Handle challenging connections with these helpful tips.

conference preview

SIMPLIFYING TRICKY CONNECTIONS

BY LOGAN CALLELE, P.ENG.

ANY DISCUSSION OF STEEL CONNECTION DESIGN is sure to elicit strong opinions and a wide variety of approaches to the design process.

This variance reflects both the wide range of connection geometry and types as well as the lack of codified design procedures that deal with connections as a whole—most codified design guidance deals with the connection components only. Furthermore, dealing with a wide range of load paths, practicalities and load combinations results in countless design approaches.

Consulting the Map

With all of these possibilities, it's helpful to have a road map for navigating the options, from simple-beam or brace-end connections to complicated vertical bracing connections. The road map's basic approach, illustrated in the following steps, will focus on critical boundaries within the connection that define the type of behavior that the designer wants to see. As with many engineering problems, it starts with what the designer knows and then logically addresses the remaining details until the design is finished.

1. Start with an understanding of the construction type expected—bolted connections, welded connections, or a combination thereof.
2. Assess the connection geometry. Draw in the parts of the connection that you know. For example, in many bracing connections the connection's capacity may be limited by a critical gusset plate mechanism, but the overall gusset geometry is primarily determined by the brace size, angle and end connection. Thus, start the design process by drawing out as much of the connection as possible, which will help establish geometric limits for the connection component calculations completed later.
3. Establish a continuous load path that will provide the connection behavior required, taking into consideration how the external forces are introduced into the connection and how they are transferred along the load path.
4. Decide what boundary within the connection will be critical for establishing an internal force distribution consistent with the desired behavior and load path. For example, take a look at the common wrap-plate connection illustrated in Figure 1. On the boundary between the connecting angle and the beam web it is critical to assume that there is only a shear force (parallel to the long axis of the beam). If a normal force (perpendicular to the long axis of the beam) at this boundary is assumed, then the beam and the beam-end connection would need to be designed for the lateral shear that this normal force would create.

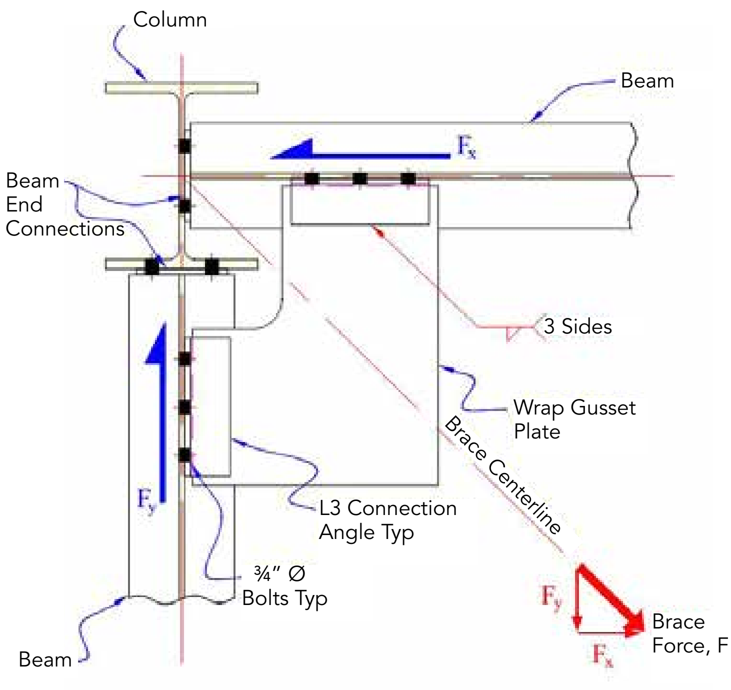

Figure 1. Wrap-plate connection boundary forces.

