Hints on Using Joists Efficiently

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Proper coordination between structural engineers and joist suppliers can make steel joists more structurally efficient and cost-effective.

Steel joists and joist girders are an efficient framing system for support of floors and roofs in a wide variety of buildings. They are easy to use and provide a great deal of flexibility in their use for many different loads, spans, shapes, or other special conditions. However, it is important that the design requirements established by the specifying professional (Structural Engineer of Record) be clearly conveyed and understood by the joist manufacturer so that the joist design is safe and economical. This paper discusses a number of topics and the coordination and options for a safe, efficient, and cost-effective design.

The Steel Joist Institute (SJI) is the governing body for joist manufacturers. For more general information about steel joists or the Institute, or to obtain contact information for a joist manufacturer, please visit **www.steeljoist.org**.

Loads and Load Combinations

The joist manufacturer will design the joists for the load combinations from the design code specified on the contract drawings. It should be noted that the current IBC 2003 offers two different load combinations for use with ASD design: Basic Load Combinations (Section 1605.3.1) and Alternate Basic Load Combinations (Section 1605.3.2). Specifying which section was used for the overall building structure will ensure that the joists are designed to the same load combinations. If a different set of load combinations is required, it should be specified on the contract drawings.

It is important for the specifying professional to provide net uplift values where the joist manufacturer needs to consider uplift in the joist or joist girder design. If the uplift forces shown on the contract drawings are displayed as gross uplift, the joist manufacturer may conservatively design for the full force without deducting any dead load, which is not cost effective, or will need to verify a net uplift value. Many contract drawings do not show the dead loads used in design, and even if they do, it is the specifying professional's judgment call if some of the dead load should be considered collateral and not be deducted from the gross uplift.

Joist girders are typically designed for the uplift reactions of the joists sitting on them, but in fact they are considered as part of the main wind force resisting system (MWFRS), which would result in lower uplift values than if they were considered "components and cladding." When is it an advantage to try to use lower uplift values on a joist girder? If the uplift forces are less than 25% of the typical girder gravity load, then the uplift will have minimal or no effect on the girder. But for uplift reactions greater than 25% of the gravity reaction, the uplift can control member selections, and lower values on the girders could create a savings.

Another note about joist girders: The presumption is that the design load specified includes an allowance for the self-weight of the girder. If this is not the case, it needs to be clearly noted on the contract documents.

For joists that have more than a nominal double pitch, an unbalanced loading case may need to be considered. This is not automatically covered by the SJI specifications, so the specifying professional should provide the necessary instructions on the contract drawings.

For earthquake loads, the joist manufacturer will use different load combinations for *E* or *Em* loads, so the contract drawings need to make a clear distinction between the two types of loads.

Axial Loads and End Moments

Standard K-Series, LH, DLH-Series and joist girders are designed in accordance with the latest SJI specifications as simply supported underslung joists/joist girders, which support symmetrically placed gravity loads applied to the top chord. Occasionally it is desirable to extend and connect the bottom chord to

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the supporting column so the joist/joist girder and column together form a rigid frame supporting gravity and wind/seismic loads. Axial loads or end moments may be induced into the joists/joist girders when joists/joist girders are used as part of the rigid frame, moment frame, or other bracing systems. Joist/joist girder load diagrams or schedules are used to specify the magnitude and direction of the moments and axial forces for each load case that is required to be considered. The diagrams or schedules should distinguish between, and show, both the live load and wind/seismic moments for the most efficient and timely design. Also, the specifying professional should ensure that the contract drawings state that all dead loads are to be applied before the bottom chord extensions are welded to the column, thereby eliminating the moment generated by the dead load. The joists/joist girders are checked for the specified load cases and the effect of the moments and axial chord forces, and the design of the chords and webs, plus the quantity and spacing of the bottom chord braces, is adjusted accordingly.

