World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT

Unreinforced brick masonry building with reinforced concrete roof slab

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Report#	21
Last Updated	
Country	India
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Important

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General Information

Building Type:	Unreinforced brick masonry building with reinforced concrete roof slab
Country:	India
Author(s):	Ravi Sinha Svetlana Brzev
Last Updated:	
Regions Where Found:	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.
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 mainload-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.
Length of time practiced:	51-75 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwellingMixed residential/commercial
Typical number of stories:	1-4

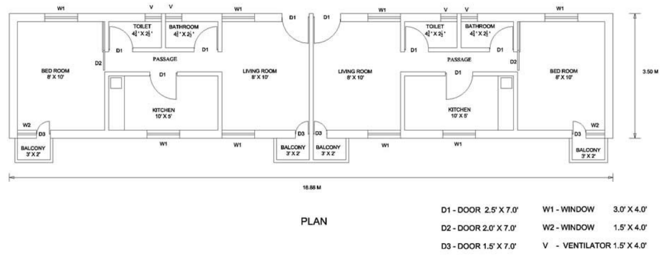
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	Cement mortar and reinforced concrete are relatively recent introductions to the local construction practice. These houses may b

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	The building type is typically regular and is rectangular in plan. However, some buildings on sloping terrain may have split-level leading to stiffness discontinuity.
Typical plan length (meters)	10-20
Typical plan width (meters)	5-20
Typical story height (meters)	3
Type of Structural System	Masonry: Unreinforced Masonry Walls: Brick masonry in lime/cement mortar
Additional comments on structural system	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 walls and strip footing is very commonly used for these constructions. In rural areas, the walls are directly extended into the ground; the behaviour of these foundations is similar to strip footing. 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.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in	15-20%

direction 1	15-20%
Typical wall densities in direction 2	15-20%
Additional comments on typical wall densities	The wall density typically ranges from 0.12 to 0.15.
Wall Openings	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 sq. m. and the doors are typically 1.75 sq. m. The total opening length is typically 20-25% of wall length. RCC lintel beams are commonly provided over the openings.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	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.
Type of Foundation	Shallow Foundation: Wall or column embedded in soil, without footingShallow Foundation: Rubble stone, fieldstone strip footing
Additional comments on foundation	
Type of Floor System	Other floor system
Additional comments on floor system	Structural concrete: cast-in-place and precast solid slabs 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.
Type of Roof System	Roof system, other
Additional comments on roof system	Structural concrete: cast-in-place and precast solid slabs 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.
Additional comments section 2	This housing type is found on both flat and hilly terrain. However, brick masonry houses are not constructed on a very steep terrain When

section 2	separated from adjacent buildings, the typical distance from a neighboring building is 3-5 meters.



Plan of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Brick Cement mortar	Brick: < 2.5 MPa (compressive) Typical brick size 230 mm x 115 mm x 75 mm Bricks are low strength, very low compressive and shear strength. 1:6 cement/sand mortar Low compressive strength (< 5 MPa)
Foundations	Stone or brick Cement mortar	Brick: < 2.5 MPa (compressive)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 Low compressive strength (< 5 MPa) Bricks are low strength. Stone blocks are high strength but are uncoursed and have poor bond. Very low compressive and shear strength
Floors	RCC	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
Roof	RCC	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
Other		

Design Process

Who is involved with the design process?	None of the above
Roles of those involved in the design process	
Expertise of those involved in the design process	In rural areas engineers and architects do not play any role. In urban areas, the structural design may be carried out by the architect. in several situation, the architectural and structural design is also carried out by the contractor since development control rules, where they exist, and very seldom enforced.

Construction Process

Who typically builds this construction type?	MasonOther
Roles of those involved in the building process	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.
Expertise of those involved in building process	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.
	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

Construction process and phasing	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.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	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.
Process for building code enforcement	Building codes, even if they are notified, are seldom enforced. There is no formal procedure for enforcing the building codes.

