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
Timber Frame Brick House with Attic

Report #	116
Report Date	19-01-2005
Country	INDIA
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in mud/lime mortar, with vertical posts
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Summary

This type of house is used for residential purposes. The building type under study has been picked the from central part of India (Madhya Pradesh), but it is found throughout India with small or large variations. Timber is primarily used for the frame structural elements but due to an acute shortage of timber, this construction type is not practiced anymore. Various

components of the building change from place to place depending on climate, socio-economic conditions, availability of material, etc. Timber frames, placed in longitudinal and traverse directions, are filled with brick masonry walls. The floor structure is made of timber planks. Most of the buildings are found to be rectangular in shape with few openings. The roofing material is usually light when it is made from galvanized iron sheets. Seismic performance of a perfectly framed building is very satisfactory. Existing old structures, however, require maintenance and strengthening (Figure-1a,1b). It has been observed that nominal cost will be incurred for introducing earthquake resistant features.

1. General Information

Buildings of this construction type can be found in all parts of India with small or large variations. The typical construction type has been taken from the Nimar region of Madhya Pradesh, which is prone to moderate earthquakes in seismic zone III (I.S. 1893:2002) but this construction type is spread uniformly over central and southern India. This type of housing construction is commonly found in both rural and urban areas.

These buildings are found in both rural and urban areas. The percentage of houses in urban areas is high. Only the affluent sector in rural areas possesses this type of housing in villages due to high construction costs.

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

Currently, this type of construction is not being built. Construction of this type of structure has slowed due to the absence of wood/timber, government policies for protecting forested areas, a developing economy and the availability of alternate building materials. Even now if a building of this type is constructed, it is found that it is not a perfectly framed structure. Many times the workmanship is not satisfactory.


