

Starting from August 2004, *Resonance* is publishing in the Classroom section, a series of short articles, 'Earthquake Tips', related to earthquakes, their effects on civil structures, and design and construction of earthquake resistant buildings. The concepts are clearly explained with sketches and analogies. We hope the *Resonance* readers will benefit from this series of articles.

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Learning Earthquake Design and Construction

15. Why is Vertical Reinforcement Required in Masonry Buildings?

Response of Masonry Walls

Horizontal bands are provided in masonry buildings to improve their earthquake performance. These bands include *plinth band*, *lintel band* and *roof band*. Even if horizontal bands are provided, masonry buildings are weakened by the openings in their walls (*Figure 1*). During earthquake shaking, the masonry walls get grouped into three sub-units, namely *spandrel masonry*, *wall pier masonry* and *sill masonry*.

Keywords

Earthquake, masonry buildings, vertical reinforcement.

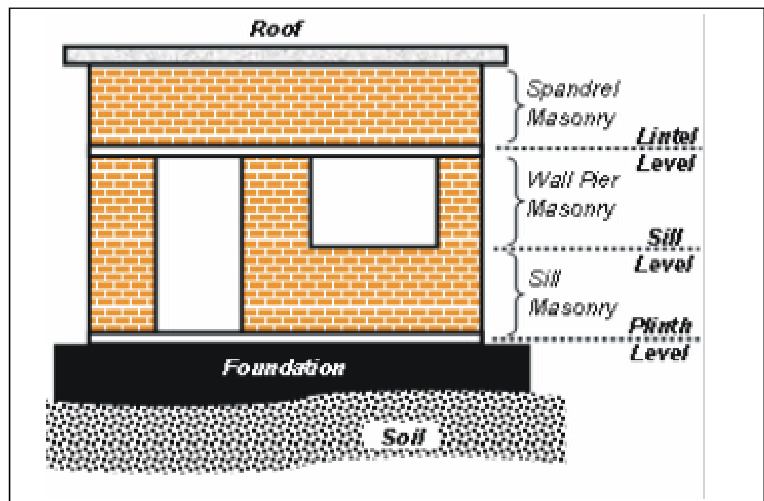


Figure 1. Sub-units in masonry building – walls behave as discrete units during earthquakes.



Consider a hipped roof building with two window openings and one door opening in a wall (Figure 2a). It has *lintel* and *plinth bands*. Since the roof is a hipped one, a *roofband* is also provided. When the ground shakes, the inertia force causes the small-sized masonry *wall piers* to disconnect from the masonry above and below. These masonry sub-units rock back and forth, developing contact only at the opposite diagonals (Figure 2b). The rocking of a masonry pier can crush the masonry at the corners. Rocking is possible when masonry piers are slender, and when weight of the structure above is small. Otherwise, the piers are more likely to develop diagonal (X-type) shear cracking (Figure 2c); this is the most common failure type in masonry buildings.

In un-reinforced masonry buildings (Figure 3), the cross-section area of the masonry wall reduces at the opening. During strong earthquake shaking, the

