World Housing Encyclopedia

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

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HOUSING REPORT
Unreinforced brick masonry building with reinforced concrete roof slab

Report #	21
Report Date	06-05-2002
Country	INDIA
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in lime/cement mortar
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Summary

Typical rural and urban construction in western and southern India. This construction is widely prevalent among the middle-class population in urban areas and has become popular in rural areas in the last 30 years. Brick masonry walls in cement mortar function as the main

load-bearing element. The roof structure is a cast-in-situ reinforced concrete slab. If constructed without seismic features, buildings of this type are vulnerable to earthquake effects. They exhibited rather poor performance during the Koyna (1967), Killari (1993), Jabalpur (1997), and Bhuj (2001) earthquakes in India.

1. General Information

Buildings of this construction type can be found in all parts of southern and western India. About 20% of housing units in Maharashtra state (approximately 3 million housing units in total) are of this type. Their number in urban areas is greater, and about 30% of all houses in Mumbai are of this type. Similar construction technology is used in northern and eastern India, but the bricks in those areas are of far superior quality. This type of housing construction is commonly found in both rural and urban areas.

Most buildings in rural areas are of single-storey construction, however in urban areas multi-family housing of this type is very common.

This construction type has been in practice for less than 75 years.

Currently, this type of construction is being built. Cement mortar and reinforced concrete are relatively recent introduction to the local construction practice. These houses may be up to 50-60 years old in urban areas while the penetration of cement in rural constructions is more recent. This is the construction practice of choice amongst the lower middle class and middle class in both rural and urban areas. In rural areas, even the rich generally prefer brick masonry structures with RCC roof slabs.

Figure 1: Typical Building

Figure 1A: Typical Rural Building

Figure 2A: Key Load-Bearing Elements - A Building Under Construction

Figure 2B: Key Load-Bearing Elements - A Building Under Construction

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. This housing type is found on both flat and hilly terrain. However, brick masonry houses are not constructed on a very steep terrain When separated from adjacent buildings, the typical distance from a neighboring building is 3-5 meters.

2.2 Building Configuration

The building type is typically regular, mainly rectangular in plan. However, some buildings on sloping terrain may have split-level leading to stiffness discontinuity. The houses typically have one door opening and one or two window openings per wall. The openings are typically away from the edges (>0.75 m). The windows are typically 1.25 m² and the doors are typically 1.75 m² The total opening length is typically 20-25% of wall length. RCC lintel beams are commonly provided over the openings.

2.3 Functional Planning

The main function of this building typology is single-family house. Single houses of this type are in rural areas. A lot of multiple housing units are found in urban areas. A small number of houses are of a mixed use (commercial on ground floor, and residential on other floors). The economic significance of damage to such mixed units for the local community may be significant and disproportionate to the number of such buildings. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Usually there is not additional door besides the main entry in this building type.

2.4 Modification to Building

In urban areas, additional floors are often added without considering structural aspects. The construction is therefore staggered and a gap of several years may exist between the construction of different portions of the building. In rural areas, where population density is lower, horizontal building expansion is more common.

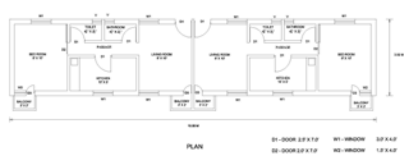

Figure 3: Plan of aTypical Building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
	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	☐

Masonry		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 load is carried by the masonry walls. The roof slab rests directly on the walls, and the total load is transferred to the foundation. The foundation generally consists of brick masonry or stone masonry strip footing. In rural areas, the walls are directly extended into the ground; the behavior of these foundations is similar to strip footing.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is un-reinforced masonry walls. The lateral load is carried by the walls in the direction of seismic forces. The masonry walls thus act as shear walls. The RCC roofs are generally flat and are directly supported on the walls, and act as rigid diaphragm. The lateral loads in these structures are distributed to the walls through the RCC slab. In rare situations where the RCC slabs are not horizontal or where the slabs do not act rigidly, the lateral loads are not fully distributed to the different shear walls.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 20 meters, and widths between 5 and 20 meters. The building has 1 to 4 storey(s). The typical span of the roofing/flooring system is 6 meters. Typical Story Height: Approximately 3 m per floor. Typical Span: The wall spans between two adjacent parallel walls typically range from 5 to 8 m. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 20 %. The wall density typically ranges from 0.12 to 0.15.

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)	☐	☐
	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐

Timber	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	☑	☑

The RCC roof slabs typically act as rigid diaphragm. On the ground floor, RCC slabs are not provided. In multi-storey constructions all other floors have RCC floor slabs.

