IITK - BMTPC Earthquake Tip 17

Learning Earthquake Design and Construction

How do Earthquakes Affect Reinforced Concrete Buildings?

Reinforced Concrete Buildings

In recent times, *reinforced concrete* buildings have become common in India, particularly in towns and cities. Reinforced concrete (or simply *RC*) consists of two primary materials, namely *concrete* with *reinforcing steel bars*. Concrete is made of *sand*, *crushed stone (called aggregates)* and *cement*, all mixed with pre-determined amount of water. Concrete can be molded into any desired shape, and steel bars can be bent into many shapes. Thus, structures of complex shapes are possible with RC.

A typical RC building is made of horizontal members (*beams* and *slabs*) and vertical members (*columns* and *walls*), and supported by *foundations* that rest on ground. The system comprising of RC columns and connecting beams is called a *RC Frame*. The RC frame participates in resisting the earthquake forces. Earthquake shaking generates inertia forces in the building, which are proportional to the building mass. Since most of the building mass is present at floor levels, earthquake-induced inertia forces primarily develop at the floor levels. These forces travel downwards - through *slab and beams* to *columns and walls*, and then to the foundations from where they are dispersed to the ground. As inertia forces accumulate downwards from the top of the building, the columns and walls at lower storeys experience higher earthquake-induced forces (Figure 1) and are therefore designed to be stronger than those in storeys above.

Figure 1: Total horizontal earthquake force in a building increases downwards along its height.

Roles of Floor Slabs and Masonry Walls

Floor slabs are horizontal plate-like elements, which facilitate functional use of buildings. Usually, beams and slabs at one storey level are cast together. In residential multi-storey buildings, thickness of slabs is only about 110-150mm. When beams bend in the vertical direction during earthquakes, these thin slabs bend along with them (Figure 2a). And, when beams move with columns in the horizontal direction, the slab usually forces the beams to move together with it. In most buildings, the geometric distortion of the slab is negligible in the horizontal plane; this behaviour is known as the *rigid diaphragm action* (Figure 2b). Structural engineers must consider this during design.

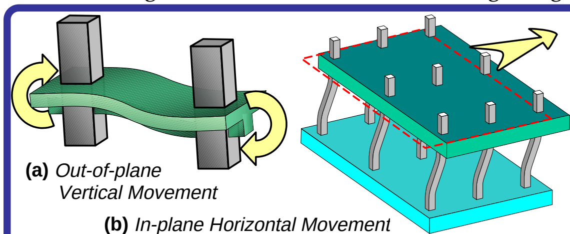

Figure 2: Floor bends with the beam but moves all columns at that level together.

After columns and floors in a RC building are cast and the concrete hardens, vertical spaces between columns and floors are usually filled-in with masonry walls to demarcate a floor area into functional spaces (rooms). Normally, these masonry walls, also called *infill walls*, are not connected to surrounding RC columns and beams. When columns receive horizontal forces at floor levels, they try to move in the horizontal direction, but masonry walls tend to resist this movement. Due to their heavy weight and thickness, these walls attract rather large horizontal forces (Figure 3). However, since masonry is a brittle material, these walls develop cracks once their ability to carry horizontal load is exceeded. Thus, infill walls act like sacrificial fuses in buildings; they develop cracks under severe ground shaking but help share the load of the beams and columns until cracking. Earthquake performance of infill walls is enhanced by mortars of good strength, making proper masonry courses, and proper packing of gaps between RC frame and masonry infill walls. However, an infill wall that is unduly tall or long in comparison to its thickness can fall *out-of-plane* (*i.e.*, along its thin direction), which can be life threatening. Also, placing infills irregularly in the building causes ill effects like *short-column effect* and *torsion* (these will be discussed in subsequent *IITK-BMTPC Earthquake Tips*).

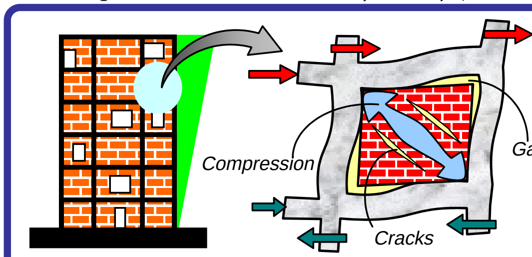

Figure 3: Infill walls move together with the columns under earthquake shaking.

