Tips for Designing Constructable Steel-Framed Buildings

BY CLIFFORD W. SCHWINGER, P.E.

Here are 26 ways engineers can enhance constructability by keeping connections in mind as they make design decisions.

THE TERM "CONSTRUCTABILITY" defines the ease with which structures can be built. The more constructable a structure is, the more economical it will be. There are four principles of constructability:

- Simplicity = economy.
- Least weight does not always equal least cost.
- The fewer the number of pieces, the more economical the design.
- Efficient connection design = economical design.

Decisions made by engineers during design affect constructability. Seemingly small changes in framing configurations, geometry and connection design requirements, can significantly affect the cost of the structure, as can numerous other variables.

There are usually several good solutions to design challenges. There is, however, one common thread in the suggestions offered below—they all relate, in one way or another, to connections. If designers think about connections during design, they will enhance the constructability and economy of the steel-framed structures they design. Here are some specific suggestions.

Show actual reactions, connection moments and member forces on the structural drawings and permit fabricators to design and detail their preferred connections. This is the single most important thing engineers can do to enhance constructability and reduce the cost of an already efficiently framed steel structure. Designers should avoid globally specifying that all connections be full depth or referring to beam reaction tables that list "one size fits all" conservative reactions for beams of specific depths. Likewise specifying that connections be designed to support arbitrary percentages of beam uniform load capacities for given spans is usually excessively conservative, but on occasion can be the exact opposite and seriously understate the required strength of a connection. The latter can occur when heavy concentrated loads occur near the ends of spans.

Avoid mandating arbitrary connection design requirements more restrictive than those required by the building code, AISC 360-05 or AISC 341-05. Much research has gone into the development of safe and reliable structural steel connections and procedures for designing those connections. Here are three examples.

- Do not require all bolted connections to be designed and detailed with slip-critical bolts, except where required by AISC 360-05 or AISC 341-05.
- Do not require that all bolt holes be standard sized holes. Fabricators and erectors need adjustability to accommodate fabrication and erection tolerances.
- Do not prohibit "one-sided" connections such as single-angle connections and single-plate shear connections. These types of connections have been used successfully for decades without problems.

Consider how connections will be designed and detailed even when delegating connection design work to an engineer working for the fabricator. Designers who consider how connections will be designed and detailed are more likely to configure their framing in a manner that will allow for fabrication of constructable and economical connections.

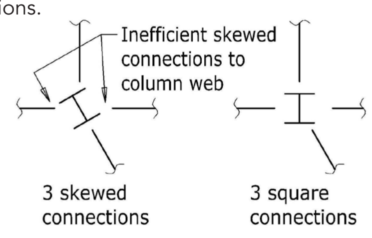
Frame beams to column webs and girders to column flanges. It's easier to maneuver small beams between column flanges than to maneuver larger girders into place. Girders with large reactions can be connected to column flanges with double angle connections. Beams with smaller reactions can be connected to column webs with single angle connections, although this may result in trapped bolts.

Consider deeper columns for easier beam-to-column web connections. Single- and double-angle connections can be made to the webs of W10, W12 and W14 columns. Bolts must be staggered in connection angles for connections to W10 and W12 column webs, but not for W14 columns. Again, beware of trapped bolts.

Minimize the number of skewed connections. All fabricators can detail and fabricate skewed connections; however skewed connections are more expensive than standard square shear connections, primarily due to the need to shop weld skewed plates or fabricate bent plate connections. Where columns are involved, consider column orientation. Square connections to columns are less complicated than skewed connections (see Figure 1). If given the choice between skewed connections to the column web or to the column flange, opt for the skewed connections to the flange.

Frame heavily-loaded members such as transfer girders to supporting members to permit square connections. Connections with large reactions can be most economically

Fig. 1: Orient columns to minimize the number of skewed connections.



fabricated when the connections are square. If heavy skewed connections to columns cannot be avoided they preferably should be made to the column flanges. Figure 2 illustrates a comparison of three girder-to-column connections designed for the same reaction. The square connection is clearly the most efficient, and the skewed connection to the column web the most costly.

