Understanding how load travels through a structure is the key to optimal design.

steelwise

ON THE RIGHT PATH

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WHAT'S ONE OF THE biggest challenges any structure on the planet has to deal with?

Gravity.

Thanks to gravity (and physics in general), load applied to any structure must travel through the structure to the foundations and ultimately to the ground. The path it travels along is considered its load path.

Load paths must be continuous and complete between elements in a structure. Discontinuities require loads to jump joints or members, an impossibility that can lead to situations where the structure may not behave as designed. The more serious the discontinuity, the greater the likelihood that it could ultimately lead to structural failure. Each element along the path must have sufficient strength and stiffness to transfer the loads in along the path. Here are some ways to properly account for an adequate load path and some pitfalls to avoid.

Keep it Short (and Simple)

When transferring gravity load through the framing, the shortest load path is typically the best solution. However, a longer load path may be required if needed to spread load or due to architectural constraints. Short and simple load paths are generally the best load paths. Figure 1 illustrates how to transfer forces from a discontinuous column above into the framing below. The example on the left has the advantage of distributing load to limit the beam depth, and the example on the right is a more direct load path and has fewer pieces.

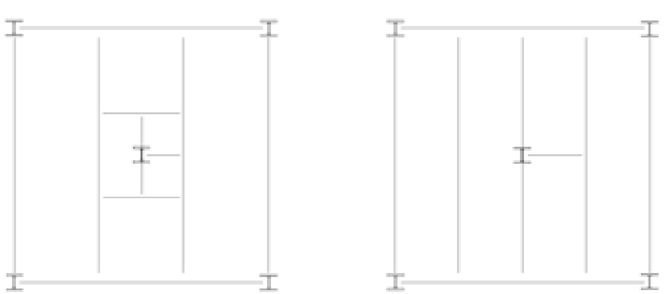

Figure 1

Force Follows Stiffness

The path that the force will follow is dependent on the stiffness of the elements in the structural system. There exist multiple load paths for forces to the foundation, and no single load path is the only means to transfer forces to the foundation; the stiffness and strength of the elements comprising the structural system are what determines the load path. Figure 2 shows a simple representation of a beam with an asymmetric point load. One end is three times stiffer than the other (remember the basic principles of compatibility, *PL/AE*) since the applied load is closer to the support resulting in a shorter segment length and both beam segments must move together.

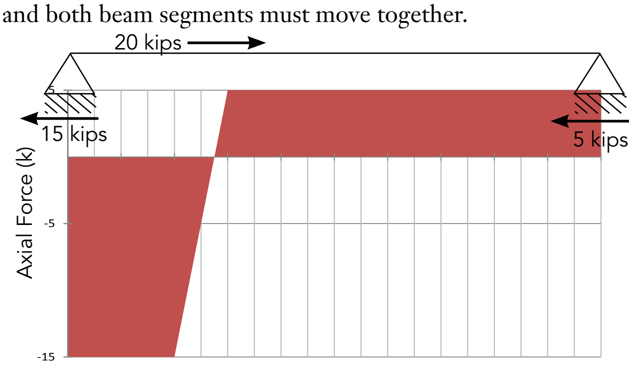

Figure 2

Don't Forget Diaphragms!

Diaphragms are an important part of the load path for the lateral system. The diaphragm not only transfers force to the lateral force resisting system (LFRS) but can also be used to transfer forces in a discontinuous bay.

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If there are discontinuities in the LFRS, then the lateral force in a discontinuous bay needs to be transferred to the lateral system below. The forces can go through the diaphragm or framing members (drag struts) if the diaphragm has insufficient strength. In the upper example of Figure 3, one might think that the force is transferred through the steel—and with the bottom example, one might think that the forces would transfer through the diaphragm. However, either way is possible. If it is a steel-to-steel transfer (meaning the diaphragm does not have sufficient strength), then the transfer forces should be noted on the design drawings indicating the proper load path to the LFRS.

