World Housing Encyclopedia Report

Country: India

Housing Type: Unreinforced brick masonry walls with pitched clay tile roof

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1 General Information

1.1 Country
India

1.3 Housing Type
Unreinforced brick masonry walls with pitched clay tile roof

FIGURE 1: Typical Building

1.4 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 of the country, where good quality soil for brick production is abundantly available. This is a single-storey 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.

1.5 Typical Period of Practice for Buildings of This Construction Type

How long has this construction been practiced	
< 25 years	
< 50 years	
< 75 years	
< 100 years	
< 200 years	
> 200 years	X

Is this construction still being practiced?	Yes	No
	X	

Additional Comments: This type of construction has been practiced for hundreds of years. All existing older brick masonry buildings are of this type.

1.6 Region(s) Where Used
Generally this type of construction is found in all over 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 clay for brick production is abundantly available.

1.7 Urban vs. Rural Construction

Where is this construction commonly found?	
In urban areas	
In rural areas	
In suburban areas	
Both in rural and urban areas	X

2 Architectural Features

2.1 Openings

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%.

2.2 Siting

	Yes	No
Is this type of construction typically found on flat terrain?	X	
Is this type of construction typically found on sloped terrain? (hilly areas)		
Is it typical for buildings of this type to have common walls with adjacent buildings?		

The typical separation distance between buildings is 3 meters

2.3 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.

2.4 Building Function

What is the main function for buildings of this type?	
Single family house	X
Multiple housing units	
Mixed use (commercial ground floor, residential above)	
Other (explain below)	

Additional Comments: Most old (>50 years) buildings of this type are public institutional structures (residential buildings have not survived this long).

2.5 Means of Escape

Usually there is one door in the building.

2.6 Modification of Buildings

More typical modification is extensions to buildings.

3 Socio-Economic Issues

3.1 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.

3.2 Number of Housing Units in a Building

1 units in each building.

Additional Comments: 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.

3.3 Average Number of Inhabitants in a Building

How many inhabitants reside in a typical building of this construction type?	During the day / business hours	During the evening / night
< 5	X	
5 to 10		X
10-20		X
> 20		X
Other		

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 1
Number of Latrines: 1

Additional Comments: 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.

3.5 Economic Level of Inhabitants

Economic Status		House Price/Annual Income (Ratio)
Very poor		/
Poor	X	/
Middle Class	X	/
Rich		/

Additional Comments: Ratio between 1 and 3

3.6 Typical Sources of Financing

What is the typical source of financing for buildings of this type?	
Owner Financed	X
Personal Savings	X
Informal Network: friends and relatives	
Small lending institutions/microfinance institutions	
Commercial banks / mortages	
Investment pools	
Combination (explain)	
Government-owned housing	X
Other	

Additional Comments: 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.

3.7 Ownership

Type of Ownership/Occupancy	
Rent	
Own outright	X
Own with Debt (mortgage or other)	
Units owned individually (condominium)	X
Owned by group or pool	
Long-term lease	
Other	

4 Structural Features

4.1 Lateral Load-Resisting System

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).

4.2 Gravity Load-Bearing Structure

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

4.3 Type of Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	
Masonry	Stone masonry walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	
		2	Massive stone masonry (in lime or cement mortar)	
	Earthen walls	3	Mud walls	
		4	Mud walls with horizontal wood elements	
		5	Adobe block or brick walls	
		6	Rammed earth/Pise construction	
	Unreinforced brick masonry walls	7	Unreinforced brick masonry in mud or lime mortar	X
		8	Unreinforced brick masonry in mud or lime mortar with vertical posts	
		9	Unreinforced brick masonry in cement or lime mortar (various floor/roof systems)	
	Confined masonry	10	Confined brick/block masonry with concrete posts/tie columns and beams	
	Concrete block masonry walls	11	Unreinforced in lime or cement mortar (various floor/roof systems)	
		12	Reinforced in cement mortar (various floor/roof systems)	
		13	Large concrete block walls with concrete floors and roofs	
Concrete	Moment resisting frame	14	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	
		15	Designed with seismic features (various ages)	
		16	Frame with unreinforced masonry infill walls	
		17	Flat slab structure	
		18	Precast frame structure	
		19	Frame with concrete shear walls-dual system	
		20	Precast prestressed frame with shear walls	
	Shear wall structure	21	Walls cast in-situ	
		22	Precast wall panel structure	
Steel	Moment resisting frame	23	With brick masonry partitions	
		24	With cast in-situ concrete walls	
		25	With lightweight partitions	
	Braced frame	26	Concentric	
		27	Eccentric	
Timber	Load-bearing timber frame	28	Thatch	
		29	Post and beam frame	
		30	Walls with bamboo/reed mesh and post (wattle and daub)	
		31	Wooden frame (with or without infill)	
		32	Stud wall frame with plywood/gypsum board sheathing	
		33	Wooden panel or log construction	
Various	Seismic protection systems	34	Building protected with base isolation devices or seismic dampers	
	Other	35		

