World Housing Encyclopedia

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

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

HOUSING REPORT
Low-strength dressed stone masonry buildings

Report #	80
Report Date	15-08-2002
Country	INDIA
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Dressed stone masonry (in lime/cement mortar)
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Summary

Construction of stone masonry buildings using easily available local materials is a common practice in both urban and rural parts of India. Stone masonry houses are used by the middle class and lower middle class people in urban areas, and by all classes in rural areas. In rural areas, these buildings are generally smaller in size and are used as single-story, single-family housing. In urban areas, these buildings are up to 4 stories high and are used for multifamily housing. This is a typical load-bearing construction, in which both gravity and lateral loads are resisted by the walls supported by strip

footing. If the locally available stone is soft, dressed (shaped) stones are commonly used and can be chiselled at low- or moderate cost. Mud or lime mortar has been used in traditional constructions; however, more recently, cement mortar is being increasingly used. Because soft sandstone is readily available in the Kutch region of Gujarat in the western part of India, stone block masonry constructions are widely used for both single- and multi-story constructions. These houses are usually built by local artisans without formal training and the resulting constructions are structurally weak and incapable of resisting large seismic forces. In the Kutch region, which was affected by the 2001 Bhuj earthquake, this construction type is commonly used with a gable end timber roof truss or RCC roof slabs. Thousands of these houses collapsed in the 2001 Bhuj earthquake resulting in the deaths of large numbers of people. This construction type is inherently unsuitable for areas of moderate-to-high seismic hazard, such as the Kutch region of Gujarat.

1. General Information

Buildings of this construction type can be found in urban and rural areas throughout India. A very large proportion of the building stock in the Kutch region of Gujarat affected by the 2001 Bhuj earthquake was of this construction type. This type of construction is also used in other regions of India with lower seismic hazard where soft stone is easily available. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. Since the 2001 Bhuj earthquake, this construction type has been permitted in the Kutch district only with suitable earthquake-resistant features specified in IS 4326-1993.

Figure 1: Typical Suburban Building

Figure 2: Typical Rural Building

Figure 3: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 5 meters.

2.2 Building Configuration

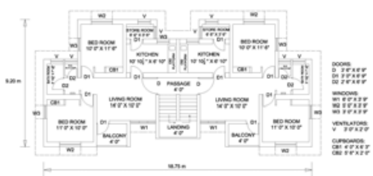
The buildings are typically rectangular or have another regular shape. The number of openings in each floor depends on the number of housing units existing on that floor. There are typically 8 doors and 10 windows in a typical 2-bedroom housing unit. The window size ranges from 1.0m X 1.2m to 2.0m X 1.2m and the door size ranges from 0.75m X 2.1m to 1.0m X 2.1m. The doors are usually located at wall junctions and the windows at both the center and corners of the wall.

2.3 Functional Planning

The main function of this building typology is multi-family housing. These are primarily used as single-family houses in rural areas and as multiple housing units in urban areas. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. All external doors of single-storeyed houses can be used for escape. In multi-storeyed construction, also a single staircase is typically available for escape. In both rural and urban areas, the windows generally have metal grills, and can not be used as a means of escape.

2.4 Modification to Building

Significant structural modifications to these buildings have not been observed. However, in rural and semi-urban areas, construction may be carried out incrementally.



TYPICAL PLAN OF THE MULTI STOREY STONE MASONRY BUILDING

Figure 4: Plan of a Typical Building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☑
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐

		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	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 stone masonry walls. The gravity load-bearing system consists of the walls which carry the floor and roof loads. The walls, in turn, transmit the loads to the foundations, which consist of strip footings, which vary in depth from 0.5m to 2.0 m (depending on the number of stories and the local soil conditions). Most rural houses have gable end timber roof truss with conventional or Mangalore type clay tiles as roofing resting on bamboo or timber purlins. The urban constructions and other multi-storeyed buildings have used reinforced concrete (RCC) floor slabs.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is stone masonry walls. This housing type is characterized with rather poor lateral load resistance. Lateral loads are resisted by the stone masonry walls; however, due to the low strength of walls in these constructions (due to use of low-strength mortar and absence of earthquake-resistant features), the walls are vulnerable to earthquake effects. In single-storey constructions, the roof may consist of wall-supported flexible truss, which is not effective in distributing the storey-level inertia forces to the different resisting elements. In these constructions, openings are often found near the corners which further weaken their resistance to lateral loads.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 15 and 20 meters, and widths between 7.5 and 10 meters. The building has 1 to 4 storey(s). The typical span of the roofing/flooring system is 5 meters. The typical storey height in such buildings is 3 meters. The typical structural wall density is none. 5% - 10%. The wall density is the same in both directions.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☑	☑
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☑	☐
Other	Described below	☑	☑

The flooring system could be either of these two choices. Most recent constructions in urban areas use RCC floor and roof 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 5: Key details: multi-wythe wall construction