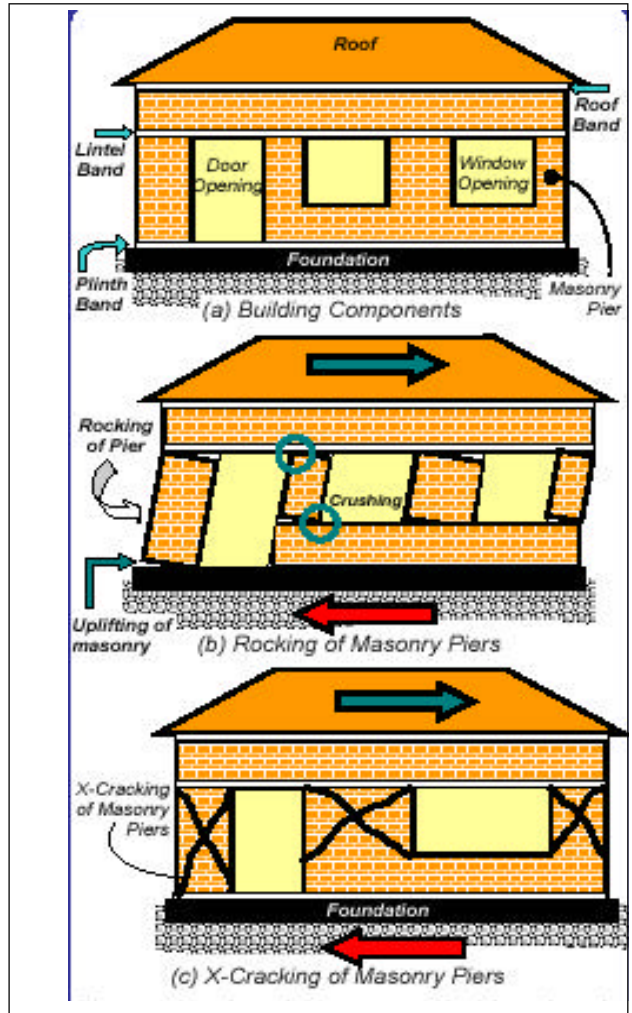


Figure 2. Earthquake response of a hipped roof masonry building – no vertical reinforcement is provided in walls.

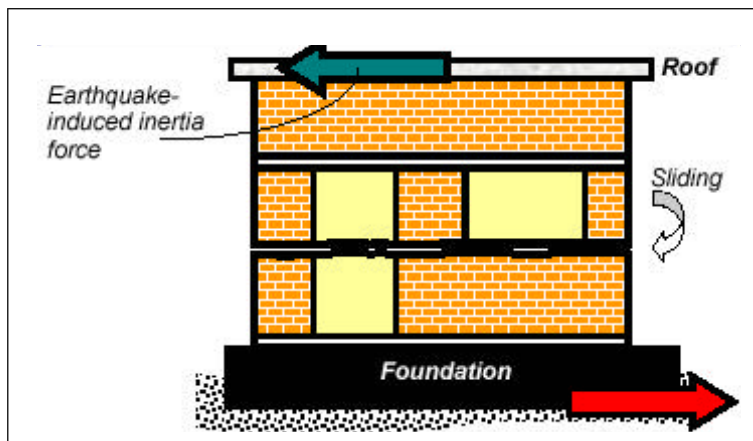


Figure 3. Horizontal sliding at sill level in a masonry building – no vertical reinforcement.



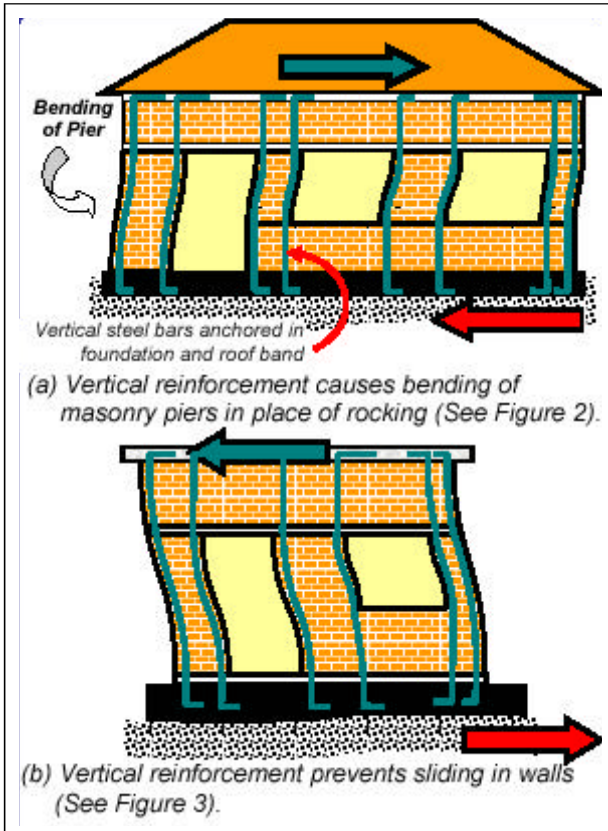


Figure 4. Vertical reinforcement in masonry walls – wall behaviour is modified.