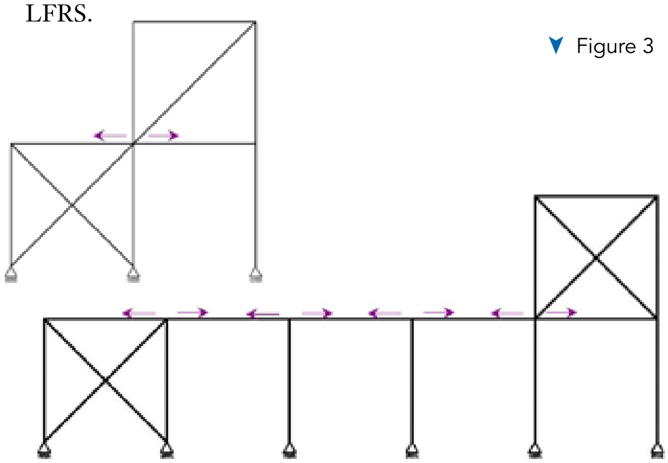


Figure 3

Also note that transfer forces on opposite sides of the column should be equal to maintain equilibrium at the joint. In addition, beams of the same nominal depth will facilitate more economical connections and framing for transferring these forces at column webs. Special attention is especially needed at the roof where the metal deck typically has limited strength. (See Figure 4.)

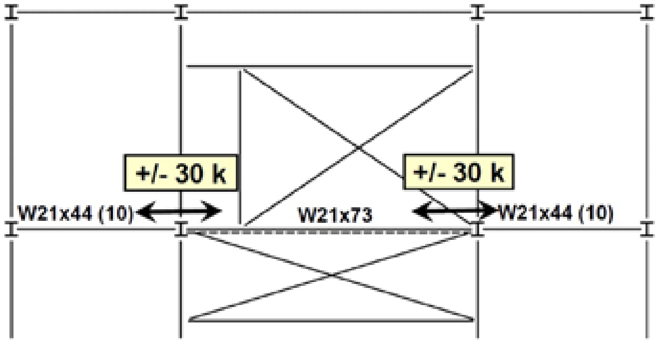


Figure 4

Forces are not Always Apparent

Overhangs, sloping columns and bracing connections that meet at a joint may require a look at the actual details to determine how the force is transferred. The force transfer may not be so apparent from a computer model or force output.

There are often transfer forces to consider when bracing connections meet at a joint. Horizontal bracing or vertical bracing connections separated by drag and strut elements in the floor diaphragms may also require that transfer forces be considered. Typically, members are denoted as single lines on plan and framing members at the joints can be oversimplified. For example, Figure 5 shows horizontal bracing on each side of the column. Horizontal gussets are used to transfer the force around the column. For a complete load path, the horizontal gussets transfer the brace force to the beams and the beam-to-column connections transfer the beam axial force to the opposite side of the column. In plan, on a set of drawings these could look like three members (two beams and a horizontal brace) framing into the column. If proper consideration of the transfer forces is not given, then there could be a discontinuity at the connection and an undersized beam for the transfer forces from the horizontal brace. The load has to get around the column, and a proper load path should be provided.

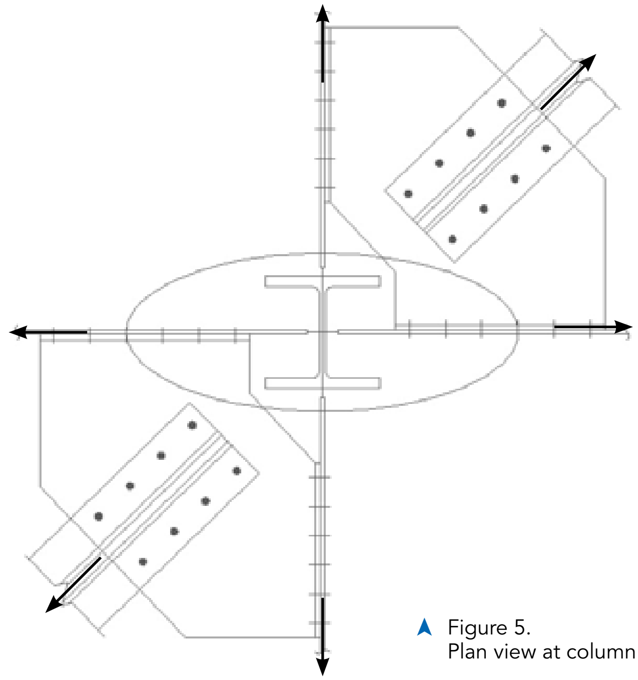


Figure 5.
Plan view at column

Consider Stability

When drawing single lines for members that meet at joints, it is often easy to overlook the connections that can result in instability of the system. The overhang (shown in Figure 6) has a complete load path but is not stable. In this instance the overhang was shown as a simple connection. When detailing the connection this potential instability was brought to light and the missing moment connection was provided. Finding potential issues can be accomplished by studying the joint equilibrium and stability of the system.

