Up on the rooftop

How to design and detail non-uniform loads on steel joists

By Tim Holtermann, P.E., S.E.

Specifying steel joists and joist girders for uniform gravity loads is a relatively straightforward process for the structural engineer of record (SER). In some cases, the joist system may participate in resisting lateral loads; but again, the process of establishing the required axial forces and end moments can be readily undertaken by the SER.

However, there are many non-uniform loads that may be applied to the steel joists which require a greater deal of consideration and coordination from the SER, the joist manufacturer, and the contractor on the project. Roof-top units (RTUs) are the principal non-uniform load type that can cause confusion and delays.

"As the trend toward design-build in mechanical systems has grown, it has made the job of the joist fabricator and the structural steel contractor much more difficult," says Terry Zwick, vice president of Atlas Ironworks, headquartered in St. Louis, Mo.

Typical joist project timeline

A frequent scenario could be described as follows: The mechanical contract has not yet been awarded, so the SER guesses at the number and location of roof-top units, adding a note to the contract drawings similar to "location and weight of roof-top units to be verified by mechanical contractor prior to joist fabrication."

In most cases, this verification will not make its way to the joist supplier before the joist submittal. So the joist manufacturer reiterates the same verification request on the submittal. The requested verification may or may not get accomplished by the time the joist submittal is returned, so in many cases, a request for information (RFI) is issued as the next step.

Four to six weeks may elapse from the beginning of the joist contract to the time the RFI is issued. But now the additional delay in getting an answer to the RFI, which may be a few days to a few weeks, can create a delay in the overall project schedule. Frustration grows quickly as the SER is pelted with RFIs for information he does not have, the joist manufacturer cannot start fabrication, and a joist delivery commitment cannot be made.

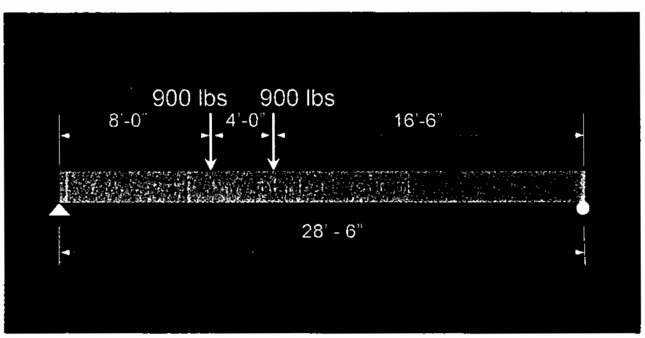
Good communication can alleviate some of the frustration from the typical questions such as: Who is the mechanical contractor, or when will that contract be awarded? Can the mechanical contractor confirm the contract drawing load and location assumptions in advance of a full submittal?

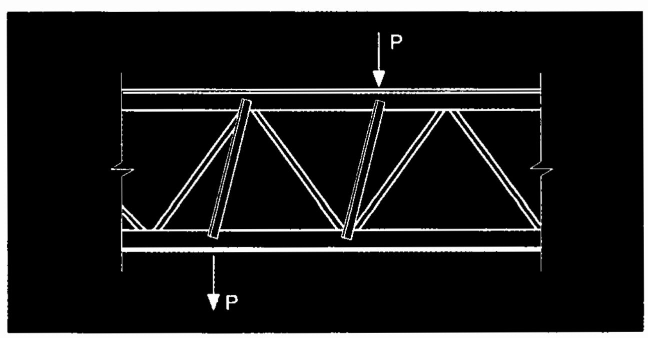
Additionally, sound engineering judgment and proper detailing on structural drawings can provide critical information to the joist supplier to keep the project on schedule. In addition to the most troublesome RTU dilemma, wind loads and hanging loads can cause problems if not proactively addressed by the SER.

Support of RTUs

A number of options exist for providing the required joist design capacity for RTUs whether specific information is available, or not. Where the loads and locations for the RTUs are known, special joists can be designated with a simple load diagram such as that shown in Figure 1. Note that seats deeper than 2-1/2 inches are suggested for any special joist end reaction

Figure 1 (left): Where the loads and locations for the RTUs are known, special joists can be designated with a simple load diagram. Figure 2 (right): While KCS-series joists are specifically designed to handle non-uniform loads, any concentrated loads need to be placed at panel points, or a field-added strut, to mitigate localized bending.





that would exceed 10 kips.

