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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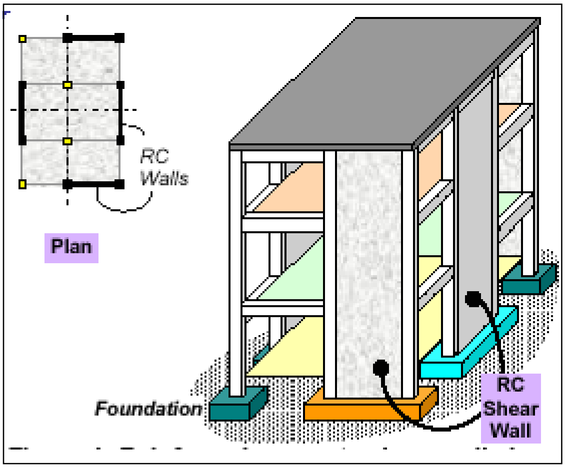
Learning Earthquake Design and Construction
23. Why are Buildings with Shear Walls Preferred in Seismic Regions?

Keywords
Earthquake, shear wall building.

What is a Shear Wall Building

Reinforced concrete (RC) buildings often have *vertical plate-like* RC walls called *Shear Walls* (*Figure* 1) in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. Their thickness can be as low as 150mm, or as high as 400mm in high rise buildings. Shear walls are usually provided along *both* length and width of buildings (*Figure* 1). Shear walls are like *vertically-oriented* wide *beams* that carry earthquake loads downwards to the foundation.

Figure 1. Reinforced concrete shear walls in buildings – an excellent structural system for earthquake resistance.



Advantages of Shear Walls in RC Buildings

Properly designed and detailed buildings with shear walls have shown *very good* performance in past earthquakes. The overwhelming success of buildings with shear walls in resisting strong earthquakes is summarised in the quote:

"We cannot afford to build concrete buildings meant to resist severe earthquakes without shear walls."

:: Mark Fintel, a noted consulting engineer in USA

Shear walls in high seismic regions require special detailing. However, in past earthquakes, even buildings with sufficient amount of walls that were not specially detailed for seismic performance (but had enough well-distributed reinforcement) were saved from collapse. Shear wall buildings are a popular choice in many earthquake prone countries, like Chile, New Zealand and USA. Shear walls are easy to construct, because reinforcement detailing of walls is relatively straight-forward and therefore easily implemented at site. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and non-structural elements (like glass windows and building contents).

Architectural Aspects of Shear Walls

Most RC buildings with shear walls also have columns; these columns primarily carry *gravity* loads (i.e., those due to self-weight and contents of building). Shear walls provide large strength and stiffness to buildings in the direction of their orientation, which significantly reduces lateral sway of the building and thereby reduces damage to structure and its contents. Since shear walls carry *large* horizontal earthquake forces, the overturning effects on them are large. Thus, design of their foundations requires special attention. Shear walls should be provided along preferably *both* length and width. However, if they are provided along only one direction, a proper grid of beams and columns in the vertical plane (called a *moment-resistant frame*) must be provided along the other direction to resist strong earthquake effects.

Related – Earthquake Tip
Tip 6: How Architectural Features Affect Buildings During Earthquakes?
Tip 19: How do Columns in RC Buildings Resist Earthquakes?

Door or window openings can be provided in shear walls, but their size must be small to ensure least interruption to force flow through walls. Moreover, openings should be symmetrically located. Special design checks are required to ensure that the net cross-sectional area of a wall at an opening is sufficient to carry the horizontal earthquake force.

Shear walls in buildings must be symmetrically located in plan to reduce ill-effects of twist in buildings (*Figure* 2). They could be placed symmetrically along one or both directions in plan. Shear walls are more effective when located along exterior perimeter of the building – such a layout increases resistance of the building to twisting.

