised or checked. Theoretically, all the buildings constructed in urban areas require building permits, though these are hardly exercised. In rural areas, both Pakistan and India, building permits are not thought to have been ever enforced. There are generally no standards or planning or building control systems for housing in rural areas. However, after the 2005 Pakistan earthquake, and although dhajji construction was initially restricted, its use became later acknowledged as a reasonable means by which the earthquake affected people could start rebuilding their homes. The dhajji construction method is now even recognised in the ERRA guidelines (See Reference 3). Compliance with the guidelines formed the basis by which affected people were able to claim some limited government monies to help with their reconstruction costs. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s) and No one. Generally home owners may not be aware of maintenance issues and the degree to which maintenance is undertaken depends mainly on the practical abilities of the individual home owners and their priorities to look after the fabric of their houses. It is commonly known that poorly maintained buildings will lead to severe timber rotting which will completely undermine the buildings construction form and inherent seismic resistance. This is a major issue arising out of the inadequate plinths used for dhajji houses, along with poor grade timber and limited use of preservative. Secondly lack of protection from site moisture due to back walls being built against the ground. A number of measures are proposed to improve site drainage, timber preservation, and wall protection. This include very simple measures like making sure the roof extends outward more, use of a gutter and rainwater harvesting, constructing a veranda, apart from intrusive repairs and replacement.

6.8 Construction Economics

The concept of a construction cost in the strict sense of $/m2 or similar does not mean much for this building type as this construction type is not based on cash economics. It is an informal construction where building owners collect materials over the years and many materials come from local sources. Typically large cash flow required for the construction phase is not required. Costing construction is based on square foot cost for the building or cubic foot for the timber. It is not thought that banks or other lending institutions make money available for people building in dhajji. There is no funding by banks for other construction techniques either, so marginalisation is not an issue. There is effectively no housing mortgage system. Banking is well developed, but housing finance is not. The cost of dhajji house is from $2000 upwards depending on timber availability. Skilled labour cost is currently minimum $6 per day. Both at 2009 prices. This policy of not funding people who build in dhajji further marginalises the construction form and send the somewhat signal that the building system must be inherently unsafe as otherwise funding for dhajji construction would be freely available. It needs to be stressed that western sense of banking is probably not yet widely established in the regions of India and Pakistan where these buildings are typically used anyway. The decision by ERRA to provide financial assistance equally for dhajji and for reinforced and confined masonry gave people an equal choice and helped ensure a regeneration of dhajji as it was perceived as a safe, cost effective and fast solution in the boom of reconstruction after the earthquake.

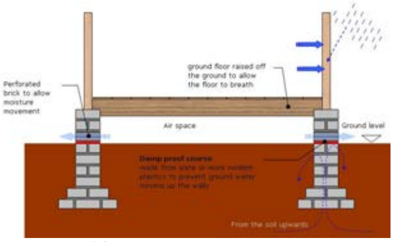

Figure 6 1. Typical foundation detail and lack of considered protection to the timber frame. Traditionally the floor is always raised on stone and it is 1 ft above ground level.

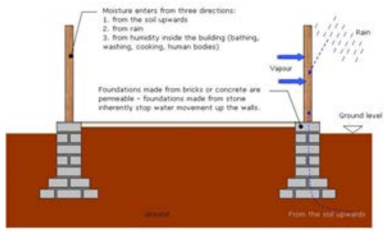

Figure 6 2. Construction methodology that would help keep the timber frame dry. Note that the introduction of modern materials, such as sand and cement mortar makes the control of moisture harder to achieve as it requires a damp proof course detailed. Note 1: In the Leepa region construction uses a semi basement or full ground floor in stone, due to high snow levels, but these are areas where timber is plentiful. It is not feasible to make a suspended timber floor in normal dhajji areas where it has evolved as a means of economizing on timber. It is easier to build up the plinth. Note 2: Most buildings are not well sealed, dont have lobbies or other air tight measures and are therefore draughty/well ventilated.