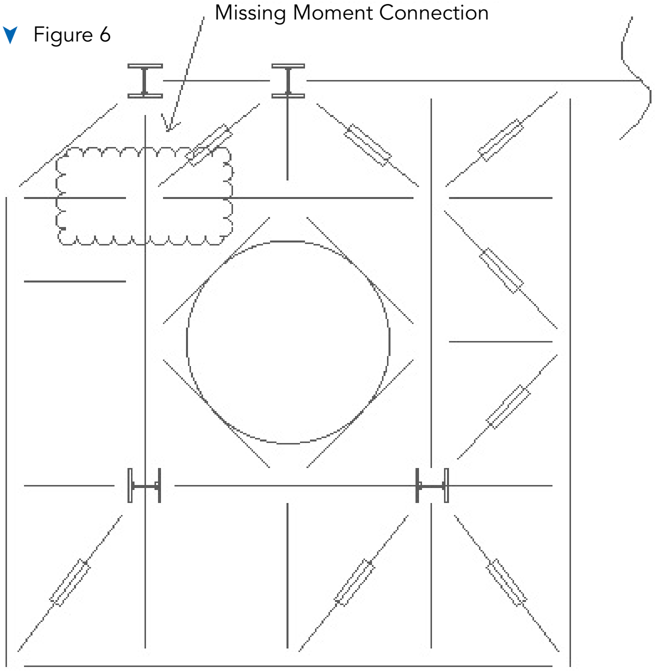


Figure 6

Joint Equilibrium

The joint is in equilibrium when summation of the forces at the joint equals zero. Checking equilibrium is a good way to find discontinuities or unbalanced forces. For example, sloping columns produce thrust (in the form of a force couple) at the floors connected to the column. The floor framing must resist the resulting loads from the force couple and transfer them to the LFRS through the floor diaphragm. If the thrust forces are not properly considered, then the beam might not have sufficient strength to resist the imposed loads. Therefore, a sufficient continuous load path must be well thought out for the applied thrust to travel through the framing to the LFRS and into the foundation. It is important to provide these thrust loads on the design drawings and to properly account for them in the member and connection design. This is also true when designing kickers. The kickers impose a thrust force on the beam and column that that might not be intuitive when designing this type of system. Looking at joint equilibrium explains the load path and makes clearer how forces are transferred (see Figure 7).

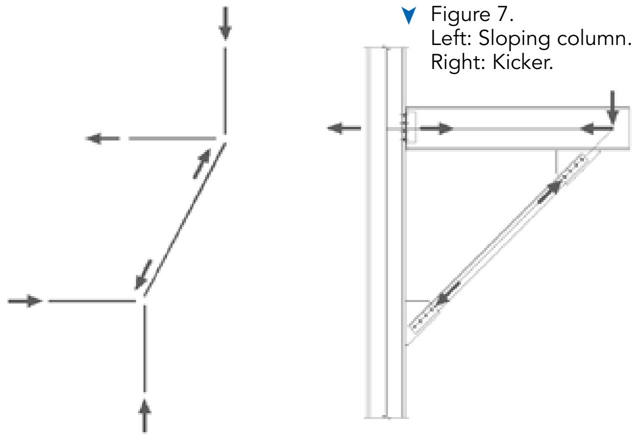


Figure 7.
Left: Sloping column.
Right: Kicker.

The Weakest Link

A continuous load path is only as strong as its weakest link. Looking at joint equilibrium will help the understanding of how the load travels into the framing through the connections. For moment connections, considering joint equilibrium as related to load paths can help determine doubler and stiffener requirements. Based on joint equilibrium, the correct loads are established, which can be used to assess the need for doublers at the column web of a moment connection. These correct loads are also used to size the column stiffeners, the stiffener welds and doublers (see Figure 8).