Building Permits and Development Control Rules

Are building permits required?	No
Is this typically informal construction?	Yes

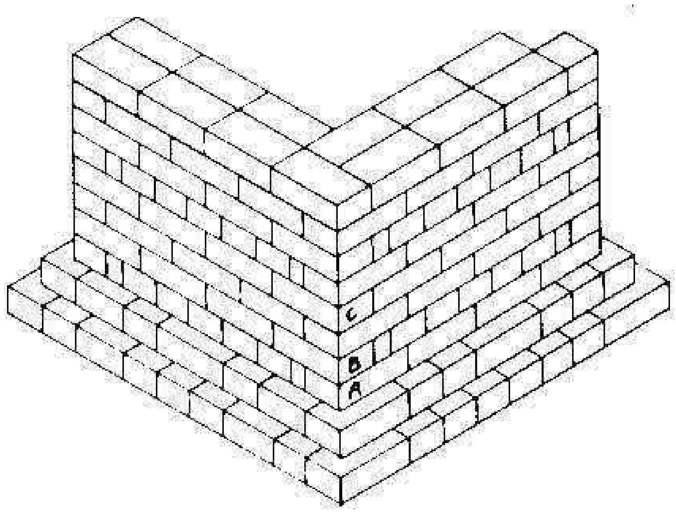
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	Are building permits required? Yes, in large cities e.g. Mumbai; permits are not required in smaller municipalities and villages.

Building Maintenance and Condition

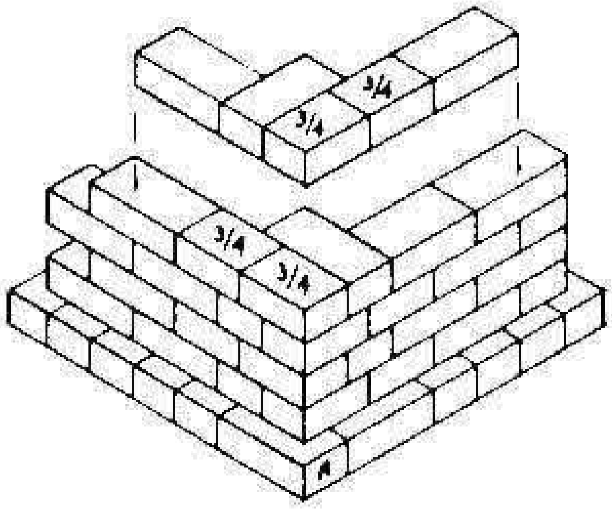
Typical problems associated with this type of construction	Due to very poor compressive and shear strength of brick walls, earthquake loading leads to shear cracks and crushing of bricks. Partial collapse of brick walls has been observed during past earthquake that can be directly attributed to low strength masonry and mortar. The pattern of damage also makes repair difficult and expensive. In some places, differential settlement has been observed due to inadequate foundation.
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	

Construction Economics

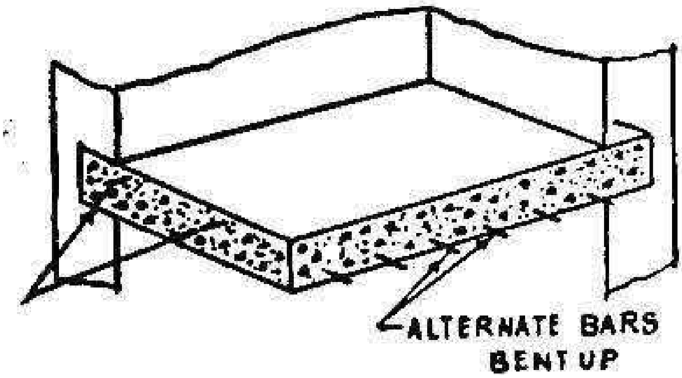
Unit construction cost	In urban areas, the cost of construction is in the range of Rs. 4,500 to Rs. 5,500 per sq m (US$ 90-110 per sq m). In rural areas, the cost is by approximately 10-25 % lower due to lower labor cost and possibly due to inferior quality of work.
Labor requirements	Single family dwelling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