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	☐

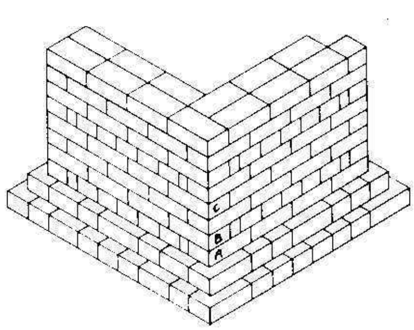

Figure 4A: Critical Structural Details - Full Brick Wall Section

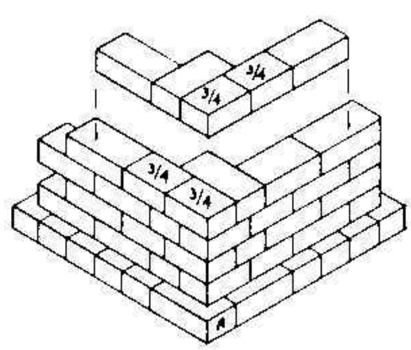

Figure 4B: Critical Structural Details - Half Brick Wall Details

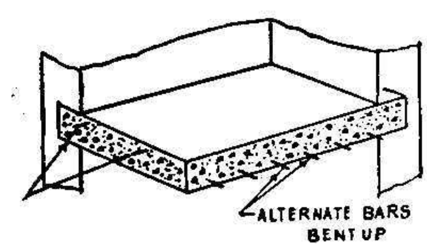

Figure 4C: Key Structural Details: Wall-slab Connection (slab may also extend for a full wall thickness)

Figure 5A: Key Seismic Resilient Features - RC Lintel Band and Good Quality Construction; note example of a building that sustained the effects of the 1993 Killari earthquake (M6.4) without damage although located very close to the epicentre

Figure 5B: Construction Deficiency - Excessively Thick Mortar Bedding Joints

Figure 5C: Construction Deficiency - Discontinuous RC Lintel Band (Bond Beam)

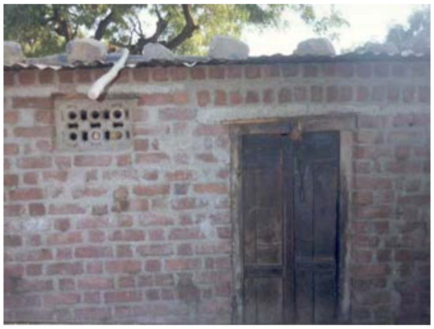

Figure 5D: Construction Deficiency - Discontinuous RC Lintel Band

Figure 5E: Construction Deficiency - Exposed Steel Reinforcement in RC Lintel Band Construction

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. Typically one housing unit per building (rural areas) and a good mix of single and multi-family dwellings (urban areas). The number of inhabitants in a building during the day or business hours is 5-10. The number of inhabitants during the evening and night is 11-20.

4.2 Patterns of Occupancy

In rural areas, houses of this type are typically occupied by a single extended family, with several generations staying together. In urban areas, the houses may be multiple housing units with different families living in different apartments/floors.

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)	☑

Brick masonry houses are used by lower middle class and middle class in both rural and urban areas, and the rich class in rural areas. The middle class dwellings are typically smaller in size (less than 100 m^2) while the rich class dwellings may be much larger and even multi-storied.

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 no bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) including toilet(s).

In rural areas, bathrooms and toilets are usually constructed separately from the houses. In urban areas, it is common to find at least two toilets in each dwelling or housing unit. .

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	The building is regular with regards to both the plan			

Configuration	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	- Absence of RC bands or poorly constructed bands - Brick masonry strength very low - Poor mortar quality; excessively thick bedding joints - load-bearing walls not properly interlocked - Poor quality of construction - Openings are not properly proportioned; the distance between corner and opening is not as per recommended practice	- When present, seismic features (in particular RC bands) are very effective in enhancing seismic resistance, as confirmed in the 1993 Killari earthquake (Figure 5A) and 2001 Bhuj earthquake (Figure 6j)	- Shear cracks in the walls, mainly starting from corners of openings. - Partial or complete out-of-plane wall collapse due to the lack of wall-roof anchorage and large wall slenderness ratio

Frame (columns, beams)			
Roof and floors	- Roof not integrally connected to walls (poor torsional resistance) - Poor quality concrete may compromise rigid diaphragm action - Poor maintenance		- Partial caving-in of roof due to collapse of supporting walls - Horizontal crack at the wall-roof connection - Shifting of roof from the wall due to torsional motion of roof slab.
Other			

