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
Unreinforced brick masonry walls with pitched clay tile roof

Report #	22
Report Date	06-05-2002
Country	INDIA
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in mud/lime mortar
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Summary

This is a traditional construction practice followed in India for centuries. Buildings of this construction type are used for residential, commercial, and public purposes throughout India, especially in the northern and central parts, where good quality soil for brick production is

widely available. This is a single-story construction used both in rural and urban areas. The walls are constructed using clay bricks laid in mud, brick-lime or cement/sand mortar. The roof does not behave as a rigid diaphragm. These buildings are built without any seismic provisions and are considered to be moderately-to-highly vulnerable to earthquake effects.

1. General Information

Buildings of this construction type can be found in all parts of India and neighboring countries like Nepal and Bangladesh. In India these buildings are commonly found in North, extending from Punjab to West Bengal and Central India, from Haryana to Madhya Pradesh. These buildings are most commonly found in regions where good quality day for brick production is abundantly available. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. This type of construction has been practiced for hundreds of years. All existing older brick masonry buildings are of this type.

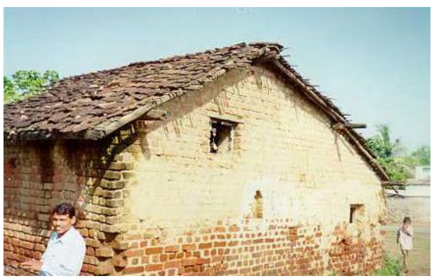

Figure 1: Typical Building

Figure 1A: Typical Rural Building in Maliya Village, Gujarat (Source: IIT Powai 2001)

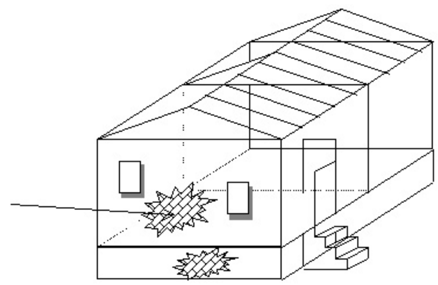

Figure 2: Key Load-Bearing Elements

Figure 2A: Key Load-bearing Elements: Typical Village House in Gujarat (source: IIT Powai 2001)

Figure 2B: Key Load-Bearing Elements: Roof Construction (Source: Sudhir K. Jain, IIT Kanpur)

Figure 2C: Key Loadbearing Elements: Laying of Magalore Roof Tiles (Source: Sudhir K. Jain, IIT Kanpur)

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 3 meters.

2.2 Building Configuration

These buildings are Rectangular, L, and C-shaped in plan. In practice, most public buildings like Schools and Government offices are rectangular or L-shaped. Residential buildings are generally rectangular in plan. The style and size of openings in the walls have changed with time. In 50-75 year-old residential buildings, the proportion of openings is comparatively lower than in recently constructed buildings. The older buildings also have higher ceilings, and the size of individual doors and windows are also larger. The ceiling height may reach 20 feet, while the doors and windows may have height of 8 feet and 6 feet, respectively. The rooms are also larger with dimensions reaching 15 X

25 feet. The size of newer construction is relatively lower. The room size is smaller at 12 X 15 feet. The doors and window sizes have also reduced accordingly. The door and windows are commonly 7 feet and 4.5 feet high, respectively. However, the newer construction typically has more windows so that the total area of openings is greater than in older construction. The opening of the door and windows are placed according to user requirements. It is common to find openings located at wall corners. Public buildings may have larger windows and doors, and the opening to wall area ratio may reach 30%. However, for residential buildings, the size of windows and doors are comparatively small; and the opening to wall area ratio rarely exceeds 10%.

2.3 Functional Planning

The main function of this building typology is single-family house. Most old (>50 years) buildings of this type are public institutional structures (residential buildings have not survived this long). In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Usually there is one door in the building.

2.4 Modification to Building

More typical modification is extensions to buildings.