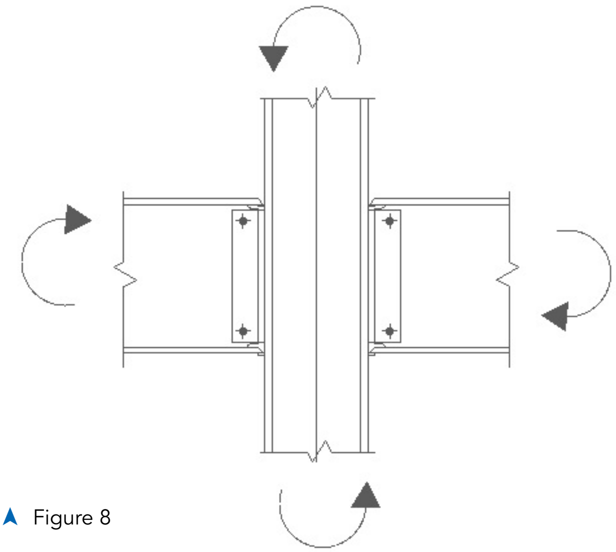


Figure 8

Limiting Forces

When looking at joint equilibrium of moment connections, there are some important points to consider. For example, if you're thinking about incorporating doublers at moment connections to column flanges, note that the sum of the beam moments cannot exceed the sum of the column moment strengths. Failure to recognize this limit may lead to the use of excessively large doublers or even unnecessary doublers. Therefore, it is important to properly size the doublers with the correct load at the connection and not overestimate the load being transferred.

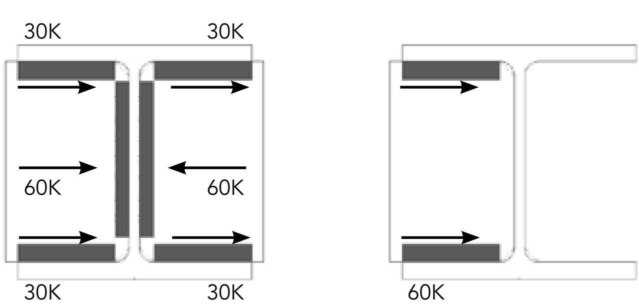
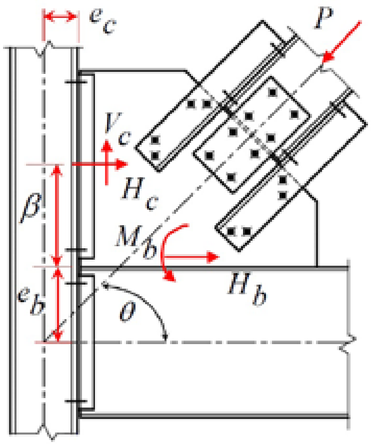


Figure 9. Two-sided (left) and one-sided (right) stiffener connections.

When designing moment connections to column webs, stiffeners are often two-sided but can also be one-sided. The number of stiffeners will impact the load distribution to the column (either through flange welds on one side of the column or both sides of the column). Since considering the load path will help size the stiffener welds, it is important to pick a load path and stick with it (see Figure 9).

Design Tip:
When designing gusset connections, if you prefer the KISS (keep it simple, stupid) method but the uniform force method (UFM) seems like a more economical choice, then you can easily use UFM Special Case II. This method has the advantage, associated with UFM, of not designing the column flange for moment and the KISS method benefit of simple statics.



True Load Paths

In the case of trusses, the truss members are depicted as lines that join at the center of the joint. In the model, you have three lines coming into a point but in reality you have three members being connected. The flow of forces must be understood to properly design the connection. A free body diagram similar to what is shown in Figure 10 can facilitate this understanding. Not accounting for this load path can result in an undersized flange thickness to adequately transfer the forces.

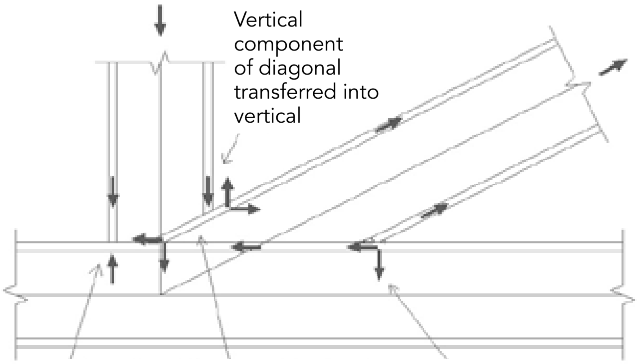


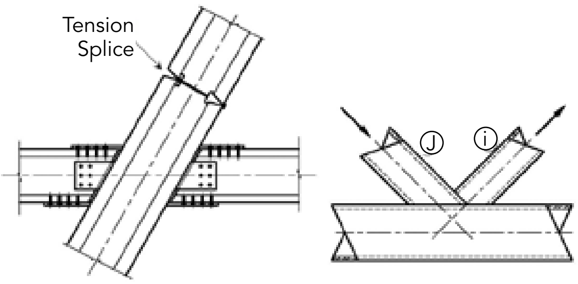
Figure 10. Connections – Trusses

- Welded Truss—understand load path
- Joint must be in equilibrium
- Check for stiffeners and doublers at relevant sections
- Pick a load path and stick with it
- See Blodgett's *Design of Welded Structures*

