The Benefits of Showing Reactions

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This is the first in a series of articles relating to structural engineering Quality Assurance that will be appearing in STRUCTURE magazine. QA Corner articles will be published four times a year, and will discuss issues related to the broad topic of Quality Assurance within the structural engineering profession – specifically how structural engineering firms can improve the quality of design and documentation of their design. The author welcomes feedback on the topics discussed, as well as suggestions for future QA Corner articles – so please email your comments and suggestions.

This month's topic deals with the issue of structural steel connections and how best to specify connection design requirements on structural drawings.

Documentation of structural steel connection design requirements on the contract documents is an important responsibility for engineers. Most structural failures are connection failures. Likewise, the cost of connections is a significant percentage of the in-place cost of structural steel buildings. It is therefore crucial that engineers specify accurate connection requirements to insure structural integrity while not being overly conservative. Although precise figures are hard to come by, a case can be made that approximately one half of the total cost of in-place structural steel is in some way associated with the cost of connections. Specifying overly conservative connection design requirements can penalize the cost of structural steel by ten percent or more. In contrast, clearly specifying accurate and reasonable connection design capacities can result in savings of five to ten percent depending on the complexity of the framing.

In steel framed construction, many Engineers of Record delegate responsibility for design of connections to the steel fabricator's engineer. In order to most accurately convey connection design requirements, engineers delegating connection design responsibility should show all beam reactions, connection moments and member forces. Engineers should indicate preferred connection details; however, fabricators should be permitted to recommend alternative details, provided those details meet the performance requirements specified by the engineer and provided that those alternative details are justified by engineering calculations provided by the steel fabricator's engineer. This process contributes to the most efficient and cost-effective design by allowing fabricators to detail connections for the actual reactions and forces using their preferred connection details.

Some engineers elect not to show reactions, moments and member forces on the drawings and instead specify that connections be designed for a defined strength – quite often the "full strength of the member". For beams, "full strength" is usually defined as an often arbitrary and usually conservative percentage of the total uniform load capacity of the member. Moment connections are likewise often specified to develop the "full moment capacity" of the beams. While this procedure may have been a good idea years ago, it is no longer the best way to indicate required connection strengths. Specifying that connections be designed for "full strength" or a percentage of uniform load capacity will usually result in connections designed with substantially more strength than required. While some reserve capacity in connections is good, having substantially more usable strength than required by analysis is a wasteful practice. In reality, connections designed for the exact applied design loads will, in fact, have a safety factor (ratio of nominal strength to required service level load capacity) of about two.

Fortunately, the additional effort required by engineers to document required connection design strengths is minimal. With the use of computer analysis and design software, designers can easily indicate reactions, moment

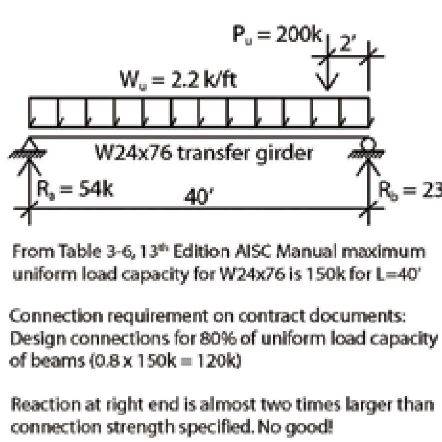

Figure 2: Specifying required connection strength as a percentage of beam uniform load capacity can result in dangerously under-strength connections.

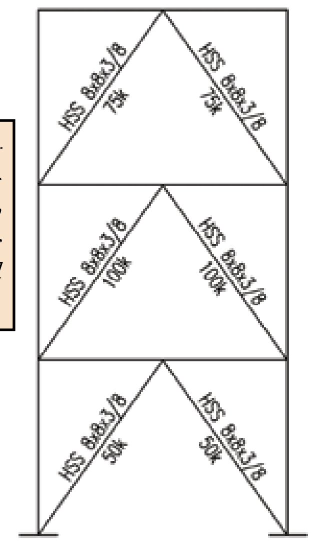

Figure 1: Anomaly in path of lateral loads through braced frame would not be evident were brace forces not indicated.

connection capacities and member axial forces on the contract documents with little more than the push of a button.

There is another benefit to showing reactions on the drawings. From a quality assurance standpoint, when reactions, connection moments and member forces are shown on the drawings, engineers reviewing the drawings can more readily see the flow of load through the structure and spot mistakes that might otherwise be hard to find. Showing reactions and forces on the drawings can reveal flaws in the computer design model. *Figure 1* shows a braced frame with member forces indicated. An engineer looking at this braced frame would question why the brace force is smaller on the lower level than on the levels above. Although the reason for the smaller brace force may be valid (such as a rigid diaphragm diverting load into adjacent lateral load resisting elements), it could point to a mistake with the computer model or a load path issue that was not considered. Had the forces not been indicated, this error would have been less evident.

Some argue that showing reactions on the drawings increases the chances of making a mistake, and it is therefore better to specify conservative global connection design requirements. Although this concern is understandable, it is not a valid reason to omit such critical information from the drawings – especially if connection design responsibility is being delegated to the steel fabricator's engineer. The solution to the concern of mistakes slipping by is to have another engineer review the drawings to catch the mistakes before they are issued. An in-house quality assurance review will not only catch errors with connections, but will catch other errors as well.