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
1967	Koyna	6.7	VIII (MSK)
1993	Killari	6.4	VIII (MSK)
1997	Jabalpur	6.1	VII (MSK)
2001	Bhuj	7.6	X (MSK)

Building construction of this type (without seismic provisions) suffered significant damage during Koyna (1967) and Killari (1993) earthquakes. Some damage was also observed during Jabalpur (1997) earthquake. The main damage patterns consisted of: shear cracks in walls, mainly starting from corners of openings; partial out of plane collapse of walls; partial caving-in of roofs due to collapse of supporting walls, and shifting of roof from wall due to torsional motion of roof slab. This construction has experienced moderate to very heavy damage in the 2001 Bhuj earthquake (M 7.6). In the epicental region several buildings of this type suffered total collapse of the walls resulting in the death and injury to a large number of people. The overall building performance was dependent on the type of roof system: buildings with lightweight roof suffered relatively less damage while buildings with RC roofs suffered much greater damage (Source: IIT Powai 2001). Importance and effectiveness of seismic provisions was confirmed both in the 1993 Killari earthquake and the 2001 Bhuj earthquake. A building with RC lintel band (located in the Killari village only few kilometers away from the epicentre) shown on Figure 5a sustained the earthquake effects with a minor damage while large majority of other buildings in the same village collapsed, causing over 1,400 deaths. Similarly, unreinforced masonry buildings with RC bands sustained the effects of the 2001 Bhuj earthquake with moderate damage while the neighbouring buildings of similar construction without seismic provisions collapsed (see Figure 6J).

Figure 6A: Typical Earthquake Damage - Roof Collapse Caused by the Wall Collapse (1993 Killari Earthquake)

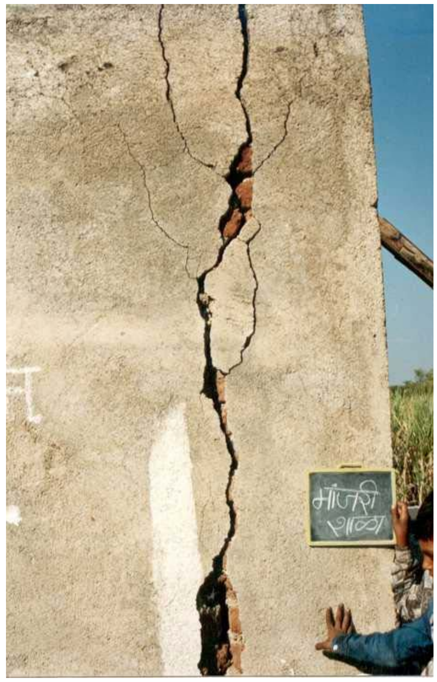

Figure 6B: Typical Earthquake Damage - Wall Corner Cracking (1993 Killari Earthquake)

Figure 6C: Typical Earthquake Damage - Wall Cracking above the Door Opening (1993 Killari Earthquake)

Figure 6D: Typical Earthquake Damage - Wall Corner Failure (1993 Killari Earthquake)

Figure 6E: Typical Earthquake Damage - Sliding Failure of Roof-Wall Connection Due to the Absence of Wall Reinforcement (1993 Killari Earthquake)

Figure 6F: Typical Earthquake Damage: In-Plane Wall Cracking (1993 Killari Earthquake)

Figure 6G: Partial Building Collapse in the 1997 Jabalpur Earthquake

Figure 6H: Faillure of Brick Masonry Walls in the 1997 Jabalpur Earthquake

Figure 6I: Collapse of Brick Masonry Buildings in the 2001 Bhuj Earthquake (Source: IIT Powai, 2001)

Figure 6J: View of a Collapsed traditional brick masonry building in cement mortar (foreground) and masonry building with lintel bands which sustained only a moderate damage in the 2001 Bhuj earthquake (Source: IIT Powai, 2001)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Brick Cement mortar.	< 2.5 MPa (compressive) Low compressive strength (< 5 MPa).	Typical brick size 230 mm X 115 mm X 75 mm 1:6 cement/sand mortar.	Bricks are low strength Very low compressive and shear strength.
Foundation	Stone or brick Cement mortar.	Brick: < 2.5 MPa (low compressive strength) Low compressive strength (< 5 MPa).	Typical brick size 230 mm X 115 mm X 75 mm or locally available uncoursed random rubble stone blocks are used 1:6 cement/sand mortar.	Bricks are low strength. Stone blocks are high strength but are uncoursed and have poor bond. Very low compressive and shear strength.
Frames (beams & columns)				
Roof and floor(s)	Reinforced concrete.	Compressive strength (10-20 MPa).	1:2:4 to 1:3:6 cement/coarse aggregate/fine aggregate mix.	Average to low compressive strength, but very strong compared to walls.