4.4 Type of Foundation

Type	Description	
Shallow Foundation	Wall or column embedded in soil, without footing	
	Rubble stone (fieldstone) isolated footing	
	Rubble stone (fieldstone) strip footing	X
	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	
	Wood piles	
	Steel skin friction piles	
	Cast in place concrete piers	
	Caissons	
Other		

4.5 Type of Floor/Roof System

Material	Description of floor/roof system	Floor	Roof
Masonry	Vaulted		
	Composite masonry and concrete joist		
Structural Concrete	Solid slabs (cast in place or precast)		
	Cast in place waffle slabs		
	Cast in place flat slabs		
	Precast joist system		
	Precast hollow core slabs		
	Precast beams with concrete topping		
	Post-tensioned slabs		
Steel	Composite steel deck with concrete slab		
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 single roof		
	Wood planks or beams that support clay tiles		X
	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			

Additional Comments: 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.

4.6 Typical Plan Dimensions

Length: 4 - 15 meters
Width: 4 - 15 meters
Additional Comments: 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.

4.7 Typical Number of Stories

1

4.8 Typical Story Height

3 meters

4.9 Typical Span
4 meters

Additional Comments: It depends upon the size of the building

4.10 Typical Wall Density
25% - 30%
Total wall area/plan area (for each floor) : Approximately 25% - 30%

4.11 General Applicability of Answers to Questions in Section 4
This contribution describes a generic building type and it is not based on the case study of a particular building.

5 Evaluation of Seismic Performance and Seismic Vulnerability

5.1 Structural and Architectural Features: Seismic Resistance

Structural/ Architectural Feature	Statement	True	False	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 form the building to the foundation.		X	
Building configuration	The building is regular with regards to both the plan and the elevation.	X		
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.		X	
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.		X	
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.			X
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	X		
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: 1) Less than 25 (concrete walls); 2)Less than 30 (reinforced masonry walls); 3) Less than 13 (unreinforced masonry walls).		X	
Foundation- wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.		X	
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.		X	
Wall openings	The total width of door and window openings in a wall is: 1) for brick masonry construction in cement mortar: less than 1/2 of the distance between the adjacent cross walls; 2) for adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; 3) for precast concrete wall structures: less than 3/4 of the length of a perimeter wall.		X	
Quality of building materials	Quality of building materials is considered to be adequate per requirements of national codes and standards (an estimate).		X	
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).		X	
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).		X	
Other				

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)			
Roof and floors	- The roofing elements are not interconnected. - The roof structure is not anchored to the wall - Poor maintenance		
Other			

5.3 Seismic Vulnerability Rating

	Vulnerability					
	High (Very Poor Seismic Performance) A	B	Medium C	D	E	Low (Excellent Seismic Performace) F
Seismic Vulnerability Class	<	0	>			

0 - probable value
< - lower bound
> - upper bound

6 Earthquake Damage Patterns

6.1 Past Earthquakes Reported To Affect This Construction

Year	Earthquake Epicenter	Richter magnitude(M)	Maximum Intensity (Indicate Scale e.g. MMI, MSK)
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)

Additional Comments: **** - 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).

7 Building Materials and Construction Process

7.1 Description of 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
Foundations	Brick	Not available	230 X 150 X 10	As per Indian standard
Roof and floors	Timber /Wood /Built-up steel sections	The section of truss or frame depends upon the cladding materials		

7.2 Does the builder typically live in this construction type, or is it more typically built by developers or for speculation?