An alternative for cases in which the exact RTU loads and locations are not known would be KCS-series joists. The KCS-series Load Table provides moment and shear capacities. The final RTU configuration, or any future RTU changes, can be easily checked against the moment and shear capacity "envelope" of the joist. While KCS-series joists are specifically designed to handle non-uniform loads, any concentrated loads need to be placed at panel points, or a field-added strut, as shown in Figure 2, is required to mitigate localized bending.

Traveling loads — Another way to provide an "envelope" of capacity is to specify traveling loads, or "add loads" for the affected joists. There are many possibilities here — any magnitude of traveling-concentrated load can be specified in addition to the uniform load. And the traveling load could be applied to either the top or bottom chord, and can travel from panel point to panel point (assuming field-added struts if the load cannot be applied at a panel point); or it can travel anywhere along the chord and include the effects of localized bending in the chord design. Figures 3 and 4 demonstrate the traveling load concept and the information to be specified.

RTU zones — An effective way to establish capacity for RTUs while specifying the joists is to create RTU zones and define the parameters, in terms of location and RTU weight, that the mechanical contractor must follow. Figure 5 demonstrates a simple RTU zone using KCS-series joists. Note that the additional kip panel point loads have been specified for the joist girder that supports the KCS-series joists. Another way to create a RTU zone is to specify a traveling load, but within a limited range of length along the joist — for example, 1,000 pounds anywhere along the top chord within the first 8 feet from a column line.

Cost comparison — Considering costs is an important aspect of specifying joists. Figure 6 provides a relative cost comparison for a joist with two concentrated top-chord loads of 300 pounds each. The table shows the percentage of increase in cost compared with a joist designed only for the roof uniform load and no point loads, with the first comparison being a special design for known RTU loads and locations. Other options, with and without the need for field-added struts, are compared. Finally, an estimate is shown for the costs required to field-reinforce the joist if it had been designed and built solely for the uniform load. It becomes clear that it can be very cost effective to design in some extra RTU capacity in order to avoid the possibility of field reinforcement later. Figure 7 makes a similar comparison, but for a larger RTU — two loads of 1,200 pounds each.

Other RTU considerations — The specifier is cautioned that a typical RTU is not likely to have uniform density, so the weight distribution to each corner will be unequal. Also, the weight of the curb or support frame needs to be included in the specified joist design load. For large units in cold-weather regions, the possibility of snow drifts around the unit needs to be considered.

With the use of the new Steel Joist Institute 42nd Edition Specification, the SER has the option of specifying ASD or LRFD joists. When working with LRFD, the contract drawings need to clearly indicate if the given RTU loads are already factored, or are un-factored.

Additional consideration is required when the architect desires a roof screen around the units. If the RTUs themselves do not create coordination challenges and delays, the roof screens often can if they are not properly specified. Typically, the screen will create both a vertical-gravity load, plus a wind-overturning moment. Where the overturning moment is along the axis of the joist, it is best to extend the post all the way to the bottom chord, and the moment is resolved as a couple, creating axial loads on the top and bottom chords. Where the overturning moment is lateral to the joist, the