Avoid skewed columns in braced frames. Do this at all cost—especially when the diagonal braces would frame on a skew to the column web. Large reactions often occur at diagonal brace connections to columns. Figure 2 illustrates the inefficiency of having to design skewed connections to columns. Strive to configure columns in braced frames so that bracing connections are square to the columns.

Head off steeply skewed connections. Steeply skewed connections can require large beam copes and limit connection options, primarily due to difficulty installing field bolts to the webs of the supported beams. When skew angles are steep and reactions are large, consider heading off skewed members to simplify connection geometry (see Figure 3).

Size columns to avoid the need for stiffener plates. Installation of column stiffener plates at beam-to-column moment connections adds cost and complexity. Connections to the column web will become more complex due to interference with the stiffeners. See Figure 4.

Configure framing so that no more than one member frames to any one side of a column. While computer software can easily design framing with multiple members connecting to one side of a column, detailing and fabricating connections for such conditions can be difficult. The biggest challenge is usually that of access for bolt installation.

Where skewed connections occur to HSS columns, favor round over square or rectangular columns. All beam-to-pipe column connections are square connections, regardless of the angle at which the beam frames.

Increase beam depth to avoid reinforcing webs at large copes. Large copes at the ends of beams can occur where high beams frame to low girders or at steeply skewed connections between beams and girders.

Configure braced frames with optimal column orientations, brace geometry and brace types. Orient columns square with diagonal bracing, preferably connecting bracing to the column flanges. Configure diagonal braces to have slope angles between 35° and 55°.

Select appropriate brace types. *Single angle cross bracing* is good for loads in tension only; efficient bolted connections. *Double angle bracing* using double shear bolts has very effi-

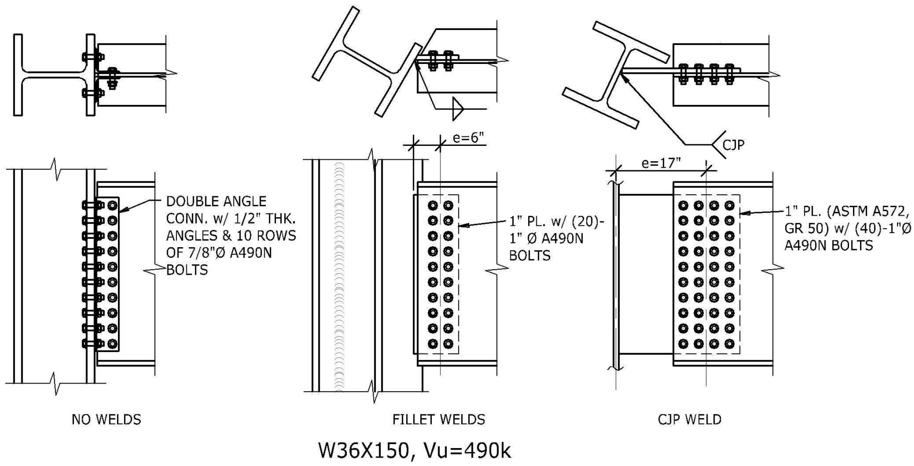


Fig. 2: Square connections to columns are the most efficient; skewed connections to columns are the most complex.

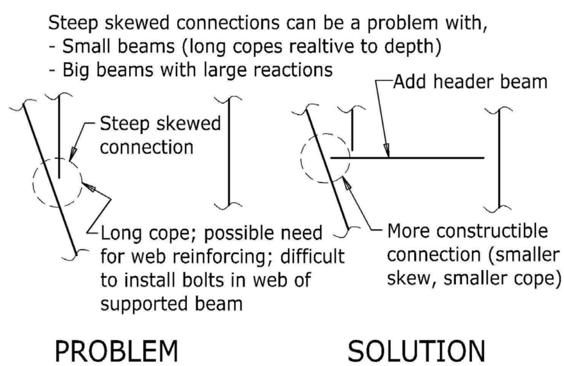
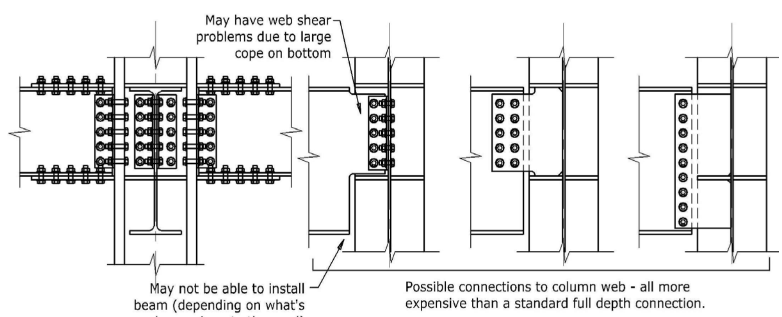


Fig. 3: Head off steeply skewed beams.