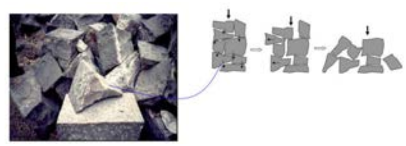
Figure 6 3. Wedge-shaped semi-dressed stones for wall construction with sketch indicating likely failure mechanism. Note: This wedge shape is shown as part of a two wythe wall, but use of wedges in infill is a different behaviour so long as they are not wedged with the large dimension towards the face of the wall.


Figure 6 4. Cutting of timber sections with the help of motorised saws is rarely available. Old fashioned labour is more common, especially in more rural settings. Note: Motorised saws travel to sites on hire and this is becoming more common.

Figure 6 5. Improvised tools to guide the carpenter made from scrap wood and nails on an ad hoc basis.

Figure 6 6. Hammer, chisel and saw are the main tools to construct a dhajji house.

Figure 6 7. Cutting of timber sections. Note the child watching and learning.

Figure 6 8. Infill construction from stone, mud and backing board that acts as temporary form work. Note: CGI as sometimes used for the form work these days and sometimes left then as permanent formwork/weather protection (used for this reason rather than to stiffen the frame). It is still the case that timber planks are most common.


Figure 6 9. Child holding his fathers tools during a construction training workshop. This is to some degree the start of the informal training in the region where children learn by observing and helping their elders. The family system of trades are within specific families.

Figure 6 10. Same child observing and learning from his father.

Figure 6 11. Construction of the infill walls. Note the very thin timber section sizes being used for both vertical and zigzag bracing pieces.

Figure 6 12. Construction of the infill walls continued.

Figure 6 13. Construction of the infill walls continued. Note: Note he was breaking the stones as he went along. Previously large stones from an old unreinforced stone house on the same site.

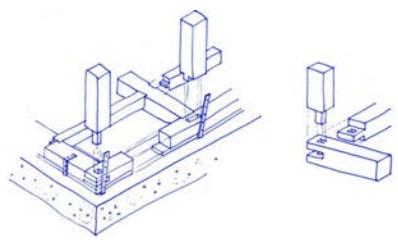

Figure 6 14. Corner post connection details. Note: This joint is difficult to make but crucial to keeping the dhajji frames together. More work is needed to optimise corner connection details for such traditional construction forms. The corners are potential locations for strategic strengthening.

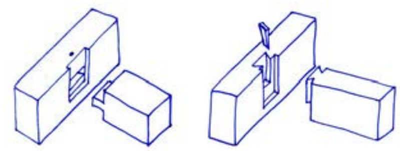

Figure 6 15. Orthogonal beam to beam connections for base plate, floor beams, and roof level. (left) The use of a peg (timber or metal) would give this connection some limited tension capacity. (right) The dovetail shape gives the connection tensile capacity, an important feature under reversing loads. (Note: Such joints are however rarely used. Same plane joints are usually cross halved joints which cannot open and work well in tension. Dovetail is not used. Blocking pieces are often added in same plane joints if it was not cross halved. They dont fix the tension issue but they can add more interfaces and help avoid the joint opening.)

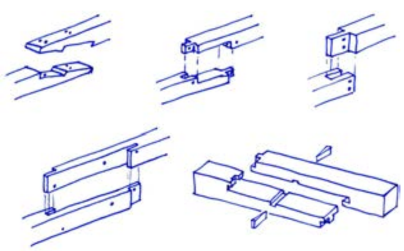

Figure 6 16. Beam to beam longitudional connections, the use of wooden pegs is important to pre-stress the connection. Use of metal strapping and or nailing can improve the strength of these connections if done properly. Note: The first joint is used 95% of the time, the others rarely. Part of the problem is the small timber section size, 4 x 4 or 5 x 5 timber.

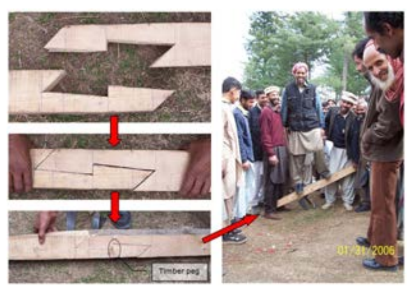

Figure 6 17. Public demonstration of a Kashmiri Joint in Malot, Bagh district of Pakistani Kashmir.