Critical Structural Details - Full Brick Wall Section



Critical Structural Details - Half Brick Wall Details



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

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

Construction Deficiency - Excessively Thick Mortar Bedding Joints

Construction Deficiency - Discontinuous RC Lintel Band (Bond Beam)

Construction Deficiency - Discontinuous RC Lintel Band

Construction Deficiency - Exposed Steel Reinforcement in RC Lintel Band Construction

Socio-Economic Issues

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 have multiple dwellings with different families living in different apartments/floors.
Number of inhabitants in a typical building of this construction type during the day	5-10
Number of inhabitants in a typical building of this construction type during the evening/night	10-20
Additional comments on number of inhabitants	
Economic level of inhabitants	Middle-income classHigh-income class (rich)
Additional comments on economic level of inhabitants	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 sq m) while the rich class dwellings may be much larger and even multi-storied. Ratio of housing unit price to annual income: 1:1 or better
Typical Source of Financing	Personal savingsInformal network: friends or relatives

Additional comments on financing	
Type of Ownership	RentOwn outright
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	Earthquake insurance for residential dwellings is not currently available in India.
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1967	Konya
1993	Killari
1997	Jabalpur
2001	Bhuj

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	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 epicenter 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 epicenter) shown on Figure 9 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 23).
Additional comments on earthquake damage patterns	Wall: - 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 Roof and floors: - 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.

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
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.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
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.	FALSE
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.	FALSE
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.	N/A
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE

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);	FALSE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	FALSE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		FALSE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and	

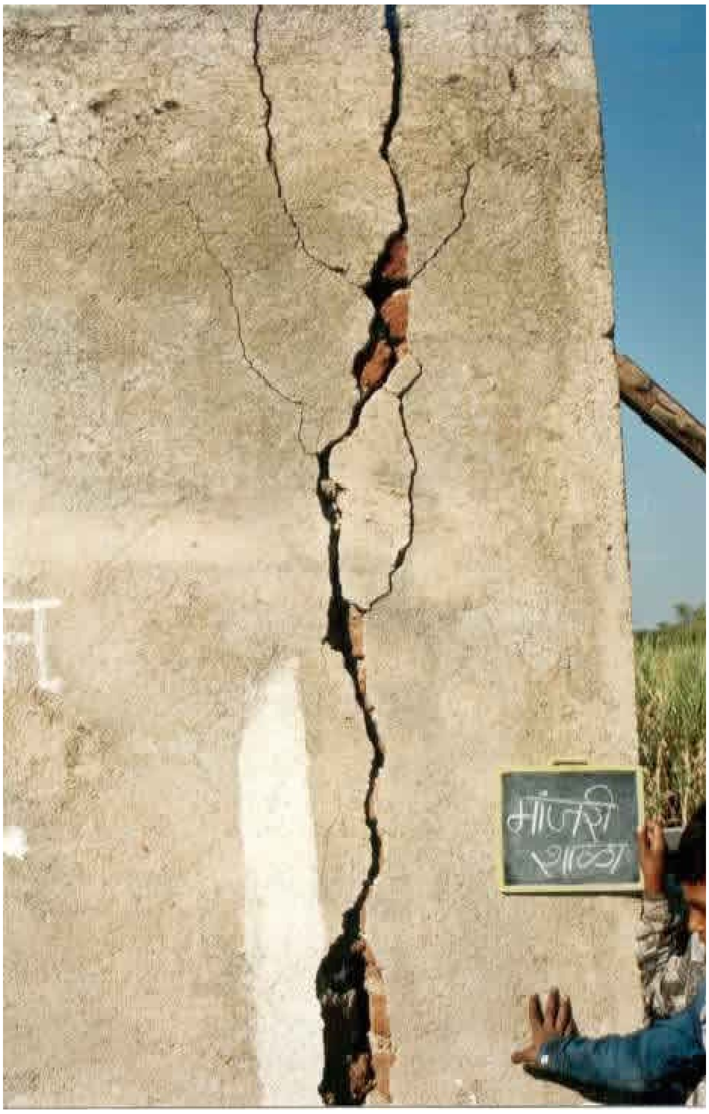
architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	- Absence of RC bands or poorly constructed bands - Brick masonry strength very low - Poor mortar quality; excessively thick bedding joints - load-bearing walls not properly interlocked - Poor quality of construction -Openings are not properly proporti
Earthquake-resilient features in walls	- When present, seismic features (in particular RC bands) are very effective in enhancing seismic resistance, as confirmed in the 1993 Killari earthquake (Figure 9) and 2001 Bhuj earthquake (Figure 23)
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	#NAME?
Earthquake resilient features in roof and floors	
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class	|-	o	-|			

