

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.

Earthquake Tips have been brought out by the Department of Civil Engineering, IIT Kanpur and sponsored by Building Materials and Technology Promotion Council, New Delhi, India. These articles are reproduced here with permission from IIT Kanpur and BMTPC, New Delhi.

C V R Murty  
 Indian Institute of Technology  
 Kanpur, Kanpur 208 016, India  
 Email: eqtips@iitk.ac.in

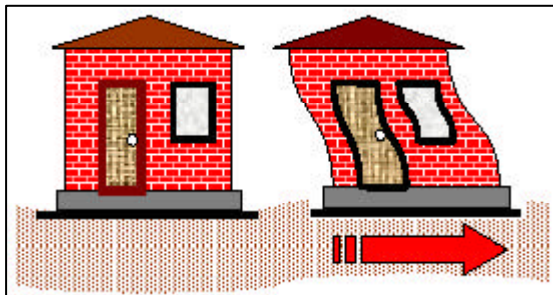
**Learning Earthquake Design and Construction**  
**5. What are the Seismic Effects on Structures?**

**Inertia Forces in Structures**

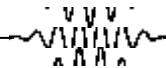
Earthquake causes shaking of the ground. So a building resting on it will experience motion at its base. From *Newton's First Law of Motion*, even though the base of the building moves with the ground, the roof has a tendency to stay in its original position. But since the walls and columns are connected to it, they drag the roof along with them. *This is much like the situation that you are faced with when the bus you are standing in suddenly starts; your feet move with the bus, but your upper body tends to stay back making you fall backwards!!* This tendency to continue to remain in the previous position is known as *inertia*. In the building, since the walls or columns are flexible, the motion of the roof is different from that of the ground (*Figure 1*).

**Keywords**  
 Earthquake, structures, seismic effects.

**Figure 1. Effect of Inertia in a building when shaken at its base.**



Consider a building whose roof is supported on columns (*Figure 2*). *Coming back to the analogy of yourself on the bus: when the bus suddenly starts, you are thrown backwards as if someone has applied a force on the upper body.* Similarly, when the ground moves, even the building is thrown backwards, and the roof experiences a force, called *inertia*



force. If the roof has a mass  $M$  and experiences an acceleration  $a$ , then from *Newton's Second Law of Motion*, the *inertia force*  $FI$  is mass  $M$  times acceleration  $a$ , and its direction is opposite to that of the acceleration. Clearly, more mass means higher inertia force. Therefore, lighter buildings sustain the earthquake shaking better.

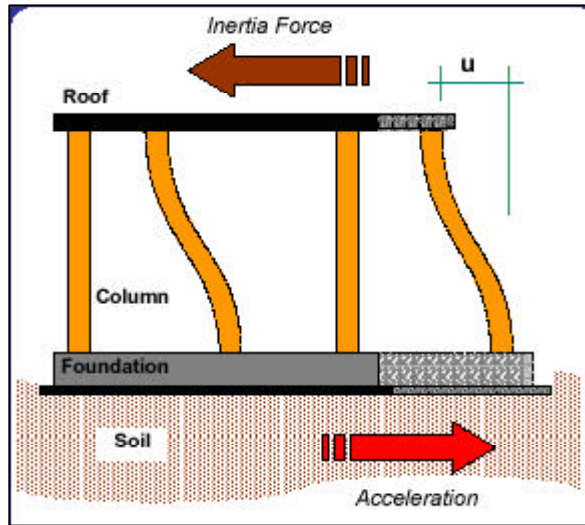
**Effect of Deformations in Structures**

The inertia force experienced by the roof is transferred to the ground via the columns, causing forces in columns. These forces generated in the columns can also be understood in another way.

During earthquake shaking, the columns undergo relative movement between their ends. In *Figure 2*, this movement is shown as quantity  $u$  between the roof and the ground. But, given a free option, columns would like to come back to the straight vertical position, *i.e.*, columns resist deformations. In the straight vertical position, the columns carry no horizontal earthquake force through them. But, when forced to bend, they develop internal forces. The larger is the relative horizontal displacement  $u$  between the top and bottom of the column, the larger this internal force in columns. Also, the stiffer the columns are (*i.e.*, bigger is the column size), larger is this force. For this reason, these internal forces in the columns are called *stiffness forces*. In fact, the stiffness force in a column is the column stiffness times the relative displacement between its ends.

