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ERECTION OF OPEN WEB LONGSPAN STEEL JOISTS

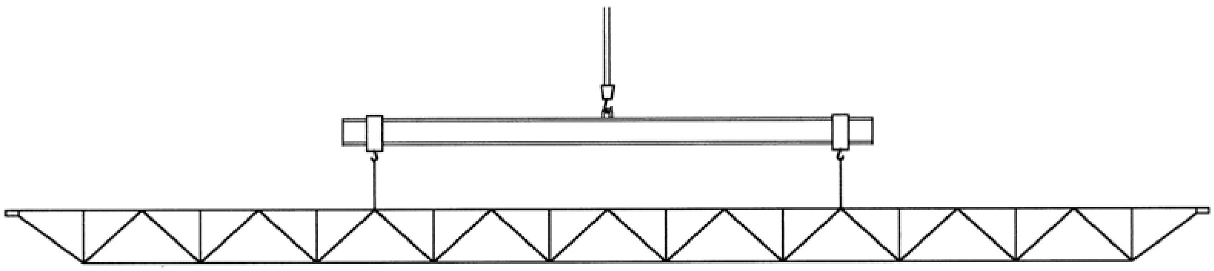

Figure 1 Longspan joist suspended from crane, using spreader beam.

This paper presents a summary of erection practices for longspan steel joists, a comparison between these practices and industry standards, and an evaluation of their safety.

The joist industry standard in the United States is Technical Digest No. 9, *Handling and Erection of steel joists and joist girders*, published in July 1987 by the Steel Joist Institute. The applicable OSHA regulations are contained in the Code of Federal Regulations, 29 CFR 1926.757, they were promulgated in 2001 and are the first set of definitive regulations by OSHA on the erection of steel joists.

Lifting Joists by Crane

Longspan joists are generally proportioned so that the joists can be picked up at their third points. The best way to lift the joists is to use a spreader beam connected to the crane hook, as shown in Figure 1. The joists are connected to hooks on the spreader beam by slings. According to Technical Digest No. 9, joists should be shipped upside down and thus need to be lifted upside down as well as right side up. The lateral stiffness of the chords of the joists must be sufficient so that the chords do not buckle when the joists are being handled by the crane.

Start of Erection

Longspan joists are so slender, that they require lateral support along the top of the joist in the erected position to prevent lateral buckling. Therefore, in order to erect the 1st joist, it must be braced to an adjacent joist on the ground by attaching all the cross-bracing (called cross-bridging) between them, to form a stable "box". The pair of joists are then erected onto the supporting steel, and thereafter, the other joists can be erected individually. Figure 2 (on page 2) depicts a section through the first two joists showing the cross-bridging between them and a hoisting sling. Also shown in Figure 2 is a temporary lateral strut at the pick-up points to prevent the squashing of the slender bridging members by the horizontal components of the sling forces. This procedure is discussed in Technical Digest No. 9; however, the lateral strut is omitted in the figure in the technical digest that demonstrates the procedure.

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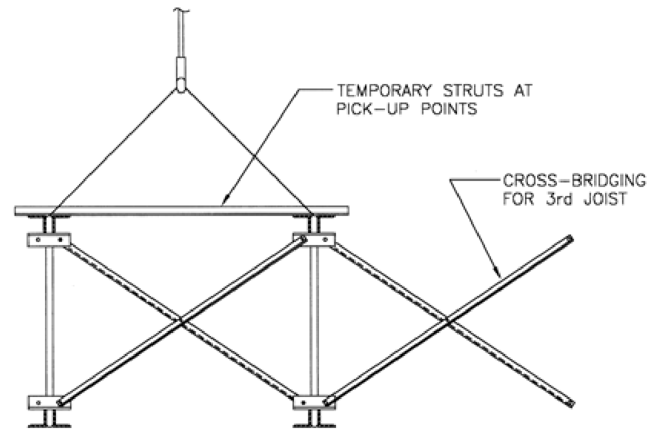

Figure 2 First two joists, suspended by the crane, in the process of being erected in-place. The bridging is attached on the ground.

General Erection Procedure

Figure 3 is a typical section through long span joists in their erected position. The joist designations (J1, J2, etc.) are in the order of their erection. When erecting the first pair of joists, one of those joists should be a tie joist. A tie joist is usually located on each column line and is needed for safe erection. Tie joists prevent the lines of girders supporting the joists from spreading apart and aid in the plumbing up of the building. The bearing plates of the tie joists are connected to the columns by bolted connections to either cap plates on top of the columns or seat angles on the sides of the columns. The bearing plates of the tie joists have slotted bolt holes to allow adjustment for plumbing the columns, and the bolts are installed loose to allow the columns to be plumbed up. (The bolts for beam to column connections are also installed loose for the same reason).