Figure 1a: Typical Brick Building With Timber Frame


Figure 1b: Typical Brick Building With Timber Frame


Figure 2a: Change in Construction Material


Figure 2b: Change in Construction Material

Figure 3: Discontinued Column and Beam Connection With Existing Part


Figure 4a: Details of Timber Frame


Figure 4b: Details of Timber Frame

Figure 5a: Column and Beam Joint


Figure 5b: Column and Beam Joint


Figure 6: Construction Details of First Floor


Figure 7: Damage Pattern of Building

Figure 8: Openings at Different Level

Figure 9a: Corner Separation


Figure 9b: Corner Separation


Figure 10: Damage to partition wall


Figure 11a: Gable Failure


Figure 11b: Gable Failure

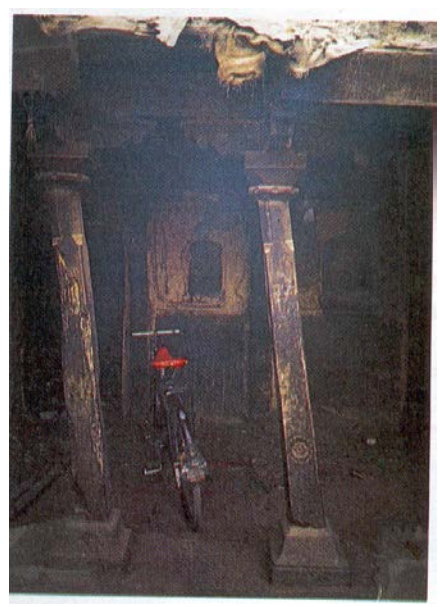
Figure 12: Swaying of Columns

Figure 13: Heavy Roofing Elements

Figure 14: No Proper Joints Between Rafters and Purlins

Figure 15: Houses Are Coved With Galvanized Iron Sheet

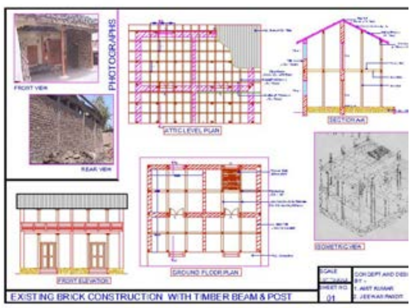

Figure 16: Construction Details of Timber Frame Brick Building

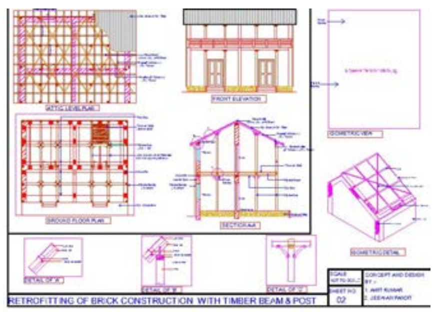

Figure 17: Retrofitting Details of Brick House

Figure 18: Graph of Time vs Occupancy Rate for residential houses

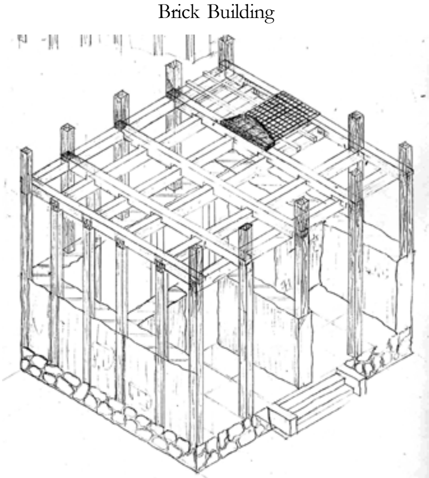

Figure 19: 3-D sketch of structural elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 5 meters.

2.2 Building Configuration

Most of the houses are rectangular in shape but sometimes depending upon functional requirements, plan irregularities are found. General shapes include rectangular with a high length-width ratio, T , L or U. Generally in semi-urban and rural areas, the old pattern of construction does not have an adequate ventilation system. In common, it is found that in each wall face, openings are limited to 5 - 8 %. Even the height of doors and windows are small at 6 feet and 2 feet respectively.

2.3 Functional Planning

Single family house and Multiple housing units. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Generally this type of building consists of a single storey. The typical building has no escape route at the rear.

2.4 Modification to Building

It is found that comparatively older buildings are generally made with sufficient precision and good building skills. Extensions or modifications, however, are generally done without appropriate building construction techniques. In urban areas, the outermost rooms are converted into shops or used for commercial purposes. It has been found that some modification and extension has been done with heterogeneous materials and structural systems. One example of such modification is the continuation of an existing brick wall with random rubble masonry (Figure-2a,2b,3). The older houses are made up with mud mortar but recently extensions are built with cement mortar. These type of modifications and alterations adversely affect the seismic performance.