Typical Earthquake Damage - Roof Collapse Caused by the Wall Collapse (1993 Killari Earthquake)



Typical Earthquake Damage - Wall Corner Cracking (1993 Killari Earthquake)

Typical Earthquake Damage - Wall Cracking above the Door Opening (1993 Killari Earthquake)

Typical Earthquake Damage - Wall Corner Failure (1993 Killari Earthquake)

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

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

Partial Building Collapse in the 1997 Jabalpur Earthquake

Faillure of Brick Masonry Walls in the 1997 Jabalpur Earthquake

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

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)

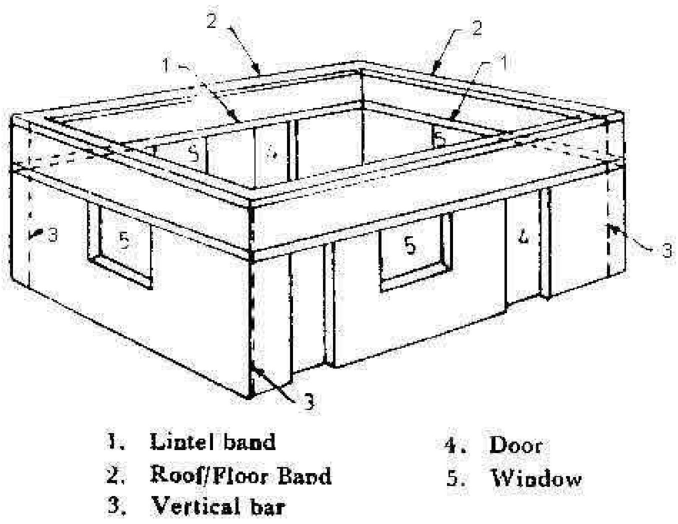
Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
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 25)
Cracks in the walls	In case of small cracks, pressure injection of epoxy grout; in case of large cracks, filling the gaps with cement grout and jacketing with reinforced cement overlay. (Source: IAEE 1986), see Figure 31.
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 integrity 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 26.

Additional comments on seismic strengthening provisions	Strengthening of New Construction: 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, how ever skilled labour and materials may not be available, see Figures 27, 28 and 29. -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. -Provision of vertical reinforcement at wall corners and intersections, see Figure 30 (Source: IAEE 1986)
Has seismic strengthening described in the above table been performed?	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.