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

7.3 Construction Process

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.

7.4 Design/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.

7.5 Building Codes and Standards

	Yes	No
Is this construction type addressed by codes/standards?	X	

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

7.6 Role of Engineers and Architects

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.

7.7 Building Permits and Development Control Rules

	Yes	No
Building permits are required		X
Informal construction	X	
Construction authorized per development control rules	X	

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

7.8 Phasing of Construction

	Yes	No
Construction takes place over time (incrementally)	X	
Building originally designed for its final constructed size		X

7.9 Building Maintenance

Who typically maintains buildings of this type?	
Builder	
Owner(s)	X
Renter(s)	
No one	
Other	

7.10 Process for Building Code Enforcement

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

7.11 Typical Problems Associated with this Type of Construction

Adverse weather conditions, poor workmanship and maintenance leads to early damage of these buildings.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

Rate/m²: Approximately Rs. 800/ m², i.e. $ US 18 per m².

8.2 Labor Requirements (estimate)

For house area 53.75 m² :
Labors required: 159 person-days; No. of days: 45

9 Insurance

9.1 Insurance Issues

	Yes	No
Earthquake insurance for this construction type is typically available		X
Insurance premium discounts or higher coverages are available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features		X

9.2 If earthquake insurance is available, what does this insurance typically cover/cost?

N/A

10 Seismic Strengthening Technologies

10.1 Description of Seismic Strengthening Provisions

Type of intervention	Structural Deficiency	Description of seismic strengthening provision used
Retrofit (Strengthening)	Lack of integrity	Installation of seismic belt
	Inadequate roof connections	Bracing of roofing elements
New Construction	Walls	-Use of rich cement/sand mortar - Provision of RC lintel band - Proper toothing joint at wall intersections
	Roof	- Proper connections of roof elements

Additional Comments: 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)

10.2 Has seismic strengthening described in the above table been performed in design 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).

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

Repair following earthquake damage.

10.4 Was the construction inspected in the same manner as new construction?

In case of the strengthening performed after the 1993 Killari earthquake, the construction was inspected better than the new construction.

10.5 Who performed the construction: a contractor, or owner/user? Was an architect or engineer involved?

Contractors performed the construction. The construction was inspected by the engineers.

10.6 What has been the performance of retrofitted buildings of this type in subsequent earthquakes?

There is no evidence of damaging earthquakes occurring after the strengthening was performed.

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13 Figures

FIGURE 1: Typical Building

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

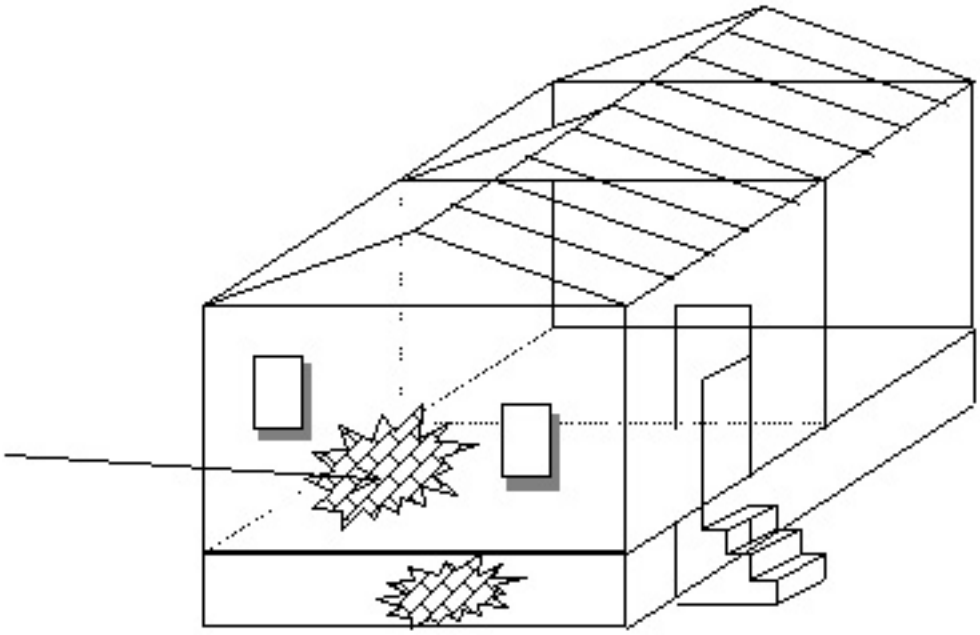

FIGURE 2: Key Load-Bearing Elements

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 Mangalore Roof Tiles (Source: Sudhir K. Jain, IIT Kanpur)