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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is confined masonry wall system. The infill walls are made of brick masonry. These infill walls are the gravity load-bearing structures. The walls partially take the load of roofing elements.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is timber frame load-bearing wall system. If the building is made with adequate engineering skills and techniques, it has sufficient lateral load resisting strength. The frames are made up of teak wood, which is considered to be very durable and free from insects and termite. The Figures 4a, 4b & 19 show the configuration of a frame. Generally the column and beams are placed longitudinally and transversely. In longitudinal direction, the columns are placed at the distance of 2 to 2.5 m center to center. The transverse columns are placed at the distance to 2.0 m center to center. The size of column varies from 0.25 m x 0.25 m to 0.35 m x 0.35 m. Beams run throughout the periphery of the house. In both directions, the beams are resting on column grids. The connectivity between the column and beam is found to be very good with proper joint system (Figure-5a,5b). The first floor is made up of timber plank (Figure-6). The thickness of wooden plank varies from 0.1m to 0.125 m. The wooden platform is covered with bamboo mat and finally plastered with mud. The thickness of mud plaster is limited to 0.05 m. The timber posts for the attic, which support the sloping roof extend from the timber rafters. The attic is used for storing grain and other household items. Sometimes it is used as a living room. It is generally observed that the gable portion of wall is not provided with a timber band. The sloping roof of the house is resting on the gable end, which is very vulnerable to lateral dynamic forces. Perfect timber framed buildings are very good at resisting earthquake forces. The evidence of the good performance of such building was shown in the Latur earthquake in 1993. The building may sway but will definitely avoid total collapse. The damage pattern of such building may be referred to in Figure-7. The damage to the building was due to heavy and thick external walls and roof. The walls are not attached to the timber frame. The only attachment is achieved by the inside and outside plastering. The roofing elements are partly resting on outer walls and partly on intermittent timber columns. These buildings do not require many resources for retrofitting and restrengthening.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 5 and 5 meters, and widths between 3.5 and 3.5 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 2 meters. Typical Plan Dimensions:The length and width change depending on requirements and certain governing factors. These factors include: (1) Occupancy rate (2) Economy background (3) Availability of resources like materials, manpower and money (4) Caste system (5) Rural or Urban area Typical Story Height: Story height can range from 3.5 to 4.0 meters with a 1.0 to 1.5 meter high attic. Typical Span: The span between columns ranges from 1.75 to 2.5 meters, center to center. The typical storey height in such buildings is 3.5 meters. The typical structural wall density is up to 20 %. 15-20% For medium size buildings, the wall density ranges from 15 to 20 %. Longitudinal Direction: 20-25 %. Transverse Direction: 15-20 %.

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	☑	☑

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	☐

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 2 housing unit(s). 2 units in each building. The number of housing units in a building is usually limited to 2 but, the number of housing units in a building changes from house to house. Generally economic factors play a major role in the number of units per building. Richer people may occupy multiple housing units while this is less likely for the poor. 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. In semi-urban to rural areas, the male members are going to agricultural fields for cultivation. The graph shows the variation in occupancy of typical building. See the graph in Figure-18.

4.2 Patterns of Occupancy

The building may be occupied by a single family or a joint family.

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)	☐

The House Price is in Indian Rupees (US$ 1 = IN Rs. 45.00) Economic Level: For Poor Class the Housing Price Unit is 100000 and the Annual Income is 25000. For Middle Class the Housing Price Unit is 200000 and the Annual Income is 40000.

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 rural house owners use money from their own savings and if not, they borrow money from small local money lenders. There are many times when illiterate rural people are cheated by those moneylenders. Now the government is providing many encouraging housing loan facilities to all groups of society with lower interest rates. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

In urban areas, the houses are built with one bathroom and one latrine. In the semi-urban and rural areas, the older houses were not provided with latrines and bathrooms. They use opens field for toilet and natural water bodies like rivers, ponds or wells for bathing. Newly constructed houses provide at least one latrine and one bathroom. .

4.4 Ownership

The type of ownership or occupancy is individual 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)	☐

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				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	--Mud mortar --No sufficient bearing for opening --The openings are at different levels (Figure-8).	--Wall as partition wall (Figure-4a) --Comparatively light in weight than conventional load bearing brick walls (Thickness ranges from 0.35 to 0.45 m	--Corner separation (Figure-9a,9b) --Damage to partition wall (Figure-10) --Overturning of walls --Deep cracking in walls --Gable failure (Figure-11a,11b).
Frame (columns, beams)	--Connection with wall is not sufficient --Column and beam bracings are not adequate (Figure-3) --Lack of proper linkage between columns and beams --Loose connection.	--Ductile beam and column thus better resistance to earthquake forces --Sometimes braces are present which links column and beams (Figure-4b).	--Swaying of columns (Figure-12) --Excessive deflection in beams --Joint failure of beams and columns(Figure-12) --Collapse of frame structure.
Roof and floors	--Heavy roofing elements(Figure-13) --No proper joints between rafters and purlins (Figure-14) --Poor linkage between roofing elements and wall.	--Many houses are covered with galvanized iron sheet, which is light in weight, thus reducing seismic forces on building (Figure-15).	--Collapse of roof (Figure-10) --Displacement of roof covering tiles --Joint failure of purlins and rafter.
Other			