Adequate cross-sectional area of these vertical bars prevents the bar from yielding in tension. Further, the vertical bars also help protect the wall from sliding as well as from collapsing in the weak direction.

Protection of Openings in Walls

Sliding failure mentioned above is rare, even in unconfined masonry buildings. However, the most common damage, observed after an earthquake, is diagonal X-cracking of wall piers, and also inclined cracks at the corners of door and window openings. When a wall with an opening deforms during earthquake shaking, the shape of the opening distorts and becomes more like a *rhombus* – two opposite corners move away and the other two come closer. Under this type of deformation, the corners that come closer develop cracks (Figure 5a). The

building may *slide* just under the roof, below the lintel band or at the sill level. Sometimes, the building may also slide at the plinth level. The exact location of sliding depends on numerous factors including building weight, the earthquake-induced inertia force, the area of openings, and type of doorframes used.

How Vertical Reinforcement Helps

Embedding vertical reinforcement bars in the edges of the wall piers and anchoring them in the foundation at the bottom and in the roof band at the top (Figure 4), forces the slender masonry piers to undergo *bending* instead of *rocking*. In wider wall piers, the vertical bars enhance their capability to resist horizontal earthquake forces and delay the X-cracking.



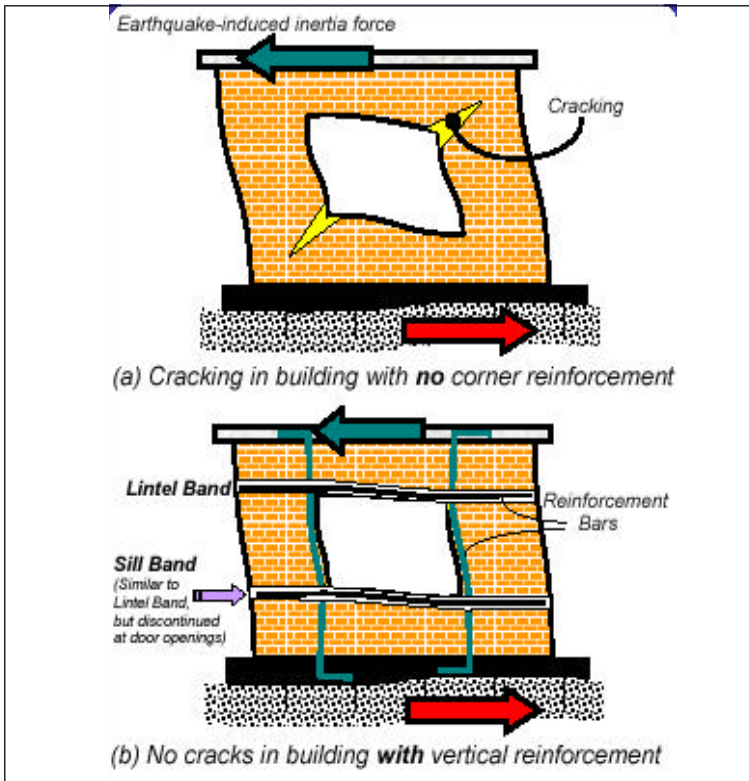


Figure 5. Cracks at corners of openings in a masonry building – reinforcement around them helps.

cracks are bigger when the opening sizes are larger. Steel bars provided in the wall masonry all around the openings restrict these cracks at the corners (Figure 5b). In summary, lintel and sill bands above and below openings, and vertical reinforcement adjacent to vertical edges, provide protection against this type of damage.