With one of the first two joists being a tie joist, erection cannot start at one end of the building, but must start at least a column bay away from the end. This situation is contrary to Technical Digest No. 9 which requires that erection start at one end of a building; that the cross-bridging be anchored to that end at that time; and that the cross-bridging be anchored to the far end when the erection reaches that end.

A typical erection crew for longspan joists would be two or three ironworkers in the air on top of the joists (called *connectors)*, and two iron workers on the ground (called *ground men* or *hooker-ons*); one of the ground men may be the iron worker foreman

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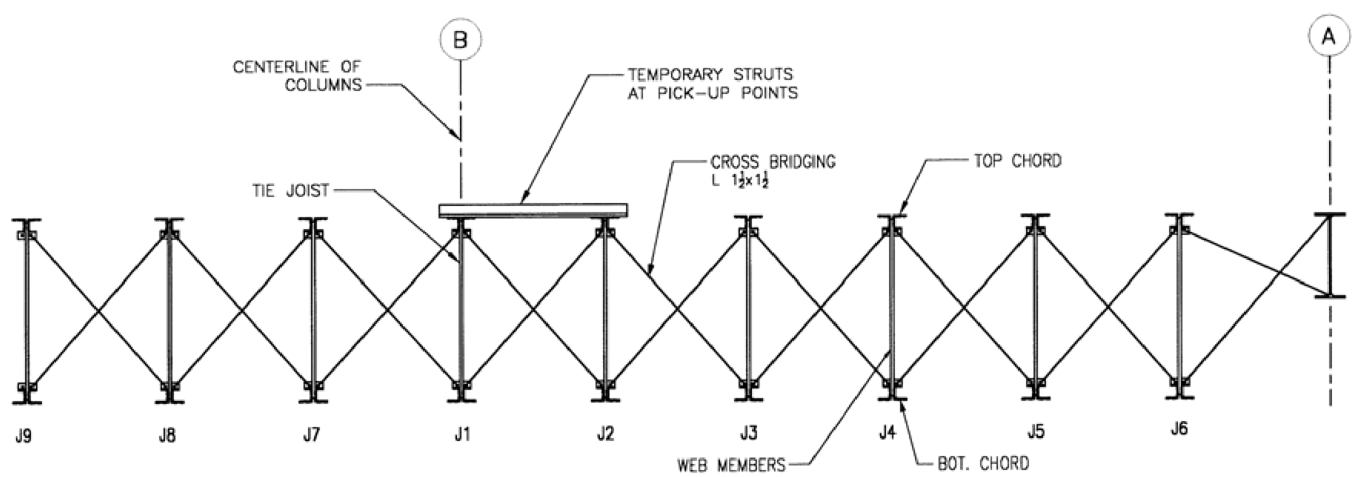

Figure 3 Section through longspan joists in their erected positions. Joist numbers indicate the order of erection.

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or superintendent. Three connectors are used for very long joists, to increase erection efficiency; otherwise only two connectors would be used.

Once the 1st pair of joists have been erected and secured to the framing, the joists are erected individually, each with the cross-bridging for the next joist attached on the ground. When a joist is near position, the ends are positioned by the connectors and one of the connectors signals the crane operator to partially release the load onto the supports (sufficient so that the ends will not move). Then the connectors attach the cross-bridging from the previously erected joist, align the joist, and tighten the cross-bridging bolts. When this work is complete one of the connectors signals the crane operator to completely release the load. Then the slings are detached from the joist and put on the spreader hooks, the crane goes to pick up another joist, and the process is repeated until all the joists are erected into place.

Welding of Joists to Supports

Up until 2001 when new OSHA regulations were issued, non-tie joists were usually welded to their supports *after* the columns were plumbed and guyed, and after all the bolts in the beam to column connections and in the tie joist to column connections were tightened. This procedure is contrary to the requirements of Technical Digest No. 9, which requires 1) that the joist bearing seats be tack welded on one side as each joist is landed on the supports; and 2) that the joist bearing seats be completely welded down after the cross-bridging is connected.

These latter welding requirements are impractical. Welding the joist seats to the steel framing will prevent the framing from being plumbed up; thus it cannot be done until the section of steel framework supporting the joists has been plumbed. It is doubtful that any experienced steel erector would weld the joist seats to their supports before plumbing up the steel frame.

Further, the advantages of welding the joist seats as they are erected, is doubtful. When the cross-bridging is connected to a joist, the joist is stabilized laterally, and the friction from the weight of the longspan joist on the supports will prevent the bearing seat from sliding (except when methods are used to purposely move the bearing seats).