To transfer the moments and chord forces from the bracing systems or columns into the joists/joist girders, suitable connections are required. The specifying authority should be knowledgeable of the inter-relationships between the joists/joist girders, columns, and connections to obtain a cost effective design. Minimizing fabrication and erection costs of the connections and reducing the special requirements for the joists/joist girders (seat stiffeners, chord reinforcements, etc.) will produce the most economical design. Generally for single story buildings, the most cost effective method of transferring the moments and axial loads from the bracing systems or columns is through the joist/joist girder bearing seats, provided that the forces are not too large. The top chord must be designed to accommodate the axial force and bending moment that is developed due to the force coming in through the bottom of the joist/joist girder bearing seat. This begins to significantly affect the joist design once the axial force exceeds 5 kips for K-Series joists, 10 kips for LH, DLH-Series joists, and 20 kips for joist girders. For larger axial loads, a better force path would need to be created by modifying the basic connection to include the use of a top plate, tie angles/rods, or knife plates from the joist/joist girder to the supporting column. Top plates or tie angles/rods should always be specified for joist-to-joist connections when supported by joist girders. If fillet welds are used for transferring the lateral forces from the bottom chord to the supporting columns, reasonable weld thicknesses should be used to create the most efficient bottom chord design – 1/8″ fillet for K-Series and 3/16″ fillet for LH-Series, if possible.

For axial loads, there can be a cost savings for making the load paths clear or indicating where the axial load is accumulating along the length of a joist.

Deck is often used in the bracing system as a diaphragm and the accommodating loads may need to be routed from the deck into the supporting beam or joist girder through the joist seats. When the lateral stiffness of the joist seat is not sufficient to transfer the required lateral loads, steel tubes or channel sections could be applied between the joists to transfer the lateral load from the deck to the supporting member.

Top Chord Extensions

Top chord extensions are commonly used to create eaves or awnings. They can be either simple (S Type), where only the top chord is extended past the bearing seat, or reinforced (R Type), where both the top chord and the bearing seat are extended. The SJI standard specification has tables for "Top Chord Extensions and Extended Ends" that provide the load capacity for various lengths of types S1 through S12 and R1 through R12 extensions. It should be noted that although a simple top chord extension can be as long as 4′-6″, the load rating for this extension is only 113 plf.

The Structural Engineer of Record should review the "Top Chord Extension Load Table" and "Extended End Load Table" to ensure that an extension can be manufactured for the length and loads required for their project. If there are concentrated loads or snow drift loads on the extension, they need to be resolved into an equivalent uniform load and added to the dead and live loads on the extension. This will allow the engineer to properly size and specify the extension needed.

The top chord extensions given in the SJI standard specification can be used for either K-Series or LH, DLH-Series joists.

The SJI "standard" bearing seat depths are 2.5″ for K-Series joists, 5″ for LH, DLH-Series joists, and 7.5″ for joist girders. However, it should be understood that a 5″-deep seat can be used on a K-Series joist or a 4″-deep seat could be used on an LH-Series joist. When the joists are installed at a slope, the minimum required bearing seat depth might have to be increased. Most manufacturers' catalogs have a table that gives the minimum required bearing seat depths for a given slope. Referring to these tables and specifying the minimum bearing seat depth in accordance with these tables will help to reduce detailing, manufacturing, and possibly erection costs. It will also reduce the number of RFIs from the joist manufacturer.

When the loads for a top chord extension of a given length are greater than the values given in the "Top Chord Extension Load Table" or "Extended End Load Table," it is an indication that a 2.5″-deep seat will not work. So what bearing seat depth should be specified? A good rule of thumb (in most cases) is that the depth of the bearing seat in inches should be equal to the length of the extension in feet.

As an example, consider a joist extension with a length of 5′-6″; the load on the joist and extension is 280 plf, and there is a 1,000 lb concentrated load at the end of the extension.

The equivalent uniform load on the extension is: 280 + (2 x 1000)/5.5 = 644 plf.

From the "Extended End Load Table (R Type)," the maximum load on a 5′-6″ extension is 375 plf for a Type R12 extended end. Therefore, a 2.5″-deep bearing seat will not work for this joist. Based on the above, the bearing seat depth should be increased to 5″. Note: If the joist had to be installed at a slope, the bearing seat depth may have to be further increased to account for the slope.

