World Housing Encyclopedia Report

Country: India

Housing Type: Unreinforced brick masonry building with reinforced concrete roof slab

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1 General Information

1.1 Country

India

1.3 Housing Type

Unreinforced brick masonry building with reinforced concrete roof slab

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

FIGURE 1: Typical Building

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	X
< 100 years	
< 200 years	
> 200 years	

Is this construction still being practiced?	Yes	No
	X	

Additional Comments: 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.

1.6 Region(s) Where Used

About 20% of housing units in Maharashtra state (approximately 3 million housing units in total) are of this type. They are found in all parts of southern and western India. 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.

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

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

2 Architectural Features

2.1 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 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.

2.2 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)	X	
Is it typical for buildings of this type to have common walls with adjacent buildings?		X

The typical separation distance between buildings is 3-5 m meters

2.3 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.

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: 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.

2.5 Means of Escape

Usually there is not additional door besides the main entry in this building type.

2.6 Modification 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.

3 Socio-Economic Issues

3.1 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.

3.2 Number of Housing Units in a Building

1 units in each building.

Additional Comments: Typically one housing unit per building (rural areas) and a good mix of single and multi-family dwellings (urban areas).

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		
5 to 10	X	
10-20		X
> 20		
Other		

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 0
Number of Latrines: 0

Additional Comments: 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.

3.5 Economic Level of Inhabitants

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

Additional Comments: 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 m²) while the rich class dwellings may be much larger and even multi-storied.

3.6 Typical Sources of Financing

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

3.7 Ownership

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

4 Structural Features

4.1 Lateral Load-Resisting System

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.

4.2 Gravity Load-Bearing Structure

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.

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	
		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)	X
	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	X
	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)	X	X
	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		
	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: 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.

4.6 Typical Plan Dimensions

Length: 10 - 20 meters
Width: 10 - 20 meters

4.7 Typical Number of Stories

1 - 4

4.8 Typical Story Height

3 meters

Additional Comments: Approximately 3 m per floor.

4.9 Typical Span

6 meters

Additional Comments: The wall spans between two adjacent parallel walls typically range from 5 to 8 m.

4.10 Typical Wall Density

0.12% - 0.15%
The wall density typically ranges from 0.12 to 0.15.

4.11 General Applicability of Answers to Questions in Section 4

This contribution is not based on a case study of one 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	- 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 (Figure 6A) - Horizontal crack at the wall-roof connection (Figure 6E) - Shifting of roof from the wall due to torsional motion of roof slab
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)
1967	Koyna	6.7	VIII (MSK)
1993	Killari	6.4	VIII (MSK)
1997	Jabalpur	6.1	VII (MSK)
2001	Bhuj	7.6	X (MSK)

Additional Comments: 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).

7 Building Materials and Construction Process

7.1 Description of 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
Foundations	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
Frame				
Roof and floors	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
Staircase (in multistory buildings)	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
Other				

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

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.

7.3 Construction Process

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.

7.4 Design/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.

7.5 Building Codes and Standards

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

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

7.6 Role of Engineers and Architects

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.

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

7.8 Phasing of Construction

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

Additional Comments: 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.

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

7.11 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.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

In urban areas, the cost of construction is in the range of Rs. 4,500 to Rs. 5,500 per m^2 (US$ 90-110 per m^2). In rural areas, the cost is by approximately 10-25 % lower due to lower labor cost and possibly due to inferior quality of work.

8.2 Labor Requirements (estimate)

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.

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

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

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

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 (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.
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, 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)

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

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

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

Repair and strengthening following earthquake damage.

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

Yes. It was a major government-sponsored program.

10.5 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.

10.6 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.

11 References

EERI (1999). Lessons Learnt Over Time, Vol. 2 "Innovative Earthquake Rehabilitation in India," Earthquake Engineering Research Institute, Oakland, USA.

GOM (1998). Manual for Earthquake-Resistant Construction and Seismic Strengthening of Non-Engineered Buildings in Rural Areas of Maharashtra. Revenue and Forests Department, Government of Maharashtra, Mumbai, India.

Damage Survey Reports of Koyna, Killari and Jabalpur Earthquakes in published literature.