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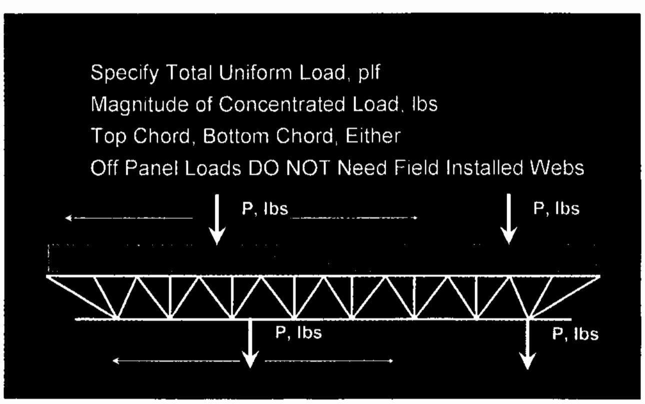
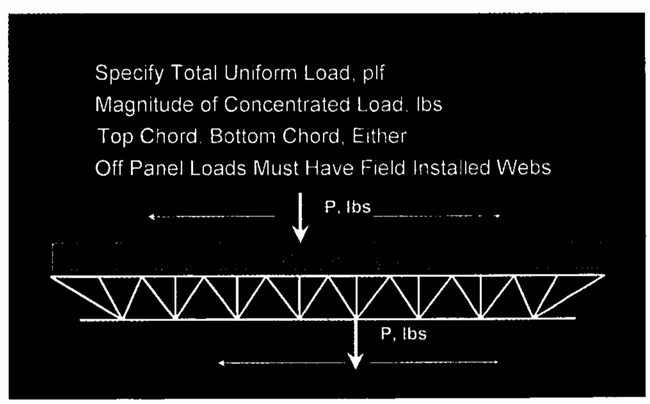
Figures 3 and 4: A way to provide an "envelope" of capacity is to specify traveling loads for the affected joists. The traveling load could be applied to either the top or bottom chord, and can travel from panel point to panel point; or it can travel anywhere along the chord and include the effects of localized bending in the chord design.





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SER needs to provide a bracing detail between two adjacent joists to resolve the overturning moment, as the joist cannot be designed for lateral forces perpendicular to the chords.

Wind loads

Typically, the wind loads on roof joists (considered components and cladding) create an uplift-loading pattern with various zones. The joist manufacturer's expectation is that the wind uplift will be provided on the structural contract drawings as net uplift (the result of the load case combining dead and wind loads), and that the width of the edge and corner zones will be defined and given. A "key plan" format is an acceptable way to convey this information to the joist manufacturer.

It is important that the SER also considers the wind forces that act down upon the roof, and may add to the effects of the gravity dead and live loads. Since the SER either selects a standard joist designation with a total load capacity, or uses a special joist designation that includes a total uniform load, the joist manufacturer will presume that the effects of any wind forces acting down upon the roof have been considered in the determination of the total load.

Hanging loads

Folding partitions, sporting equipment, and fire suppression systems that are hung directly from the joist need to be considered in the design and included in the detailing.

Folding partitions — The most obvious loading case for folding partitions or room dividers would be a uniform load along the bottom chord of the steel joist supporting the partition. However, it is important to also consider a "stacked" condition, which may produce a large, concentrated load at one or both ends of the joist. The shear from this loading case is likely to govern the joist web members near the ends. Also, if the attachment is directly to the joist bottom chord, the bottom chord may need to be extended.

Another consideration with a folding partition is the anticipated joist deflection and the clearance between the bottom of the partition and the floor. A reasonable compromise between a stringent limit for the sake of the partition, and a realistic limit for deflection of steel joists, is a one-inch, live-load deflection limit.

Basketball goals — Similar to RTUs, the loads and locations of basketball goals must be considered in the joist design and selection, although this specific information is typically not available at the time the structural contract drawings are produced. Basketball goals merit particular attention in the design of the supporting joists for a number of reasons. First, the "dynamic" loads of a player on the rim create forces in addition to the actual self-weight of the goal assembly. Secondly, if long-span joists are used to provide a clear span across the entire gym, the joists will be large and deep with long bottom-chord panel lengths. The long panel lengths make it less likely that an attachment point may hit a panel point, and for loads at attachments off of panel points, the bending moments are significantly larger when the panel length increases. And thirdly, for long and deep joists, field-added struts become less practical. This is due to the length of the struts, making them more difficult to handle in the field, as well as "fit-up" problems since these types of joists are more likely to have numerous web members attached on the outside of the chords already, making it difficult to have room to land struts at a panel point.

It is critical that the contractor coordinate the basketball goal information between the successful supplier, the SER, and the joist manufacturer.

