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
Rural mud house with pitched roof

Report #	23
Report Date	06-05-2002
Country	INDIA
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Mud walls
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Summary

This is a typical rural construction found throughout India, except in the high rainfall areas in the northeastern part of the country. It is a single-family house, mainly occupied by the poorer segment of the population. The main load-bearing system consists of mud walls, which carry the roof load. In some cases wooden posts are provided at the wall corners and at intermediate locations. The wooden posts and walls are not structurally integrated, and therefore the loads

are shared by the walls and the frame. There are very few openings (doors and windows) in these buildings. In rural areas there are usually no windows at all. In general, this type of construction is built by the owners and local unskilled masons and the craftsmanship is very poor. This building type is classified as grade-A (most vulnerable) per the IAEE building classification and IS Code 1893:1984. This is a low-strength masonry construction and it is considered extremely vulnerable to seismic forces.

1. General Information

Buildings of this construction type can be found in all parts of India. Variations of this type of construction are found all over India except where very high rainfall is experienced, such as in the Northeast states of India. Information on percentage of housing stock of this type is not available, but their number is expected to be substantial. This type of housing construction is commonly found in rural areas. This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. .

Figure 1: Typical Building

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 in plan. Generally the owners and local unskilled masons construct this type of building. The craftsmanship of these buildings is very poor. The walls are often found to be out of plumb. The door and windows openings of such buildings are very small. In rural India windows are generally not provided in such houses. Both gravity and lateral loads are resisted by the mud walls. The doors are typically of size 1.75 m X 0.75 m.

2.3 Functional Planning

The main function of this building typology is single-family house. 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 2: Typical Building

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	☐
		24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐

	Precast concrete	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 earthen walls. The roof loads are directly supported by the walls/frames whose loads are supported by the wall/frame foundations.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is earthen walls. The mud walls take the load of the roofing and wall elements. Sometimes the walls are provided with wooden posts at the corners and at intermediate locations. These are generally provided at spacing not exceeding 2 m center to center. However, the wooden posts and walls are not structurally integrated, and the loads are partially shared by walls and partially taken by frame, with each behaving independently of the other.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 8 and 8 meters, and widths between 4 and 4 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 2.5 meters. Typical Plan Dimension: It is average. It is difficult to state the actual length and width of a typical building. The length and width varies according to the requirements. The ratio of such length and width can be 1½:1, 2:1 or 2 ½:1. Typical Span: The building size and typical span depends on the number of occupants. Generally wooden posts are provided at the distance of 2 - 2.5 m centre-to-centre longitudinally and transversely. The typical storey height in such buildings is 3.5 meters. The typical structural wall density is more than 20 %. The wall density of typical houses is approximately

40%.

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	☑
	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐

Deep foundation	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

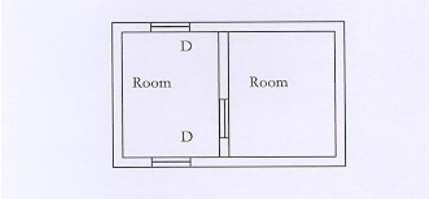

Figure 3: Plan of a Typical Building


Figure 4: Critical Structural Details: Wall Section (Source: Sudhir K. Jain)

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). One or two units in each building. 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.

4.2 Patterns of Occupancy

Generally a single family occupies a single dwelling.

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 price is expressed in US$. For Poor Economic Level the Housing Price unit is 350.

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)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) induding toilet(s).

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

4.4 Ownership

The type of ownership or occupancy is renting and outright ownership.

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

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	Very poor lateral resistance No lintel band is present Opening proportion is not proper The distance between corner and opening is not according to IS code specifications.	Provision of wooden columns at regular interval.	Partially or complete collapse of wall with failure.
Frame (columns, beams)	No proper connection between column and beam.	Partially, it works as a frame structure.	Damage observed at weaker sections i.e. joint of column and beam.
Roof and floors	Roof: The roofing elements are not interconnected. The roofing truss is not fully anchored to the wall Poor maintenance makes the roof truss more vulnerable to damage Roof does not provide rigid-diaphragm action.		Collapse of roofing

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *A: HIGH VULNERABILITY (i.e., very 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 *B: MEDIUM-HIGH VULNERABILITY (i.e., poor 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
1997	Jabalpur	6.1	VII (MSK)
2000	Jabalpur	5.3	VI (MSK)

Jabalpur earthquake of May 22, 1997 seriously affected the life and damaged properties in the epicentral area. It is estimated that about 33,000 buildings in the urban areas and 24,000 buildings in the rural areas were partially damaged or completely destroyed. A typical earthquake damage is shown on Figure 6 (Source: BMTPC Publication, 1997, Part-1, Earthen Houses With Clay Tile Roofing Guidelines for Damage Assessment and Post-Earthquake Action).