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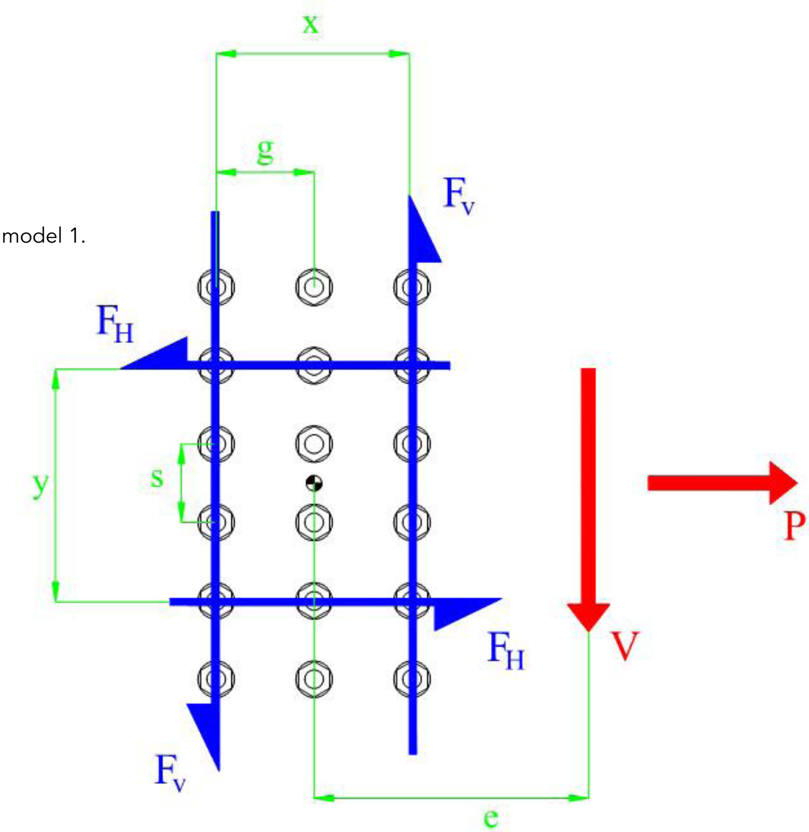


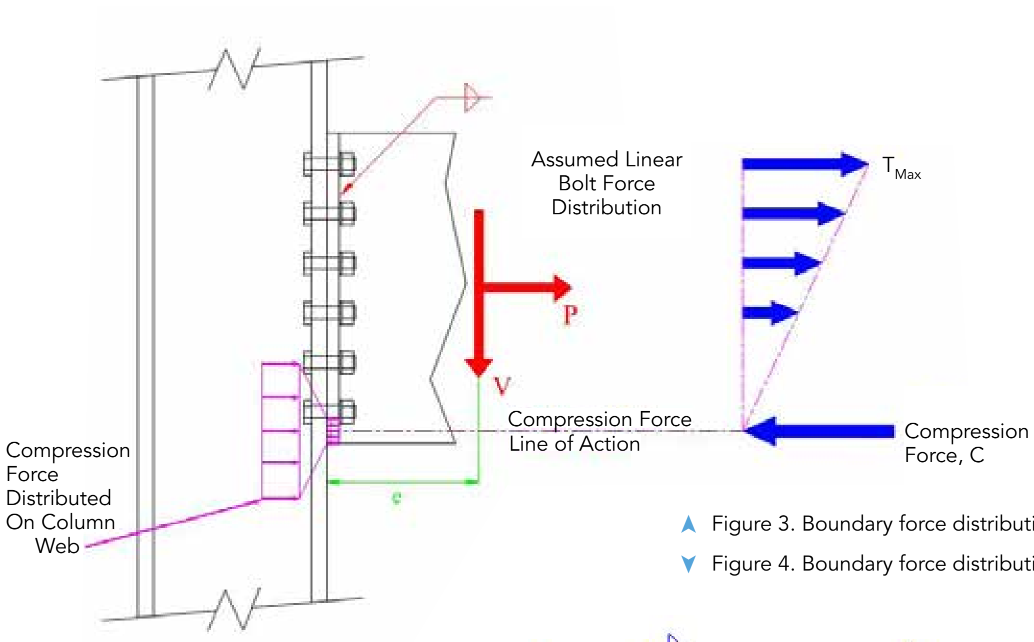
➤ Figure 2. Boundary force distribution model 1.