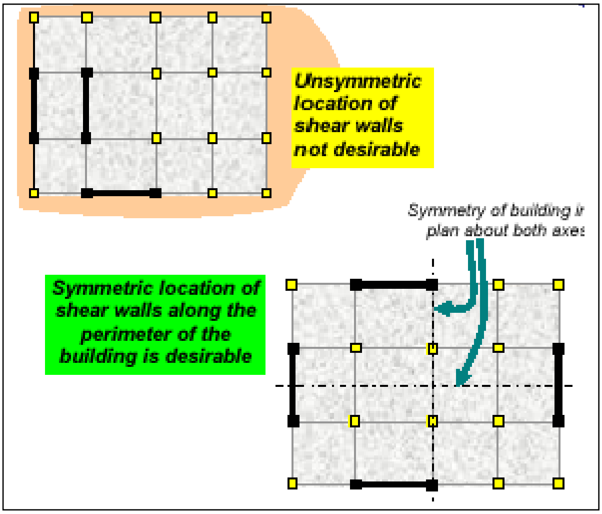


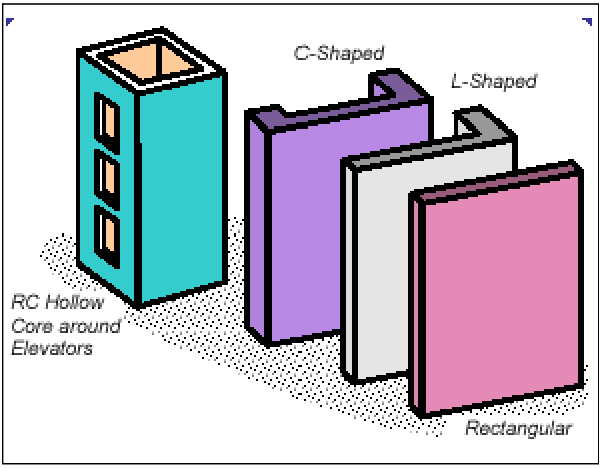
Figure 2. Shear walls must be symmetric in plan layout – twist in buildings can be avoided.

Ductile Design of Shear Walls

Just like reinforced concrete (RC) beams and columns, RC shear walls also perform much better if designed to be ductile. Overall geometric proportions of the wall, types and amount of reinforcement, and connection with remaining elements in the building help in improving the ductility of walls. The Indian Standard *Ductile Detailing Code* for RC members (IS:13920-1993) provides special design guidelines for ductile detailing of shear walls.

Overall Geometry of Walls: Shear walls are oblong in cross-section, *i.e.,* one dimension of the cross-section is much larger than the other. While rectangular cross-section is common, L- and U-shaped sections are also used (*Figure* 3). Thin-walled hollow RC shafts around the elevator core of buildings also act as shear walls, and should be taken advantage of to resist earthquake forces.

Figure 3. Shear walls in RC Buildings – different geometries are possible.



Reinforcement Bars in RC Walls: Steel reinforcing bars are to be provided in walls in regularly spaced *vertical* and

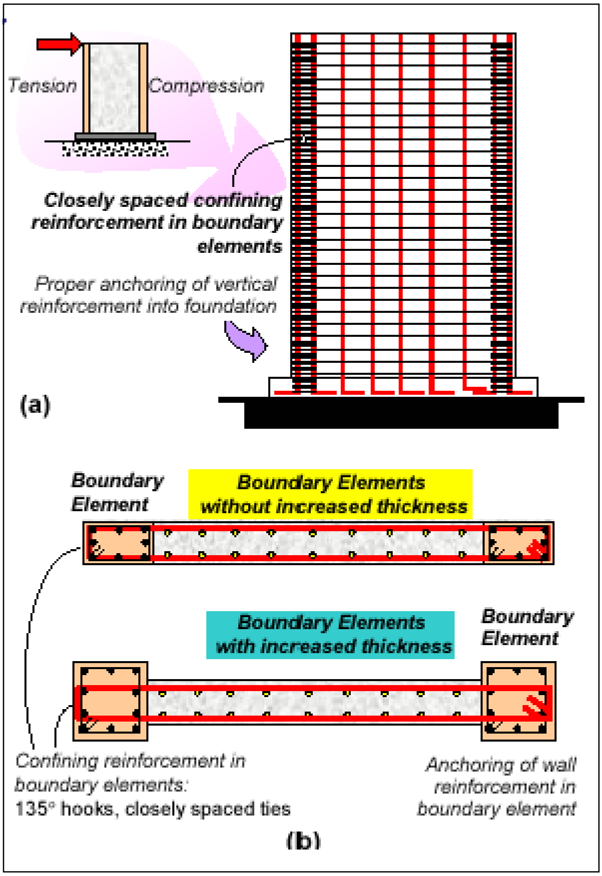


Figure 4. Layout of main reinforcement in shear walls as per IS:13920-1993 – detailing is the key to good seismic performance.

