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
# Rubble stone masonry walls with timber frame and timber roof

| | |
|---|---|
| Report # | 18 |
| Report Date | 06-05-2002 |
| Country | INDIA |
| Housing Type | Stone Masonry House |
| Housing Sub-Type | Stone Masonry House : Rubble stone without/with mud/lime/cement mortar |
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## Summary

This typical rural construction in central, southern, and northern India houses millions of people. It is cheap to construct using field stones and boulders, but extremely vulnerable in earthquakes because of its heavy roofs and poorly constructed walls. The load-bearing

structure is a traditional timber frame system, known as 'khan'. It is a complete frame with timber posts spanned at about 2.6 m. Thick stone walls (typical thickness 600 mm - 1.2 m) provide enclosure and partial support to the roof. Walls are either supported by strip footings of uncoursed rubble masonry or are without any footings at all. The roof structure consists of timber planks and joists. To help keep the interiors cooler during hot summer months (peak temperatures exceeding 40°C.), a 500-800 mm thick mud overlay covers the top the roof. This construction type is considered to be very vulnerable to earthquake effects. Many buildings of this type were damaged or collapsed in the 1993 Killari (Maharashtra) earthquake (M 6.4) with over 8,000 deaths.

# 1. General Information

Buildings of this construction type can be found in Maharashtra state (around 15% of the total housing stock of approx. 3 million houses). Particularly common for the Marathwada region (formerly a part of the kingdom ruled by Nizam of Hyderabad); typically found in villages. A very similar type of construction is found in the state of Jammu and Kashmir (according to INTERTECT, 1984); for other states in India, refer to Vulnerability Atlas of India (BMPTC, 1996). This type of housing construction is commonly found in rural areas. This construction type has been in practice for less than 100 years.

Currently, this type of construction is being built. .


Figure 1: Typical Building


Figure 1A: Typical Building

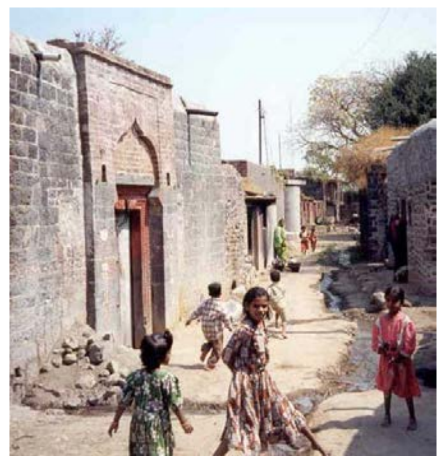
Figure 1B: A Typical Village (Maharashtra State)

# 2. Architectural Aspects

## 2.1 Siting

These buildings are typically found in flat terrain. They share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 2 meters.

## 2.2 Building Configuration

Building plan is typically of a very regular shape, usually rectangular or square. Typically one or two small door openings per wall; doors are generally smaller in size as compared to standard doors used in new houses; typically, there are no window openings, except for a small ventilator in a wall (typically 500 mm²) just below the eaves level. It is estimated that the total window and door widths constitute approximately on the order of 15-25% of the total wall length.

## 2.3 Functional Planning

The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. This is a single-storey building and there is usually no additional door - main entry is the only means of escape. This is mainly due to security reasons and is very typical for this construction type.

## 2.4 Modification to Building

In general, the buildings of this type have been modified over time. They are mainly built around the central courtyard and can be expanded horizontally by building additional rooms. In some cases, there is a vertical extension however it is not very common. Also, after the 1993 earthquake in Maharashtra, there was a general trend of removing heavy roofs in the buildings of this type.