There are some situations where specifying beams be designed for a percentage of their uniform load capacity could actually result in under-strength connections. *Figure 2* illustrates the biggest danger of specifying beam reactions as a percentage of beam capacity based on uniform loads. When large concentrated loads occur near the ends of beam spans (such as with transfer girders), reactions at supports nearest the concentrated loads can far exceed connection requirements based on percentages of uniform load capacity. Such situations can result in seriously under-designed connections.

Most floor framing members today are designed as composite beams. The uniform load capacity tables in the AISC Manual are based on non-composite beams. Engineers using the uniform load capacity tables to specify required connection strength need to select an arbitrary modification factor to apply to the values in the load tables in order to be conservative; and yet, that modification factor should not be so conservative as to add unnecessary cost to the structure. Why not just indicate the actual beam reactions on the framing plans?

Figure 3 illustrates an example where specifying connection strength based on a percentage of uniform load capacity can result in specified connections strengths far greater than actually required based on actual loads. In this illustration, a high beam frames into a low beam. The high beam was made deeper than required for strength to facilitate the connection to the low beam. Because the beam is deeper than that required for flexural strength, basing connection strength on an

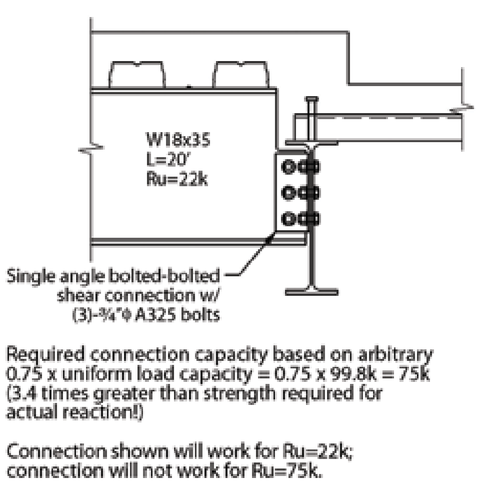

Figure 3: Specifying required connection strength as a percentage of beam uniform load capacity can result in inefficient and overly conservative required connection strengths.

arbitrary percentage of uniform load capacity would yield a connection strength requirement substantially larger than the actual reaction based on loading.

Specifying that moment connections be designed for the "full capacity" of beams is an especially wasteful practice. Required moment strengths at beam-to-column connections are usually substantially smaller than the full moment capacities of the beams. Requiring design of moment connections for the full flexural capacity of beams could result in installation of expensive and otherwise unnecessary column web stiffeners, column web doubler plates, complete joint penetration field welds or flange plates with a substantial numbers of bolts.

Many engineers specifying "full capacity" moment ($ØM_p$) connections do not realize that accomplishing the task of transferring the full moment capacity of a beam through a joint also requires special detailing of the beam web to column connection (rarely provided) in order to achieve the full $ØM_p$ moment transfer through the joint. Most beam-to-column moment connections with complete joint penetration beam flange welds to column flanges and standard beam web shear connections will only develop about 66 to 80 percent of the $ØM_p$ moment capacity of the beam. (The exact percentage depends on the beam geometry.) Likewise, the maximum capacity of flange-plate bolted moment connections can be limited by the size and configuration of bolts through the flanges of the beam.

Rather than specifying "full capacity" moment connections, a better practice is to simply show the required capacities of moment connections on the drawings, and permit the fabricator's engineer to design those moment connections to resist the indicated moments. *Figure 4* illustrates two beam-to-column moment connection details. One connection is detailed for the "full flexural capacity" of the beam (in reality probably closer to 75% of $ØM_p$) and the other is detailed for the actual moment at the joint as determined by analysis.

Forces for braced frames and truss member connections should similarly be indicated on the contract documents. The cost of connections for heavily loaded trusses can be substantial. Connection material on heavy trusses can amount to twenty to thirty percent of the truss weight. Designing connections for the actual truss member forces will minimize the cost of these connections.

There is a trend among many structural engineers today to delegate connection design to the steel fabricator. The easiest way to best accomplish this delegation of responsibility is to show the beam reactions, connection moments and member forces on the structural drawings. Doing so will most accurately convey the connection strengths required to provide for a safe design, and will allow the steel fabricator's engineer to properly design the connections in the most economic and constructible manner. This practice enhances the safety and economy of steel framed structures.

If you have any comments on this topic, or suggestions for future QA Corner topics, please email the author.▪

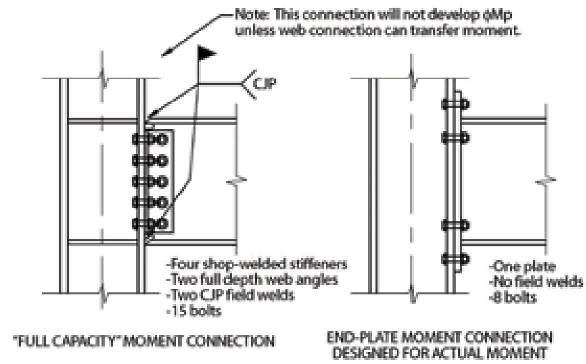

Figure 4: Comparison of "full capacity" moment connection versus moment connection detailed for actual moment.

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