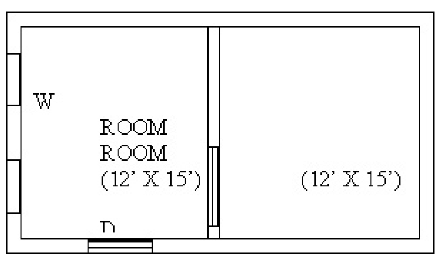

Figure 3: Plan of a Typical Building

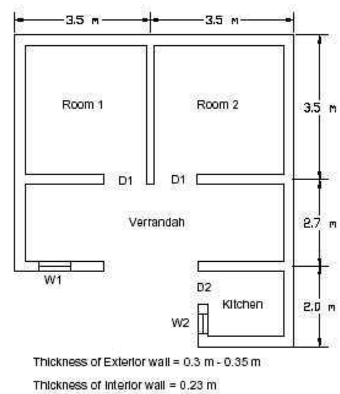

Figure 3A: Typical Plan of a Single-story Residential Building, Kuchh and Rajkot Districts, Gujarat (Source: IIT Powai 2001)

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 un-reinforced masonry walls. The gravity loads are transferred from the roof to the foundation through the walls. The roofs are generally sloping and tiled.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is un-reinforced masonry walls. The walls are generally constructed in brick masonry with mud, brick-lime or cement mortar. The walls are generally one brick thick (230 mm). In most structures, external walls are 1.5 to 2 bricks thick (350 mm to 450 mm) while the internal walls are generally one brick thick (230 mm). With time, the bond between the brick and mortar gradually weakens making older buildings more vulnerable. These buildings do not use any reinforcement to resist horizontal loads. There is generally no provision of seismic bands or lintel bands above the openings. In older constructions, arched lintels are provided above openings. The wall corners in most buildings are toothed so that cross-walls are fully connected at the joint. The foundations generally consist of field stone strip footings. The roof is constructed using timber truss having gable end resting on one central and two exterior walls (Gujarat practice). The roofing material in most of the cases is in the form of Mangalore clay tiles resting on timber purlins or bamboo when conventional clay tiles are used (Source: IIT Powai 2001).

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 4 and 15 meters, and widths between 3 and 5 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 4 meters. Typical Plan Dimension: The actual length and width of these building are widely varying depending on the requirements and economic condition of the owners. The size of the buildings may vary from 3 X 4 m to 5 X 15 m Typical Span: It depends upon the size of the building. The typical storey height in such buildings is 3 meters. The typical structural wall density is more than 20 %. Total wall area/plan area (for each floor) : Approximately 25% - 30%.

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	☐	☑

Generally the roofing elements are placed at the top of the wall without proper connection to the wall. The roofing elements such as purlins, rafters and ties rods are also not properly interconnected.

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	☐


Figure 4: Critical Structural Details: Elevation of Brick Masonry Wall in Mud Mortar (Source: Svetlana Brzev)


Figure 4A: Critical Structural Details:Good Quality Roof Construction (Source: GOM 1998)


Figure 4B: Critical Structural Details: Mangalore Tile Roof Construction (Source: Sudhir K. Jain, IIT Kanpur)

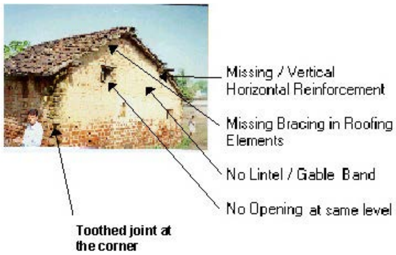

Figure 5: An Illustration of Key Seismic Deficiencies


Figure 5A: Key Seismic Resilient Features: RC Lintel Band and Good Quality Brick Masonry Construction (Source: Sudhir K. Jain, IIT Kanpur)


Figure 5B: Construction Deficiency: Poor Quality Bricks (Source: Sudhir K. Jain, IIT Kanpur)

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. The number of housing units in a building cannot be estimated as it depends upon the occupancy rate of the family. In joint family, if the occupancy rate is very high with several earning members, the living units may be large in number. 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. May be less than 5 or 5 to 10 or 11 to 20 or may be even greater than 20. 5-10 10-20 >20.

4.2 Patterns of Occupancy

Generally a single family occupies the buildings for residential purposes. Living in joint family is more common in rural India, with each household varying in size between 6 to 25 members.

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)	☐

Ratio between 1 and 3.

