SUPPORTING ROLE

Erecting steel joists without proper bridging can cause it all to come crashing down.

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ONE OF THE MOST IMPORTANT ASPECTS OF SAFE STEEL JOIST ERECTION IS PROPER BRIDGING. A joist may be unstable as soon as the hoisting cable is released, even if other applied construction loads aren't present. As such, three types of joist bridging play three different roles in creating stability: erection, construction, and permanent.

Erection bridging is required if the joist is not stable under the combination of its own weight plus the weight of the worker releasing the hoisting cable at the joist mid-point. Erection bridging is defined in the OSHA Federal Safety Standards, 29 CFR 1926.757, as "the bolted diagonal bridging that is required to be installed prior to releasing the hoisting cables from the steel joists." However, not all joists require erection bridging when being set into position on a structure.

The second bridging type—construction bridging—provides adequate lateral support for a joist and any construction loads on top of the joist while a permanent means of top chord lateral support, normally metal decking, is installed. Without proper lateral support, loads during construction can cause the joist to distort, roll over, or shift from its intended position, resulting in the ironworkers, joists, or construction loads—or all three—falling and causing injury and damage. Proper construction bridging can prevent such mishaps.

Finally, permanent bridging serves to permanently brace the top and bottom chords of the joist; it remains as part of the structural system for the life of the structure. In cases where the metal decking creates a sufficient diaphragm, permanent bridging isn't necessary at the top chord after construction is complete. One exception, however, is when a standing-seam metal roof is attached directly to a joist top chord. The Steel Joist Institute (SJI) has determined that this type of roofing system does not provide the required diaphragm strength, and permanent bridging is necessary for the joists to function properly.

For the joist bottom chord, permanent bridging is required. Since the bottom chord serves to laterally brace the joist web members—when modeled as pinned ends—it too must be braced laterally, even when it is in tension. Also, when joists are used in roof construction, they are frequently subject to a net uplift force, creating compression in the bottom chord. In this scenario, permanent bridging in the bottom chord will provide the necessary buckling resistance.

Let's take a closer look at all three types of steel joist bridging.

Erection Bridging

The SJI K-Series and LH- / DLH-Series Load Tables in the 42nd Edition *Standard Specifications Load Tables and Weight Tables for Steel Joists and Joist Girders* show the total safe uniformly distributed loads for standard products at various spans. As the span increases for a particular joist designation, the uniformly distributed load-carrying capacity decreases. The Load Tables also indicate when the span becomes too great for a particular joist designation to be erected without erection bridging.

Table A, Erection Bridging for Short-Span Joists, in the OSHA *Federal Safety Standards* gives the minimum span for each short-span joist designation (e.g., 26K8) and indicates when erection bridging must be installed. If Table A indicates that erection bridging is not mandatory (NM), the joists can be spaced out, attached, and then bridged in accordance with Section 6 of the SJI *Standard Specifications for Open Web Steel Joists, K-Series*.

The required bolted diagonal erection bridging for K-Series joists must be installed as the row of bridging nearest the mid-span of the joist. The erection bridging must also be anchored to prevent lateral movement of the joist prior to the hoisting cables being released. This can be accomplished by securing the bridging to a fixed object such as a concrete or masonry wall, steel beam, or other stable portion of the structure. OSHA refers to this anchorage point as a "bridging terminus point."

Table B, Erection Bridging for Long-Span Joists, in the OSHA Standards gives the minimum span for each long-span joist designation (e.g., 32LH06) and indicates when erection bridging must be installed. If Table B indicates erection bridging as NM, the joists can be spaced out, attached, and then bridged in accordance with Section 105 of the SJI *Standard Specifications for Longspan Joists,* LH-Series.

The required bolted diagonal erection bridging for any LH-Series joist depends on its length. Where the span of the steel joist is less than 60 ft, the bolted diagonal erection bridging must be installed as the row of bridging nearest the mid-span of the joist. Where the span of the steel joist is between 60 ft and 100 ft, the required bolted diagonal erection bridging must be installed as the two rows of bridging nearest the third points of the joist. Where the span of the steel joist is 100 ft to 144 ft, all rows of bridging are considered erection bridging and must be completely installed. As stated in Section 105 of the LH-Series Specification, the bridging row(s) must be anchored to prevent lateral movement of the joist.

Since all erection bridging will in turn become construction bridging, the more stringent construction bridging criteria are used to establish the erection bridging forces, sizes, and connections.

