Under Foot

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Horizontal floor diaphragm load effects on composite beam design.

ONE OF THE MOST NEGLECTED ELEMENTS in the design of buildings is the horizontal floor diaphragm and its interaction with the lateral load resisting systems. Most multi-story structures depend on the floor slab and roof systems to act as horizontal diaphragms to collect and distribute the lateral loads to the vertical framing members, which provide the overall structural stability.

In steel structures, floor diaphragms are most commonly constructed using composite steel deck with concrete fill, although other systems, such as pre-cast planks, formed reinforced concrete, or concrete on non-composite steel deck, may also be used. While there are numerous references that discuss the design of the diaphragm itself, there is little guidance available on the transfer of diaphragm forces into the lateral load resisting system. In addition, the specific issues related to beam design for members collecting lateral loads in composite floor systems has gone largely undocumented. The intent of this article is to help "fill in the gaps" on these issues through a discussion of the effect of diaphragm forces on the supporting steel beam behavior, as well as through practical detailing guidelines.

General Diaphragm Behavior

Before delving into the specific issues associated with the transfer of diaphragm forces to the supporting framing, it is necessary to understand general diaphragm behavior and how assumptions made affect the detailing required in establishing a robust load path. Figure 1 depicts a floor plan for a typical steel building. Braced frames are provided adjacent to stairwells near each end of the building to resist the lateral loads, and the diaphragm strength is assumed to be adequate to transfer the shear around the openings. In a simple analysis, the floor diaphragm is idealized as a continuous cantilevered beam and the braced frames are treated as beam supports. Due to the symmetry of this example and assuming the braced frames have the same geometry and stiffness, the diaphragm force at each braced frame will be equal to 50% of the total applied lateral load.

Depending on the magnitude of lateral load to be transferred to the braced frames, the designer can detail the force transfer to occur uniformly along the entire frame line between grids *A* and *D* on the grid lines where the braces occur, or they may elect to concentrate the load transfer to a segment of this length, such as the beam in the braced frame between grids *B* and *C*.

In the first scenario, the load distribution is proportional to the overall available transfer length, and beams *A-B* and *C-D* each collect 35% of the total force while beam *B-C* collects 30% of the total force. Beams *A-B*, *B-C* and *C-D* are all crucial members for getting load to the lateral load resisting system, and the connections of these beams to the columns at grids *B* and *C* must be designed for a horizontal force equal to the axial load being transferred through the column joint to the braced frame plus a vertical shear force resulting from the eccentricity of the diaphragm relative to the beam centerline. These member forces will occur simultaneously with the vertical beam shear reactions due to the gravity loads. Design and detailing of these joints for the combined forces is often overlooked.

In the second scenario, beam *B-C* collects 100% of the force. The distribution of axial, shear, and flexural member forces due to the applied lateral load for this beam will depend on the specific braced frame configuration. Once defined, these forces can be transferred into the braces with standard braced frame connections. Figure 2 illustrates the shear flow associated with this scenario.

Tension and compression chord forces are developed at the perimeter of the floor diaphragm due to the lateral loads. Typically, the floor slab concrete can resist the compression chord forces. Tension chord forces can be resisted by the spandrel steel beams, continuous steel closure plates, or by reinforcing steel within the concrete slab. In order to use the spandrel steel beams as the tension chord, the diaphragm chord forces must be transferred into the steel beams, and the steel beam connections at the columns must have sufficient strength to transfer the beam forces through the column joints. Again, this is a condition that often is overlooked, where the beam connections must be designed for the combined effects of vertical shear loads and horizontal axial loads.

Once the basic distribution of horizontal forces is understood, the effect of these forces on the design of the composite beams can be examined.

Figure 1. Typical building floor plan

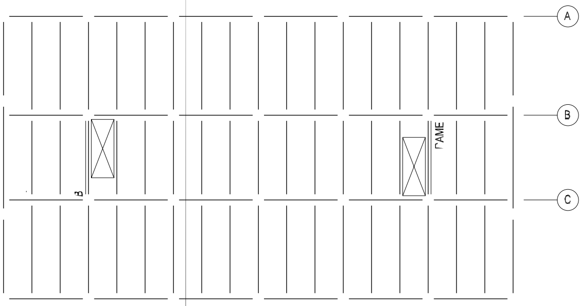

Figure 2. Shear flow from lateral loads

Force Interaction

The rigorous design of composite beams for combined axial force and flexure is complex. As a reasonable simplification for design purposes, it is acceptable to use the non-composite axial strength and the composite flexural strength in combination using the interaction equations in the AISC , Chapter H. Note that for compressive loading, this type of composite beam-column is generally considered unbraced for buckling between braced points about the major axis, and fully braced by the composite diaphragm for buckling about the minor axis.

As with all structural systems, there is an element of engineering judgment involved in the proper design and detailing of horizontal diaphragms and composite beam interaction. Careful consideration should be made to provide a continuous load path. The designer must account for the required axial forces and shears to be transferred at the end connections of all beams. Though there are many aspects to consider for the design of composite beams subject to horizontal diaphragm forces as reviewed in this article, their implementation is straightforward, thus allowing the composite beams to be used as an economical and efficient component of the lateral force resisting system.