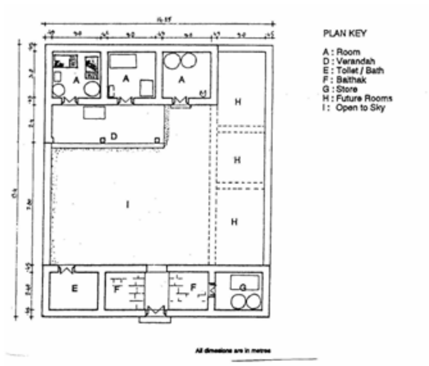


Figure 2A: Plan of aTypical Building

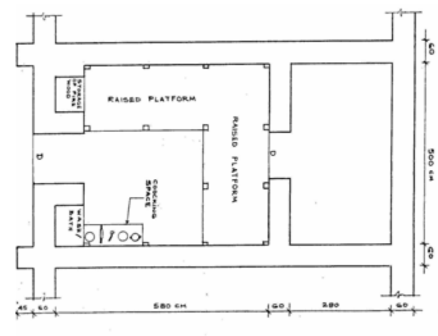


Figure 2B: Plan of Typical Building

# 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 | ☐ |
| | | 14 | Stone masonry in cement mortar | ☐ |

| | | | | |
|---|---|---|---|---|
| | Reinforced masonry | 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 timber frame load-bearing wall system. Gravity load-bearing system consists of timber frames-khands, which carry the weight of the roof and frame self-weight down to the stone pedestals. Stone walls act as enclosure and carry mainly the self-weight down to the foundations (if provided). An exception is the case when there are no timber posts provided; in such a case the entire roof weight is carried by the walls.

## 3.3 Lateral Load-Resisting System

The lateral load-resisting system is timber frame load-bearing wall system. The load-bearing structure for this housing type is a traditional timber frame system, known as "khan". It is a complete frame with timber posts spanned at about 2.6 m, with an average height of approximately 2 meters; spacing between the successive frames is 1.2 to 1.5 m. The posts are supported by above ground stone pedestals (there is no anchorage between the pedestals and the ground). Thick stone walls (typical thickness 600 mm - 1.2 m) provide enclosure and partial support to the roof. Walls are supported either by strip footings of uncoursed rubble masonry or there are no footings at all. Roof structure consists of timber planks and joists. For the sake of thermal comfort during hot summer months (peak temperatures exceeding 40°C.), a 500-800 mm thick mud overlay is provided atop the roof. Lateral seismic forces are transferred from the roof to the timber posts, which tend to sway laterally. As the posts are typically constructed adjacent to the stone walls (with a very small gap or no gap at all), the swaying timber frames induce out-of-plane seismic forces in the stone walls. In some cases, there are no timber posts in portions of a house, and entire lateral load from the roof is transferred to the walls.

## 3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 14 and 14 meters, and widths between 10 and 10 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 4 meters. Typical Plan Dimensions: It is average. Variation of length is 10-17 meters and width is 6-17 meters. Typical Story Height: Usually typical story height is 2.4-2.6 meters Typical Span: Wall span (between two adjacent cross walls) typically ranges from 3 to 6 meters. The typical storey height in such buildings is 2.5 meters. The typical structural wall density is none. Wall density (area of walls in one direction/total plan area) ranges from 0.12 (larger houses) to 0.25 (houses with smaller plan dimensions and thick walls).

## 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 | ☐ | ☑ |

Wood planks and joists covered with thick mud overlay. The buildings of this type are typically of a single-storey construction; therefore no floors have been provided. The roof structure per se is a flexible diaphragm, however due to a heavy mud overlay (a rigid block) the whole system behaves as a rigid diaphragm (this is an estimate).

## 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 | ☐ |

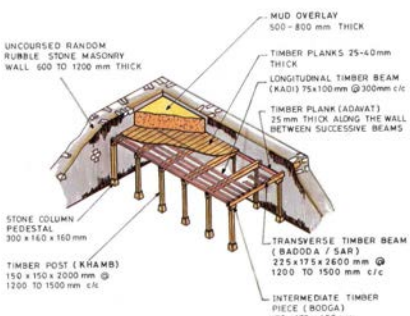

Figure 3: Key Load-bearing Elements (Source: GOM 1998)