horizontal grids (*Figure* 4a). The vertical and horizontal reinforcement in the wall can be placed in one or two parallel layers called *curtain*s. Horizontal reinforcement needs to be anchored at the ends of walls. The minimum area of reinforcing steel to be provided is *0.0025* times the cross-sectional area, along *each* of the horizontal and vertical directions. This vertical reinforcement should be distributed uniformly across the wall cross-section.

Boundary Elements: Under the large overturning effects caused by horizontal earthquake forces, edges of shear walls experience high compressive and tensile stresses. To ensure that shear walls behave in a ductile way, concrete in the wall end regions must be reinforced in a special manner to sustain these load reversals without loosing strength (*Figure* 4b). End regions of a wall with increased confinement are called *boundary element*s. This special confining transverse reinforce-ment in boundary elements is similar to that provided in columns of RC frames (See *IITK-BMTPC Earthquake Tip* 19). Sometimes, the thickness of the shear wall in these boundary elements is also increased. RC walls *with boundary elements* have substantially higher bending strength and horizontal shear force carrying capacity, and are therefore less susceptible to earthquake damage than walls *without boundary elements*.

Suggested Reading

[1] **IS 13920, Indian Standard Code of Practice for Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces, Bureau of Indian Standards, New Delhi, 1993.**

[2] **T Paulay and M J N Priestley, Seismic Design of Masonry and Reinforced Concrete Buildings, John Wiley & Sons, USA, 1992.**

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Learning Earthquake Design and Construction
24. How to Reduce Earthquake Effects on Buildings?

Why Earthquake Effects are to be Reduced

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements (like glass facades) and to some structural members in the building. This may render the building non-functional after the earthquake, which may be problematic in some structures, like hospitals, which need to remain functional in the aftermath of the earthquake. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. Buildings with such improved seismic performance usually cost more than normal buildings do. However, this cost is justified through improved earthquake performance.

Two basic technologies are used to protect buildings from damaging earthquake effects. These are *Base Isolation Devices* and *Seismic Dampers*. The idea behind *base isolation* is to detach (*isolate*) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced. *Seismic dampers* are special devices introduced in the building to absorb the energy provided by the ground motion to the building (much like the way shock absorbers in motor vehicles absorb the impacts due to undulations of the road).

Base Isolation

The concept of base isolation is explained through an example building resting on frictionless *rollers* (*Figure* 1a). When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to shaking of the ground; simply, *the building does not experience the earthquake*. Now, if the same building is rested on flexible pads that offer resistance against lateral movements (*Figure* 1b),

Keywords
Earthquake, base isolation.