OSHA regulations now require that all joists with spans of 40 feet or greater be bolted to their supports. The joist bearing plates have slotted holes, the same as for tie joists, and the same as for tie joists, the bolts should be installed loose when the joists are landed, and tightened only after the section of steel framework supporting the joists has been plumbed up. Although bolted connections provide definitive locations for the joist bearing plates, which is an advantage, it is doubtful whether they significantly increase erection safety.

Connection of Bottom Chords of Joists to Columns

OSHA regulations require that the "bottom chords of steel joists at columns shall be stabilized to prevent rotation during erection." This requirement is in conjunction with the requirement for a vertical stabilizer plate on each column extending below the bottom chord of the joist and having a 3/4" diameter hole for a guying or plumbing cable. The bottom chords of the joists need to extend to the columns and engage the stabilization plates between the chord angles.

Anchoring Cross-Bridging Lines

As noted above, Technical Digest No. 9 requires the cross-bridging to be anchored to the ends of the building. The question arises: anchor to what? In Figure 3, the only place to anchor is a row of light steel beams and columns on Line A. However, the anchorage could only be effective if each of the columns on Line A were plumbed and guyed, which would not usually be done until the framing and

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joists for the section of building which includes Line A are erected, the section is plumbed and guyed, and all the bolts in the section are tightened. Then the end line of beams and columns are plumbed and the bridging from J6 to these beams and columns are attached. In effect, however, the bridging acts to brace the framing on Line A in the plane of the paper, not the other way around.

A common practice for anchorage, where the enclosure walls are masonry, is to connect the ends of the rows of bridging to the masonry walls, such as shown in Figure 4. However, if the walls do not have independent lateral bracing, they are probably too slender to provide effective anchorage to the cross-bridging. There have been many buildings constructed with the ends of the bridging anchored to masonry walls before the installation of the roof deck, without any independent lateral bracing of the masonry walls, and without failure; therefore the cross-bridging/joist system must be providing the requisite stability for the joists and the masonry walls to which they are anchored.

The horizontal bending strength of the joists spanning between their supports is very limited; also, horizontal load on the cross-bridging/joist system can substantially reduce the lateral stability of the joist/cross-bridging system. If the masonry wall is not temporarily braced by diagonal struts to the ground, a strong wind load could cause collapse of the wall and the longspan joists.

OSHA requires anchorage of bridging rows similar to the anchorage requirements of Technical Digest No. 9; however, OSHA permits self anchoring systems such as the one shown on Figure 5.

Safety

There are two possible modes of failure of the longspan joists as erected: 1) the top chord of an individual joist buckling laterally accompanied by the twist-

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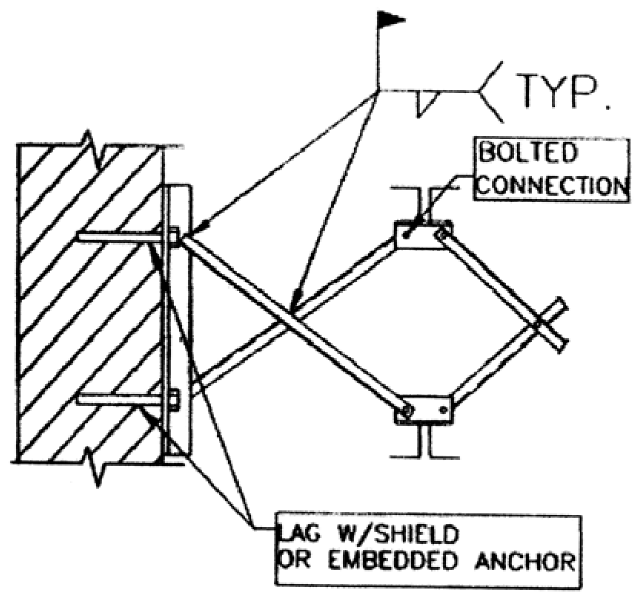

Figure 4 **Anchorage of row of bridging to masonry wall. From non-mandatory OSHA guidelines (29 CFR 1926 Subpart R, Appendix C).**

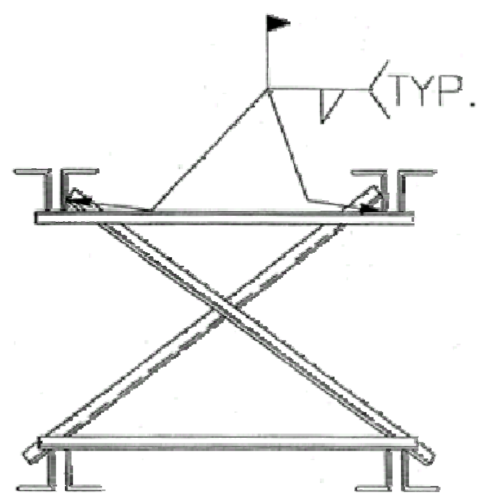

Figure 5 **Self-anchorage of row of bridging. From non-mandatory OSHA guidelines (29 CFR 1926 Subpart R, Appendix C).**

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ing of the joist between lateral supports (e.g. between the bridging); and 2) overall horizontal buckling of the entire joist/bridging system. The latter mode involves bending of the cross-bridging and overall twisting of the individual joists between their end supports. There are many variables that affect the safety of the joists against buckling, such as the lateral stiffness of the joist chords, the spacing of the cross-bridging, and the size of the cross-bridging. It is the responsibility of the joist manufacturer to combine all of the variables into a design so that erection of the joists will be safe.