The structural system connectivity for a good timber frame brick building is perfect at its wooden joints but most of the time it has been found that poorly constructed buildings are missing such important parameters. In this regard, the survey was conducted and found that about 85 % of the buildings in the study area do not have adequate structural connectivity.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), the lower bound (i.e., the worst possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), and the upper bound (i.e., the best possible) is D: MEDIUM-LOW VULNERABILITY (i.e., 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
1988	Eastern Nepal between Udaipur and Dharan (Bihar-Nepal Earthquake)	6.6	IX
1993	Killari (Maharashtra)	6.4	IX

1997	Kosma Ghat (Jabalpur)	6	VII

In the Bihar Nepal Earthquake (1988), with isoseismal areas of IX, nearly 75 % of these buildings experienced moderate to severe damage ranging from wide cracks to partial collapse. More damages were reported due to liquefaction than ground shaking. In Killari earthquake (1993), typical timber framed brick buildings at Intensity VII to IX, performed satisfactorily. The damage varied from minor cracks to swaying of the timber frame without partial or complete collapse. In Jabalpur earthquake(1997), similar building types performed differently in various places. Although the statistical data for damage of this building type is not available, the range of damage varies from unaffected to complete collapse.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Brick	N/A	N/A	
Foundation	Rubble Stone with Mud mortar.	N/A	N/A	
Frames (beams & columns)	Timber (Teak Wood).	N/A	N/A	
Roof and floor(s)	Timber planks (Teak).	N/A	N/A	GROUND FLOOR: Mud Plaster. FIRST FLOOR: Wooden planks.

6.2 Builder

Builders live in this type of construction.

6.3 Construction Process, Problems and Phasing

The building is constructed by local artisans and skilled and unskilled manpower with locally available material and tools. The typical house of two rooms for single family may take nearly four to six weeks of time. FOUNDATION: For brick wall construction, a spread footing foundation is generally practiced. The depth of foundation is about 0.60 m. The foundation is made up of random rubble masonry with mud mortar. The thickness of the footings varies from 0.60 to 0.75 m. In many cases, the width of the foundation continues above the plinth level and gradually tapers down to the wall thickness. The timber columns are erected and placed during the foundation construction phase. TIMBER FRAME AND WALL CONSTRUCTION: The timber frame is erected before masonry work. All necessary bracings are done. Once the frame is erected, then brick work starts. The brick may be burnt or sun dried. The characteristics and quality of brick has been discussed in section 7.1. Major construction work is done by the family members. Only specific technical jobs, are done by skilled or semi-skilled masons or carpenters. WALL CONSTRUCTION: The walls are constructed after erection of timber frame. Generally mud mortars are used for the brick masonry work. The english bond system is applied for walling but many times this feature is missing in rural construction. There are no provisions for waterproofing the walls. (Figure-16). ROOFING SYSTEM: The roof has two tiers. A flat roof is constructed just above the ground floor. The flat roof is made up of timber. The details are shown in Figure-16. The roof above the attic, which is exposed to the outside, is covered with galvanized iron sheets or clay tiles. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size.