IAEE (1986). Guidelines for Earthquake-Resistant Non-Engineered Construction. The International Association for Earthquake Engineeing, Tokyo, Japan (also available via Internet at www.nicee.org)

IIT Powai (2001). The Bhuj Earthquake of January 26, 2001 - Consequences and Future Challenges. Department of Civil Engineering, Indian Institute of Technology Bombay, India and Earthquake Disaster Mitigation Research Center (EdM), Miki, Hyogo, Japan (CD-Rom)

12 Contributors

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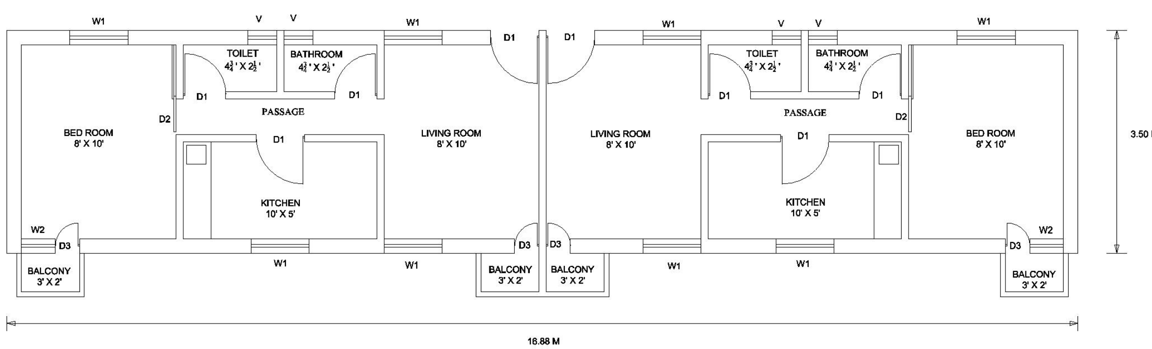
13 Figures

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



PLAN

D1 - DOOR 2.5' X 7.0'
D2 - DOOR 2.0' X 7.0'
D3 - DOOR 1.5' X 7.0'
W1 - WINDOW 3.0' X 4.0'
W2 - WINDOW 1.5' X 4.0'
V - VENTILATOR 1.5' X 4.0'