5. Using the known external forces and connection geometry, draw the free-body diagram (FBD) of the connection and calculate the moments and forces at the critical boundary in a way that is consistent with the expected behavior and load path. It can be helpful to assess the local stiffness of the connection components to establish the FBD for statically indeterminate connections. In such cases it is usually best to consider a range of possible relative stiffnesses to identify the range of load distributions and see how sensitive the FBD is to the assumed behavior.
6. Apply an assumed force distribution to the boundary that will satisfy statics. Typically, selecting one of the three models presented herein will suffice, but there are many more possible distributions.
7. Follow the assumed loads through the connections and associated members. Assess ductility and make use of the lower bound theorem. Ductility demands and stability concerns are the two primary causes for having to modify the assumed loads. Ductility demands arise from either imposed deformations (beam end rotation or seismic considerations, for example) or load redistribution possibilities when dealing with statically indeterminate connections. Ductility concerns usually are associated with fracture of connection components such as plate or welds. Stability concerns often arise from two dimensional buckling concerns, out-of-plane eccentricities and end restraint assessments.
8. Following the load path and applying the assumed load distribution, the codified connection component checks, such as those found within the AISC *Specification*, can be applied. Some other design checks not covered by codes may still be called for, such as a yield-line analysis for plate flexure or checking the plastic cross-sectional strength of plates for shear and normal stress interaction.

Common Connection Boundaries

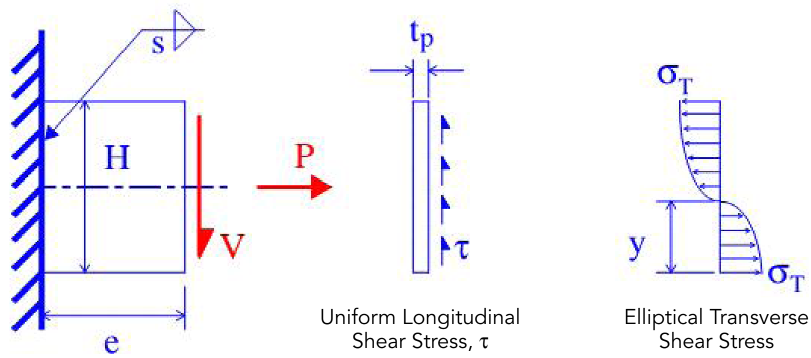
Next, let's take a look at common connection boundaries. Three common boundary force distributions are presented, all of which are easy to implement in hand calculations or simple spreadsheets. More complex models and/or finite element analysis would undoubtedly describe the actual behavior more accurately, but these models are intended for use in the above-mentioned procedure, and as such they must strike a balance between ease of use and degree of conservatism. The models are also structured so that they have clear forces that can be used to follow the assumed load path through the connection.

In-plane eccentrically loaded bolts. Though the instantaneous center of rotation approach is the most common method for analyzing eccentrically loaded bolt groups, the proposed distribution shown in Figure 2 is useful because it simplifies the force distribution from a force vector on each bolt to the two force couples, F_H and F_V, shown in the figure. Setting the ratio of F_H to F_V equal to the ratio of the force couple lever arms, y to x, produces a quick and simple model for the forces on the bolt group. If the critical connection boundary is an in plane eccentrically loaded bolt group, these forces can then be followed through the rest of the connection's load path.



▲ Figure 3. Boundary force distribution model 2.

▼ Figure 4. Boundary force distribution model 3.



Eccentrically loaded bolts in tension. If the critical connection boundary is an out of plane eccentrically loaded bolt group, such as that shown in Figure 3 for the welded T-plate, a simple linear distribution can be used to establish the bolt tensile forces (a similar model is also presented in the AISC 14th Edition *Manual* in Figure 7-6). It is possible to establish an explicit equation for the maximum tensile force in the bolts, and the designer can choose to use as many bolts in resisting the eccentric shear as is appropriate to the design scenario. Lastly, the compression force can be distributed through the connection to ensure the web of the column has sufficient capacity to resist it.

Eccentrically loaded welded plate boundary. Welded connection plates are a very common critical connection boundary. Using an elliptical distribution for the transverse shear stress on the fillet weld, the weld capacity can be estimated to be within 3% of that predicted by the instantaneous center of rotation analysis. The maximum transverse shear stress σ_T, and the uniform longitudinal shear stress, τ, conform to the fillet weld design strength given in the AISC *Specification*. In a similar manner to the previous two models, the force distribution on the welded boundary can then be followed through to the rest of the connection to ensure all connected elements on the load path are adequate. ■

This article is a preview of Session N75 "Simplifying Tricky Connections" at NASCC: The Steel Conference, taking place April 13-15 in Orlando. Learn more about the conference at www.aisc.org/nascc.