What Harms Load Paths in Buildings?

Buildings with Moment Resisting Frames

Smooth transfer of inertia forces in a Moment Resisting Frame (MRF) building is critically dependant on the geometry of the frame grid. Some desirable features of a frame grid include:

(a) Several distinct planar, regular MRFs placed parallel to each other, in each of the two perpendicular plan directions of the building;
(b) Columns running run through full height and beams through full width of the building;
(c) Uniform spacing between parallel planar MRFs in each plan direction; and
(d) Beams within each planar frame slender enough to deform in flexure: Concrete beams of very short span may damage in shear, which is undesirable.

Poor Frame Grid

For smooth load transfer in an MRF, it is necessarily for beams and columns to intersect and to form a well-defined grid. Of the two MRF buildings shown in plan in Figure 1, the first one has regular frames in both plan directions (Figure 1a), while the second has irregular beam and column layout consisting of a small MRF in the X-direction and limited frame action in the Y-direction (Figure 1b); this is NOT an acceptable earthquake-resistant solution.

Large detours in load paths result in stress concentration in the frame and in poor performance. This can happen, if frame lines are discontinuous (i.e., beam lines jog out-of-plane), and if beams frame into each other instead of into columns.

Discontinuity in Vertical Elements: Floating Columns and Setback Columns

Discontinuing a load carrying member along its length or height is harmful to earthquake performance of the building. It is not desirable to discontinue a column in the lower storey of a building (Figure 2a); such columns are called floating columns. When a column is pushed out of the vertical line in a lower storey, the forces carried by the upper portion of the column have to bend at the setback location to continue towards the foundation (Figure 2b); such columns are called setback columns. Presence of a setback column also leads to poor building performance in an earthquake; brittle damage is expected in beam-column joints and beams adjoining the setback location.

Buildings with Structural Walls

Structural walls (SWs; also called Shear Walls) have large lateral stiffness and lateral strength in the length direction and provide very good load paths. Buildings with SWs have performed well during past earthquakes. Some desirable features of buildings with SWs include:

(a) Continuous SWs running through full building height generally offer direct load paths for inertia forces collected from diaphragms at different floor levels to be carried down to the foundation;
(b) Uniformly distributed SWs in both plan directions; and
(c) Sufficient wall density, i.e., total cross-section area of structural walls in plan as a percentage of plan area of building.

Situations arise when departure occurs from good earthquake behaviour. These include:

(a) Large and/or irregular openings

SWs with smaller and uniform openings behave better (Figure 3a). In SWs with large and random openings, there are multiple load paths and each of those has long detours. As a result, the load paths become long and convoluted instead of being short...
and direct (Figure 3b). This creates undesirable interrupted load transfer along the SW height. Design codes require special attention in the design and detailing of walls between openings, to reduce negative effects of openings and ensure desirable ductile behaviour of buildings with SWs.

(b) Discontinuity, out-of-plane offsets and in-plane offsets in SWs in lower elevations

Sometimes, in the lower storeys of buildings, SWs are discontinued completely (Figures 4a and 5a), discontinued but moved in-plane (Figures 4b and 5b), or discontinued and moved out-of-plane (Figures 4c and 5c). This leads to abrupt changes in load path. Buildings with such wall configurations perform poorly in earthquakes. Such options should be avoided in earthquake-resistant buildings.

(c) Truncating structural walls in upper elevations

When SWs are discontinued at upper elevations over a part of their width (Figure 6a), or over the full width at a certain height (Figure 6b), abrupt changes occur in stiffness and strength of the building within a vertical plane. These practices should be avoided in earthquake-resistant buildings.