FIGURE 3: Plan of a Typical Building

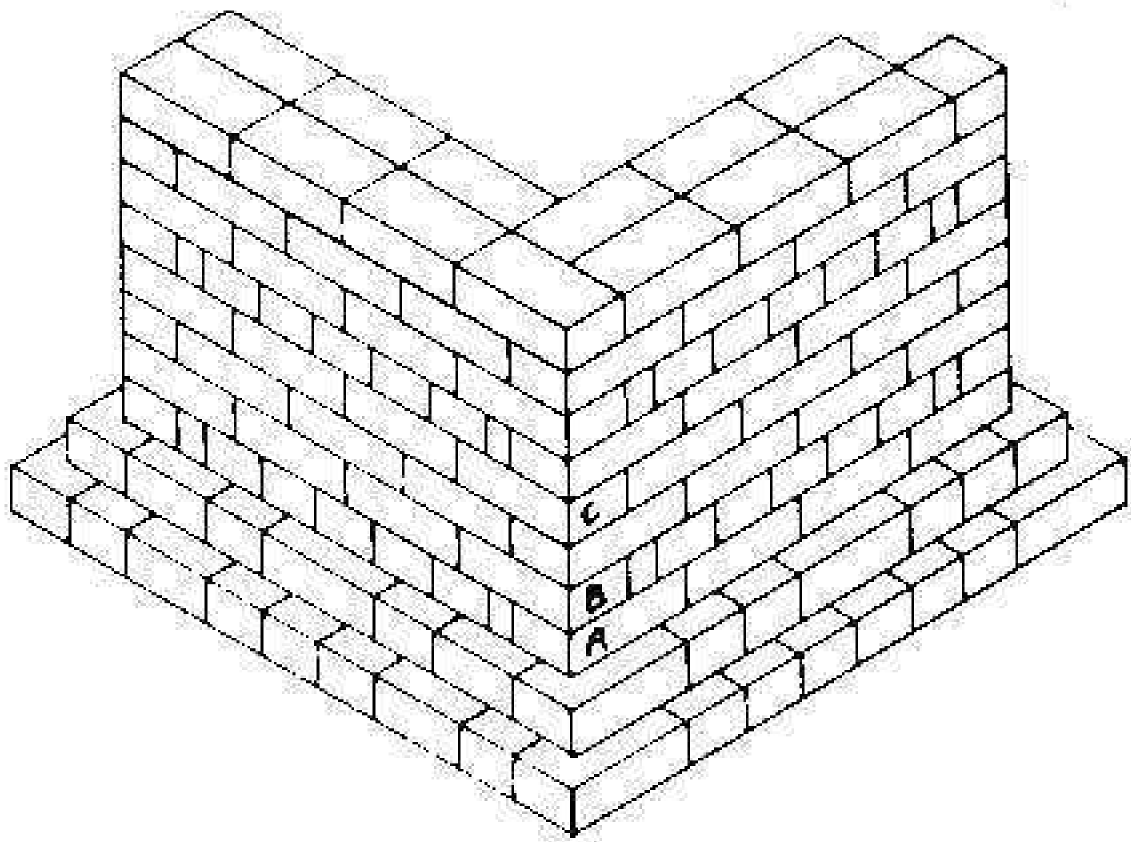


FIGURE 4A: Critical Structural Details - Full Brick Wall Section

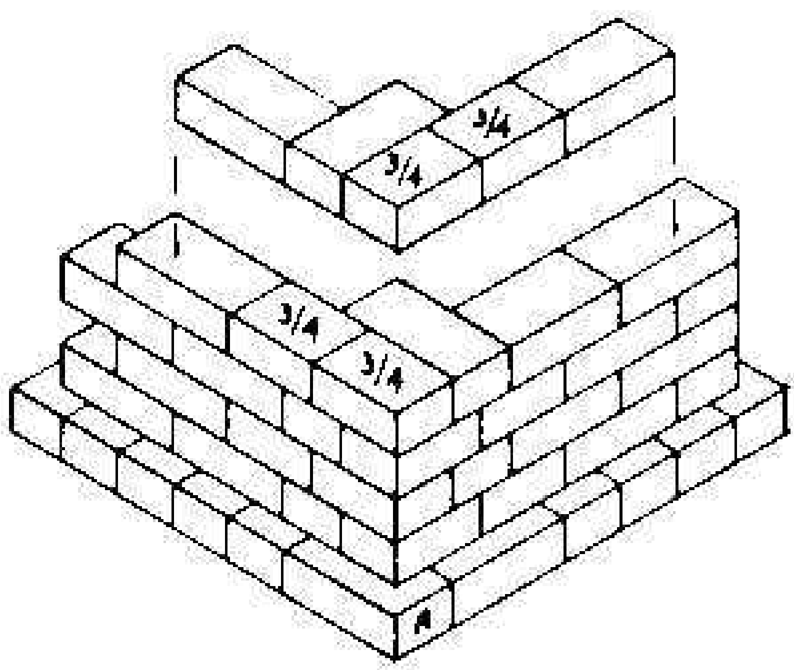


FIGURE 4b: Critical Structual Details - Half Brick Wall Details

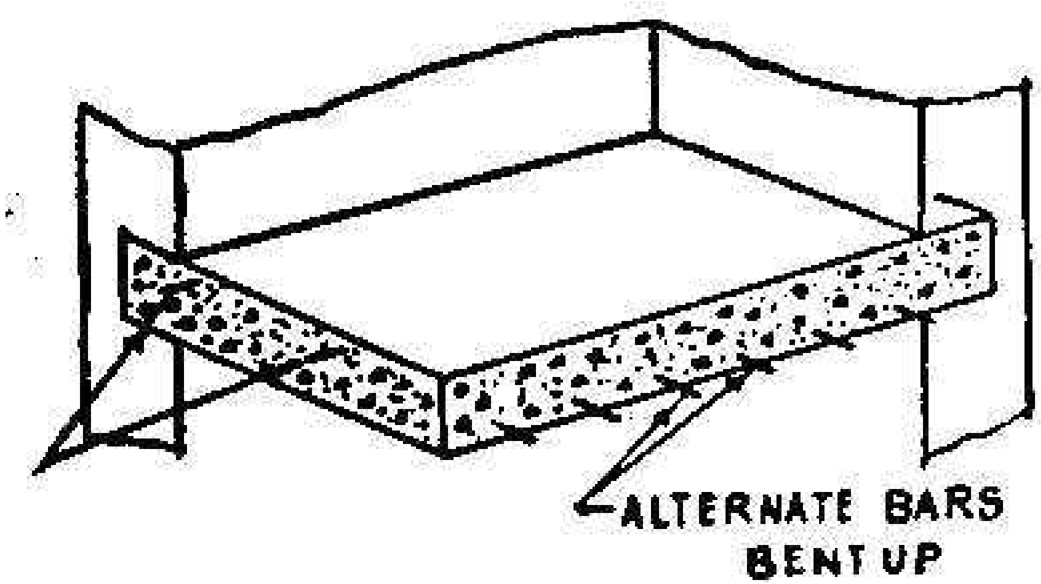


FIGURE 4C: Key Structural Details: Wall-Slab Connection (slab may also extend for a full wall thickness)

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, althouh 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

FIGURE 6a: Typical Earthquake Damage - Roof Collapse Caused by the Wall Collapse (1993 Killari earthquake)