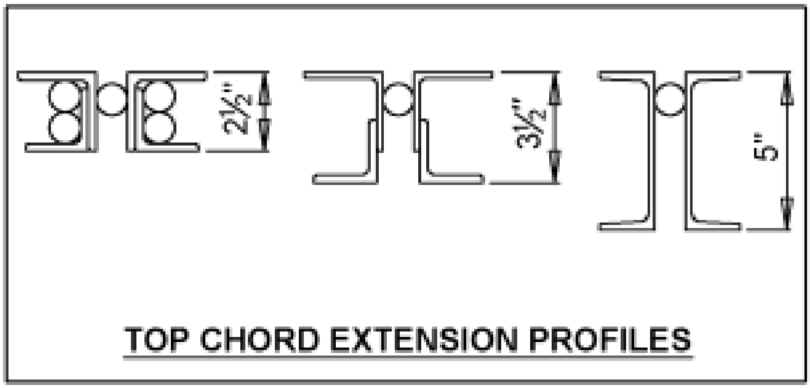
Joist Substitutes

Joist substitutes are now included as part of the SJI K-Series standard specification. These are very economical and should be specified when the length of the joist is 8′ or less. The SJI has three joist substitute designations: 2.5K1, 2.5K2, and 2.5K3. The spans for these joist substitutes are 4′ to 8′. The specifying professional should refer to the "2.5 Inch K-Series Joist Substitutes" load table for the particular joist substitute that satisfies the project requirements. Some joist manufacturers do offer joist substitutes in depths up to 5″ and lengths up to 10′. If a joist substitute must be longer than 8′, it may need to have a bearing seat deeper than 2.5″. The depth of the joist substitute should be the same depth as the joist bearing seats.

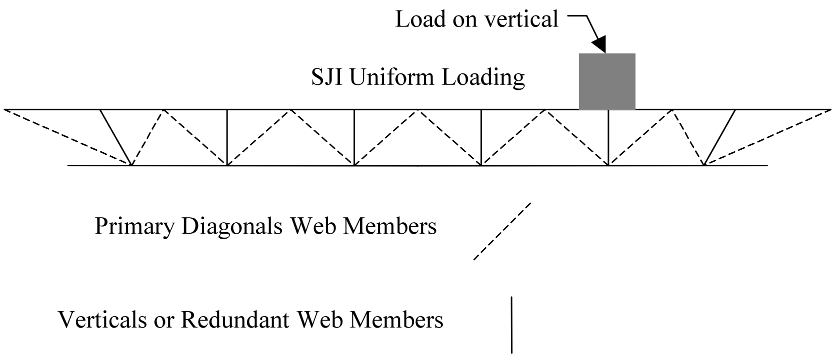
Bridging

The traditional image of horizontal bridging rows is a pair of aligned angles at the same location on the top and bottom chords. However, it is not essential or required that the top and bottom chord rows align. In fact, there can be cost savings if the spacing of the bridging rows is varied according to the structural needs. This is particularly true in regions with high uplift values. The specifying professional should avoid dimensioning specific bridging line locations on the contract drawings to allow the joist manufacturer to optimize the bridging layout. In fact, many contract drawings simply state, "bridging as required per SJI."

When selecting the joist designations for a project, the lightest joist may not be the cheapest if the lighter joist requires erection stability bridging (bolted cross bridging) and a slightly heavier joist does not. All joists in the shaded portions of the load tables require erection stability bridging (bolted cross bridging).



Top chord extension profiles.



The secondary web members, often referred to as "verticals" or "redundants," must be designed to support the top chord load, plus a portion of the top chord force as a bracing load.

