



PDHonline Course S117 (1 PDH)

The Analysis of Open Web Steel Joists in Existing Buildings

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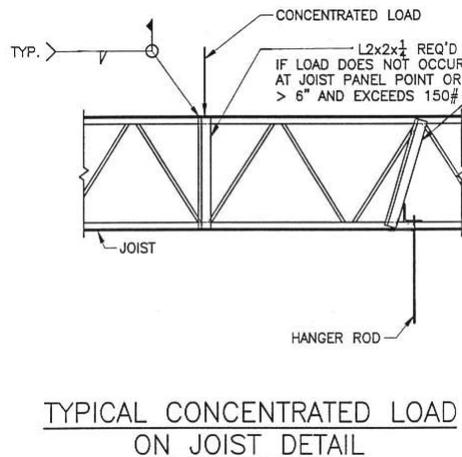
Fabricated open web joists are manufactured in this country by a number of different companies. Open web joists are designed and fabricated per the Steel Joist Institute (SJI) specifications. However, at one time there was enough variation in the design and fabrication of these types of structural members that the allowable load tables published by SJI actually represented the approximate average load carrying capacity of any given member manufactured in the industry. A comparison of some of the older SJI load tables to the allowable load tables published by any individual producer at the same time will highlight this fact. It is also important to note that because open web joists are really proprietary fabricated trusses these members do not lend themselves well to in-situ strengthening or reinforcing when compared to standard rolled steel sections. Therefore a structural engineer is often faced with a daunting task when evaluating an existing structure constructed with joists and joist girders.

ASD
STANDARD LOAD TABLE FOR OPEN WEB STEEL JOISTS, K-SERIES
Based on a 50 ksi Maximum Yield Strength - Loads Shown In Pounds Per Linear Foot (plf)

Joist Designation	24K4	24K5	24K6	24K7	24K8	24K9	24K10	24K12	24K15	24K18	24K21	24K24	24K27	24K30	24K33	24K36	24K39	24K42
Depth (in.)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Approx. Wt. (lbs/ft)	7.8	7.9	8.1	8.2	8.4	8.5	8.7	8.9	9.1	9.3	9.5	9.7	9.9	10.1	10.3	10.5	10.7	10.9
Span (ft)																		
1	650	650	650	650	650	650	650	650										
2	650	650	650	650	650	650	650	650										
3	650	650	650	650	650	650	650	650										
4	650	650	650	650	650	650	650	650										
5	650	650	650	650	650	650	650	650										
6	650	650	650	650	650	650	650	650										
7	650	650	650	650	650	650	650	650										
8	650	650	650	650	650	650	650	650										
9	650	650	650	650	650	650	650	650										
10	650	650	650	650	650	650	650	650										
11	650	650	650	650	650	650	650	650										
12	650	650	650	650	650	650	650	650										
13	650	650	650	650	650	650	650	650										
14	650	650	650	650	650	650	650	650										
15	650	650	650	650	650	650	650	650										
16	650	650	650	650	650	650	650	650										
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18	650	650	650	650	650	650	650	650										
19	650	650	650	650	650	650	650	650										
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21	650	650	650	650	650	650	650	650										
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26	650	650	650	650	650	650	650	650										
27	650	650	650	650	650	650	650	650										
28	650	650	650	650	650	650	650	650										
29	650	650	650	650	650	650	650	650										
30	650	650	650	650	650	650	650	650										
31	650	650	650	650	650	650	650	650										
32	650	650	650	650	650	650	650	650										
33	650	650	650	650	650	650	650	650										
34	650	650	650	650	650	650	650	650										
35	650	650	650	650	650	650	650	650										
36	650	650	650	650	650	650	650	650										
37	650	650	650	650	650	650	650	650										

Source: Vulcraft

Because of the reasons indicated in the previous slide it is not recommended that the engineer-of-record for the retrofit of a building assume the responsibility for the design of the strengthening of the existing joists and joist girders. The only exception to this situation should be when supplemental web members are added when loads occur between panel points and it is necessary to transfer the reaction to the closest adjacent panel point at the opposing chord.

