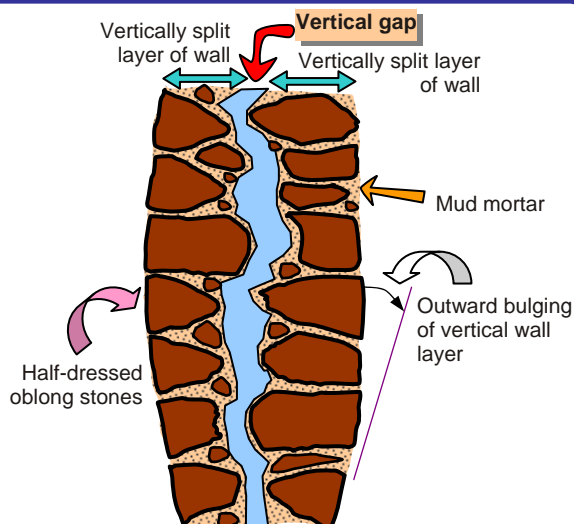


## How to make Stone Masonry Buildings Earthquake-Resistant?

### 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).

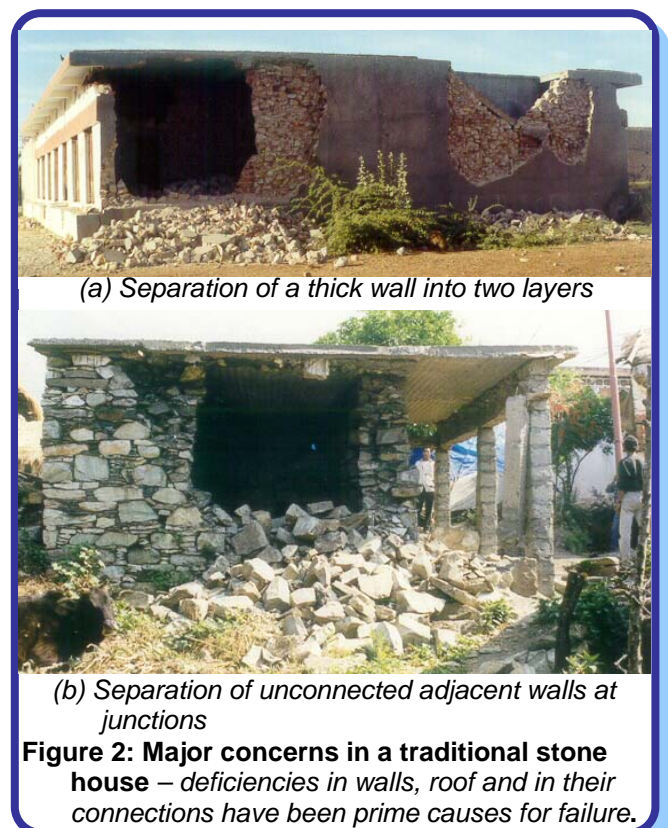


**Figure 1: Schematic of the wall section of a traditional stone house – thick walls without stones that go across split into 2 vertical layers.**

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.