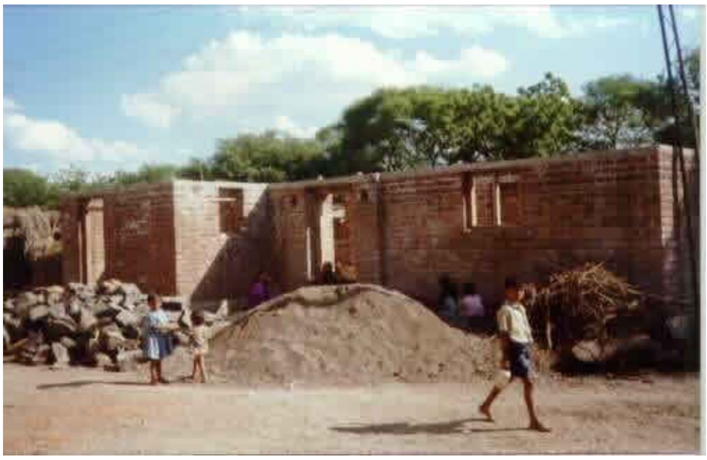
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	Repair and strengthening following earthquake damage.
Was the construction inspected in the same manner as new construction?	Yes. It was a major government-sponsored program.
Who performed the construction: 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 has been the performance of retrofitted buildings of this type in subsequent earthquakes?	Retrofitted buildings were not subjected to the damaging earthquake effects as yet.
Additional comments section 6	A summary of key seismic strengthening provisions for this construction type is presented in Figure 24.



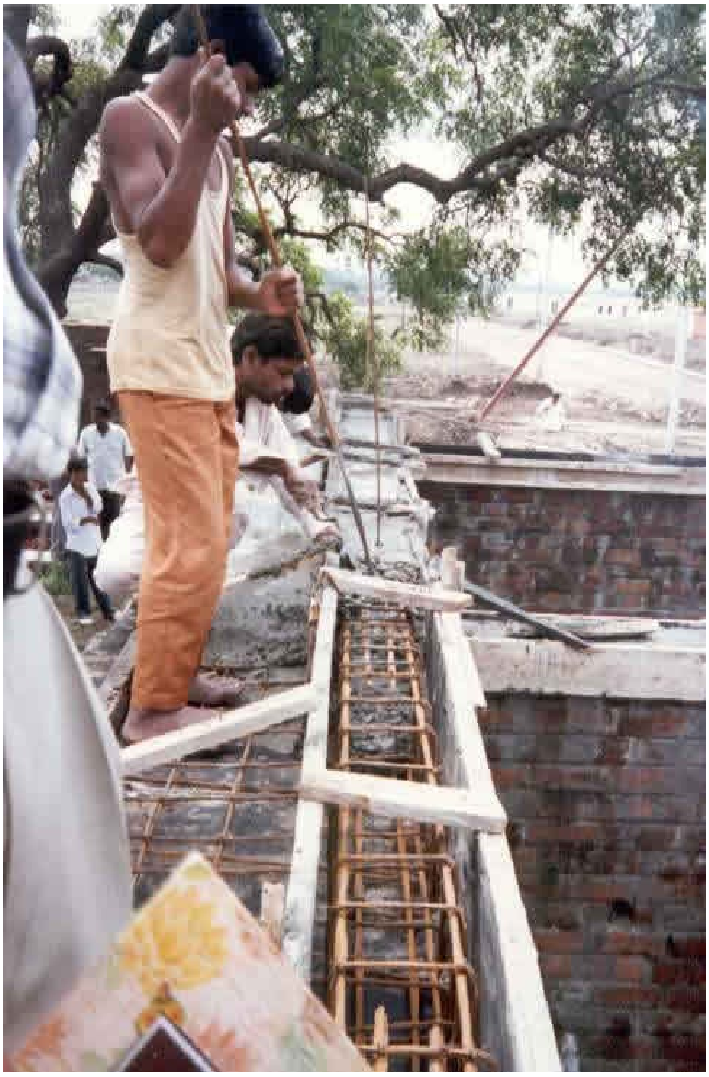
Seismic Strengthening Techniques - A Summary