Work Points Matter

When looking at overall joint geometry, consider where the work points are located when designing connections. Shifting work points may sometimes be needed due to existing interferences (e.g., a concrete slab interfering with the brace connection at column bases). Satisfying the equilibrium of the connection with shifted work points might result in a moment on the main member. Connections should not induce moments on supporting members when those moments have not been considered in the design. It is important to consider the work points that are used to design the main members when sizing the connections. Considering the load paths and following the forces can also be a check of global stability of the framing system.

Design Tip:
Which Member Should Be the Continuous Member? When connecting members, typically the larger member with the greater load should be made continuous. As an example, consider vertical trusses and HSS truss connections. The larger member at the connection should be continuous while the smaller load-carrying members connect to the larger member.



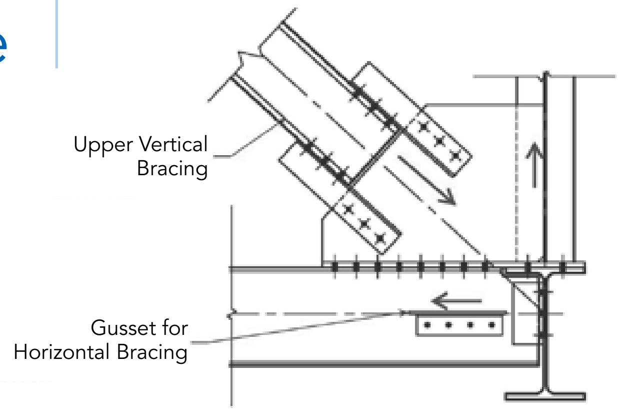
Example Load Paths

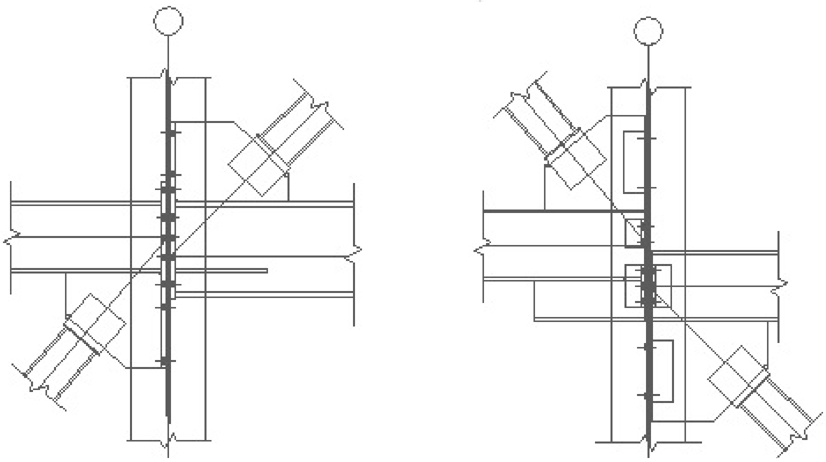
Now that we've learned some of the dos and don'ts, let's take a look at good examples of proper consideration of complete load paths. Figures 11 and 12 are some examples of a good load path. And remember these key points:

- Provide a straightforward continuous load path that does not loop
- The shortest complete load path is typically the best solution
- If the diaphragm has insufficient strength, then steel-to-steel transfer forces are required
- Satisfy joint equilibrium, which provides continuous load path through the connections
- Avoid discontinuities when transferring forces
- A continuous load path is only as strong as its weakest link

Figure 11

Figure 12





Understanding how load travels through a structure will assist with better built designs, while improper load paths can result in construction issues or loading that was not considered in the design of the system. Most importantly, a good load path is continuous and travels complete through the LFRS into the foundation.

This topic will be presented at the 2015 NASCC: The Steel Conference in Nashville. Make plans to attend the conference and see load paths explained live! ■

This article is based on the presentation "Load Paths" by Carol Drucker from AISC's Live Webinar series and the 2013 NASCC: The Steel Conference. An updated version of the presentation will be presented at the 2015 conference in Nashville (visit ***www.aisg.org/nascc****). For more on lateral load resisting systems and how to implement them, see the July 2010* Modern Steel *article "Horizontal Bracing" at* ***www.modernsteel.com****.*