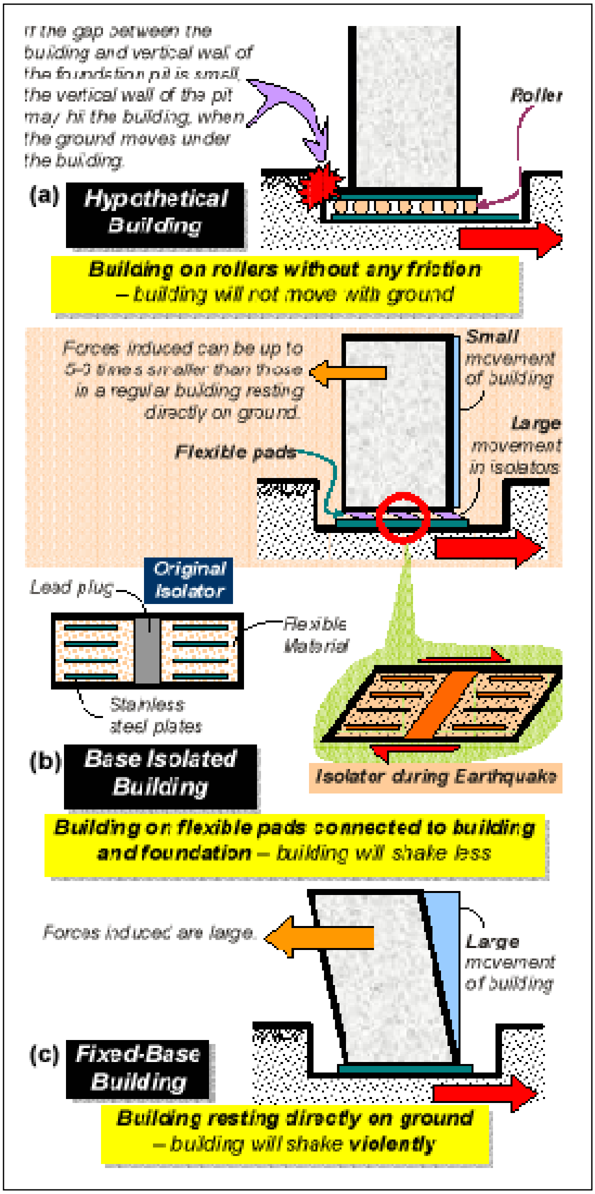

Figure 1. Building on flexible supports shakes lesser – this technique is called Base Isolation.

then *some* effect of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a *fixed base building* (*Figure* 1c).

The flexible pads are called *base-isolators*, whereas the structures protected by means of these devices are called *base-isolated buildings*. The main feature of the base isolation technology is that it introduces flexibility in the structure. As a result, a robust medium-rise masonry or reinforced concrete building becomes extremely flexible. The isolators are often designed to absorb energy and thus add damping to the system. This helps in further reducing the seismic response of the building. Several commercial brands of base isolators are available in the market, and many of them look like large rubber pads, although there are other types that are based on sliding of one part of the building relative to the other. A careful study is required to identify the most suitable type of device for a particular building. Also, base isolation is not suitable for all buildings. Most suitable candidates for base-isolation are low to medium-rise buildings rested on hard soil underneath; high-rise buildings or buildings rested on soft soil are not suitable for base isolation.

Base Isolation in Real Buildings

Seismic isolation is a relatively recent and evolving technology.

It has been in increased use since the 1980s, and has been well evaluated and reviewed internationally. Base isolation has now been used in numerous buildings in countries like Italy, Japan, New Zealand, and USA. Base isolation is also useful for retrofitting important buildings (like *hospitals* and *historic buildings*). By now, over 1000 buildings across the world have been equipped with seismic base isolation. In India, base isolation technique was first demonstrated after the 1993 Killari (Maharashtra) Earthquake [EERI, 1999]. Two single storey buildings (one school building and another shopping complex building) in newly relocated Killari town were built with rubber *base isolators* resting on hard ground. Both were *brick masonry buildings* with *concrete roof*. After the 2001 Bhuj (Gujarat) earthquake, the four-storey Bhuj Hospital building was built with base isolation technique (*Figure* 2).

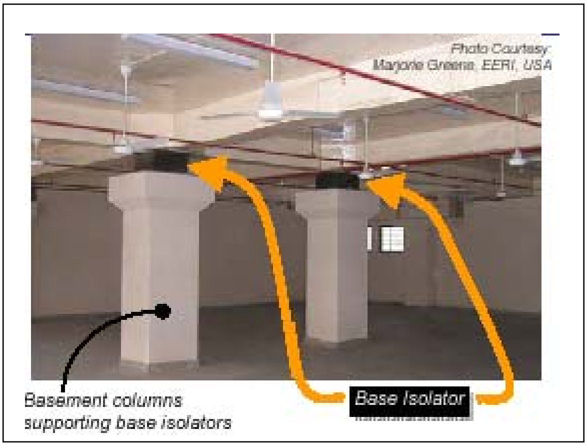

Figure 2. View of Basement in Bhuj Hospital building – built with base isolators after the original District Hospital building at Bhuj collapsed during the 2001 Bhuj earthquake.