6.2 Builder

The builder does not typically live in this building type. In most situations, the structure is built on the request of the owner and as per his requirements.

6.3 Construction Process, Problems and Phasing

This construction is typically constructed by groups of skilled and semi-skilled masons and artisans. The foundations are constructed from stone boulders (if locally available) or from bricks with lean cement mortar. The walls are constructed from brick masonry and lean cement mortar. RCC roof slabs are often constructed by the same group without any design specification for size and placement of reinforcement. In cities, simple tools such as hand-operated concrete mixers are used in some cases. In large portions of western and southern India, the climate is very hot and good quality water is not easily available. In such situations, the cement mortar and concrete may not be adequately cured. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. In urban areas, additional floors are often added without considering structural aspects. The construction is therefore staggered and a gap of several years may exist between the construction of different portions of the building. In rural areas where population density is lower, the buildings tend to expand horizontally and not vertically.

6.4 Design and Construction Expertise

In rural areas, the masons may not have formal training. In urban areas, most masons have craftsman training. The construction process in urban areas is controlled by the contractors whose commitment to quality may be questionable. In rural areas engineers and architects do not play any role. In urban areas, the structural design may be carried out by the architect. Engineers and architects are typically not involved in construction. In many cases, the architectural and structural design is also carried out by the contractor since development control rules, where they exist, and very seldom enforced.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. This type of construction is covered by several Indian Standards. IS 1905-1987 Code of practice for structural uses of unreinforced masonry (3rd edition) was first published in 1961. IS 4326-1993 Earthquake resistant design and construction of buildings (2nd revision) was first published in 1967 and has several sections pertaining to unreinforced brick construction. Earthquake resistance is also addressed in IS 13828-1993 Improving earthquake resistance of low strength masonry buildings - Guidelines, and IS 13935-1993 Guidelines for repair and seismic strengthening of buildings. The year the first code/standard addressing this type of construction issued was 1967. The most recent code/standard addressing this construction type issued was 1993. Title of the code or standard: This type of construction is covered by several Indian Standards. IS 1905-1987 Code of practice for structural uses of unreinforced masonry (3rd edition) was first published in 1961. IS 4326-1993 Earthquake resistant design and construction of buildings (2nd revision) was first published in 1967 and has several sections pertaining to unreinforced brick construction. Earthquake resistance is also addressed in IS 13828-1993 Improving earthquake resistance of low strength masonry buildings - Guidelines, and IS 13935-1993 Guidelines for repair and seismic strengthening of buildings. Year the first code/standard addressing this type of construction issued: 1967 When was the most recent code/standard addressing this construction type issued? 1993.

Building codes are rarely enforced. There is no formal procedure for enforcing the building codes.

6.6 Building Permits and Development Control Rules

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

Are building permits required? Yes, in large cities e.g. Mumbai; permits are not required in smaller municipalities and villages. 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

In urban areas, the cost of construction is in the range of Rs. 4,500 to Rs. 5,500 per m² (US$ 90-110 per m²). In rural areas, the cost is by approximately 10-25 % lower due to lower labor cost and possibly due to inferior quality of work. Single family dwelling is typically constructed in about 3 months employing about 15 people. In multi-story buildings, the time of construction may be much longer. Slabs are generally cast in a single operation and may require about 50 to 60 persons working for 12 to 18 hours.

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. Earthquake insurance for residential dwellings is not currently available in India.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Lack of integrity (box-type action)	Installation of seismic belt (bandage) at the lintel level; it consists of welded wire mesh installed above the lintel level and anchored to the wall. The mesh is covered with a thin cement plaster overlay (see Figure 7B)
Cracks in the walls	In case of small cracks, pressure injection of epoxyh grout; in case of large cracks, filling the gaps with cement grout and jacketing with reinforced cement overlay. (Source: IAEE 1986), see Figure 7H.
Inadequate wall resistance (shear and tensile)	Reinforced concrete jacketing. Difficult to find skilled labor and materials for welded wire mesh in rural areas
Flexible floor/roof diaphragm (Corrugated metal sheets/timber)	Installation of RC roof band (bond beam). Provision of roof band is expected to enhance the overall intergrity and improve torsional resistance of building
Cracking/damage of wall corners (due to improper interlocking of cross walls)	Corner strengthening of wall corners - installation of welded wire mesh anchored to the walls with steel dowels and covered with a thin cement plaster overlay (GOM 1998), see Figure 7C.