6.4 Design and Construction Expertise

In general, no formal engineering design is practiced for the construction of these houses. The building is constructed by local skilled or semi skilled workers, which have little knowledge of engineered construction. They follow rules-of-thumb for construction. In semi-urban and rural areas, civil engineers do not play a role in the design and construction of these buildings. These days, due to a lack of wood for building material, the rate of construction of these buildings has dedined.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. --IS 13828-1993: Indian standard guidelines for improving earthquake resistance of low strength masonry buildings --IS 1893-2002: Indian standard guidelines for earthquake resistant design of structures --IS 4326-1993: Indian standard code of practice for earthquake resistant design and construction of buildings. The year the first code/standard addressing this type of construction issued was N/A. N/A. The most recent code/standard addressing this construction type issued was N/A. Title of the code or standard: --IS 13828-1993: Indian standard guidelines for improving earthquake resistance of low strength masonry buildings --IS 1893-2002: Indian standard guidelines for earthquake resistant design of structures --IS 4326-1993: Indian standard code of practice for earthquake resistant design and construction of buildings. Year the first code/standard addressing this type of construction issued: N/A National building code, material codes and seismic codes/standards: N/A When was the most recent code/standard addressing this construction type issued? N/A.

The building code enforcement for this type of construction is very poor. The building bylaws in rural and semi-urban areas are not properly enforced.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and authorized as per development control rules.

Generally this type of construction is outdated and is practiced in semi-urban and rural areas where building bylaws are not strictly followed. 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).

6.8 Construction Economics

The unit cost of construction without considering the cost of land and interior fitting comes out to be Indian Rs. 1500 to Rs. 2000 (USD35 to USD 45) per square meter depending upon the place and material available. If the size of a house is considered to be 12 m X 3 m, the time required to complete the house will take 35 days provided all resources are supplied to the site without interruption. The requirement of manpower will be as follows: Labor = 38 Mason = 26 Carpenter = 5.

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. Not available.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Poor column and beam connection	Knee, horizontal and vertical bracing (Figure-17)
Poor roofing elements	Replacing the decayed wooden elements with good quality wooden members
Heavyweight roofing	Replacing heavy roofing material with galvanized iron sheet (Figure-17)
Plinth, lintel and roof band absence	Strengthening with wire mesh (Figure-17).
Poor brick mortar	Plastering with rich cement mortar with waterproofing compounds
Poor waterproofing	Plastering with rich cement mortar with waterproofing compounds

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Absence of lintel bands	Provide plinth, lintel and roof bands (Figure-17)
Heavy roofing material like country clay tiles	Lightweight roofing materials such as galvanized iron sheet
Discontinuous columns	Firm column and beam connection
Local bricks are made up of black cotton soil which contains many mineral lumps	Good quality bricks to be used
Black cotton soil mortar	Cement mortar in place of mud mortar
Absence of building codes practices	Good practice of building codes
No proper bonding techniques are applied in field	Proper bonding of walls

METHOD FOR RETROFITTING / STRENGTHENING Process Overview: (A) Removal of Excess Heavy Roof Covering (B) Insertion of a Timber Frame (C) Strengthening the Timber Frame (D) Seismic Bandage (E) Roof Strengthening (F) Pointing of Poor Mortar Brick Walls (G) GI Sheet of Tile Roof Fixing (A) Removal of Excess Heavy Roof Covering i.e Tiles, Timber Planks, GI Sheets, Clay Tiles, Etc. Earthquake induced seismic forces are directly proportional to the mass of structural elements; the larger the mass, the larger are the seismic forces to be resisted by the structure. Therefore, the weight of the roof must be reduced to the greatest possible extent. The following procedure has to be adopted: 1. Removal of clay tiles or GI roofing sheets carefully without altering the existing load path of system. 2. Careful removal of roofing and truss materials; the roofing elements should not be repositioned until all other retrofitting work at and above eave level has been completed. 3. Placement of the wooden purlins and rafters (50-75 diameter) at a spacing of 250 mm center to center. The purlins must be placed firmly within proper grooves in the rafters. The rafters are fixedly placed on a wooden "Eaves Band" with a steel strap, placed all around the top of wall. (B) Insertion of a Timber Frame. The existing frame structure has its own strength and acts perfectly well during ground shaking. The load bearing brick walls perform comparatively poorly, so effort should be spent to convert the load bearing structure from the brick walls to frame. It is observed that this rural construction type is partially framed so less effort is required to convert a house into a fully framed structure. The loads coming from the super-structure to the foundation should be studied. Columns should be inserted in the necessary locations using a proper foundation construction technique that ensures the loads can transfer from the structure to the ground. The eaves band must be positioned on the wall properly by making grooves and inserting the column. (C) Strengthening the Timber Frame. The strengthening is done by bracing the frame and wooden members. It includes installation of timber band, knee bracing as well as diagonal and horizontal bracing of timber frame. (i) Installation of Timber Band. The top most portion of the wall should be dismantled just below the eaves level and the timber band should be installed at this level; the parapet wall should be reconstructed using the same material. The timber band is to be also provided at gable tops. (ii) Knee Bracing of a Timber Frame. Knee bracing should be introduced at top of each timber post to reduce the likelihood of lateral sway and to strengthen timber frame against a possible earthquake. Two bracings are required for corner posts and four bracings are required for inside posts in a bidirectional column-beam system. There are several possible types of knee bracing, depending on the availability of construction materials (steel or timber). The length of the knee bracing should be approximately 60 cm. When steel bracing is employed, rolled steel angles with a minimum size of 35 X 3 mm should be used. For timber bracing, a timber plank of 30x80-mm cross-section may be used. SEE THE REMAINING SECTIONS (c-iii, d,e,f,g) IN SECTIONS 10.4 & 10.6.