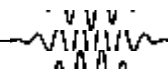
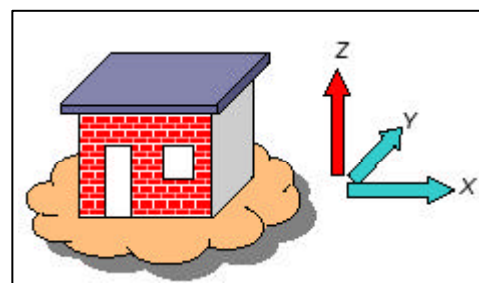
**Horizontal and Vertical Shaking**

Earthquake causes shaking of the ground in all three directions – along the two horizontal directions ( $X$  and  $Y$ , say), and the vertical direction ( $Z$ , say) (*Figure 3*). Also, during the earthquake, the ground shakes randomly *back and forth* (– and +)



**Figure 2. Inertia force and relative motion within a building.**

**Figure 3. Principal directions of a building.**

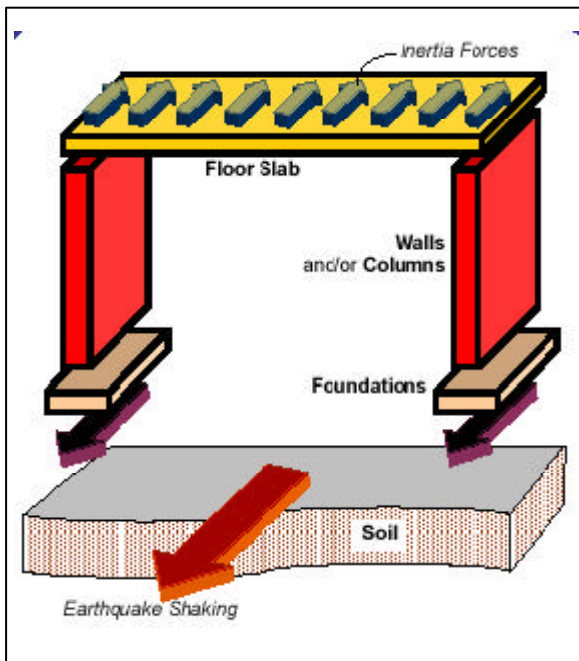


along each of these X, Y and Z directions. All structures are primarily designed to carry the gravity loads, *i.e.*, they are designed for a force equal to the mass  $M$  (this includes mass due to own weight and imposed loads) times the acceleration due to gravity  $g$  acting in the vertical downward direction ( $-Z$ ). The downward force  $Mg$  is called the *gravity load*. The vertical acceleration during ground shaking either adds to or subtracts from the acceleration due to gravity. Since factors of safety are used in the design of structures to resist the gravity loads, usually most structures tend to be adequate against vertical shaking.

However, horizontal shaking along X and Y directions (both + and - directions of each) remains a concern. Structures designed for gravity loads, in general, may not be able to safely sustain the effects of horizontal earthquake shaking. Hence, it is necessary to ensure adequacy of the structures against horizontal earthquake effects.

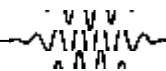
**Figure 4. Flow of seismic inertia forces through all structural components.**