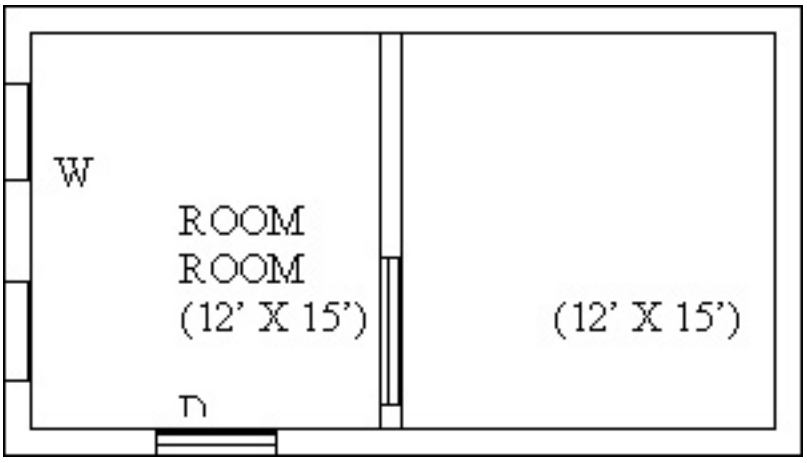

FIGURE 3: Plan of a Typical Building

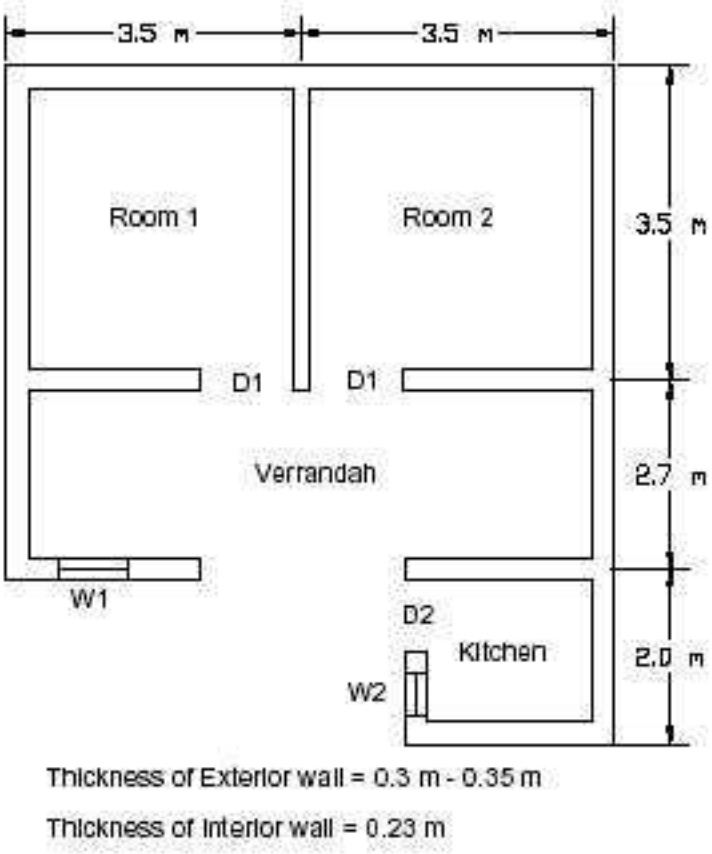

FIGURE 3A: Typical Plan of a Single-Storey Residential Building, Kuchchh and Rajkot Districts, Gujarat (Source: IIT Powai 2001)

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)