Retrofit Joists

When the retrofit of an existing structure requires that the joist capacities be increased, adding new additional intermediate joists may be more cost effective than modifying or extensively reinforcing existing joists. If the deck will be replaced in the area of the new joists, the procedures are essentially the same as for new construction. But if the metal decking will not be removed, there are a number of special considerations to be made:

- The new joists can be provided with a field bolted splice at mid-span to allow each half to be raised independently and then joined together in the air.
- The camber of the new joists should be reduced or eliminated to attempt to match the current as-built deck profile.
- It is common to reduce the joist bearing seat depth slightly, and then call for field shimming to the required height. This allows for tolerances that may vary from the existing to the new construction.
- The lateral support of the new joist top chord needs to be addressed. Typically, the metal deck is attached at a maximum spacing of 36" on center to laterally support the top chord. But it may not be possible to make a welded connection to the existing deck. Therefore, an alternative is to call for extra bridging rows, and to coordinate with the joist manufacturer so that the joist design considers only those bridging rows as lateral support points.

Point Loads

When joists will be used to support non-uniform, concentrated loads, such as roof top units, a number of options are available to provide the required joist capacity. This section will outline those options and provide a relative price comparison.

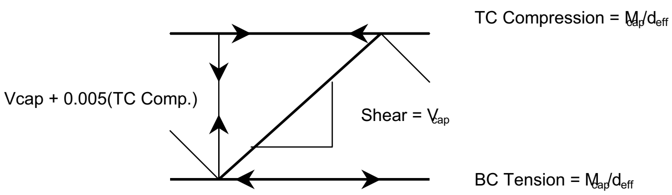
Loads and Locations Known

If the exact magnitude and location of the point loads are known to the specifying professional, the most efficient joist design will be obtained if a load diagram is provided or the loads and locations are clearly shown on the contract drawings. Because every joist manufacturer custom designs all the joists for the specific project, there is no cost savings if the specifying professional attempts to select a larger standard designation joist to cover the additional loads.

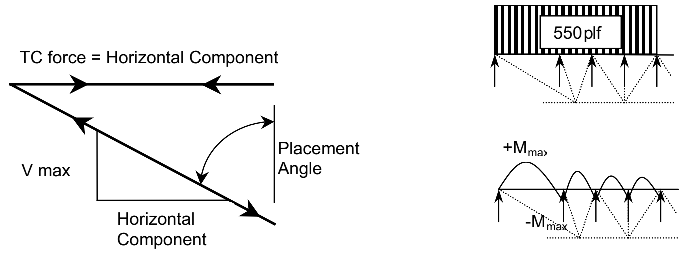
KCS-Series Joists

When exact locations of the point loads are not available to the specifying professional, a KCS-Series joist is an alternative that provides flexibility within a moment and shear envelope. By evaluating two possible locations for point loads, the end of the span and the mid-span, a design envelope can be established. With maximum moment and shear values, a KCS-Series joist can be selected that will perform satisfactorily regardless of the locations of the loads. However, there are a number of issues pertaining to design that need to be understood and considered when selecting KCS joists. Below is a brief explanation of how a KCS joist design differs from that of a K-Series joist. Then, specific items are addressed illustrating the impact of the use of KCS joists.

A KCS joist is a modified K-Series joist. The K-Series standard specification requires the diagonal web members be designed for the shear resulting from the published uniform load or a minimum of 25% of the SJI end reaction, whichever is greater. The primary modification to the K-Series joist specification is that the web



The chords of a KCS-Series joist are designed for the axial force—compression in the top chord and tension in the bottom chord—resulting from dividing the published maximum moment by the effective depth of the joist.



The end panels of the top chord of a KCS-Series joist are designed for the combined effects of the axial force resulting from the horizontal component of the end web and bending calculated using an assumed four span continuous beam model loaded with 550 plf.

RELATIVE PRICE COMPARISON								
LOAD CASE 1: 2 @ 300#	UNIFORM LOAD	WITH POINT LOADS	KCS	KCS/ FIELD STRUTS	TRAVEL/ ADD LOAD @ PANEL POINT	TRAVEL/ ADD LOAD WITH FIELD STRUT	TRAVEL/ ADD LOAD WITH LOCAL BENDING	FIELD REINF.
COST	$239	$247	$355	$410	$253	$308	$260	8 ELEMENTS $239 + $340
%	100%	103%	149%	172%	106%	129%	109%	242%
LOAD CASE 2: 2 @ 1200#	UNIFORM LOAD	WITH POINT LOADS	KCS	KCS/ FIELD STRUTS	TRAVEL/ ADD LOAD @ PANEL POINT	TRAVEL/ ADD LOAD WITH FIELD STRUT	TRAVEL/ ADD LOAD WITH LOCAL BENDING	FIELD REINF.
COST	$239	$281	$401	$456	$292	$347	$308	22 ELEMENTS $239 + $680
%	100%	118%	168%	191%	122%	145%	129%	385%