Bridging for Construction Loads

After any required erection bridging is installed and the hoisting cables have been released, additional bridging rows required for construction bridging need to be installed before the application of additional construction loads. Under no circumstances should construction loads of any description to be placed on unbridged joists. As previously described, many joists are laterally unstable until the joists are properly bridged and the bridging and joists are properly anchored. The joists should be completely bridged immediately after final placement and end attachment is completed in accordance with OSHA and SJI requirements.

Construction loads are defined in the OSHA *Federal Safety Standards* as "any load other than the employee(s), the joists, and the bridging bundles." These loads include the weight of metal deck bundles and individual sheets being placed, the weight of multiple erectors placing the deck, and equipment loads such as welding machines and leads, hand tools, bridging for adjacent bays, etc. The OSHA Standards strictly prohibit placing construction loads on unbridged joists and give the proper procedure for landing bridging bundles on unbridged joists; see 29 CFR 1926.757 (e) (1), (2), and (3). It is critical that construction loads on any one joist be minimized, and it is advisable that the loads be placed as close as possible to the ends of the joist. There is an exception for the placement of a bundle of decking after the installation of at least one but not all bridging rows if certain stringent conditions are met. Any erector who allows construction loads to be placed on unbridged joists is in direct violation of the OSHA standards, as well as Section 6 and Section 105 of SJI's K-Series and LH- / DLH-Series Specifications.

SJI *Standard Specifications for Open Web Steel Joists, K-Series*, Section 5.4 requires that each bridging connection resist a nominal (unfactored) horizontal force of not less than 700 lb. The spacing of the bridging rows is determined by the radius of gyration of the top chord about its vertical axis and shall not be less than $\ell/145$. Also, to meet this criteria the quantity of top chord bridging rows shall not be less than the number shown in Table 5.4-1. The number of rows of bottom chord bridging shall not be less than the number of top chord rows; the top and bottom chord bridging rows may be spaced independently.

SJI *Standard Specifications for Longspan Steel Joists, LH-Series and Deep Longspan Steel Joists, DLH-Series*, Section 104 requires that each bridging connection to the joist must be able to resist a horizontal force not less than that specified in Table 104.5-1. Where two attachment points to a joist are utilized, each attachment must be able to resist one-half of the bridging force given in the table. The spacing of the bridging rows shall be determined by the radius of gyration of the top chord about its vertical axis and shall not be less than $\ell/170$, and to meet this criteria the maximum spacing of lines of top chord bridging shall not exceed the values in Table 104.5-1. The number of rows of bottom chord bridging shall not be less than the number of top chord rows; the top and bottom chord bridging rows may be spaced independently.

The bracing force that a joist imparts on the bridging is based on three assumptions: 1) an initial out-of-straightness in the chord of $\ell/920$; 2) a resultant total nominal bracing force of $0.0044P$ (in other words, the horizontal bridging rows must be continuous and each joist must be braced from both sides; therefore, the total bracing force is divided by two and rounded up to $0.0025P$, where P represents the chord axial force); and 3) there is an assumed construction stress in the top chord due to the chord axial force P. For K-Series joists, the bridging criteria are based on a top chord axial construction ultimate stress (F_{cr}) of 17 ksi. Due to the continuity of the top chord on either side of the bridging attachments, a K-factor of 0.9 is used in calculating the top chord slenderness ratio. Hence, for an ultimate Euler stress of 17 ksi and a K-factor of 0.9, the permissible slenderness ratio l/r_y is limited to 145 for K-Series as given above. LH- and DLH-Series joists are similar, except that the assumed construction stress is taken as 12 ksi, and the resultant slenderness limit, l/r_y, is 170.

Therefore, the nominal compressive force that accumulates in a horizontal bridging row is:

$$P_{br} = 0.0025\, n\, A_t F_{construction}$$

where

$F_{construction}$ = 17 ksi for K-Series joists, and 12 ksi for LH- and DLH-Series joists, as noted above

A_t = is the top chord area

n = the number of joists

For horizontal bridging, n is taken as eight joist spaces because the construction loads tend to be localized, rather than spread uniformly over an entire bay. Also, the probability is low that all joists in a bay would exhibit the maximum out-of-straightness all in the same direction at any given time. For horizontal bridging, the bracing force P_{br} must be taken in compression. Diagonal bridging creates a load path whereby the forces are resolved at each braced joist space and do not accumulate. However, recall that the bracing force was divided by two on the presumption of continuous bridging on each side of the joist chord. Since continuity is not required of diagonal bridging rows, and to allow the diagonal bridging force to be considered only in tension, n is taken as two for diagonal bridging.