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?
This seismic strengthening procedure has been described based on post-earthquake rehabilitation of the Killari earthquake, earthquake retrofitting techniques adopted for earthquake prone areas of Nimar and Indian standard codes. No retrofitting programs have been initiated before earthquake occurrence for this type of construction.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
In India, mitigative measures have only been instituted in large scale after earthquakes. Examples can be sited after the Killari earthquake in Maharashtra, India, where this type of construction, namely Khan construction, was retrofitted and strengthened.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
Yes BELOW ARE ADDITIONAL SECTIONS (c-iii, d) FOR THE METHOD OF RETROFITTING/STRENGTHENING DISCUSSION STARTED SECTION 10.1: (iii) Diagonal and Horizontal Bracing of the Timber Frame. As an alternative to knee bracing, bracing of a timber frame by means of either diagonal bracing elements or horizontal struts is recommended. The purpose of providing diagonal and horizontal bracing is: 1. To prevent swaying of a timber frame during an earthquake and 2. To prevent tilting of the wall to the inside of the house and/or to reduce the effective wall height. Bracing of the core house area, particularly all the bedrooms, is of the highest priority. Consequently, diagonal or horizontal bracing should be provided inside first, and then on the outside of the house. For diagonal bracing applications, a minimum of two bracings should be installed in adjacent spans with alternate directions. Alternatively, "X" bracing can be installed within one frame span. Timber planks used for diagonal or horizontal bracing should be at least 30x80 mm in cross section. (D) Seismic Bandage. To ensure integral action of the walls during an earthquake, installation of seismic bandage at the lintel level is recommended for UCR stone masonry as well as for BB and solid concrete block masonry walls. Seismic bandage is an alternative to a reinforced concrete (RC) band at the eave level, and it should be provided whenever it is not feasible to install a RC band at the eaves level by dismantling a portion of the parapet. When the masonry work is not in good condition, bandage can be provided, without dismantling a portion of wall. Seismic bandage can be installed, whenever: a) the height of the wall (from the ground level to eaves level) is over 3 m, and/or b) the distance between the top of the openings (windows) and the eaves level is at least 1m. In such a case, seismic bandage should be installed at the lintel level. Construction of seismic bandage should be carried out as per the following procedure: · Clean a 80 cm wide horizontal strip of the exterior wall face all around the building, starting at the lintel level. · Remove the plaster from the wall surface. Rake the joints between the stones to a depth of approximately 20 mm. Surface should be cleaned with a wire brush until all vegetation and dust particles are removed. · Provide an opening for a shear key (approximately size 15 x15) by removing one stone from the wall below the roof level. Shear keys should be spaced horizontally every 2 m. · Two pairs of "U" shaped stirrups (6mm diameter mild steel bars) should be inserted in each shear key. Four longitudinal bars of 8 mm diameter TOR steel should be placed in the corners of the "U" stirrups. · Fill the space in the shear keys with micro-concrete (1:2:4 mix, maximum 6 mm diameter aggregate). · Affix a 60 cm wide strip of welded wire mesh reinforcement of 2 - 3 mm diameter @ 25 - 50 mm c/c spacing (i.e. Wire mesh of size 25 x 25 x 2 mm or 50 x 50 x 3 mm or with intermediate diameter and appropriate spacing) to the walls at the roof level by means of long nails. The mesh should also be connected to the shear key reinforcement with the binding wire. · Provide a 10 mm wide gap between the mesh and the wall. · Overlap the mesh to ensure the continuity of reinforcement. The overlapping length should be approximately 60 cm. · Wet the wall surface by sprinkling water. Apply a 15mm thick layer of 1:3 cement-sand mortar to cover the mesh. · After one hour, apply another layer of 1:3 cement-sand mortar of the same thickness (15mm). · Cure the belt continuously for 14 days by sprinkling water. · For a house having more than one room, seismic bandage should be provided along with tie bars as shown in figure 17 SEE THE REMAINING SECTIONS (e,f,g) IN SECTION 10.6.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
The house was constructed by the contractor with overall supervision of engineers deployed for the redevelopment and rehabilitation.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
No such case is apparent. BELOW ARE ADDITIONAL SECTIONS (e,f,g) FOR THE METHOD OF RETROFITTING/STRENGTHENING DISCUSSION STARTED SECTIONS 10.1 & 10.4: (E) Roof Strengthening. a. Weld or clamp suitable diagonal bracing members in the vertical as well as horizontal planes to brace roof truss frames. b. Improve the roof truss anchors that connect to the supporting walls to eliminate the roof thrust