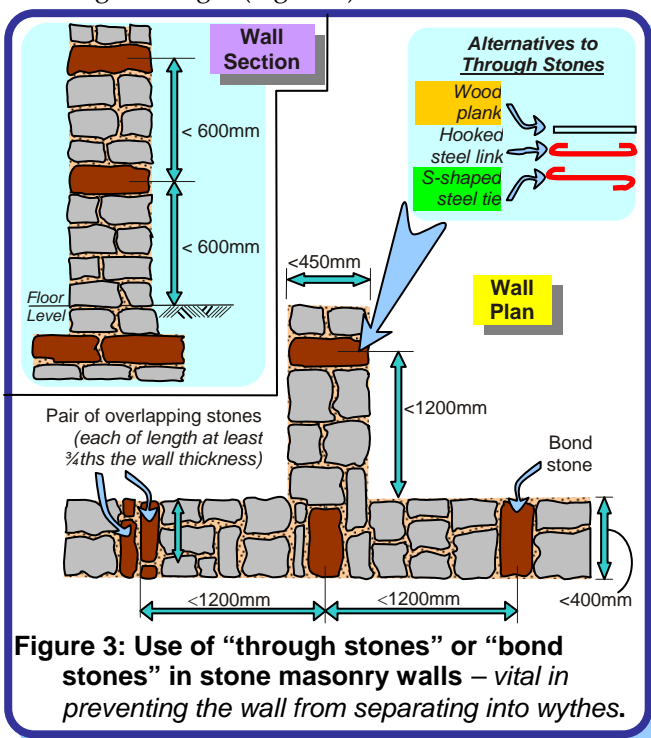
The main patterns of earthquake damage include: (a) bulging/separation of walls in the horizontal direction into two distinct *wythes* (Figure 2a), (b) separation of walls at corners and T-junctions (Figure 2b), (c) separation of poorly constructed roof from walls, and eventual collapse of roof, and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

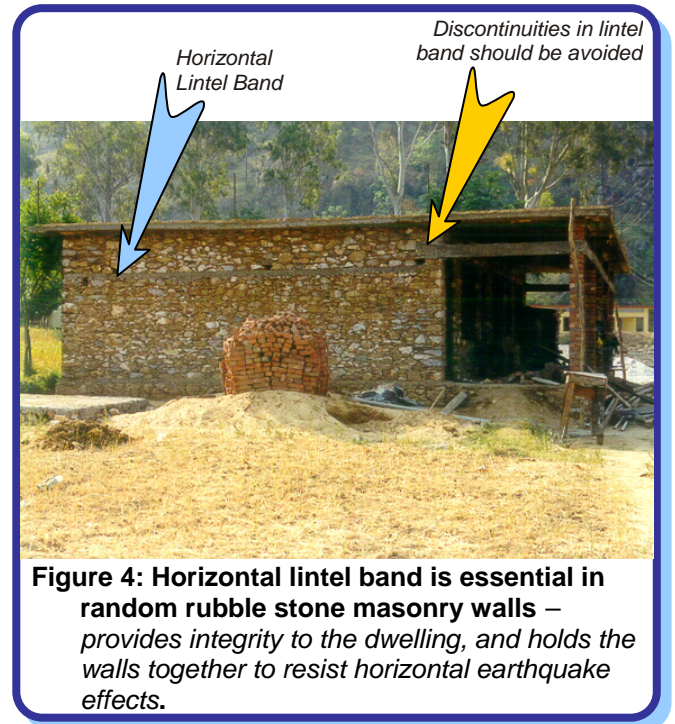
- (a) *Ensure proper wall construction* The wall thickness should not exceed 450mm. Round stone boulders should not be used in the construction! Instead, the stones should be shaped using chisels and hammers. Use of mud mortar should be avoided in higher seismic zones. Instead, cement-sand mortar should 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 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  $\frac{3}{4}$ th the 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).



### Related IITK - BMTPC Earthquake Tip

Tip14: Why horizontal bands are required in masonry buildings?

### Reading Material

- Brzev, S., Greene, M. and Sinha, R. (2001), “Rubble stone masonry walls with timber walls and timber roof,” *World Housing Encyclopedia* ([www.world-housing.net](http://www.world-housing.net)), India/Report 18, published by EERI and IAEE
- IAEE, (1986), *Guidelines for Earthquake Resistant Non-Engineered Construction*, The ACC Limited, Thane, 2001 (See [www.nicee.org](http://www.nicee.org)).
- 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](http://www.bmtpc.org)):
- Retrofitting of Stone Houses in Marathwada Area of Maharashtra
  - Guidelines For Improving Earthquake Resistance of Housing
  - Manual for Repair and Reconstruction of Houses Damaged in Earthquake in October 1991 in the Garhwal Region of UP

Authored by:

C.V.R.Murty  
Indian Institute of Technology Kanpur  
Kanpur, India

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Building Materials and Technology Promotion  
Council, New Delhi, India

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