Fig. 4: Column stiffeners add complexity and cost.



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cient connections. *HSS braces* provide more strength per lb than any other type of brace but the connections are more involved. *W-shape braces* can resist large axial loads, but connections are also more involved.

Do not use a Seismic Response Coefficient greater than *R*=3 unless required by code. Seismic Design Category B and C structures in areas of low to moderate seismicity are most economically designed using *R*=3. The use of higher Seismic Response Coefficients will impose additional and more stringent connection and member design requirements.

Avoid arbitrarily specifying CJP groove and "all around" fillet welds. Requiring welds larger than those required for strength is wasteful and inefficient.

Consider large fillet welds instead of CJP groove welds. Backing bars, weld access holes and bevel preparations are not required when beam flanges are moment-connected with fillet welds.

Use 5⁄16-in. or less fillet welds when possible. Fillet welds up to 5⁄16 in. can be made with a single pass, so when given the option of using a 3⁄8-in. fillet weld or using a longer 5⁄16-in. fillet weld, use the longer 5⁄16-in. fillet weld.

Use AISC 360-05 Equation J2-5 when designing transversely loaded fillet welds. Equation J2-5 permits up to a 50% increase in weld strength for transversely loaded fillet welds.

Use beams with flanges wide enough to accommodate bolts at bolted flange plate moment connections. Generally beam flanges must be at least 5 in. wide to accommodate ¾-in. diameter bolts, and 6 in. wide for ⅞-in. diameter bolts.

Coordinate beam web penetrations and design reinforcing at web penetrations where required. Do not delegate the design of reinforcing around beam web penetrations under the guise that such reinforcing is part of connection design. Doing so may lead to beam web penetrations slipping through the design process that are too large to be efficiently and economically reinforced.

Camber intelligently. Do not camber beams less than 25 ft long, beams in braced frames, beams with moment connections at one or both ends, nor beams smaller than W14. Do not specify camber ordinates less than ¾ in. Anticipate that there will be some loss of camber by the time the beam is erected. Do not require that the indicated beam cambers shall be the cambers measured after the framing is erected. Doing so is contrary to the AISC *Code of Standard Practice*. See the AISC website for additional information regarding cambering.

Configure framing to minimize the number of beams. The fewer the number of beams, the fewer the number of pieces to fabricate, ship and erect. Where bays are rectangular, beams should be oriented spanning in the long direction if doing so reduces the number of beams. Likewise, slabs-on-metal deck should be selected so as to maximize the slab span in order to reduce the number of beams. These recommendations not only reduce the number of beams, they have the added benefit of putting more tributary floor area on the beams which in turn permits a greater live load reduction (when live load reduction is permitted) leading to reduced steel tonnage. Larger tributary areas on beams also can reduce vibration. Thicker floor slabs increase the efficiency of composite beams.

Discuss preferred connection details with fabricators. Most fabricators are more than willing to share their thoughts with regard to preferred connection details and the economy of proposed framing schemes.

Engage in early, proactive communication with other consultants to avoid inefficient framing configurations. This will head off problems early in design when coordination issues are easy to deal with.

Summary

Efficient connection design is the single most significant element required in order to enhance the constructability of steel-framed building structures. Engineers who consider connection issues during design will improve the constructability and economy of their designs. MSC

*This article is an abbreviated preview of "50 Tips for Designing Constructable Steel-Framed Builings" which the author will present at NASCC: The Steel Conference, scheduled for May 11-14 in Pittsburgh. Learn more about The Steel Conference at **www.aisc.org/nascc**.*