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Roof	Reinforced concrete roof band; provision of roof band results in an improved overall integrity and torsional resistance of the building.
Wall	RCC lintel band; very effective, however skilled labour and materials may not be available, see Figures 7D, 7E and 7F
Wall	Improved quality of masonry (bricks and mortar) use of better quality bricks will drastically improve the wall seismic resistance; use or richer cement/sand mortar will improve wall shear resistance.
Wall	Provision of vertical reinforcement at wall corners and intersections, see Figure 7G (Source: IAEE 1986)

A summary of key seismic strengthening provisions for this construction type is presented in Figure 7a.

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?
Yes. Seismic strengthening was implemented after the 1993 Maharashtra earthquake. Some existing buildings were strengthened after the earthquake, however majority of new masonry buildings were constructed with seismic provisions incorporated.

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

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
Yes. It was a major government-sponsored program.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
The construction was performed by the contractors, and the owners were overseeing the construction.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Retrofitted buildings were not subjected to the damaging earthquake effects as yet.

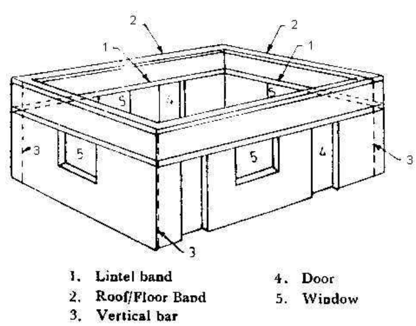

Figure 7A: Seismic Strengthening Techniques - A Summary

Figure 7B: Seismic Strengthening Techniques - Lintel Bandage

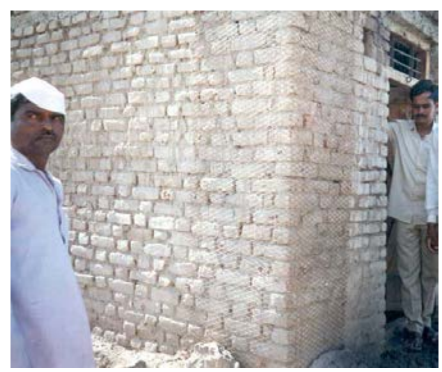

Figure 7C: Seismic Strengthening Techniques - Corner Strengthening

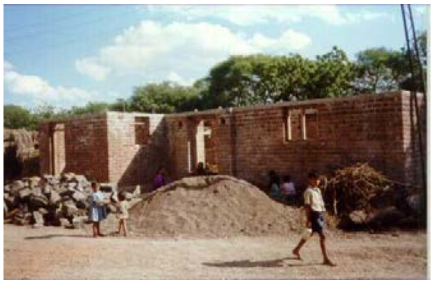

Figure 7D: An Example of New Construction with Sesimic Features (note RC lintel band)

Figure 7E: Construction of RC Lintel Band

Figure 7F: Construction of RC Lintel Band - Pouring of Concrete Completed

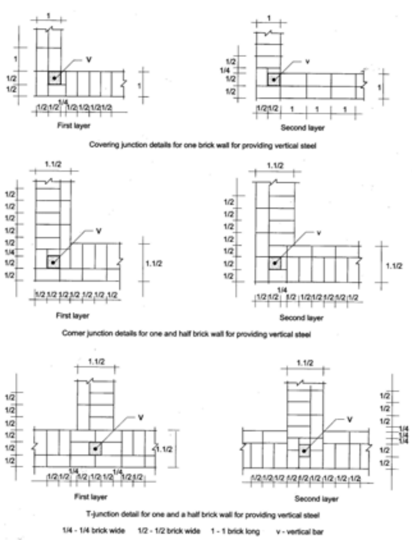

Figure 7G: Seismic Strengthening of New Construction - Provision of Vertical Reinforcement at Wall Corners and Intersections (Source: IAEE 1986)

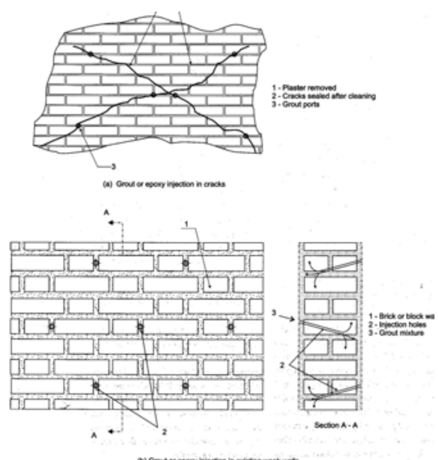

Figure 7H: Repair of Wall Cracks by Epoxy Injection (Source: IAEE 1986)

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