Suggested Reading

- [1] J Amrose, *Simplified Design of Masonry Structures*, John Wiley & Sons, Inc., New York, USA, 1991.
- [2] BMTPC, *Guidelines: Improving Earthquake Resistance of Housing*, Building Materials and Technology Promotion Council, New Delhi, 2000.
- [3] IS 4326, *Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings*, Bureau of Indian Standards, New Delhi, 1993.
- [4] IS 13828, *Indian Standard Guidelines for Improving Earthquake Resistance of Low-strength Masonry Buildings*, Bureau of Indian Standards, New Delhi, 1993.

Related IITK-BMTPC Earthquake Tip:

- Tip 5: What are the seismic effects on structures?
- Tip 12: How brick masonry houses behave during earthquakes?
- Tip 13: Why masonry buildings should have simple structural configuration?
- Tip 14: Why horizontal bands are required in masonry buildings?

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Learning Earthquake Design and Construction

16. How to make Stone Masonry Buildings Earthquake Resistant?

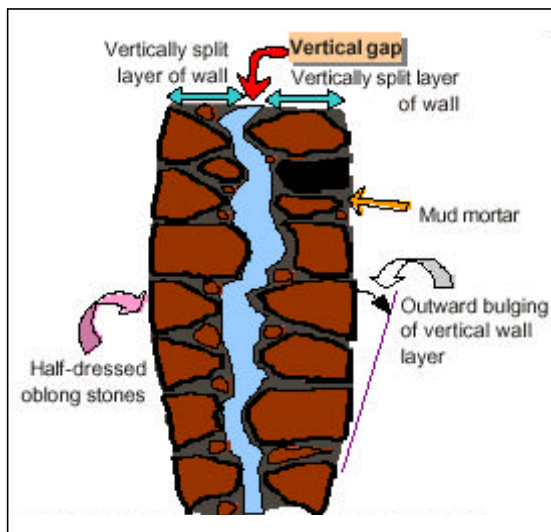
Behaviour during Past India Earthquakes

Stone has been used in building construction in India since ancient times since it is durable and locally available. There are huge numbers of stone buildings in the country, ranging from rural houses to royal palaces and temples. In a typical rural stone house, there are thick stone masonry walls (thickness ranges from 600 to 1200 mm) built using rounded stones from riverbeds bound with mud mortar. These walls are constructed with stones placed in a random manner, and hence do not have the usual layers (or *courses*) seen in brick walls. These uncoursed walls have two exterior vertical layers (called *wythes*) of large stones, filled in between with loose stone rubble and mud mortar. A typical *uncoursed random* (UCR) stone masonry wall is illustrated in *Figure 1*. In many cases, these walls support heavy roofs (for example, timber roof with thick mud overlay).

Keywords

Earthquake, stone masonry buildings, earthquake resistant.

Figure 1. Schematic of the wall section of a traditional stone house – thick walls without stones that go across split into 2 vertical layers.



Laypersons may consider such stone masonry buildings robust due to the large wall thickness and robust appearance of stone

construction. But, these buildings are one of the most deficient building systems from earthquake-resistance point of view. The main deficiencies include excessive wall thickness, absence of any connection between the two wythes of the wall, and use of *round* stones (instead of *shaped* ones). Such dwellings have shown very poor performance during past earthquakes in India and other countries (e.g., Greece, Iran, Turkey, former Yugoslavia). In the 1993 Killari (Maharashtra) earthquake alone, over 8,000 people died, most of them buried under the rubble of traditional stone masonry dwellings.



Likewise, a majority of the over 13,800 deaths during 2001 Bhuj (Gujarat) earthquake is attributed to the collapse of this type of construction.