मांजरी
शाळा

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

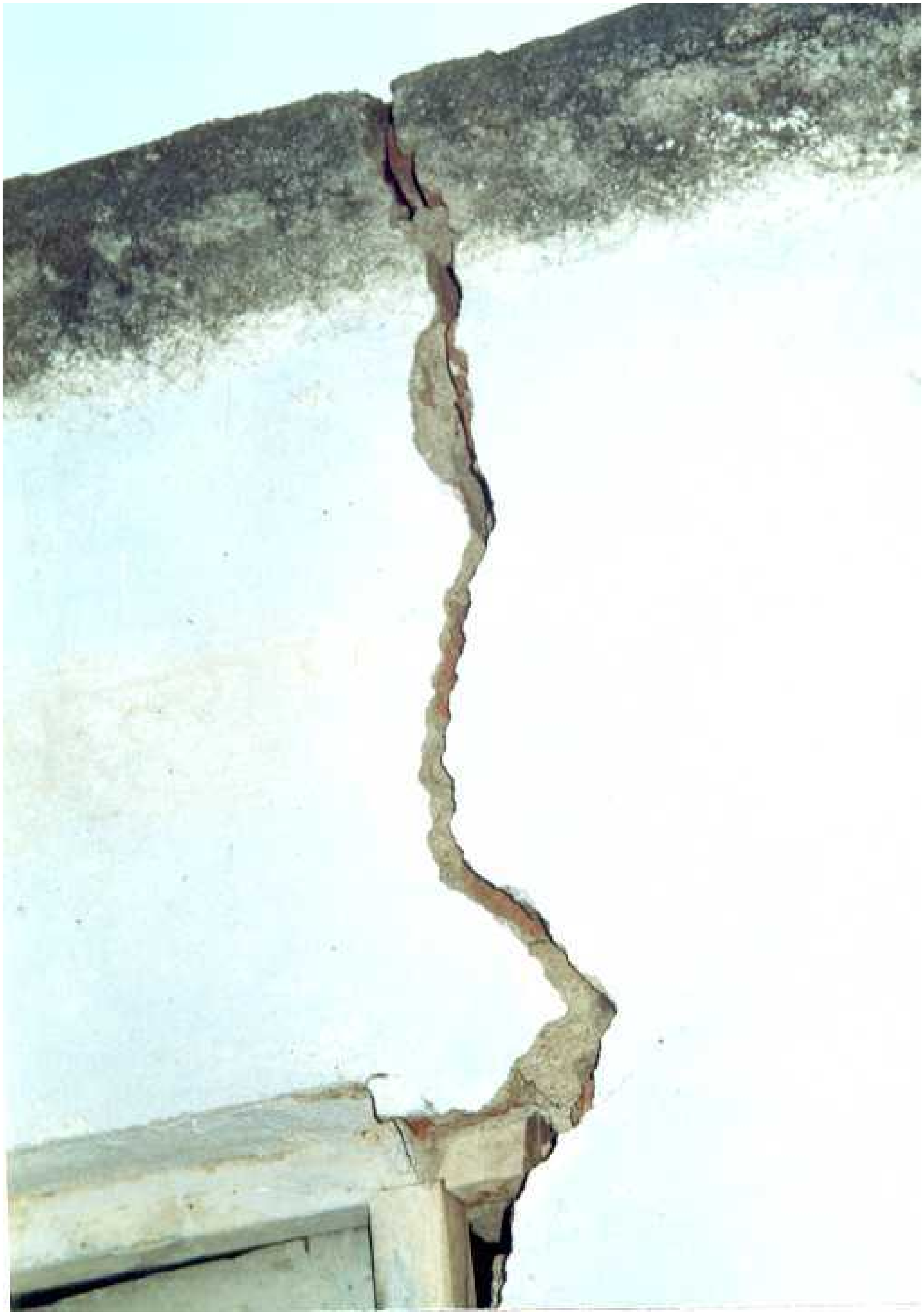


FIGURE 6C: Typical Earthquake Damage - Wall Cracking above the Door Opening (1993 Killari earthquake)

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: Failure 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)