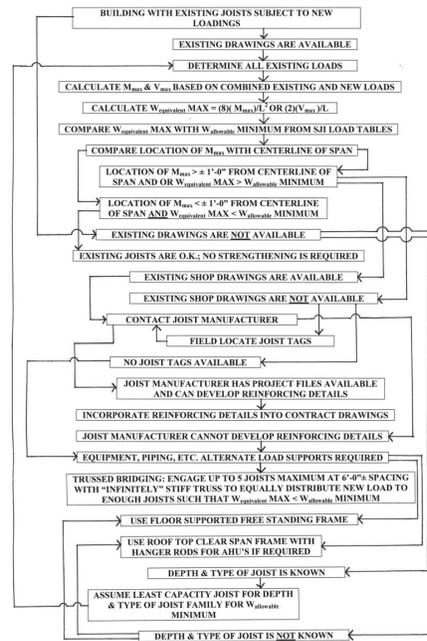


The reason for this position is as follows. Although it is possible to analyze individual component members of joists or joist girders for increased loads, it is very difficult if not impossible to document the capacity of existing welds at the panel points. Although bottom chord panel point welds can usually be documented in the field fairly easily, this task can still be a considerable undertaking. In addition, more often than not the welds at the top chord panel points are not accessible because of the interference from roof or floor decking. In fact, in situations where the manufacturer of a particular joist is known, unless the same producer has enough information archived on the particular project members, the manufacturer's engineer can only assume that their minimum standard weld was provided. If this minimum information is available the manufacturer can develop strengthening details for the joists, however, the reinforcing is typically conservative because of the assumptions made by the manufacturer.



Source: Electronic Library of Construction Occupational Safety & Health

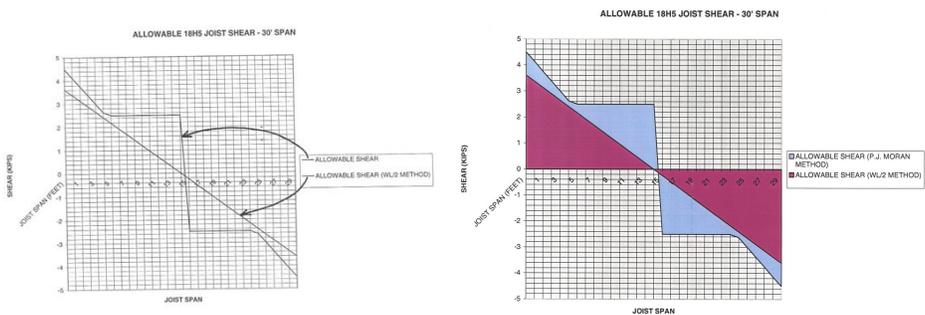
In either case, if the manufacturer of the joist cannot be located or contacted but the type of the joist and individual member sizes can be established, it is still recommended that the engineer-of-record should not design strengthening measures for the joists. To assist the engineer through the process of reviewing existing joists and determining the options available to safely support new loads the following flowchart can be used.



Assume an existing 18H5 joist spanning 30'. The SJI allowable joist load table indicates that the Maximum Allowable End Reaction for this joist is 4,500 LBS, which is significantly higher than 3615 LBS allowable shear capacity derived from the formula $wL/2$ (based upon an allowable uniform load of 241 PLF for a 30' 18H5 joist span).

These differences in shear capacities result from the following. On the allowable load tables, each joist column has a horizontal blue line separating where the allowable uniform loading of the joists is controlled by the shear capacity of the joist and where the allowable uniform loading of the joist is controlled by the moment capacity. The allowable shear for an H-Series joist starts at the Maximum End Reaction value (given in the table) and decreases by the allowable uniform load value just above the blue transition line until it reaches a minimum value of 1/2 of the maximum end reaction. For this example, the allowable joist shear starts at 4,500 LBS at each end of the joist and decreases by 375 pounds per foot (the allowable uniform load value just above blue line for a 18H5) until it reaches a value of 2,250 LBS (1/2 of 4,500 LBS) at which point the slope of the allowable shear line is flat.