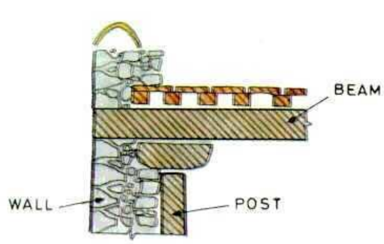

Figure 4A: Critical Structural Details - Wall-to-Roof Connection


Figure 4B: Critical Structural Details - Good Quality Timber Roof Structure

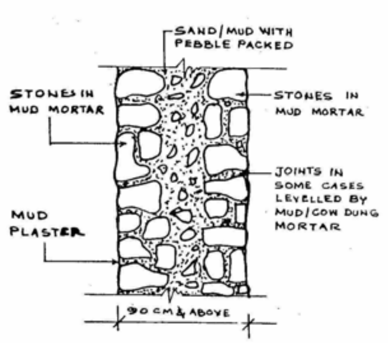


Figure 4C: Detail of an UCR Stone Masonry Wall

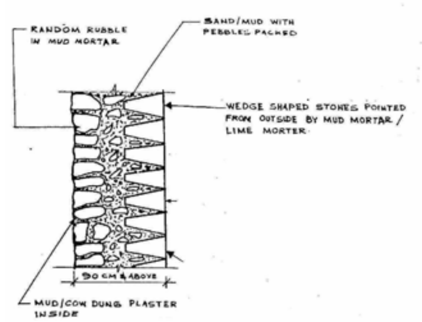


Figure 4D: Detail of an UCR Stone Masonry Wall

Figure 4E: A Typical Wedged-Shape Stone Used for the Exterior Wall Wythe

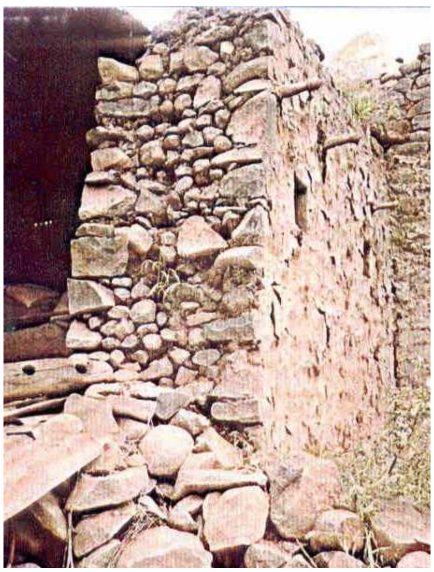

Figure 5: Key Seismic Deficiency - Extremely Thick Stone Walls

Figure 5A: Seismic Resilent Feature - Well Constructed Stone Wall

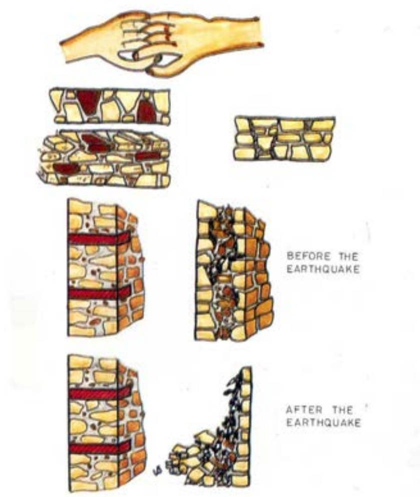


Figure 5B: Seismic Resilent Feature - Importance of Through Stones and Interlocking (Source: GOM 1998)

Figure 5C: Structural Deficiency - Absence of Foundations

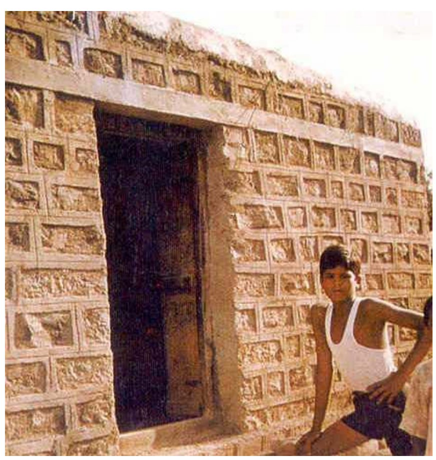

Figure 5D: Earthquake-Resistant Feature - RC Lintel Band

Figure 5E: Seismic Deficiency - Excessive Mud Overlay Atop the Roof

# 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. 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

Houses of this type are typically occupied by extended families, consisting of parents and one or two children (usually sons) and their families. Several generations live under one roof.