Figure 6: Key details: section through a single-wythe wall

Figure 7: Key details: stone lintels

Figure 8: Key details: size of stones used in construction

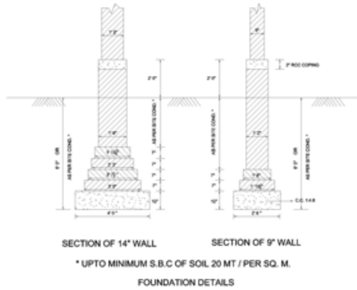


Figure 9: Key details: foundations

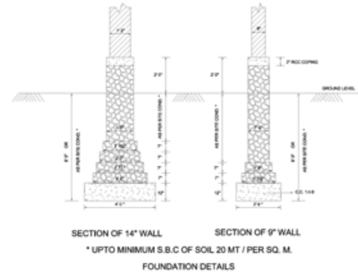


Figure 10: Key details: rubble stone masonry strip footings

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 5-10 housing unit(s). 8 units in each building. In rural areas, each building typically consists of a single housing unit. 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 more than 20.

4.2 Patterns of Occupancy

In rural areas, each house may be occupied by a single family. In urban areas where multi-storeyed housing blocks are also used, up to 16-20 housing units may be constructed in each building (of 4 storeys).

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)	☐

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 2 bathroom(s) without toilet(s), 2 toilet(s) only and 2 bathroom(s) including toilet(s).

In rural areas, the houses may not have bathrooms or latrines at all. .

4.4 Ownership

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

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

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☑	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☐	☑	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls);	☑	☐	☐

	Less than 13 (unreinforced masonry walls);			
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☑	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☐	☑	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Wall	-Very thick load-bearing walls constructed with poor quality materials; -Absence of headers and through stones in multi-wythe walls and use of mud mortar; -Poor wall connections; -Absence of any earthquake-resistant features such as horizontal bands and vertical reinforcement.		-Out of plane wall failure; -Failure of wall corners and junctions; -Bulging type failure of the wall; -Vertical shearing of wall; -Shear failure of walls near openings.
Frame (Columns, beams)			
Roof and floors	- Inadequate timber roof joists-wall connections; - Use of tiled roofs, especially with Mangalore clay tiles, makes the roof very heavy; - Poor quality of timber used in roof truss construction; - Lack of timber protection against termites and weather effects. - Absence of horizontal bracing between the roof trusses.		-Movement of roof relative to the wall causing sliding of roof structure and complete failure in some cases.
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 *D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance)*.

Vulnerability	**high**	**medium-high**	**medium**	**medium-low**	**low**	**very low**
	very poor	poor	moderate	good	very good	excellent
Vulnerability	A	B	C	D	E	F

Class	☑	☐	☐	☑	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1819	Kutch, Gujarat	8.1	XI (MSK)
2001	Bhuj, Gujarat	7.6	X (MSK)

During the 2001 Bhuj earthquake, a very large number of stone masonry houses collapsed or were severely damaged, resulting in a large number of casualties. Old stone masonry houses, which were typicaly constructed using mud or lime mortar performed very poorly and exhibited brittle collapse. Thick multi-wythe walls experienced separation of wythe resulting in loss of strength. Stone masonry houses constructed with cement mortar exhibited relatively higher resistance to the earthquake. However, the number of such houses was very small. It is interesting that "engineered" stone masonry houses, which were designed with technical assistance from Architect and Engineers also did not have earthquake-resistant features as specified in the Indian Code of Practice for such structures.


Figure 11: Seismic deficiencies: collapse of stone masonry building due to inadequate wall connections (2001 Bhuj earthquake)


Figure 12: Seismic deficiencies: in-plane shear wall failure (2001 Bhuj earthquake)


Figure 13: Seismic deficiencies: improper wall-concrete floor slab connection resulting in the out-of-plane wall


Figure 14: Seismic deficiencies: separation of wall wythes due to absence of through-stones (2001 Bhuj earthquake)


Figure 15: Seismic deficiencies: poor mortar strength in stone masonry walls resulting in the wall collapse (2001 Bhuj Earthquake)


Figure 16: Earthquake damage: complete collapse of a stone masonry building due to inadequate mortar strength (2001 Bhuj Earthquake)

Figure 17: Earthquake damage: out-of-plane wall corner failure (2001 Bhuj Earthquake)

Figure 18: Building Collapse due to Lack of Earthquake Resistant Features (2001 Bhuj Earthquake)

Figure 19: Building Collapse due to the Torsional Motion of Reinforced Concrete (RCC) Roof Slab (2001 Bhuj Earthquake)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Rectangular sandstone masonry blocks with mud or cement mortar	Compressive strength of masonry varies between 30- 50 kg/sq.cm	Cement mortar mix (1:6 cement/sand)	Both the masonry blocks and mortar have low strength
Foundation	Uncoursed stone rubble masonry with mud or cement mortar	Compressive strength of masonry varies between 30- 50 kg/sq.cm	Cement mortar mix (1:6 cement/sand)	Mortar has low strength
Frames (beams & columns)				
Roof and floor(s)	Timber with clay tiles, and reinforced concrete (RCC) floor slabs in urban constructions	Concrete compressive strength 10 -15 MPa for RCC floor slabs	Concrete mix 1:2:4 (cement/sand/aggregate)	RCC construction quality is generally very poor with improper mixing and inadequate curing

6.2 Builder

In rural areas, the owner typically lives in this construction type. In urban areas, such dwellings are also sometimes built by developers for sale.