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 buildings are the main symbol of prosperity for rural Indians. Most personal savings are invested in constructing houses. Additional funds are normally borrowed from informal sources. Sometimes for socially backward community, government also provides financial assistance through schemes such as Inidra Awas Yojana. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

Generally in rural India, the bathrooms and toilets are located away from the housing units. Houses belonging to poor families in urban areas often do not have any toilet facilities, while the others may have a single toilet per living unit. .

4.4 Ownership

The type of ownership or occupancy is outright ownership and 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	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or	☐		

performance	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	- Poor lateral resistance - Lintel band is absent - Openings are not properly proportioned - The distance between corner and opening is not as per recommended practice		
Frame (columns, beams)			
Other	- The roofing elements are not interconnected. - The roof structure is not anchored to the wall - Poor maintenance		

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 C: MEDIUM VULNERABILITY (i.e., moderate 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	Bihar-Nepal Earthquake*	6.4	IX (MSK)
1993	Killari (Maharashtra)**	6.4	VIII (MSK)
1997	Jabalpur (MP)***	6.1	VII (MSK)
2001	Bhuj (Gujarat)****	7.6	X (MSK)

**** - Brick masonry buildings with pitched roofs and clay tiles were found in the area affected by the 2001 Bhuj (Gujarat) earthquake. In general, these structures performed poorly in the earthquake. In the epicentral region, several buildings of this type suffered total collapse of the walls resulting in the death and injury to large number of people. In masonry buildings with pitched roof, the roof tiles performed very poorly. In most cases, the roof tiles were damaged and in several instances, the tiles slid off the roof. Most of the dwellings have experienced failure of roofing tiles inside the house and rafters supporting the roof truss have also failed in some cases (Source: IIT Powai 2001).

Figure 6A: Typical Earthquake Damage - Wall Collapse Due to Poor Quality Brick Construction and Poor Inadequate Wall Connections in the 2001 Bhuj Earthquake (Source: IIT Powai 2001)

Figure 6B: Failure of a Residential Building, Chobri Village near Bhachau, 2001 Bhuj Earthquake (Source: IIT Powai 2001)

Figure 6C: Typical Earthquake Damage: Collapse of Roof and Walls of a Brick Lime Mortar House in the 2001 Bhuj Earthquake (Source: Sudhir K. jain, IIT Kanpur)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Brick	Not available	230 X 150 X 10	As per Indian standard.
Foundation	Brick	Not available	230 X 150 X 10	As per Indian standard.

Frames (beams & columns)				
Roof and floor(s)	Timber /Wood /Built-up steel sections	The section of truss or frame depends upon the cladding materials.		

6.2 Builder

Yes. Very often the buildings of this type are occupied by the builder.

6.3 Construction Process, Problems and Phasing

The buildings are constructed by locally available skilled masons. Locally available building materials are generally used for this construction. 1. Foundation: The trench is excavated up to 1 m depth. The first layer of the foundation is made up of broken stones, rammed properly. The strip footing foundation is either made up of stone masonry or brick masonry. For masonry construction either mud or cement mortar (1:6 cement sand mix) is used. The masonry is constructed up to 3 feet in case of mud mortar and 4.5 feet in case of cement mortar in each rise. 2. Wall: The wall is constructed in mud or cement mortar using procedure similar to that of foundation. Buildings of such type in rural areas are found to be having poor workmanship. English bond is generally used for wall construction. 3. Roofing: The roof truss is either made up of bamboo, wood or built up steel section. The spacing between purlines and rafters are generally not regular. Older buildings often used heavy clay tiles on the roof cladding. The cladding material and roof tiles are not usually firmly anchored to the trusses and wall. 4. Location of openings: The openings are not provided as per the recommendations of IS Code of Practice. 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