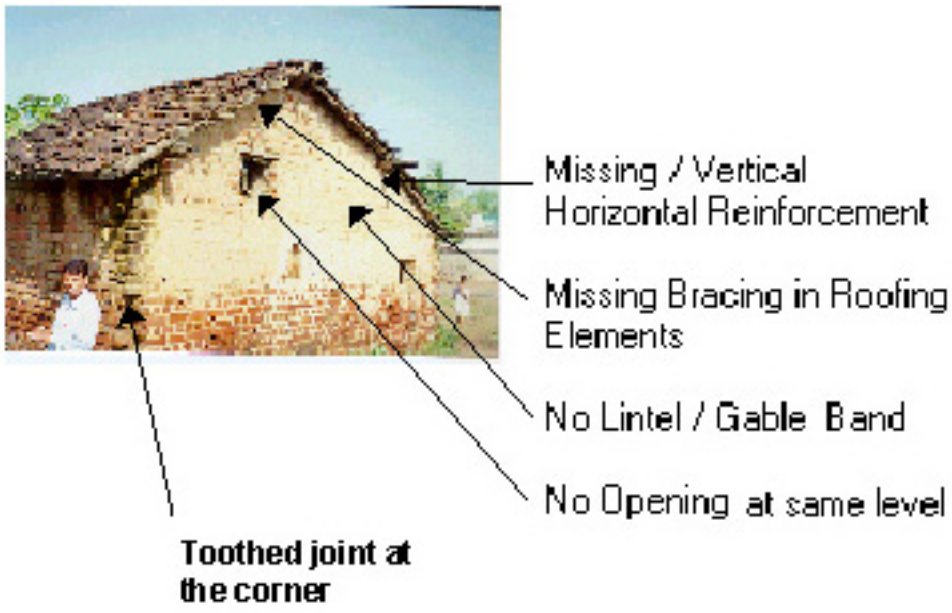

FIGURE 5: An Illustration of Key Seismic Deficiencies

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)

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)

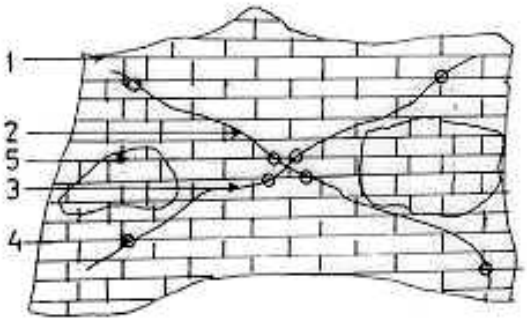

Figure 5
1. Plaster
2. Plaster removed and cracks cleaned
3. Cracks sealed with 1:2 mortar
4. Grout ports
5. Plaster fallen

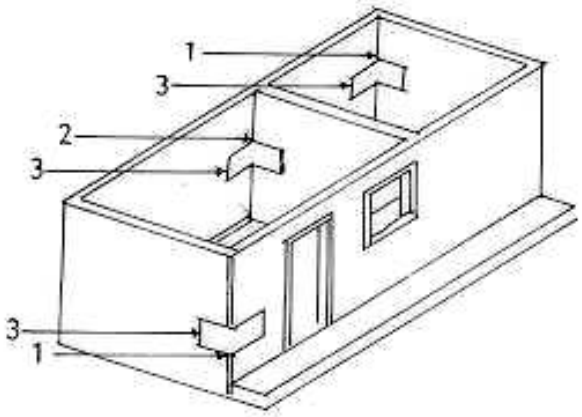

Figure 6
1. Correction of cracked walls at corners and junctions
2. Connecting corners
3. Weld-mesh

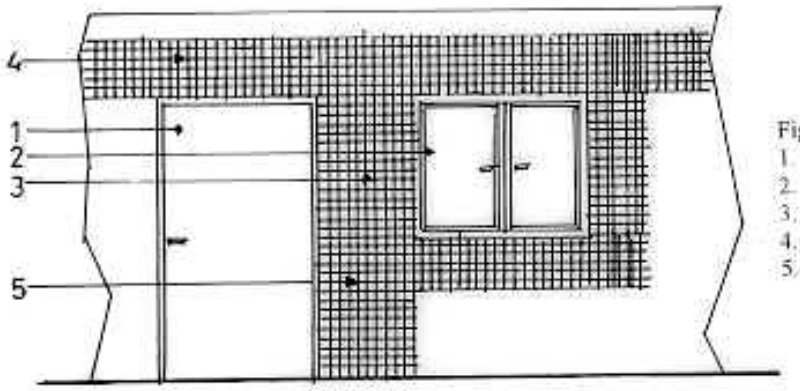

Figure 7
1. Door
2. Windows
3. Mesh of Ferro- cement
4. Seismic Belt
5. Overlap of mesh