Seismic Dampers

Another approach for controlling seismic damage in buildings and improving their seismic performance is by installing *seismic dampers* in place of structural elements, such as diagonal braces. These dampers act like the hydraulic shock absorbers in cars – much of the sudden jerks are absorbed in the hydraulic fluids and only little is transmitted above to the chassis of the car. When seismic energy is transmitted through them, dampers absorb part of it, and thus *damp* the motion of the building. Dampers were used since 1960s to protect tall buildings *against wind effects*. However, it was only since 1990s, that they were used to protect buildings *against earthquake effects*. Commonly used types of seismic dampers include *viscous dampers* (energy is absorbed by silicone-based fluid passing between piston-cylinder arrangement), *friction dampers* (energy is absorbed by surfaces with friction between them rubbing against each other), and *yielding dampers* (energy is absorbed by metallic components that

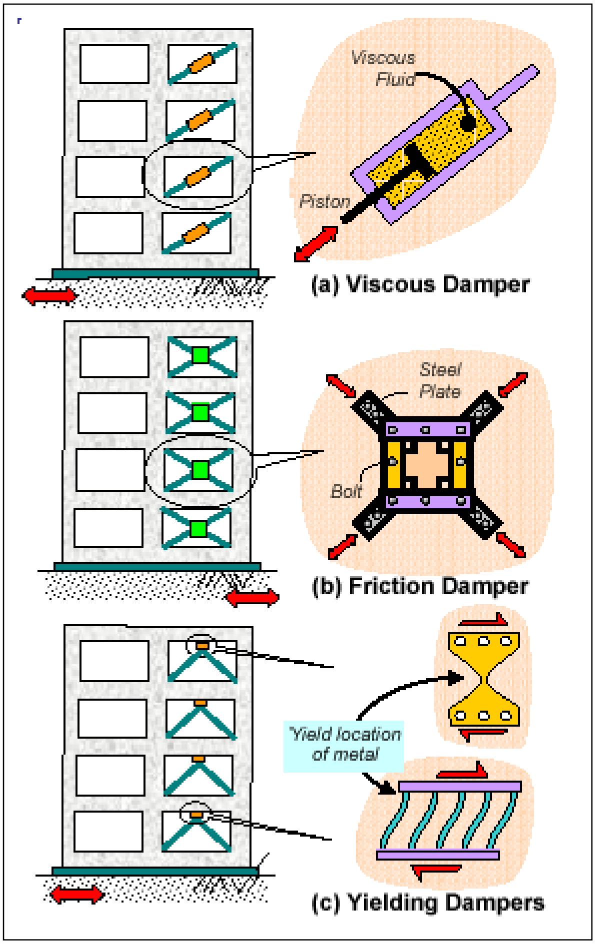

Figure 3. Seismic Energy Dissipation Devices – each device is suitable for a certain building.

yield) (*Figure* 3). In India, friction dampers have been provided in a 18-storey RC frame structure in Gurgaon (See *http://www.palldynamics.com/main. htm*).

Related – Earthquake Tip
Tip 5: What are the Seismic Effects on Structures?
Tip 8: What is the Seismic Design Philosophy for Buildings?

Suggestions/comments may be sent to: eqtips@iitk.ac.in.

Suggested Reading

[1] EERI, *Lessons Learnt Over Time – Learning from Earthquakes Series: Volume II Innovative Recovery in India,* Earthquake Engineering Research Institute, Oakland (CA), USA, 1999; also available at *http://www.nicee.org/readings/EERI_Report.ht*m.

[2] R D Hanson and T T Soong, *Seismic Design with Supplemental Energy Dissipation Device*s, Earthquake Engineering Research Institute, Oakland (CA), USA, 2001.

[3] R I Skinner and W H Robinson and G H McVerry,G.H., *An Introduction to Seismic Isolation,* 1999, John Wiley & Sons, New York.