IITK - BMTPC Earthquake Tip 25

Learning Earthquake Design and Construction

Why are Load Paths Important in Buildings?

What are Load Paths?

Mass is present all through in a building - from roof parapet to foundation. Earthquake ground shaking induces inertia forces in a building where mass is present. These inertia forces are transferred downwards through horizontally and vertically aligned *structural elements* to foundations, which, in turn, transmit these forces to the soil underneath. The paths along which these inertia forces are transferred through building are *Load Paths* (Figure 1a). Buildings may have *multiple load paths* running between locations of mass and foundations. Load paths are as much a concern for transmitting vertical loads (*e.g.*, self-weight, occupancy load, and snow; Figure 1b) as for horizontal loads (*e.g.*, earthquake and wind; Figure 1c). Structural elements in buildings that constitute load paths include:

(a) *Horizontal diaphragm* elements laid in horizontal plane, *i.e.*, roof slabs, floor slabs or trussed roofs and bracings;

(b) *Vertical elements* spanning in vertical plane along height of building, *i.e.*, planar frames (beams and columns interconnected at different levels), walls (usually made of RC or masonry), & planar trusses;

(c) *Foundations and Soils*, *i.e.*, isolated and combined footings, mats, piles, wells, soil layers and rock; and

(d) *Connections* between the above elements.

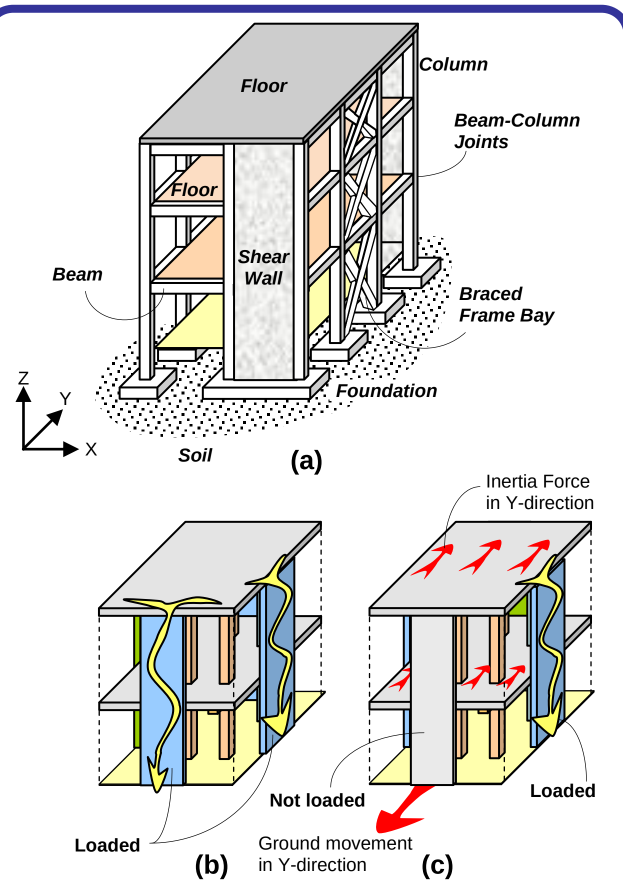


Figure 1: Load paths for different load actions – *(a) key structural elements constituting load paths, (b) vertical load paths, and (c) lateral load paths*

Importance of Load Paths

Buildings perform best in earthquakes, when inertia forces generated in them are transmitted to foundation by continuous and direct load paths *without being bent or interrupted*. When some structural elements are discontinued along a direct load path, loads have to bend and take detours to other load paths; buildings with *discontinuous* or *indirect load paths* are undesirable, because *brittle damage* can occur in structural elements at the interruptions or bends.

Horizontal Diaphragms

Floor and roof slabs are thin, wide structural elements laid in a horizontal plane at different levels. They transfer inertia forces induced by their own masses, to vertical elements on which they rest. During earthquake shaking, horizontal diaphragms act like *beams in their own horizontal plane* and transmit inertia forces to vertical elements, such as *structural walls* or *planar frames*. Slabs that are long in plan (*i.e.*, flexible in their own plane), bend and undergo undesirable *stretching* along one edge and *shortening* along the other (Figure 2); they perform best when relative deformations are minimal and in-plane stiffness and strength sufficiently large. In general, slabs should be rectangular with *plan length/plan width ratio* less than 3.