Seismic Strengthening Techniques - Lintel Bandage

Seismic Strengthening Techniques - Corner Strengthening

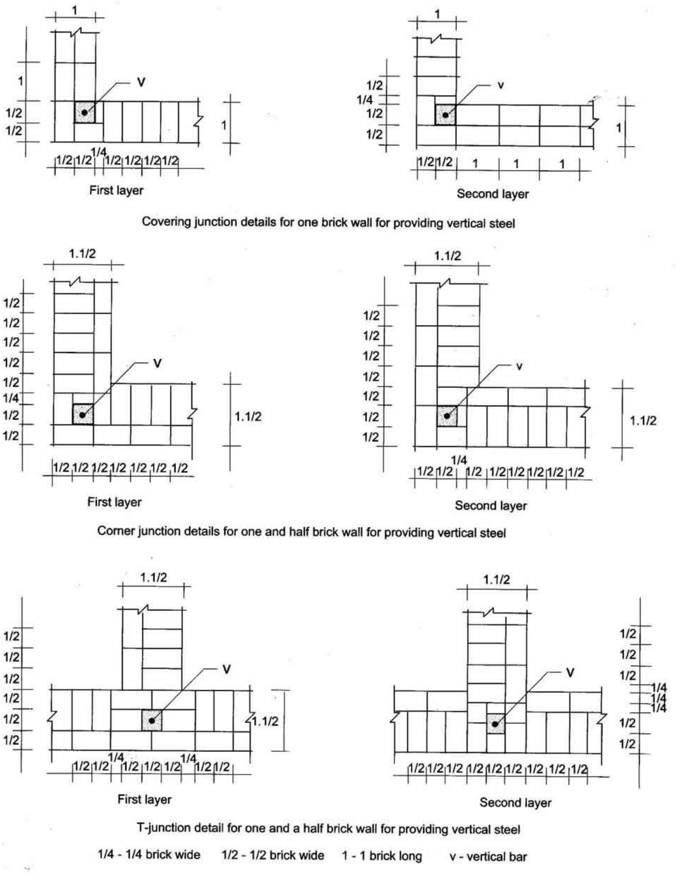


An Example of New Construction with Sesimic Features (note RC lintel band)

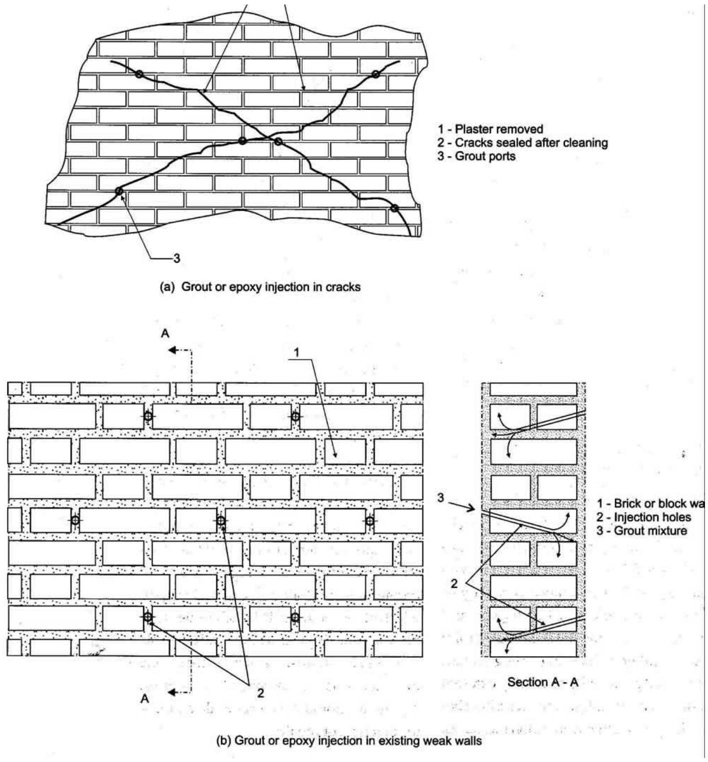


Construction of RC Lintel Band

Construction of RC Lintel Band - Pouring of Concrete Completed



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



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

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