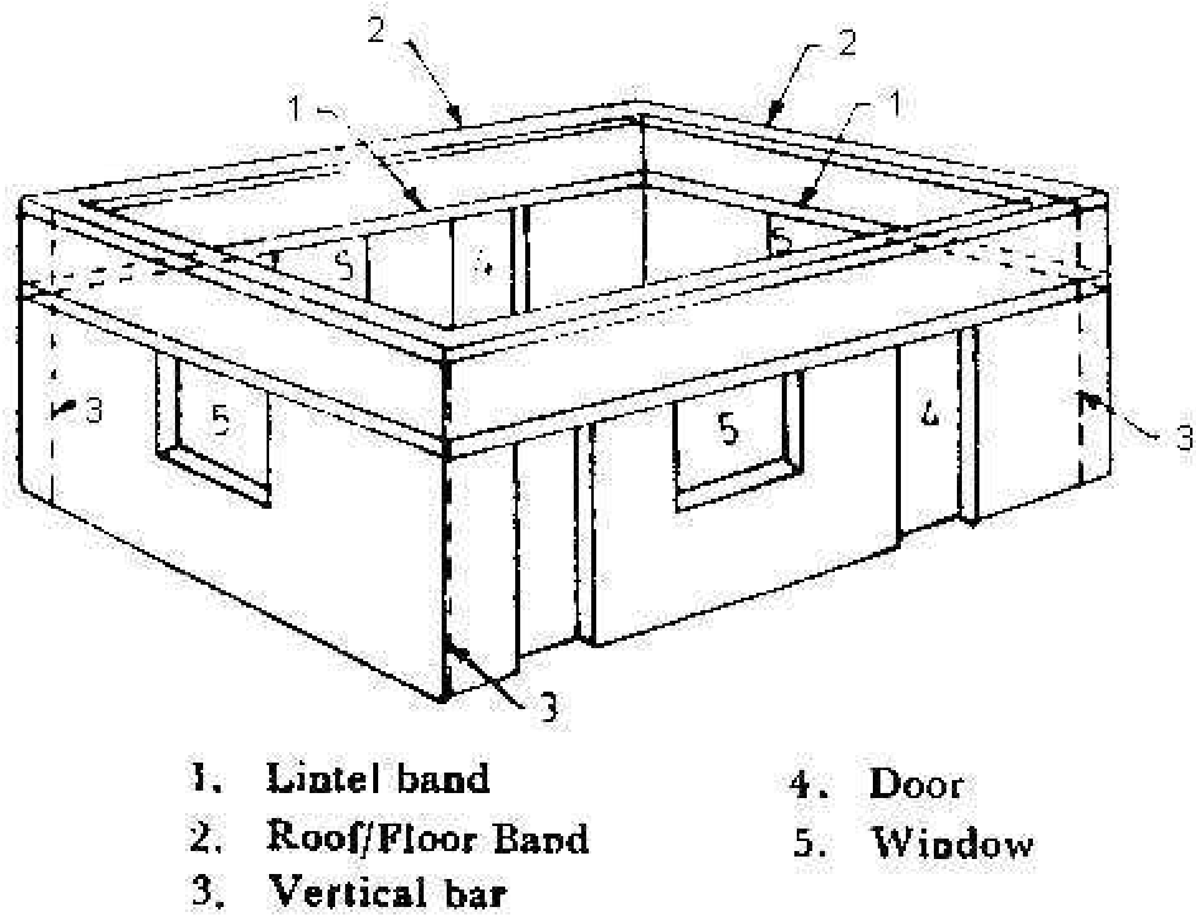


FIGURE 7A: Seismic Strengthening Techniques - A Summary

FIGURE 7B: Seismic Strengthening Techniques - Lintel Bandage

FIGURE 7C:Seismic Strengthening Techniques - Corner Strengthening

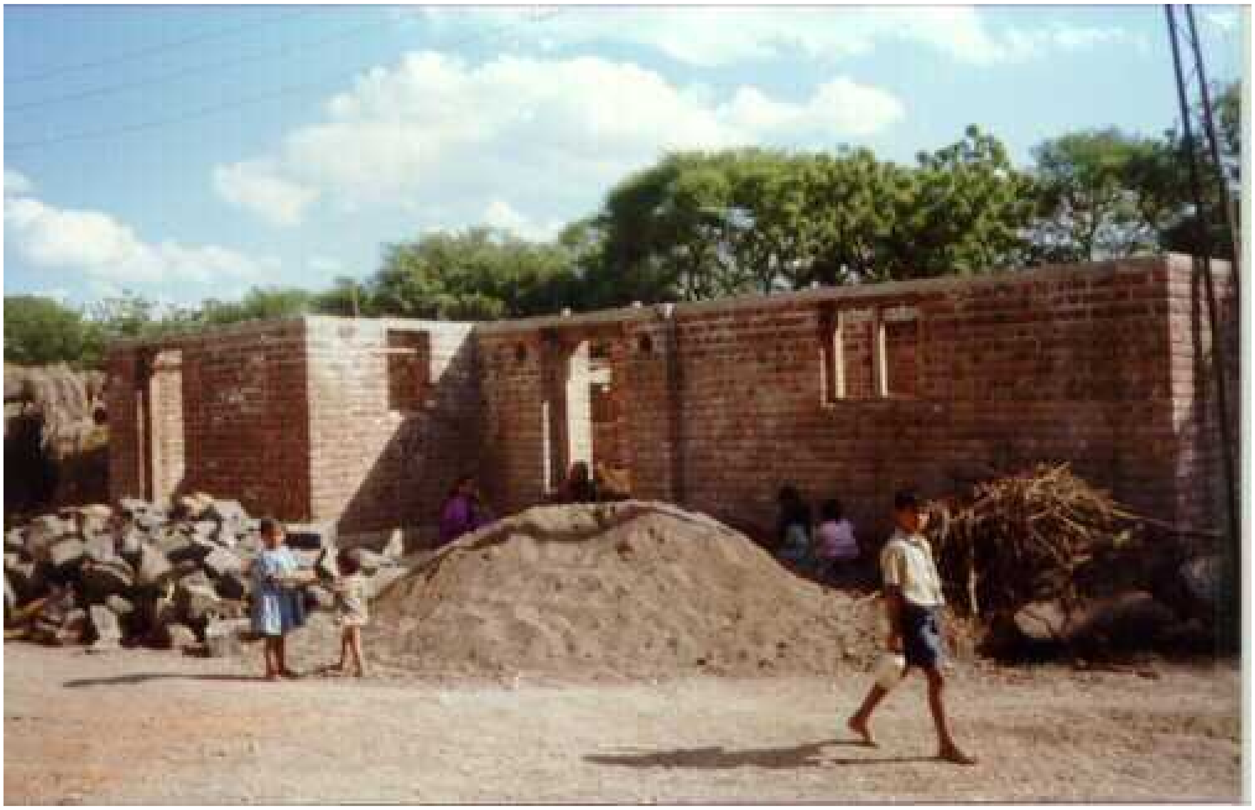


FIGURE 7D: An Example of New Construction with Seismic Features (note RC lintel band)