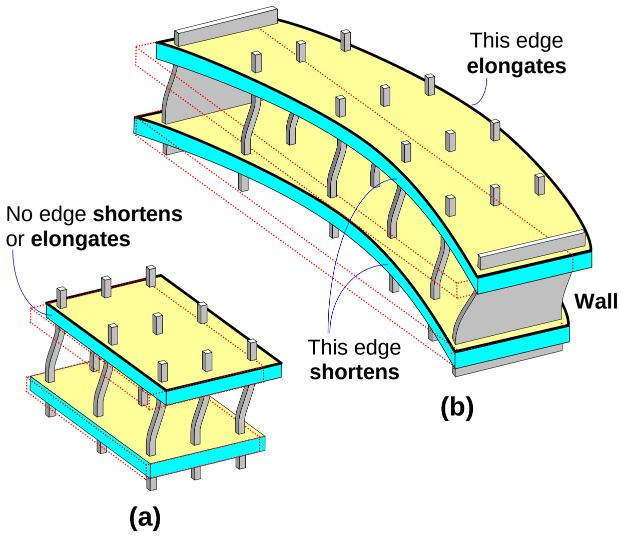


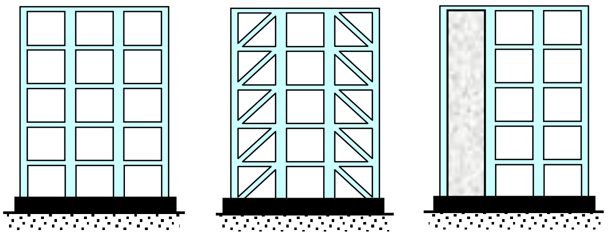
Figure 2: In-plane deformation in horizontal diaphragms – *(a) absent, if plan aspect ratio is up to 3, and (b) present, if plan aspect ratio exceeds 5*

Horizontal floors can effectively resist and transfer earthquake forces through direct load paths, provided that they do not have significant openings. Large openings or cut-outs in floors interrupt load paths and may prevent smooth, direct transfer of forces to vertical elements. Openings in floors are necessary, *e.g.,* to allow for elevator core or staircase to pass through. But, these should be as small as possible, and as few as possible. Their locations should be carefully considered; the ideal location for openings is close to center of floor slabs in plan.

Vertical Elements

Typical structural elements (present in vertical planes) of buildings are *columns*, *braces* and *structural walls* or a combination of these (Figure 3). They collect gravity and (*horizontal* and *vertical*) earthquake inertia forces from floor diaphragms at different levels, and bring them down to the foundations below.

It is possible to design and construct earthquake-resistant buildings with various structural systems, including *Moment Resisting Frames* (MRFs), Frames with Brace Members (called *Braced Frames* (BFs)), *Structural Walls* (SWs; also called *Shear Walls*), or a combination of these. Some of these systems require more advanced knowledge of design and higher quality control during construction than others, as reflected by their relative performance during earthquakes. For instance, buildings with SWs are easy to design and construct, and generally perform better during earthquakes, than buildings with MRFs alone.



(a) (b) (c)

Figure 3: Structural systems in buildings that help resist lateral earthquake-induced inertia loads – *(a) MRFs : moment-resisting frames, (b) BFs : braced frames, and (c) frame-wall dual systems*

Key Requirements of Load Paths

Earthquake performances of buildings are determined by *soundness* of their load paths, independent of the material with which buildings are built, *e.g.,* masonry, RC or structural steel. Earthquake codes require designers to ensure presence of adequate lateral load paths in buildings in two horizontal plan directions. Salient requirements of load paths are:

(a) *Load paths must exist in all directions of a building*: Earthquake shaking occurs in all directions, and can be expressed as a combination of shaking in *one vertical* and *two (mutually perpendicular) horizontal directions*. Hence, adequate load paths are needed along the *vertical* and the two mutually perpendicular *horizontal directions*.

(b) *Load path geometry must be simple*: Uninterrupted, direct load paths should be provided at regular intervals along length and width of the building;

(c) *Load paths must be symmetrical in plan*: A building will sway uniformly in two horizontal directions, when structural elements constituting load paths are placed *symmetrically in plan*. Otherwise, it may twist about a vertical axis, which is detrimental to its earthquake performance.

(d) *Robust connections are needed between structural elements along load paths*: In an earthquake-resistant structure, *every* connection is tested during *strong* earthquake shaking. These connections should be *stiff* and *strong* to offer continuous load paths without being damaged during strong earthquake shaking (Figure 4).

Photo Courtesy: Sudhir K. Jain

Figure 4: Deficient connection between slabs and vertical elements – *collapse of an RC frame building during 2001 Bhuj (India) earthquake*

Related IITK - BMTPC Earthquake Tip

Tip 5: What are seismic effects on structures?
Tip 6: How architectural features affect buildings during earthquakes?

Resource Material

Arnold,C., and Reitherman,R., (1982), *Building Configuration and Seismic Design*, John Wiley, USA

Ambrose,J., and Vergun,D., (1999), *Design for Earthquakes*, John Wiley & Sons, Inc., USA

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