## 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) | ☐ |

Houses of poor people are smaller in size, plan size ranges from 15 to 50 m². Plan areas for houses of middle income population are usually between 50 and 100 m². Plan areas of the houses of high-income households are over 100 ft. m.

| 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 the past, there were no bathrooms or latrines available in this type of houses. At the time of the 1993 Killari earthquake, less than 50% of the population of the affected districts (Latur and Osmanabad) had access to the toilets. There is currently an ongoing program of the Government of Maharashtra with an objective to build one toilet per household in rural areas of the Maharashtra State. .

### 4.4 Ownership

The type of ownership or occupancy is 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 | | |
|---|---|---|---|---|
| | | 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 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:<br><br>Less than 25 (concrete walls);<br><br>Less than 30 (reinforced masonry walls);<br><br>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 | ☐ | ☑ | ☐ |
| | The total width of door and window openings in a wall is:<br><br>For brick masonry construction in cement mortar : less | | | |

| | | | | |
|---|---|---|---|---|
| Wall openings | than ½ of the distance between the adjacent cross walls;<br><br>For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls;<br><br>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 | -Extremely large thickness; -Absence of through-stones; -Unshaped boulders used in construction; -Absence of header stones at corners and junctions; -Vertical separation joints at wall corners and junctions. | | -Delamination and failure of inner and outer wall wythes; -Separation of walls at the corners; -Out-of-plane collapse of the walls. |
| Frame (columns, beams) | -Ambiguous system of vertical load transfer: transverse timber beams supported simultaneously by timber posts and stone masonry walls; - Inadequate post-to-beam connection; -Poor quality of timber frame construction; -Poor maintenance of timber elements | Provided that post-to-beam connections in timber frames are adequate, the frames could serve as restraint and prevent the inwards collapse of the walls (an observation made after the 1993 Maharashtra earthquake). | lateral swaying of the frames due to poor post-to-beam connections (mainly deteriorated due to aging and insect attacks). |
| Roof and floors | Excessive weight of mud overlay atop the roof, thickness ranging from 50 to 80 cm. | | -Collapse of roofs due to excessive weight and loss of stability in the frames. |
| | | | |

## 5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is A: HIGH VULNERABILITY (i.e., very poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance).

| Vulnerability | high | medium-high | medium | medium-low | low | very low |
|---|---|---|---|---|---|---|
| | very poor | poor | moderate | good | very good | excellent |
| Vulnerability Class | A | B | C | D | E | F |
| | ☑ | ☑ | ☐ | ☐ | ☐ | ☐ |

## 5.4 History of Past Earthquakes

| Date | Epicenter, region | Magnitude | Max. Intensity |
|---|---|---|---|
| 1993 | Killari, Latur District, Maharashtra State | 6.4 | VIII (MMI SCALE) |

Buildings of this construction type suffered substantial damage in the 1993 Maharashtra earthquake. Close to 30,000 houses of this type collapsed, and other 200,000 houses were damaged. Typical patterns of earthquake damage and failures reported in the 1993 earthquake were: delamination and failure of stone masonry walls (out-of-plane) separation of the walls at corners and junctions lateral swaying of timber frames due to heavy roof weight and inadequate post-to-beam connections.

Figure 6: An Areal View of the Killari Village Devastated by the 1993 Earthquake (Source: GSI 1996)

Figure 6A: Massive Collapse of Stone Masonry Buildings in the 1993 Killari Earthquake (Yelvat Village, Source: GSI 1996)

Figure 6B: Typical Earthquake Damage - Partial Collapse of the Exterior Wall in the 1993 Killri earthquake (Salegaon Village, Source: GSI 1996)

Figure 6C: Typical Earthquake Damage - Delamination of the Exterior Wall Wythe (the interior wythe remained undamaged due to restraint provided by timber posts), 1993 Killari Earthquake