The tables provided in the SJI specifications for bridging sizes are based upon the force P_{br} for the typical top chord areas for a given designation. Table 2.6-1a of the SJI *Code of Standard Practice* gives the maximum joist spacing for certain horizontal bridging sizes based on joist chord section numbers for K-Series joists and using K = 0.9 for the bridging design; Table 2.6-1b provides the same information for LH- and DLH-Series joists. Diagonal bridging is only subject to tension forces, and so the bridging size is governed by a slenderness limit (between connections) of 200, rather than by strength.

Recently, SJI has begun to investigate the difference between the assumed K-Series construction stress of 17 ksi verses 12 ksi for LH- and DLH-Series joists. Preliminary findings indicate that the construction stress has very little to do with the chosen joist series but is heavily influenced by both the span and depth of a joist. For a given span length and joist spacing, the construction load arguably will be the same regardless of joist depth, while the top chord construction stress will clearly be less for a deeper joist. On this basis, equations were developed for the newest SJI *Standard Specification for Composite Steel Joists, CJ-Series*, in which $F_{construction}$ and the top chord slenderness limit varies depending on the depth and span length as follows:

$$F_{construction} = \frac{\pi^2 E}{\left(\frac{0.9\ell_{br}}{r_y}\right)^2} \geq 12.2 \text{ ksi}$$

$$\ell_{br} = \left(100 + 0.67 d_j + 40\frac{d_j}{L}\right) r_y$$

but not greater than, $\ell_{br} = 170\, r_y$

It is anticipated that a similar methodology may be adopted for the K- and LH-/DLH-Series joists in the future. However, they would not exactly match the CJ-Series equations, because the CJ-Series allows for an ultimate top chord construction stress in excess of 17 ksi. This is due to the fact that composite joist top chords are inherently smaller than comparable non-composite top chord sizes, and the maximum span to depth ratio is greater for composite than non-composite joists.

In certain design applications that use bottom bearing or square-ended joists, the product is designed to bear on the bottom chord. This produces a "top-heavy" condition. Therefore, their ends must be restrained laterally in accordance with SJI *Standard Specifications*, *K-Series*, Section 5.4(d) or LH- and DLH-Series Section 104.5(f). This is accomplished by means of an additional row of diagonal bridging placed at or near the bearing support ends of the joists as they are being erected. Where a bottom bearing joist is extended beyond its support to form a cantilevered end, a row of diagonal bridging near the support should first be installed. In addition, the structural drawings may indicate a row of diagonal bridging in the cantilevered portion to provide lateral stability. If the joists have bottom chords extended over and connected to a column, beam, wall, or other structure, the connection should be made in accordance with the structural drawings and/or instructions from the engineer of record.

Bridging for Permanent Loads

Top chord bridging serves a role as permanent bridging in the absence of a deck diaphragm, as is the case with a standing-seam metal roof applied directly to the joist top chords. Sections 5.8(g) and 104.9(g) of the SJI *Standard Specifications* for K-Series and LH-/DLH-Series joists, respectively, provide the requirements for the horizontal bridging design. The compressive force equation is:

$$P_{br} = 0.0025nP$$

This equation is similar to the equation given above for construction bridging, but here, n is not limited to eight, and is equal to the total number of joists between end anchors. P represents the actual top chord design force, rather than the chord area times an arbitrary construction stress.

Bottom chord bridging is always permanent bridging, and either limits slenderness for bottom chords in tension or braces the bottom chord laterally for compression forces, such as those present in a net uplift loading case. Traditionally, and for simplicity in the field, the bottom chord bridging size is equal to the size as determined for the top chord.

When uplift forces are a design consideration, a row of bottom chord bridging is required near each end of short-span joists in accordance with the SJI *Standard Specifications*, *K-Series*, Sections 5.6 and 5.11 and long-span joists in accordance with the SJI *Standard Specifications*, *LH-/DLH-Series*, Sections 104.7 and 104.12.

What's Next?

Future research on joist bridging requirements is likely to include a review of the construction stress levels, a unification of the K-Series and LH-/DLH-Series bridging requirements, and a better understanding of the accumulation of bridging forces when a net uplift loading condition is present. MSC

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The SJI 42nd Edition Catalog *containing the above referenced* Standard Specifications *and the* Code of Standard Practice *can be found at www.steeljoist.org*.