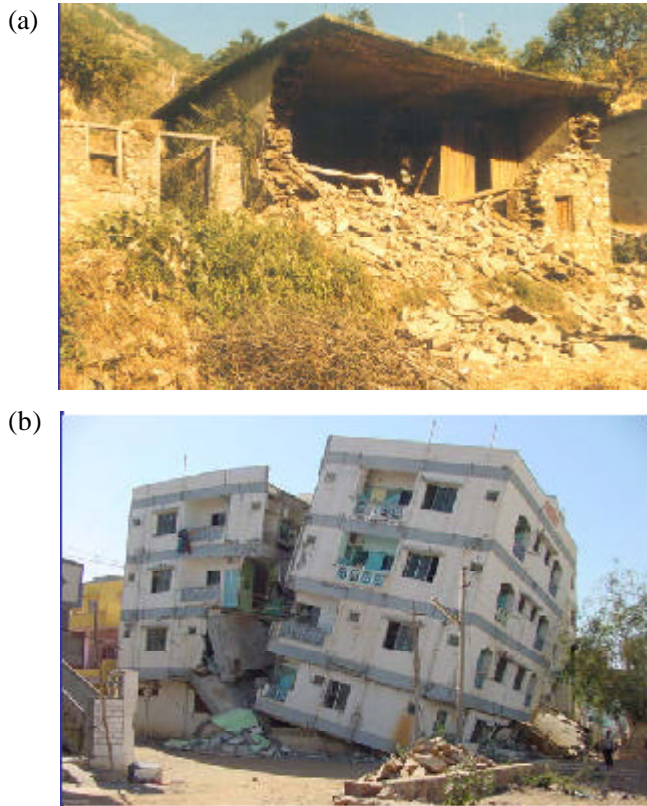
**Flow of Inertia Forces to Foundations**



Under horizontal shaking of the ground, horizontal inertia forces are generated at level of the mass of the structure (usually situated at the floor levels). These lateral inertia forces are transferred by the floor slab to the walls or columns, to the foundations, and finally to the soil system underneath (*Figure 4*). So, each of these structural elements (floor slabs, walls, columns, and foundations) and the connections between them must be designed to safely transfer these inertia forces through them.

Walls or columns are the most critical elements in transferring the inertia forces. But, in traditional construction, floor slabs





**Figure 5. Importance of designing walls/columns for horizontal earthquake forces.**

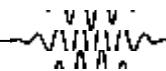
**(a) Partial collapse of stone masonry walls during 1991 Uttarkashi (India) earthquake; (b) Collapse of reinforced concrete columns (and building) during 2001 Bhuj (India) earthquake.**

and beams receive more care and attention during design and construction, than walls and columns. Walls are relatively thin and often made of brittle material like masonry. They are poor in carrying horizontal earthquake inertia forces along the direction of their thickness. Failures of masonry walls have been observed in many earthquakes in the past (e.g., Figure 5a). Similarly, poorly designed and constructed reinforced concrete columns can be disastrous. The failure of the ground storey columns resulted in numerous building collapses during the 2001 Bhuj (India) earthquake (Figure 5b).

### **Suggested Reading**

- [1] A K Chopra, *Dynamics of Structures – A Primer*, EERI Monograph, Earthquake Engineering Research Institute, USA, 1980.

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



C V R Murty  
 Indian Institute of Technology  
 Kanpur, Kanpur 208 016, India  
 Email: eqtips@iitk.ac.in

## Learning Earthquake Design and Construction

### 6. How Architectural Features Affect Buildings During Earthquakes ?

#### Importance of Architectural Features

The behaviour of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. Hence, at the planning stage itself, architects and structural engineers must work together to ensure that the unfavourable features are avoided and a good building configuration is chosen.

The importance of the configuration of a building was aptly summarised by Late Henry Degenkolb, a noted Earthquake Engineer of USA, as:

*“If we have a poor configuration to start with, all the engineer can do is to provide a band-aid – improve a basically poor solution as best as he can. Conversely, if we start-off with a good configuration and reasonable framing system, even a poor engineer cannot harm its ultimate performance too much.”*

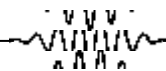
#### Architectural Features

A desire to create an aesthetic and functionally efficient structure drives architects to conceive wonderful and imaginative structures. Sometimes the *shape* of the building catches the eye of the visitor, sometimes the *structural system* appeals, and in other occasions *both shape and structural system* work together to make the structure a marvel. However, each of these choices of shapes and structure has significant bearing on the performance of the building during strong earthquakes. The wide range of structural damages observed during past earthquakes across the world is very educative in identifying structural configurations that are desirable versus those which must be avoided.

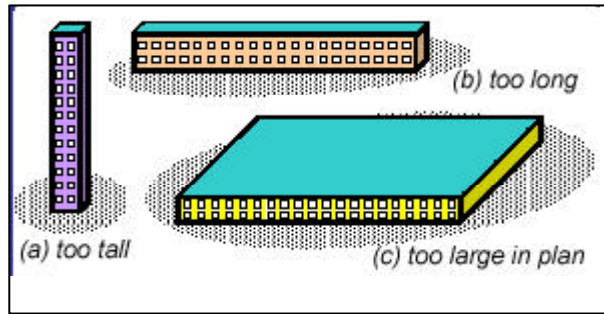
#### Keywords

Earthquake, architectural features.