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

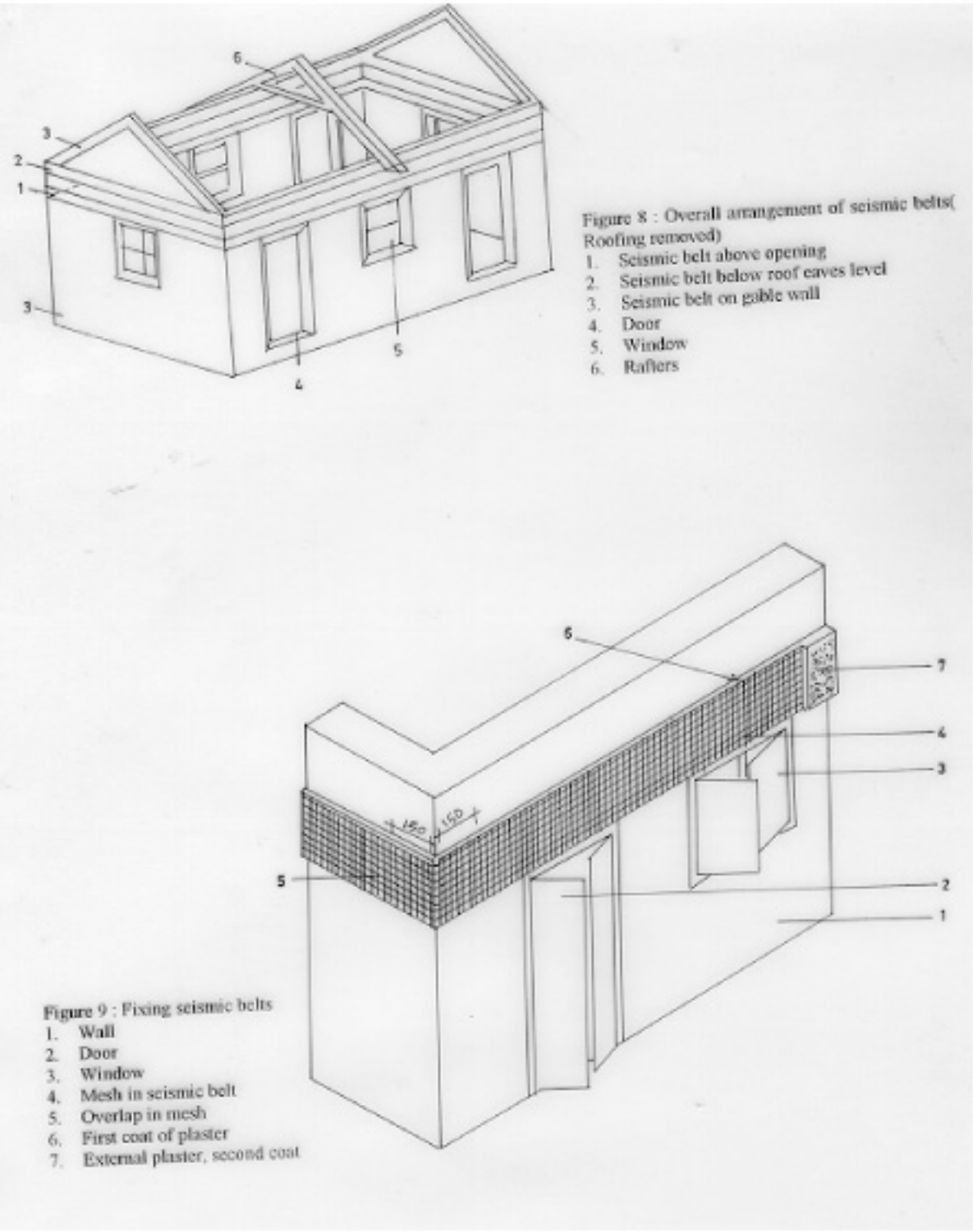

FIGURE 7B: Seismic Strengthening Techniques (Source: BMTPC)