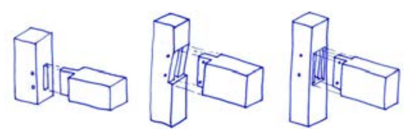

Figure 6 18. Beam to column connections with increasing levels of beam shear capacity but reduced levels of column capacity. The presence of pegs enables these connections to have a limited amount of tension capacity. Note: Beam/wall plate is fixed directly on top of the posts, never to the side of the post. It is therefore usually a mortise and tenon joint or a simple nailed connection, maybe with additional blocking pieces. The wall plate may be a thinner section size.

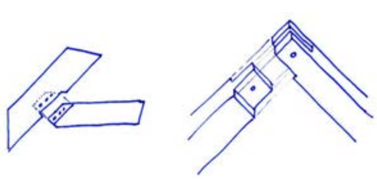

Figure 6 19. Connections for roof trusses. Note face nailed connections are more likely.

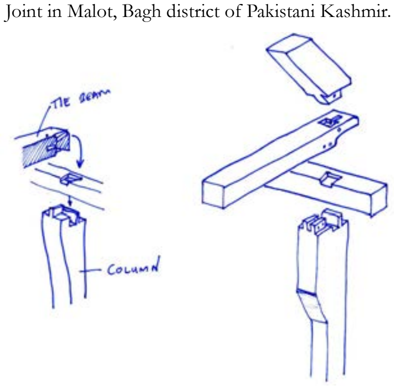

Figure 6 20. Column to orthogonal timber floor beams and possible connection to roof truss. Rather than varying the timber section consider nailing additional pieces to give larger seat for beams to connect to.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. The concept of a dhajji building that has been seismically strengthened does not exist to date and insurance is probably not available or sought after by building owners anyway. Therefore it is somewhat of an irrelevant issue to the current realities of people building in dhajji. The concept of formal insurance, in general, is not part of the rural culture in the area where such buildings are typically found. However, people from these parts of India and Pakistan will have the informal insurance system consisting of the extended family coping mechanisms.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	**Description of Seismic Strengthening provisions used**
Foundations may not have been provided (or not raised enough) placing the timber frame in direct contact with the ground.	Slowly install at least a stone base under the timber frame to help spread the load a little and possibly more importantly try and keep the timber frame dry.
General deficiency: drainage not provided to the foundations away from the building	Install stone/gravel drains away from the building thereby ensuring the timber frame stays as dry as possible.
Built directly on to the ground leading to rapid rotting of the timber frame. Or built directly on to masonry or concrete base.	Slowly install at least a stone base under the timber frame to help spread the load a little and possibly more importantly try and keep the timber frame dry. Try and insert a damp proof course to prevent moisture travelling up to the timber frame. Treat timber with preservatives if possible.
Traditionally anchorage will not have been provided between the timber frame and the foundation	Lack of anchorage may have provided some form of natural base isolation to the building. The common fix may be detrimental and requires engineering analysis to guide the design direction. If there is no fixing make sure the base is large enough, not too high and that it is stabile
Base beam not connected perpendicular to the wall direction	Retrospectively install steel ties/straps to connect perpendicular walls so that the walls become self supporting and do not pull apart.
Wall principle posts do not align with roof trusses or second floor principal beams	Install posts under the roof truss locations to provide direct load path this will likely require local demolition of a dhajji wall. New post is to be connected to the ground beam and roof beam.
Walls posts are not properly connected to the timber base plate	Insert metal straps, working in tension, if possible. Use appropriate rust protection for the metal straps. Use additional timber splices (probably nailed on) to connect disconnected members.
Perpendicular walls are not properly interconnected	Use timber or metal splices to inter connect perpendicular frames.
Bracing too few resulting in large infill panels	Systematically dismantle a panel and rebuild with a denser bracing pattern filled with more brick shaped stones or plain bricks laid in mortar.
Round stones used for the infill material which will pop out when squeezed.	Systematically dismantle and rebuild infill wall with cut stone or bricks.