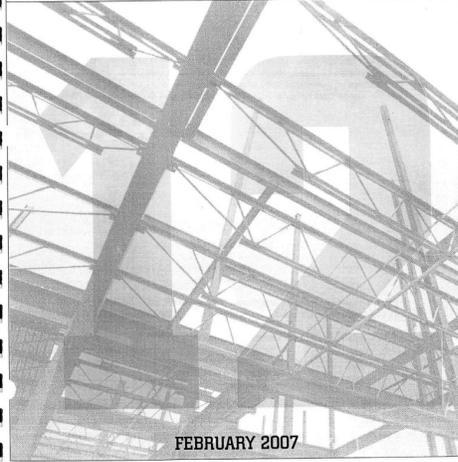
The following graphs show the comparison of the allowable shear of the 18H5 joist example based upon both a $wL/2$ calculation and the more accurate method described in the previous slide. As you can see, this later method gives higher values for allowable shear at every location on the joist.



The evaluation and strengthening of existing open web steel joists and joist girders is often required as a result of equipment upgrades or new installations, and adaptive reuse or change in use of a facility. The SJI provides an excellent resource for the evaluation and modification of existing joists and joist girders in Technical Digest No. #12.



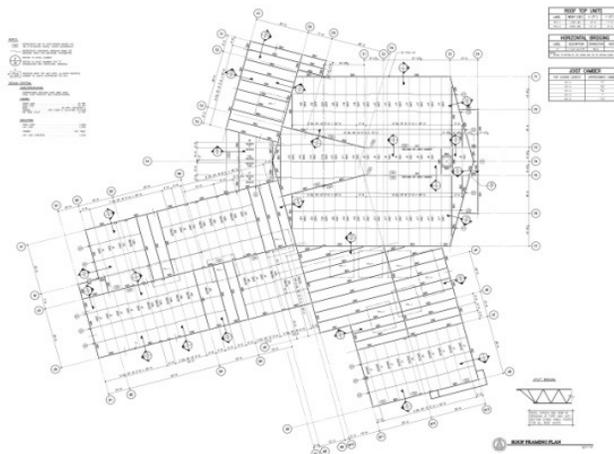
TECHNICAL DIGEST 12
EVALUATION AND MODIFICATION OF OPEN-WEB STEEL JOISTS AND JOIST GIRDERS
By James M. Fisher, Ph.D., P.E.



FEBRUARY 2007

Source: Steel Joist Institute

The first step in the process of evaluating an existing joist is to determine the capacity of the member. Ideally, the best method of determining the member capacity is through the original construction or shop drawings, which allow the identity of the joist to be established. Similarly, it is also sometimes possible to identify the joist via fabrication tags left attached to the joists in the field. However, if tags can be found, more often than not the tag only identifies the shop piece mark number rather than the actual joist designation.



Source: Precision CADD & Graphics

In some instances, it may only be possible to establish the type or series of the joist through the available documentation. In this situation it is possible to conservatively assume that the capacity of the existing joist is no more than the lightest joist in the series for the given depth. In addition, if it is not clear whether a J or an H-Series joist is involved, the J-Series joist should always be conservatively assumed because of its lower load carrying capacity. However, if a definitive distinction is required, and it is possible to secure a material sample in order to obtain results from a standard ASTM tension coupon test, a determination as to whether the joist is 36 ksi (J-Series) or 50 ksi (H-Series) can be made.

STANDARD SPECIFICATIONS FOR OPEN WEB STEEL JOISTS, J- & H- SERIES

Adopted by Steel Joist Institute and American Institute of Steel Construction, Inc., December 15, 1970

SECTION 1. SCOPE

These specifications cover the design, manufacture and use of Open Web Steel Joists, J and H-Series.

SECTION 2. DEFINITION

The term "Open Web Steel Joists J and H-Series", as used herein, refers to open web parallel chord load-carrying members suitable for the direct support of floors and roof decks in buildings, utilizing hot-rolled or cold-formed steel, including cold-formed steel whose yield strength* has been attained by cold working. They are designed in accordance with these specifications to develop the resisting moments and maximum and reactions shown in the Standard Load Tables for Open Web Steel Joists, J- or H-Series attached hereto.

The design of J-Series joists shall be based on a yield strength of 36,000 psi and steel used for J-Series joists shall have a minimum yield strength of 36,000 psi in the hot-rolled condition prior to forming or fabrication.

The design of chord sections for H-Series joists shall be based on a yield strength of 50,000 psi. The design of web sections for H-Series joists shall be based on a yield strength of either 36,000 psi or 50,000 psi. Steel used for H-Series joist chord or web sections shall have a minimum yield strength determined in accordance with one of the procedures specified in Section 3.2, which is equal to the yield strength assumed in the design.