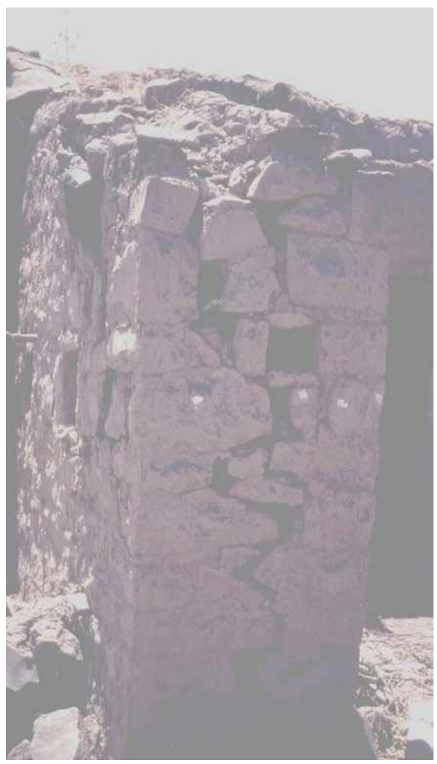

Figure 6D: Typical Earthquake Damage - Delamination of Stone Wall Wythes due to the Absence of Through Stones (1993 Killari earthquake)

Figure 6E: Typical Earthquake Damage - Building and Cracking of a Thick Stone Wall in the 1993 Killari Earthquake (Source: GSI 1996)

# 6. Construction

## 6.1 Building Materials

| Structural element | Building material | Characteristic strength | Mix proportions/dimensions | Comments |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Walls | Stone. | | Large round boulders (size 300 mm or larger). | Uasalt stone, hard for cutting in a regular block shape. |
| Foundation | Mud (mortar). | Very low compressive strength and no tensile strength. | | used for mortar, typical; in some cases, mud with good binding properties (containing high percentage of clay) is used; |
| Frames (beams & columns) | Timber (teak wood, jungle wood) | | | Good quality timber commonly used for the construction of front portion of the building; low quality timber (jungle wood) used for the rear rooms. |
| Roof and floor(s) | Timber. | | | used for planks and beams. |

## 6.2 Builder

The builder (mason) does not necessarily live in this construction type; this is a single-family house occupied by inhabitants of various occupations.

## 6.3 Construction Process, Problems and Phasing

Typically constructed by village artisans. Walls are constructed in a random uncoursed manner by using simply piled stones bound with mud mortar. Round stone boulders are usually picked up in the field and then used without any additional shaping. In some cases stones are cut with chisels and hammers in wedge-shaped blocks. Space between the interior and exterior wall wythes is filled with loose stone rubble and mud mortar. 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

Skilled artisans-wadars cut stones; masons (with a very basic training) construct walls and foundations; skilled carpenters-sutars construct timber frames. Engineers are generally not involved in this type of construction. After the 1993 Maharashtra earthquake, engineering staff of the Public Works Department was involved in the repair and strengthening program that included the construction of this type-they provided technical assistance and oversaw the construction process in the villages affected by the earthquake.

## 6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. IS13828-1993 Improving Earthquake Resistance of Low Strength Masonry Buildings-Guidelines. The year the first code/standard addressing this type of construction issued was 1993. IS 4326-1993 Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings IS 1893-1984 Indian Standard Recommendations for Earthquake Resistant Design of Structures. The most recent code/standard addressing this construction type issued was 1993. Title of the code or standard: IS13828-1993 Improving Earthquake Resistance of Low Strength Masonry Buildings-Guidelines Year the first code/standard addressing this type of construction issued: 1993 National building code, material codes and seismic codes/standards: IS 4326-1993 Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings IS 1893-1984 Indian Standard Recommendations for Earthquake Resistant Design of Structures When was the most recent code/standard addressing this construction type issued? 1993.

There is presently no process for building code enforcement in the rural areas of Maharashtra. However, as a part of its Disaster Management Plan (see EERI, 1999), Government of Maharashtra is planning to enforce the implementation of building codes in rural areas.