Sprinkler lines — Typically, branch lines of sprinkler systems for fire protection can be accommodated with a pound-per-square-foot format allowance in the design loads used to specify and select the steel joists. This leaves only the sprinkler mains as requiring special consideration and coordination. Notes such as "joist manufacturer shall consider the weight of sprinkler mains in the joist design" are usually too vague. The structural drawings should

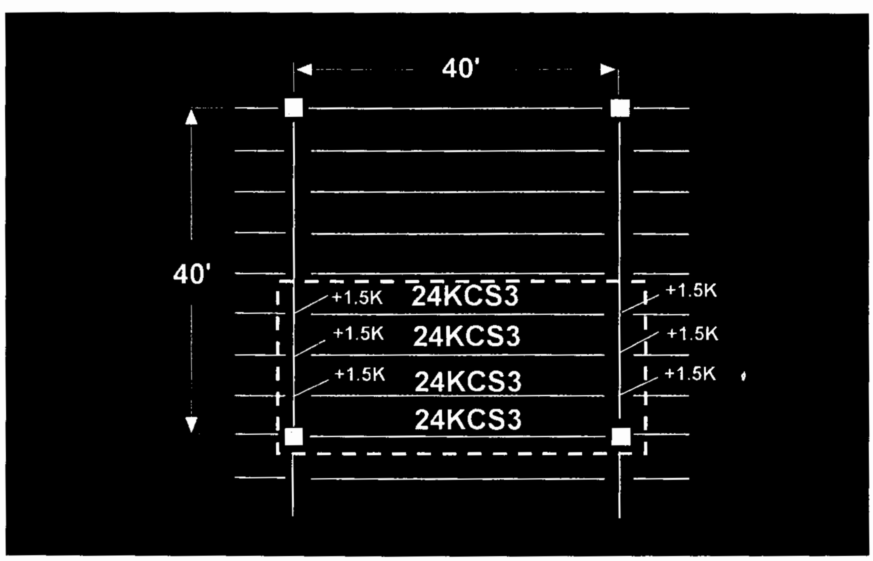

Figure 5: An effective way to establish capacity for RTUs while specifying the joists is to create RTU zones and define the parameters, in terms of location and RTU weight, that the mechanical contractor must follow.

Figures 6 and 7: In the following tables, relative cost comparisons are made for two RTU scenarios. The percentages represent the increase in cost for a given design/detailed scenario.

Figure 6: Estimated Relative Cost Comparisons, Case 1 (Two concentrated loads on joist, P = 300 pounds as compared with joist with uniform load only.)

	Percent Increase in cost
Uniform load plus concentrated loads	3
KCS (loads at panel points)	49
KCS (field-installed webs)	72
Traveling loads at panel points	6
Traveling loads (field-installed webs)	29
Traveling loads between panel points	9
Field reinforcement of eight elements	142

Figure 7: Estimated Relative Cost Comparisons, Case 2 (Two concentrated loads on joist, P = 1,200 pounds as compared with joist with uniform load only.)

	Percent Increase in cost
Uniform load plus concentrated loads	18
KCS (loads at panel points)	68
KCS (field-installed webs)	91
Traveling loads at panel points	22
Traveling loads (field-installed webs)	45
Traveling loads between panel points	29
Field reinforcement of 22 elements	285

make clear which specific pipe sizes are already accommodated and which are not, as well as the design loads for the mains. With the sprinkler mains, the joist manufacturer can typically be instructed to consider the loads as acting at panel points. Often, there is some latitude in placing the mains, or a trapeze-type of hanger can be used and be attached at panel points.

Conclusion

While gravity and lateral loads are easily determined and considered in the joist design and selection, there are a number of non-uniform joist loads for which all of the details may not be known at the time the structural contract drawings are created. Therefore, careful coordination is required between the SER, the joist manufacturer, and the contractor or sub-contractors. Roof-top units are the most common type of non-uniform load, and a number of options exist to make allowances for these units even when exact details are not known. Although designing in extra capacity in the joist and joist girder system will add slightly to the overall project cost, it is more cost effective than field reinforcement of joist elements, which could be avoided.

Finally, to aid designers where non-uniform loads were not considered, or allowed for, in the steel joist selection and design, the Steel Joist Institute has recently published a new Technical Digest #12, Evaluation and Modification of Open-Web Steel Joists and Joist Girders. ▼

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