Generally the contractors supervising and executing construction work, may not have any engineering background. Generally skilled masons after certain experience work as contractor. In rural areas the house owner without having knowledge of building construction also sometimes constructs the buildings. At the time of construction, the mason gives advice regarding the construction techniques. Engineers and architects do not have any role in performing this construction. Even in urban areas, engineers and architects are normally not involved in design and construction of brick masonry residential buildings. Large institutional buildings were constructed under the supervision of engineers and master-builders in the past. However, modern institutional buildings do not use this construction technique any more.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. IS13828-1993 Improving Earthquake Resistance of Low Strength Masonry Buildings-Guidelines. The year the first code/standard addressing this type of construction issued was 1993. IS 4326-1993 Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings IS 1893-1984 Indian Standard Recommendations for Earthquake Resistant Design of Structures According to the IAEE Classification/ IS Code 1893, buildings of this type are classified as Class B. The most recent code/standard addressing this construction type issued was 1993. Title of the code or standard: IS13828-1993 Improving Earthquake Resistance of Low Strength Masonry Buildings-Guidelines Year the first code/standard addressing this type of construction issued: 1993 National building code, material codes and seismic codes/standards: IS 4326-1993 Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings IS 1893-1984 Indian Standard Recommendations for Earthquake Resistant Design of Structures According to the IAEE Classification/ IS Code 1893, buildings of this type are classified as Class B. When was the most recent code/standard addressing this construction type issued? 1993.

Building codes are very poorly enforced in urban areas. They are not legally applicable to rural areas.

6.6 Building Permits and Development Control Rules

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

The building byelaws do not exist for rural areas. In urban areas building by-laws are seldom enforced. 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

Rate/m²: Approximately Rs. 800/ m², i.e. $ US 18 per m². For house area 53.75 m² : Labors required: 159 person-days; No. of days: 45.

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.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Lack of integrity	Installation of seismic belt
Inadequate roof connections	Bracing of roofing elements

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Walls	-Use of rich cement/sand mortar - Provision of RC lintel band - Proper toothing joint at wall intersections
Roof	- Proper connections of roof elements

Retrofit (strengthening): The suggestions for modification are not complex and can be carried out by local masons and labor (Reference code IS code 13935-1993) New construction: Only few provisions like installation of lintel bands are required for walls; also, proper arrangements of roofing elements are required. (Reference code IS 4326-1993).

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?
Seismic strengthening of some buildings of this construction type was performed after the 1993 Killari (Maharashtra) earthquake. However, it is not common (and not widely acceptable) for the owners to undertake strengthening. In the case of the 1993 Killari earthquake, the strengthening was mainly sponsored by the Government of Maharashtra.

Owners are more interested to undertake new construction with seismic features than to strengthen the existing buildings of this type (Source: EERI 1999).

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Repair following earthquake damage.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
In case of the strengthening performed after the 1993 Killari earthquake, the construction was inspected better than the new construction.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
Contractors performed the construction. The construction was inspected by the engineers.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
There is no evidence of damaging earthquakes occurring after the strengthening was performed.

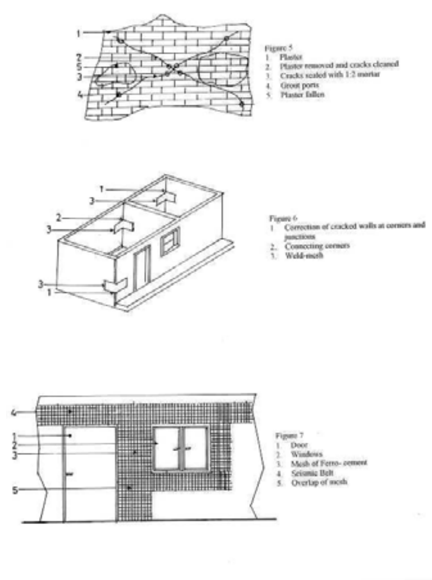

Figure 7A: Seismic Strengthening Techniques (Source: BMPTC)

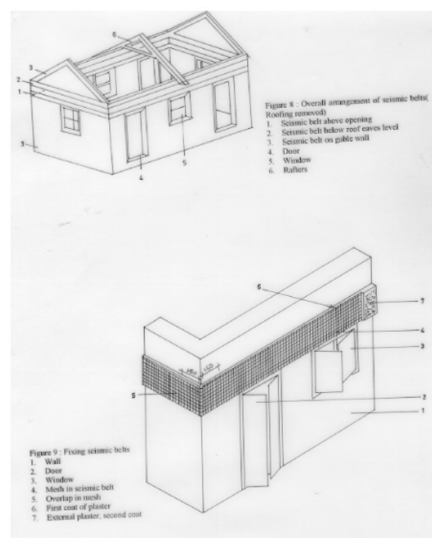

Figure 7B: Seismic Strengthening Techniques (Source: BMTPC)

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