Cost comparisons for two traveling loads of 300 lb, or two at 1,200 lb.

members are designed for a constant shear value regardless of position within the joist, thus the KCS designation. The secondary web members, often referred to as "verticals" or "redundants," must be designed to support the top chord load, plus a portion of the top chord force as a bracing load. The primary web members, except the end web, of a KCS-Series joist are designed for 100% of the published shear capacity as a compressive load. Only the end web is designed as a tension member for the force that results from the published shear capacity.

The chords of a KCS-Series joist are designed for the axial force—compression in the top chord and tension in the bottom chord—resulting from dividing the published maximum moment by the effective depth of the joist. This design force is used for all the bottom chord panels and all top chord panels, except the first and last. SJI recognizes that the maximum shear and moment capacities cannot develop simultaneously in the end panel. The end panels of the top chord are designed for the combined effects of the axial force resulting from the horizontal component of the end web and bending calculated using an assumed four span continuous beam model loaded with 550 plf. It should be noted that the top chords of KCS joists, as with K-Series joists, are not designed for any bending between the panel points except in the end panel as described above. A KCS joist cannot support a concentrated load between panel points. A field applied member must be installed at all loads that are not at panel points.

Because of this approach, the chord and web sizes for KCS joists will rarely change, regardless of length. A 30KCS5 that has a 30′span will have the same member sizes as one that has a 60′ span. With the chord sizes established, a moment of inertia is calculated and published in the tables. This information provides the specifying professional the stiffness that can be used for checking deflection and analyzing lateral frame action.

Another advantage of a KCS-Series joist is that if the loads ever change over the life of the structure, the moment and shear capacities are clearly known, making it easy to evaluate new loading conditions.

Traveling Loads or Add Loads

Another possibility for providing flexibility in the placement of point loads is to specify a traveling, added load that could occur anywhere along the joist span. The joist manufacturer will model the joist with the loads in a large number of possible locations so that the maximum possible shear and moment is calculated for each individual element of the joist. There are two possibilities for the type of traveling load being specified: It could be applied at any panel point (such that local bending between panel point is not considered), or it could be applied anywhere along the span (such that local bending is considered and field added struts would not be required). The specifying professional needs to clearly indicate the desired type on the contract drawings, as well as an indication of the chord to which the traveling load will be applied.

The table shows the cost comparisons for two traveling loads of 300 lb, or two at 1,200 lb. Three comparisons are made for each loading case: Loads applied at panel points only, loads applied at panel points for the joist design but field added struts used at the actual locations, or loads applied anywhere along the span with local bending considered. In general, for something like a roof top unit that will have a frame that may not correspond to joist panel lengths, it is cost effective to require the design for anywhere along the span. But for hanging loads, such as sprinkler lines, that have the field flexibility to be hung only at panel points, the "at any panel point" option makes sense.

The chart demonstrates that the specification of a traveling, added load can be a cost effective alternative and shows that the costs of having flexibility in the placement of the loads is not significantly greater than the cost of a joist designed for the loads at a known location.

Field Reinforcement

To complete the cost comparison in the table, the estimated costs of reinforcing the joist that was designed only for uniform loads so that it can support the point loads is considered. This column of the chart shows the number of overstressed joist elements for this example and the cost of the original joist plus the cost of the field reinforcement. It should be noted that the actual field costs can vary greatly depending on location and conditions. However, the cost of the field reinforcing will be several multiples of the original joist cost, and it is clear that it is far more expensive than other costs shown to build the original joist with additional capacity. ★

This paper has been edited for space considerations. To learn more about using joists efficiently, read the complete text online at www.modernsteel.com or in the 2005 NASCC Proceedings.