Horizontal Earthquake Effects are Different

Gravity loading (due to self weight and contents) on buildings causes RC frames to bend resulting in *stretching* and *shortening* at various locations. Tension is generated at surfaces that stretch and compression at those that shorten (Figure 4b). Under gravity loads, tension in the beams is at the bottom surface of the beam in the central location and is at the top surface at the ends. On the other hand, *earthquake loading* causes tension on beam and column faces at locations different from those under gravity loading (Figure 4c); the relative levels of this tension (in technical terms, *bending moment*) generated in members are shown in Figure 4d. The level of bending moment due to earthquake loading depends on severity of shaking and can exceed that due to gravity loading. Thus, under strong earthquake shaking, the beam ends can develop tension on either of the top and bottom faces. Since concrete cannot carry this tension, steel bars are required on both faces of beams to resist *reversals* of bending moment. Similarly, steel bars are required on all faces of columns too.

Strength Hierarchy

For a building to remain safe during earthquake shaking, columns (which receive forces from beams) should be stronger than beams, and foundations (which receive forces from columns) should be stronger than columns. Further, connections between beams & columns and columns & foundations should not fail so that beams can safely transfer forces to columns and columns to foundations.

When this strategy is adopted in design, damage is likely to occur *first* in beams (Figure 5a). When beams are detailed properly to have large ductility, the building as a whole can deform by large amounts despite progressive damage caused due to consequent yielding of beams. In contrast, if columns are made weaker, they suffer severe local damage, at the top and bottom of a particular storey (Figure 5b). This localized damage can lead to collapse of a building, although columns at storeys above remain almost undamaged.

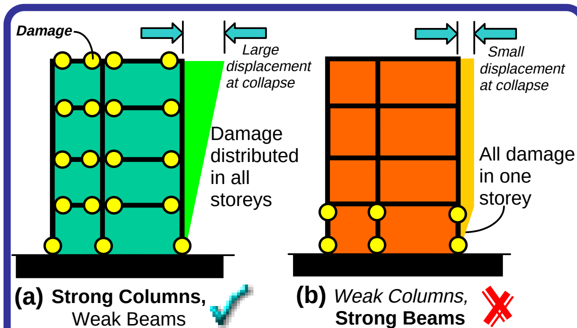

Figure 5: Two distinct designs of buildings that result in different earthquake performances – *columns should be stronger than beams.*

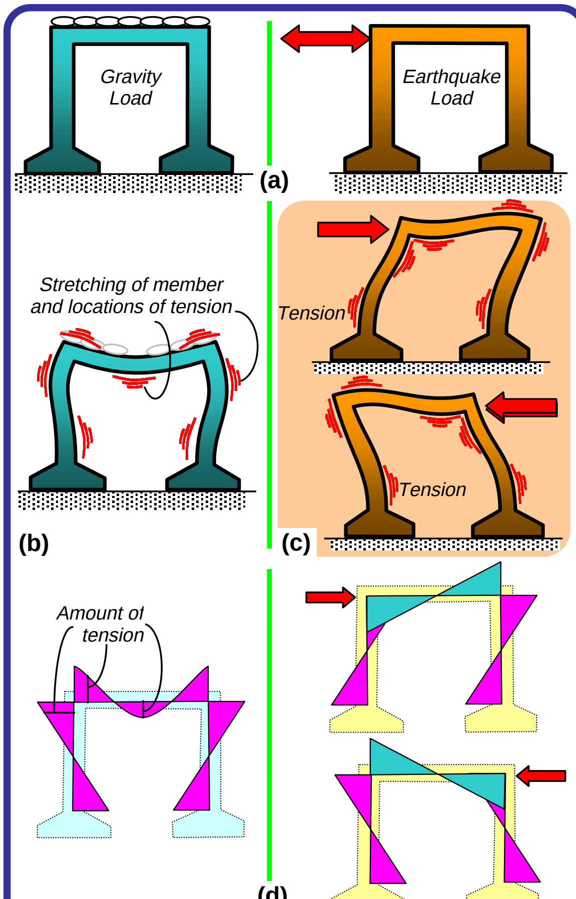

Figure 4: Earthquake shaking reverses tension and compression in members – *reinforcement is required on both faces of members.*

Relevant Indian Standards

The Bureau of Indian Standards, New Delhi, published the following Indian standards pertaining to design of RC frame buildings: (a) Indian Seismic Code (IS 1893 (Part 1), 2002) – *for calculating earthquake forces*, (b) Indian Concrete Code (IS 456, 2000) – *for design of RC members*, and (c) Ductile Detailing Code for RC Structures (IS 13920, 1993) – *for detailing requirements in seismic regions*.

Related IITK - BMTPC Earthquake Tip

Tip 5: What are the seismic effects on structures?

Resource Material

Englekirk,R.E., *Seismic Design of Reinforced and Precast Concrete Buildings*, John Wiley & Sons, Inc., USA, 2003.

Penelis,G.G., and Kappos,A.J., *Earthquake Resistant Concrete Structures*, E&FN SPON, UK, 1997.

Next Upcoming Tip

How do Beams in RC Buildings Resist Earthquakes?

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