**Size of Buildings:** In tall buildings with large height-to-base size ratio (*Figure 1a*), the horizontal movement of the floors during

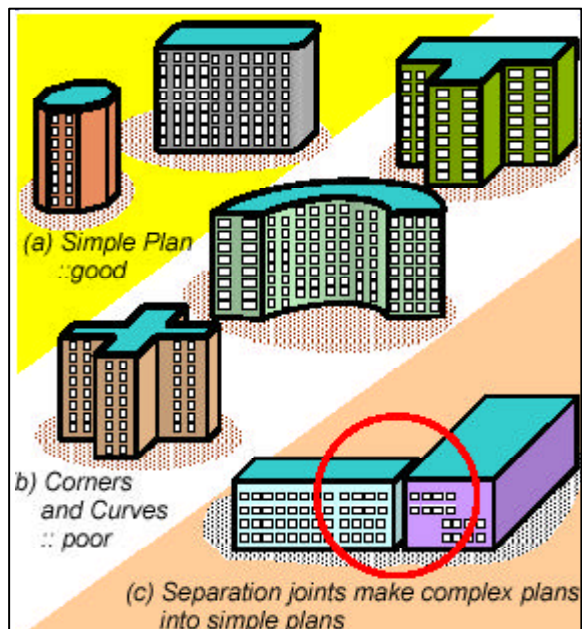


ground shaking is large. In short but very long buildings (Figure 1b), the damaging effects during earthquake shaking are many. And, in buildings with large plan area like warehouses (Figure 1c), the horizontal seismic forces can be excessive to be carried by columns and walls.

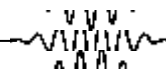


**Horizontal Layout of Buildings:** In general, buildings with simple geometry in plan (Figure 2a) have performed well during strong earthquakes. Buildings with re-entrant corners, like those U, V, H and + shaped in plan (Figure 2b), have sustained significant damage. Many times, the bad effects of these interior corners in the plan of buildings are avoided by making the buildings in two parts. For example, an L-shaped plan can be broken up into two rectangular plan shapes using a separation joint at the junction (Figure 2c). Often, the plan is simple, but the columns/walls are not equally distributed in plan. Buildings with such features tend to twist during earthquake shaking. A discussion in this aspect will be presented in the upcoming

**Figure 1. Buildings with one of their overall sizes much larger or much smaller than the other two, do not perform well during earthquakes.**



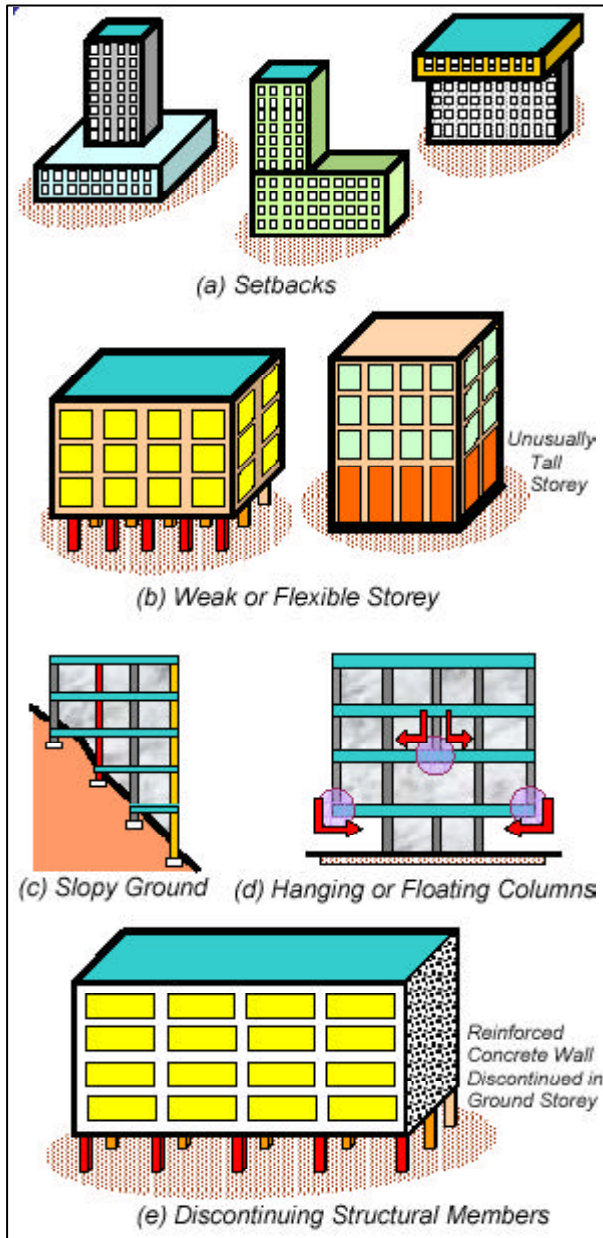
**Figure 2. Simple plan shape buildings do well during earthquakes.**