The main patterns of earthquake damage include: (a) bulging/separation of walls in the horizontal direction into two distinct wythes (*Figure 2a*), (b) separation of walls at corners and T-junctions (*Figure 2b*), (c) separation of poorly constructed roof from walls, and eventual collapse of roof, and (d) disintegration of walls and eventual collapse of the whole dwelling.

Earthquake Resistant Features

Low strength stone masonry buildings are weak against earthquakes, and should be avoided in high seismic zones. The Indian Standard IS:13828-1993 states that inclusion of special earthquake-resistant design and construction features may raise the earthquake resistance of these buildings and reduce the loss of life. However, in spite of the seismic features these buildings may not become totally free from heavy damage and even collapse in case of a major earthquake. The contribution of the each of these features is difficult to quantify, but qualitatively these features have been observed to improve the performance of stone masonry dwellings during past earthquakes. These features include:

(a) Ensure proper wall construction: The wall thickness should not exceed 450mm. Round stone boulders should not be used in the construction! Instead, the stones should be shaped using chisels and hammers. Use of mud mortar should be avoided in higher seismic zones. Instead, cement-sand mortar should be 1:6 (*or richer*) and lime-sand mortar 1:3 (*or richer*) should be used.

(b) Ensure proper bond in masonry courses: The masonry walls

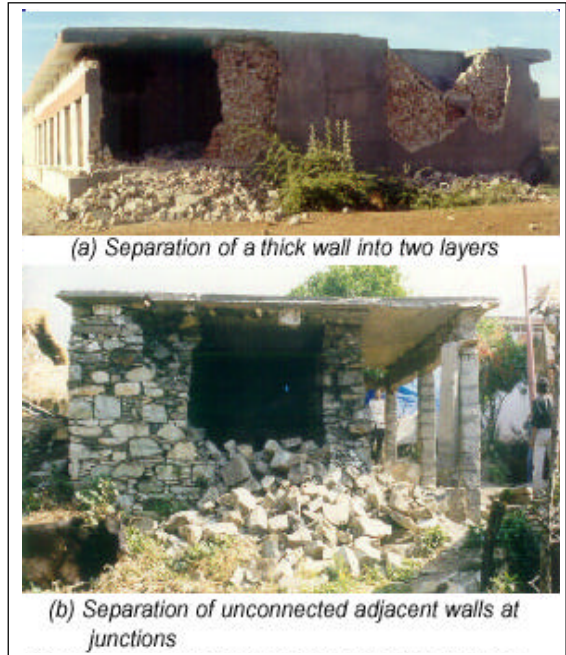


Figure 2. Major concerns in a traditional stone house – deficiencies in walls, roof and in their connections have been prime causes for failure.



Figure 3. Use of “through stones” or “bond stones” in stone masonry walls – vital in preventing the wall from separating into wythes.

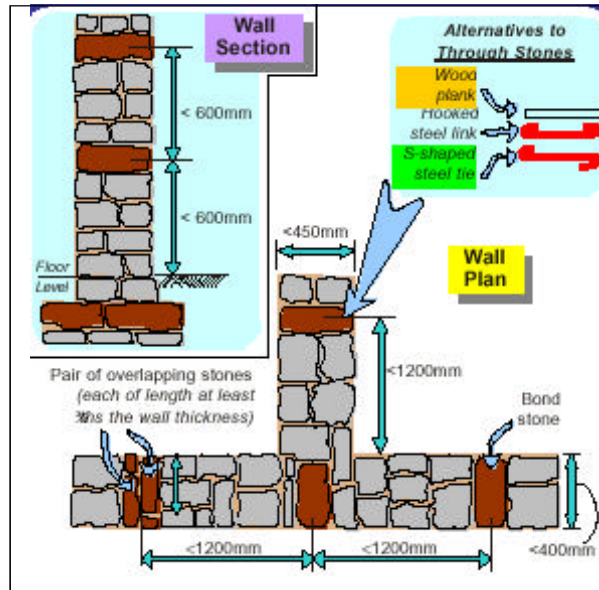
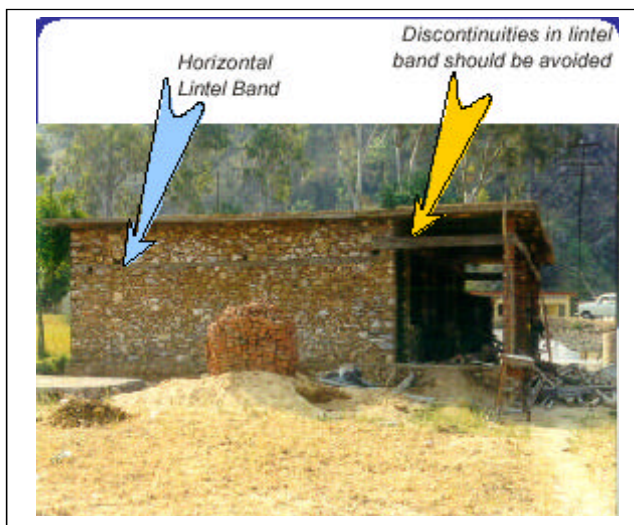