## 6.6 Building Permits and Development Control Rules

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

There is a formal approval procedure for rural housing in the Maharashtra State (at a village level), however this does not indude verification of structural stability. In many cases of rural housing, no permits are issued at all. 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

Unit construction cost: approximately US$50 (Rs.2,100) per m². Note that the unit cost can be lower than the stated value, provided that the owners contribute own labor. The cost also depends on the type of mortar used in the construction; the stated value applies if cement mortar is used; if mud mortar is used instead of cement mortar, then the cost would be substantially lower. The cost would also be lower if recyded materials (stone boulders and headers from old house) are used. The smallest houses take about 50 effort-days for construction. Larger houses may take much longer (even one order of magnitude longer).

## 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. Not applicable.

## 8. Strengthening

### 8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

| Seismic Deficiency | Description of Seismic Strengthening provisions used |
|---|---|
| Heavy roof | removal of mud overlay atop the roof; simple construction. |
| Deficient timber frame connections | Bracing of frame (knee-brace/diagonal brace) to strengthen post-to-beam connections using timber or steel elements; simple construction; some materials (e.g. rolled steel sections) may not be locally available; timber braces considered to be more appropriate. |
| Thick multi-wythe walls without through-stones | Installation of through-stones; requires training of local artisans (new skills); must be performed very carefully; |
| Separation joint at wall corners | Strengthening of wall corners using wire mesh and cement overlay; welded wire mesh usually not available locally in rural areas. |
| Lack of integrity of load-bearing structure to lateral loads | Installation of concrete ring beam (band) at the lintel/roof level |
| Delamination of exterior wall wythe | Pointing of exterior walls in cement mortar |

Strengthening of New Construction :

| Seismic Deficiency | Description of Seismic Strengthening provisions used |
|---|---|

| | |
|---|---|
| Walls | Use shaped stones in construction; Use cement/sand mortar; Construct concrete ring beam at the roof level; Use throughstones (header stones); |
| Roof | limit the thickness of mud overlay to 200 mm |
| Timber frame | Install knee-braces to reinforce post-to-beam connections |

## 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?
Several thousand buildings of this type have been retrofitted using the above methodology after the 1993 Maharashtra earthquake.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
The work was done as a post-earthquake rehabilitation effort following the 1993 Maharashtra earthquake.

## 8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
In this case, the same extent of inspection was made for the new construction and for the retrofitted buildings.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
The work was performed by the contractors (masons) contracted by the owners. Financial and technical resources were provided by the Government of Maharashtra. In some cases, owners subsidized the construction. In other cases, construction was sponsored by NGOs.

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

Figure 7: Seismic Strengthening Technologies for Stone Masonry Buildings (Source: GOM 1998)

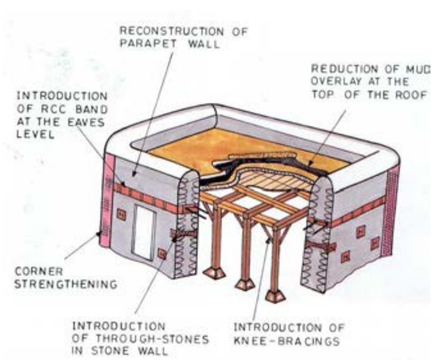


Figure 7A: Seismic Strengthening - Installation of RC Lintel Band in an Existing Building

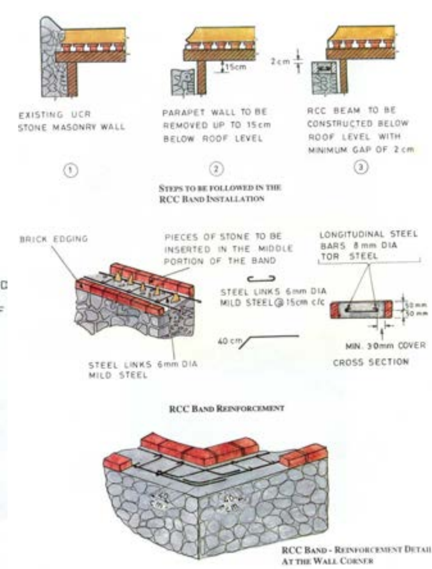


Figure 7B: Seismic Strengthening - Field Application of RC Lintel Band

Figure 7C: Seismic Strengthning - Installation of a Bandage at the Lintel Level (an alternative to the installation of RC band) Source: GOM 1998