**Figure 3. Sudden deviations in load transfer path along the height lead to poor performance of buildings.**

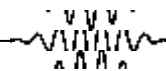
*IITK-BMTPC Earthquake Tip 7 on How Buildings Twist During Earthquakes?*

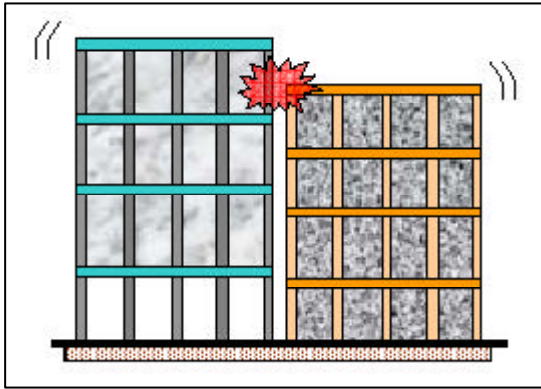
**Vertical Layout of Buildings:** The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path;



or dis-continuity in this load transfer path results in poor performance of the building. Buildings with vertical setbacks (like the hotel buildings with a few storeys wider than the rest) cause a sudden jump in earthquake forces at the level of discontinuity (Figure 3a). Buildings that have fewer columns or walls in a particular storey or with unusually tall storey (Figure 3b), tend to damage or collapse which is initiated in that storey. Many buildings with an open ground storey intended for parking collapsed or were severely damaged in Gujarat during the 2001 Bhuj earthquake.

Buildings on slopy ground have unequal height columns along the slope, which causes ill effects like twisting and damage in shorter columns (Figure 3c). Buildings with columns that hang or float on beams at an intermediate storey and do not go all the way to the foundation, have discontinuities in the load transfer path (Figure 3d). Some buildings have reinforced concrete walls to carry the earthquake loads to the foundation. Buildings, in which these walls do not go all the way to the ground but stop at an upper level, are liable to get severely damaged during earthquakes.





**Figure 4. Pounding can occur between adjoining buildings due to horizontal vibrations of the two buildings.**

**Adjacency of Buildings:** When two buildings are too close to each other, they may pound on each other during strong shaking. With increase in building height, this collision can be a greater problem. When building heights do not match (*Figure 4*), the roof of the shorter building may pound at the mid-height of the column of the taller one; this can be very dangerous.

### **Building Design and Codes...**

Looking ahead, of course, one will continue to make buildings interesting rather than monotonous. However, this need not be done at the cost of poor behaviour and earthquake safety of buildings. Architectural features that are detrimental to earthquake response of buildings should be avoided. If not, they must be minimised. When irregular features are included in buildings, a considerably higher level of engineering effort is required in the structural design and yet the building may not be as good as one with simple architectural features.

Decisions made at the planning stage on building configuration are more important, or are known to have made greater difference, than accurate determination of code specified design forces.

### **Suggested Reading**

- [1] C Arnold and R Reitherman, *Building Configuration and Seismic Design*, John Wiley, USA, 1982.
- [2] H J Lagorio, *EARTHQUAKES An Architect's Guide to Non-Structural Seismic Hazard*, John Wiley & Sons, Inc., USA, 1990.

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