Figure 4. Horizontal lintel band is essential in random rubble stone masonry walls – provides integrity to the dwelling, and holds the walls together to resist horizontal earthquake effects.



should be built in construction lifts not exceeding 600mm. *Through-stones* (each extending over full thickness of wall) or a pair of overlapping *bond-stones* (each extending over at least $\frac{3}{4}$ ths thickness of wall) must be used at every 600mm along the height and at a maximum spacing of 1.2m along the length (Figure 3).

(c) Provide horizontal reinforcing elements: The stone masonry dwellings must have horizontal bands (See IITK-BMTPC *Earthquake Tip 14* for *plinth, lintel, roof and gable bands*). These bands can be constructed out of wood or reinforced concrete, and chosen based on economy. It is important to provide at least one band (either *lintel band* or *roof band*) in stone masonry construction (Figure 4).

(d) Control on overall dimensions and heights: The *unsupported length of walls* between cross-walls should be limited to 5m; for longer walls, cross supports raised from the ground level



called buttresses should be provided at spacing not more than 4m. The height of each storey should not exceed 3.0m. In general, stone masonry buildings should not be taller than 2 storeys when built in cement mortar, and 1 storey when built in lime or mud mortar. The wall should have a thickness of at least one-sixth its height.

Although, this type of stone masonry construction practice is deficient with regards to earthquake resistance, its extensive use is likely to continue due to tradition and low cost. But, to protect human lives and property in future earthquakes, it is necessary to follow proper stone masonry construction as described above (especially features (a) and (b) in seismic zones III and higher). Also, the use of seismic bands is highly recommended (as described in feature (c) above and in *IITK-BMTPC Earthquake Tip 14*).

Suggested Reading

- [1] S Brzev, M Greene and R Sinha, **Rubble stone masonry walls with timber walls and timber roof**, *World Housing Encyclopedia* (www.world-housing.net), India/Report 18, published by EERI and IAEE, 2001.
- [2] IAEE, *Guidelines for Earthquake Resistant Non-Engineered Construction*, The ACC Limited, Thane, 2001 (See www.niceee.org).
- [3] IS 13828, (1993), **Indian Standard Guidelines - Improving Earthquake Resistance of Low-Strength Masonry Buildings**, Bureau of Indian Standards, New Delhi.

Publications of Building Materials and Technology Promotion Council, New Delhi (www.bmtpc.org):

- (a) **Retrofitting of Stone Houses in Marathwada Area of Maharashtra**
- (b) **Guidelines For Improving Earthquake Resistance of Housing**
- (c) **Manual for Repair and Reconstruction of Houses Damaged in Earthquake in October 1991 in the Garhwal Region of UP**

Related IITK-BMTPC Earthquake Tip

Tip 14: Why horizontal bands are required in masonry buildings?

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