Strengthening of New Construction :

Seismic Deficiency	**Description of Seismic Strengthening provisions used**
Land on which the building is built is unsafe (see Section 9).	Move to a safe site or mitigate by undertaking ground improvements (rock anchoring, cutting back slopes, building appropriate structural retaining walls)

On hilly sites slopes are sometimes retained by the back wall of the house.	Build well detailed retaining wall away from the house (also ensures water seepage through the retaining wall does not enter the house directly If a retaining wall is part of the house ensure the wall is adequately engineered to resist the forces from the building as well as the retained ground and that there is good external drainage to guide water away from the house.
Timber base ring beam anchored to the foundations	Fixity to the foundations ensures building does not fall of its base, especially if the house has been built on a slope where the downhill side of the building is raised much more than the back of the house
When more than one storey columns are rarely continuous from floor to floor. Always a platform frame and each storey is constructed as a separate box.	Continuity of main timber columns ensures load path continuity but having discontinuous columns may provide a form of limited seismic isolation as long as the upper columns cannot get dislodged. Engineering study required to gain a better understanding of this. As a minimum ensure that the tendons connecting the upper post to the lower frame is long so that it is a good shear key. Where it is know that shear keys are not provided alternative ways to ensure upper columns do not dislodge and fall down need to be investigated, such as extending the size of the seat on to which disconnected timber columns may be bearing.
Poorly built infill large stones that have limited planes over which energy can be lost. Limited opportunity to absorb energy by yielding the mortar material	Systematically dismantle an infill panel and rebuild with bricks or well prepared stones laid tightly to ensure good bond between each stone/brick and one another, the timber frame and the timber bracing
Infill made from mass concrete which will fail as a rigid body	Rather than looking at the building as a dhajji building it might be better to reclassify the building as a reinforced concrete building and follow retrofitting guidelines for this form of construction. If not, dismantle the large mass concrete wall, install adequate levels of bracing an infill material. Limit the panel size above which to replace?. It is often more harm than good to remove infill as there is a lot of movement due to demolition. Clearly research is required.
Infill poorly built with lots of gaps masonry will not be able to arch properly	Remove plaster, remove large chunks of weak mortar and rebuild locally, fill large gaps with stone or brick ensuring that the infill material can arch.

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?
Because these buildings are low tech compared to modern forms of construction they are adjusted and tweaked constantly. It could be said that these buildings are constantly being modified but it is not thought that the modifications will be due to seismic considerations. In reality the buildings will be improved, expanded as needed and as resources become available to the family units.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Much of the reconstruction in Pakistan will have been to build dhajji houses from scratch. The extent to which seismic retrofitting is being carried out to dhajji buildings is not really known. After the 2005 EQ many people strengthened their houses by diagonal bracing, particularly at corners, face nailed flat boards, After EQ 2005 the common other improvements were propping, replacing stones with concrete, Houses constructed after EQ 2005 have also been improved if constructed rapidly and substandard. After 2009 EQ people fixed wire mesh to the inside of their walls, at the top 2 ft of the walls, to protect from falling stones.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
There is no formal construction inspection system in place. Building quality is nearly completely dependant on the individual home owner and the skills they can bring to the building construction. However after the 2005 earthquake the post earthquake reconstruction was managed with financial assistance which was linked to stage inspections. Likewise the strengthening of substandard houses.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
The training structure included engineers, architects, sub engineers, who were responsible for maintaining consistency in the promotion of standards for dhajji, including practical training by carpenters, information and explanations The home owner will procure materials and do most of the construction with the help of the nuclear and extended family. Local master craftsmen will be employed occasionally for the more complicated parts of the building. People with formal education in construction (architects and engineers) as a rule would state that these buildings are old fashioned, dangerous and should

not be continued with. Such views are based on not understanding the construction method and incomplete training.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
New and old dhajji performed well in the 2009 earthquake, except where people had used sand cement plaster which fell off in complete sheets.

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