6.3 Construction Process, Problems and Phasing

The construction process is totally manual and very low-tech. The local stone blocks are purchased along with rubble stones for foundation. The construction is carried out by local skilled or semi-skilled artisans with the assistance of unskilled assistants. Engineers and architects are generally not involved in the process. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size.

6.4 Design and Construction Expertise

This construction type generally does not utilize engineering skills. The local artisans carry out the construction with the assistance of unskilled labor. The engineers and architects do not have any role in the entire design and construction process.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. IS 4326-1993 (Earthquake resistant design and construction of buildings - code of practice). The year the first code/standard addressing this type of construction issued was 1976. IS 4326-1993. The most recent code/standard addressing this construction type issued was 1993. Title of the code or standard: IS 4326-1993 (Earthquake resistant design and construction of buildings - code of practice). Year the first code/standard addressing this type of construction issued: 1976 National building code, material codes and seismic codes/standards: IS 4326-1993 When was the most recent code/standard addressing this construction type issued? 1993.

There is no mechanism for enforcement of the relevant 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.

This construction is typically NOT authorized per development control rules in urban areas unless earthquake-resistant features are incorporated. 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) and Tenant(s).

6.8 Construction Economics

The construction cost varies between 2500 - 3500 Rs/sq.m. (US$60-90/m.sq.) of built area. The lower cost corresponds to poor quality stone blocks and use of mud or lime mortar, while the higher cost corresponds to urban constructions with cement mortar. Each housing unit in rural area takes around 8-12 man-months (counting skilled man-months only) for construction. Only one or two skilled artisans are used, while the remaining are unskilled workers.

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.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Inadequate lateral load resistance of masonry walls due to the absence of through stones in the walls	Lateral strength of masonry units can be increased by inserting new walls in one or both directions; through-stones can also be added to tie the wythes.
Inadequate timber roof joists-wall connections	Installation of proper roof-wall connections; addition of vertical reinforcement at the corners to tie the intersecting walls.
Heavy clay roofing tiles	Tiled roofs are replaced by corrugated iron or asbestos sheet roofing.
Absence of horizontal bracing between trusses along with vertical post and improper connections.	Roof trusses are braced by welding or clamping with suitable diagonal bracing members in vertical as well as horizontal planes.

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Use of horizontal bands at plinth, lintel and roof levels	Use of bands ties the walls together and ensures effective load transfer under earthquake loading

Vertical reinforcement adjacent to openings and at the wall corners	Vertical reinforcement confines the masonry under earthquake loading and increases its earthquake resistance.
Rigid concrete (RCC) roof slabs or light-weight truss roof	Concrete (RCC) roof slabs are very effective in transferring the inertia forces between the different walls. Use of low weight truss roof reduces the inertia force under earthquake loading.

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?
After the 2001 Bhuj earthquake, the existing stone masonry structures in Kutch district are to be retrofitted as described above by the individual house owners.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
The strengthening is to be carried out to both damaged as well as undamaged structures.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
There is no effective inspection and monitoring mechanism.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
The constructions do not use engineers, and are carried out by the contractor or the owner.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Not applicable.

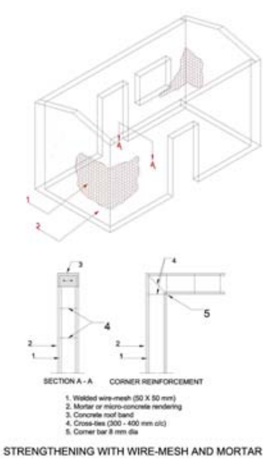


Figure 20: Seismic strengthening of stone walls using steel wire-mesh and mortar

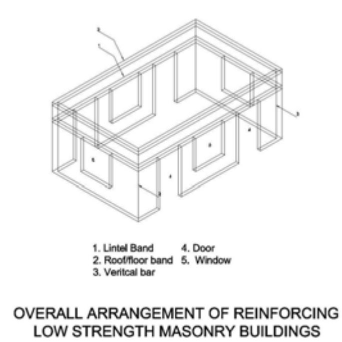


Figure 21: Seismic strengthening technologies: an overview of key seismic strengthening provisions

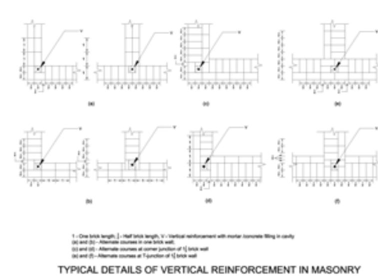


Figure 22: Seismic strengthening technologies: typical wall reinforcement details

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