FIGURE 7E: Construction of RC Lintel Band

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

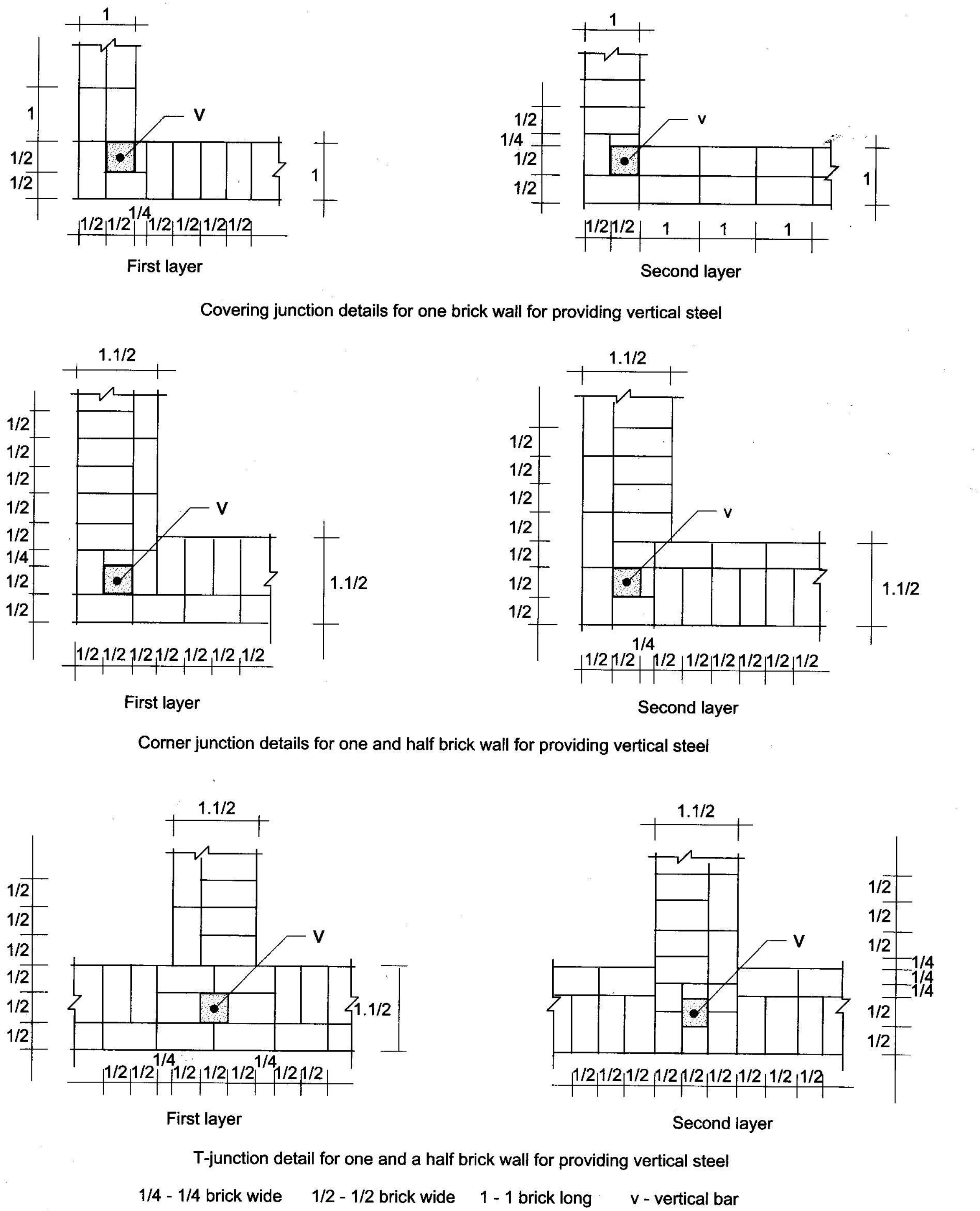
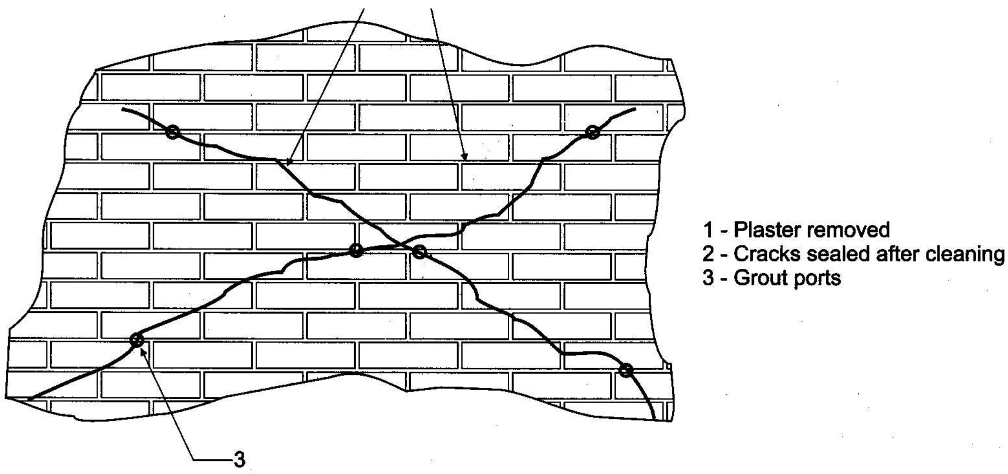
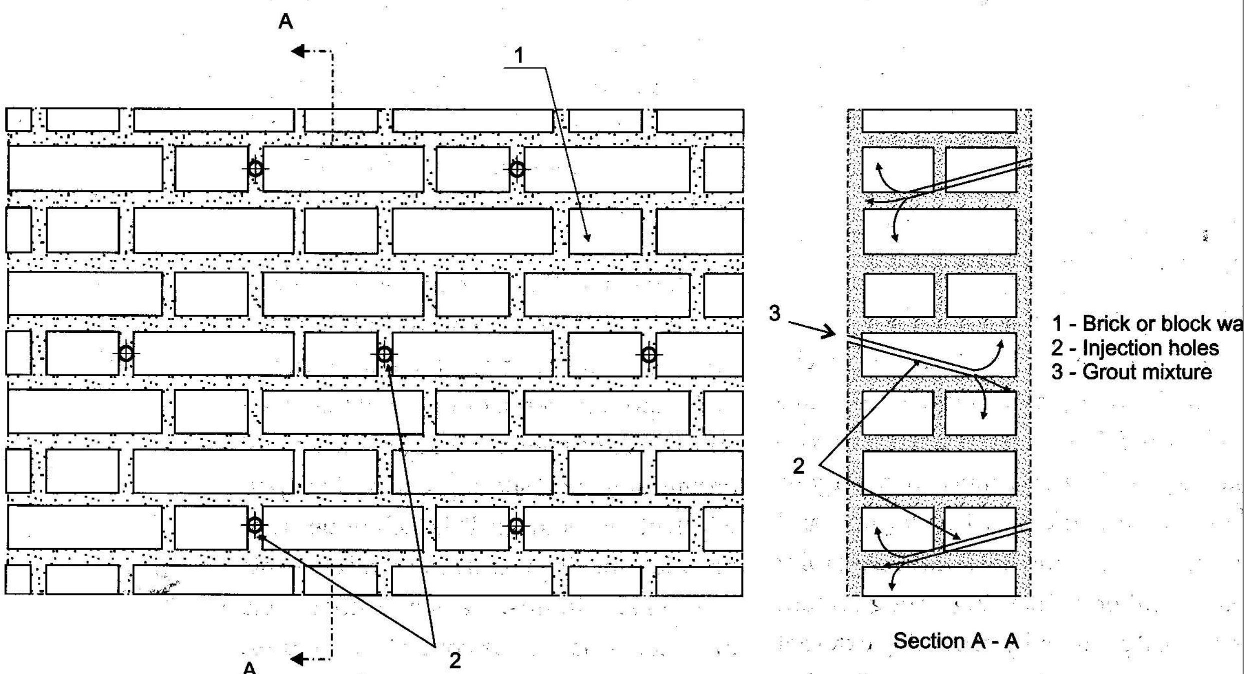


FIGURE 7G: Seismic Strengthening of New Construction - Provision of Vertical Reinforcement at Wall Corners and Intersections (Source: IAEE 1986)



(a) Grout or epoxy injection in cracks



(b) Grout or epoxy injection in existing weak walls

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