on the walls. c. Integrate roof and floor systems that consist of prefabricated units like RC rectangular/T/channel units or wooden poles/joists carrying brick tiles. Timber elements could be connected by nails to diagonal planks and spiked to an all around wooden frame at the ends. (F) Pointing Exterior Walls. Joints of the brickwork must be raked out to a depth of 20 mm (3/4 inches) and the surface of the wall must be washed, cleaned and kept wet for two days before pointing. The mortar materials should be either a mix of cement and sand or a mix of kankar lime, surkhi and sand. The materials of mortar shall be dry mixed first by measuring with boxes to have the required proportion as specified (1:2 or1:3 for cement sand mortar, 1:1 for Lime surkhi (Crushed burnt brick bats) mortar of kankar lime); only then can the mortar be thoroughly mixed by adding water slowly and gradually. Mortar shall then be applied in the joints slightly in excess. If there is any extra mortar, it should be removed and the surface finished. Mortar shall not spread over the face of bricks, and the edges of bricks shall be clearly defined to give a neat appearance. After pointing the surface shall be kept wet for seven days. (G) GI Sheet or Tile Roofing. It is observed that a suitable connection between the roof structure and the walls is absent in most of these houses. A GI sheet, when improperly supported directly on the roof band, requires a cut in a portion of the band. (A cut in the band is also required to embed the rafters or purlins.) However, such a cut in the band is not permitted. Instead, one or two courses of burnt brick masonry should be provided to connect the GI sheet roofing. On the front side, bolts can be embedded in the burnt brick masonry over the band and the GI sheet should preferably be held by a flat 30x3 mm which in turn should be embedded in the end of parapet walls. Alternatively, on the front side, a purlin can be used along the inside or outside of the band and J bolts can be connected through this purlin (which is flat on top) to hold the GI sheets in place.

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