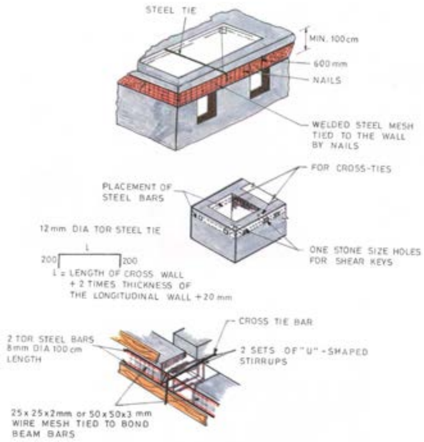


Figure 7D: Seismic Strengthening - A Field Application of Bandage (Source: GOM 1998)

Figure 7E: Seismic Strengthening - Installation of Through Stones (Source: GOM 1998)

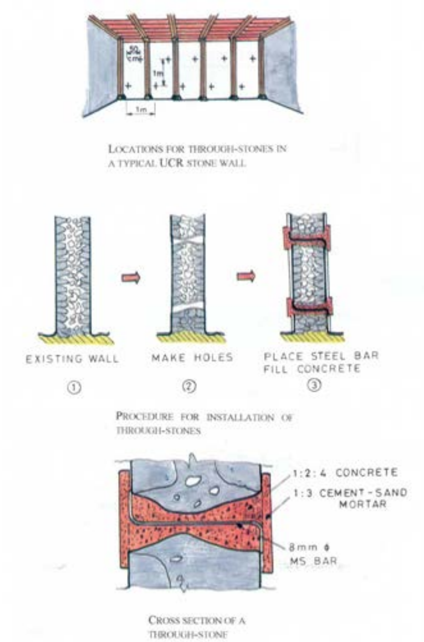


Figure 7F: Seismic Strengthening - Installation of Through Stones (Source: GOM 1998)

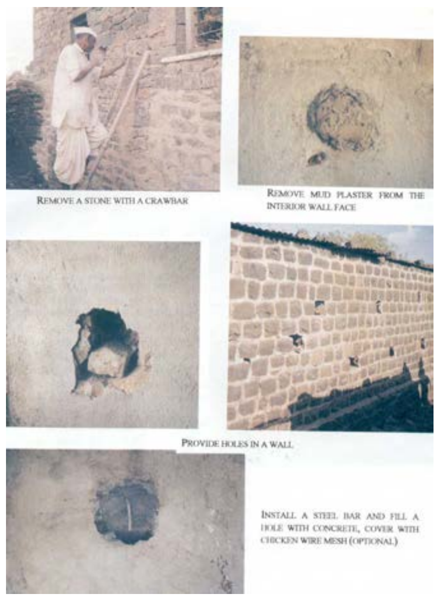


Figure 7G: Seismic Strengthening - A Field Application of Through Stones (Source: GOM 1998)

Figure 7H: Seismic Strengthening - An Example of a Retrofitted Building (note through-stones and RC lintel band)

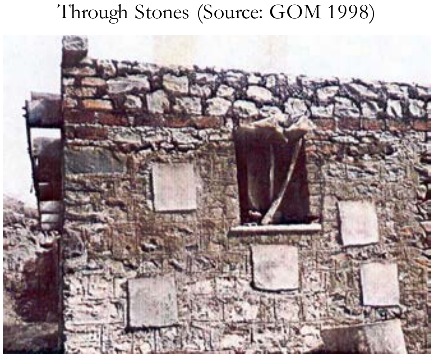

Figure 7I: Seismic Strengthening - An Illustration of Corner Strengthening Technique (Source: GOM 1998)

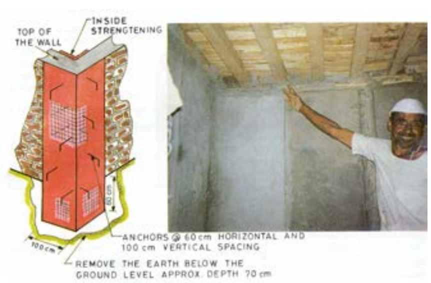


Figure 7J: Seismic Strengthening - Installation of Knee-Bracing (Source: GOM 1998)

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