On-Line Edition No. 10 of *Forensic Engineering in Construction* reports on the collapse of 112 foot span deep longspan steel joists. See Figure 6. These joists were 5 feet deep, were typically spaced at 3'-11" on center, and had 5 rows of cross-bridging. Using the joist layout scheme shown in Figure 3, but without the cross-bridging attached to the beams on Line A, Zallen Engineering performed various buckling analysis to determine the safety factors against collapse for Failure Mode 2. These safety factors are for illustrative purposes and apply to this individual case only; other cases will give different safety factors. The loads on the joists are the weight of the joists (45 lbs/ft each) and the weight of three ironworkers, which is negligible..

For the 1st two joists (J1 and J2) erected in place and cross-bridged, the safety factor is 2.1; for 4 joists (J1 through J4) erected in-place and cross-bridged, the safety factor is 2.8, and for 8 joists (J1 through J8) erected in-place and cross-bridged, the safety factor is 3.9. The safety factor increases with the number of joists but at a decreasing rate.

When the steel erector erected the 1st two joists, he welded 3" x3" angle strongbacks across the top and bottom chords of the two joists, near each pick-up points (4 strongbacks), as shown on Figure 7. These angles served to restrain the twisting of the chords of the 1st two joists and increased the safety factor. The safety factors with the strongbacks left in place are 3.4, 3.8, and 4.8, for 2, 4, and 8 joists in-place, respectively, an increase of 61%, 35%, and 24%, respectively, over that for the joists with only cross-bridging. Although the strongbacks have a significant

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Figure 6

Deep longspan joists involved in the collapse reported in On-Line Edition No. 10.

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effect in increasing the safety factor, this effect is reduced with an increasing number of joists.

In the self-anchoring scheme shown in Figure 5, the horizontal angles do not restrain the chords from twisting. The increases in safety factors over that for the joists with only cross-bridging are less than 10%, bringing into question the value of the struts in "anchoring" the bridging. To significantly increase the safety factors, the struts would have to be attached so as to restrain the chords from twisting.

For J1 and J2 erected in place and cross-bridged, and with the bottom chord of J1 (a tie joist) laterally supported by stabilizer plates on the columns, as described above, the increase in safety factor over that for the joists with cross-bridging is only 1%, which is negligible. For this case the 5 rows of cross-bridging provide the dominant resistance against Failure Mode 2; however, for shorter joists with only one or two rows of cross-bridging, lateral support of the bottom chord of the tie joists at the columns will be more important.

Conclusion

It is clear from the above discussion and examples that the requirements in both Technical Digest No. 9 and the OSHA regulations to anchor the bridging lines, and to provide lateral support for the bottom chords of tie joists at the columns, will not significantly increase the safety against overall lateral buckling of the erected joists (Failure Mode 2), and that the cross-bridging system itself can and must provide an adequate safety factor against failure during erection. Determining and providing adequate erection safety is an engineering problem that should be addressed on an individual case basis.

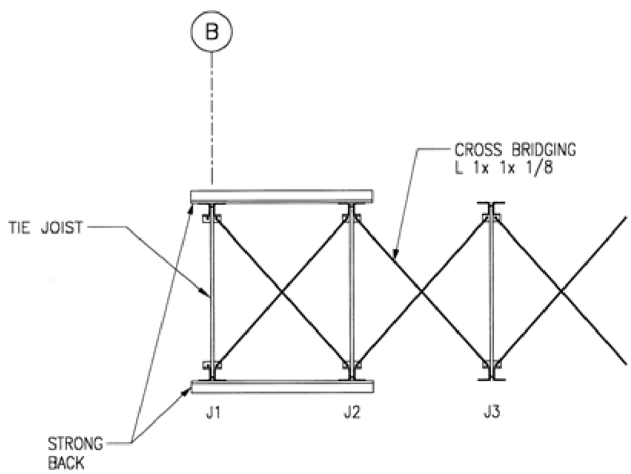

Figure 7 Strongbacks attached to first two joists such that the rotation of the joist chords is restrained.

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