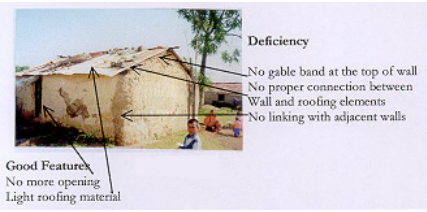

Figure 5: An Illustration of Key Seismic Features

Figure 6: Typical Earthquake Damage

Figure 6A: Typical Earthquake Damage - Cracking and Separation of Walls in the 1997 Jabalpur Earthquake (Source: Sudhir K. Jain, IIT Kanpur)

Figure 6B: Typical Earthquake Damage - Collapse of roof in the 1997 Jabalpur Earthquake (Source:

Figure 6C: Typical Earthquake Damage - Cracking and Separation of Walls in the 1997 Jabalpur

Figure 6D: Typical Earthquake Damage - Cracking of Walls in the 1997 Jabalpur Earthquake (Source:

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Stone	N/A	N/A	
Foundation	Mud	N/A	N/A	
Frames (beams & columns)	Timber	N/A	N/A	
Roof and floor(s)	Timber	N/A	N/A	

6.2 Builder

These buildings are typically self-owned wherein the owner is directly involved in the construction process, and may also contribute labor.

6.3 Construction Process, Problems and Phasing

The building is constructed with the help of masons. Generally no technical and engineering input is used during the construction process. Foundation: Trench of about 2.5 feet is excavated along the walls. Stone blocks are rammed with mud into the trench to form consolidated foundation. Timber posts, if used, are erected during the ramming of stones. The load-bearing wall is erected above the ground level. The stone walls are sometimes constructed up to 2 feet above ground level, and the mud wall is extended above this level. Wall construction: The wall is made up of mixed mud with wheat husks and water (mud-polymer composite). Generally the wheat husk is mixed and kept for about a week to give it a homogenous texture. The mud mortar is placed and rammed to make it compacted. The wall is erected up to about 2.5 feet in each lift and allowed to dry for one or two days before the next lift. Roofing: Roof truss is either made up of bamboo, wood or built up steel section. The spacing between purlines and rafters are generally not regular. Generally old conventional typical house is covered with heavy day tiles. The cladding material may not be firmly anchored to the trusses and wall. Openings : Generally mud wall buildings are provided with very few large openings. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. The building byelaws in rural areas are not yet enforced. It requires proper enforcement to the rural and urban areas.

6.4 Design and Construction Expertise

The buildings are constructed by local unskilled persons and villages with out any technical inputs. Engineers or architects do not have a role in the design/construction of this housing type.

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. 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 When was the most recent code/standard addressing this construction type issued? 1993.

There is no proper building code enforcement in rural areas.

6.6 Building Permits and Development Control Rules

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

Rs. 440 per m^2 ($10 per m^2). Labor requirement is approximately 85 man-days for the construction of 22.5 m^2 plan building.

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. N/A.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
No connection between adjacent walls	Provision of wooden bracing at regular interval in walls
Poor connection between roofing elements	Strengthening of roofing elements through bracings Securely tying of rafters to roof truss after removal of all tiles and purlins at the roof level
Large Opening	Reducing the openings and provide additional strength to openings (Refer figure 7A)
Wall	Filling of cracks with good fiber-reinforced mortar.
Wall	Stitching of corner cracks with bamboo ties at 75 cm c/c.

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Wall span	Provide additional support if span exceeds 5 m.
Planning	Place roof truss and rafters in a symmetric or regular arrangement.
Wall	Reduce height of wall to ensure height/thickness ratio less than 8.
Wall	Provide bamboo seismic bands at lintel and roof level.

The suggested retrofit provisions are not complex and can be done by local masons and labor.

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?

No.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Even small shocks may damage mud buildings to a greater extent. So, in general, after earthquake, delapitated dwellings are replaced with brick buildings.

8.3 Construction and Performance of Seismic Strengthening

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

N/A.

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

Owner.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

No evidence.

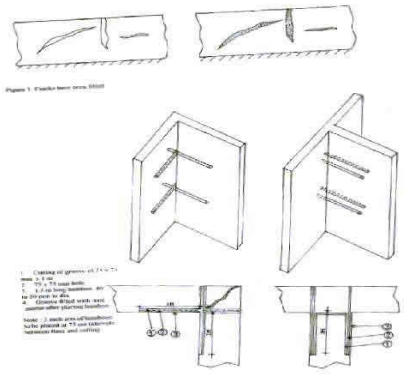

Figure 7A: Strengthening measures suggested in IAEE Manual

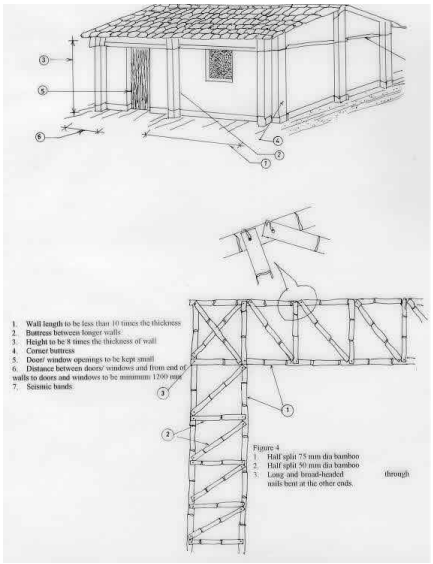

Figure 7B: Strengthening measures suggested in IAEE Manual

Reference(s)

1. Guidelines for damage assessment and post earthquake action - Part 2
   BMTPC
   Building Materials Technology Promotion Council, Ministry of Urban Affairs, Government of India, New Delhi

2. Vulnerability Atlas of India
   Ministry of Agriculture, Government of India 1997

3. Year Book
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4. Manual of Earthquake Resistant Non Engineered Construction
IAEE
Indian Society of Earthquake Technology, Roorkee 1999

5. IS 4326-1893 Indian Standard Code
Bureau of Indian Standards, New Delhi

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