*The term "yield strength" as used herein shall designate the yield point of a material specimen in the ultimate tensile strength or elongation; i.e., "Yield Strength" or "Minimum Yield Point" of ASTM Standard Mechanical Properties of Steel Products, or as defined in Section 3.2 of this Specification.

Standard Specifications, Open Web Steel Joists, J and H-Series, Copyright 1971, Steel Joist Institute and American Institute of Steel Construction, Inc.

SECTION 3. MATERIALS

3.1 STEEL

The steel used in the manufacture of chord and web sections shall conform to one of the following ASTM Specifications of latest adoption:

- (a) Structural Steel, ASTM A36
- (b) High-Strength Low-Alloy Structural Steel, ASTM A242
- (c) High-Strength Low-Alloy Structural Manganese Vanadium Steel, ASTM A541
- (d) Hot Rolled Carbon Steel Sheets and Strip, Structural Quality, ASTM A570
- (e) High-Strength Low-Alloy Columbium-Vanadium Steel of Structural Quality, ASTM A572, Grades 42, 45 and 50.
- (f) High-Strength Low-Alloy Structural Steel with 50,000 psi Minimum Yield or 4" thick, ASTM A588.
- (g) Hot Rolled or Cold Rolled Sheet, High-Strength Low-Alloy, with Improved Corrosion Resistance, ASTM A506
- (h) Steel, Cold Rolled Sheet, Carbon Structural, ASTM A583, Type 2.

or shall be of suitable quality ordered or produced to other than the listed specifications, provided that such material as the state used for final assembly and fabrication is weldable and is proved by tests performed by the producer or fabricator to have the properties specified in Section 3.2.

3.2 MECHANICAL PROPERTIES

The yield strength used as a basis for the design stresses provided in Section 4 shall be either 36,000 psi or 50,000 psi. Evidence that the steel furnished meets or exceeds the design yield strength shall be provided in the form of witness or certified test reports.

For material used without consideration of increase in yield strength resulting from cold forming, the specimens



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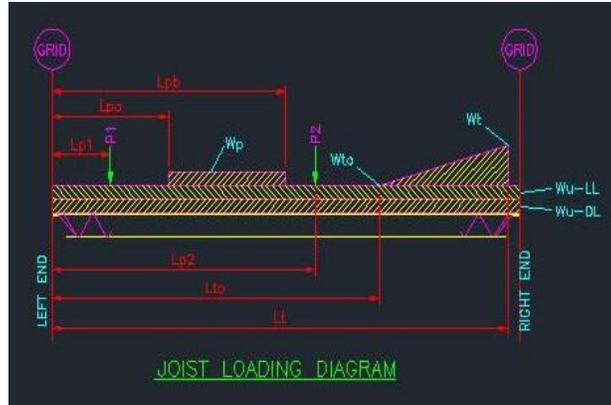
Source: Steel Joist Institute

If no drawings are available it is still possible to establish the approximate capacity of the member by field measuring the chord and web member sizes as well as the overall configuration of joist. This information can then be used to analyze the structure as a simple truss. Critical assumptions that must be made with this approach include; the yield strength of the members, and if the existing panel point welds are capable of developing the full capacity of the connected component members. An alternate method to the above approach includes filling out the Joist Information Form located on the SJI website. SJI has indicated that they have been very successful in identifying the series and designation for many older joists with this resource.

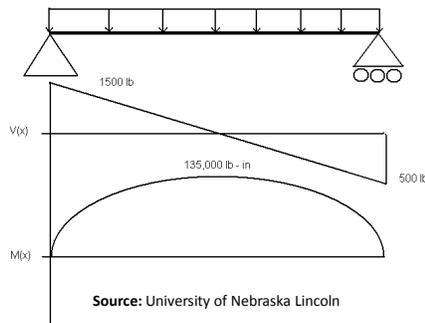
Joist Investigation Form: <http://www.steeljoist.org/investigation>

- Engineers, Architects, Specifying Professionals, Contractors, and others trying to identify older joists found in the field can now fill out the form below, or they can use this [downloadable form](#) to provide the necessary information to the SJI office. Please fill out as much information as possible. This will help the SJI office in making a proper match of your joist information to those in our extensive historical files.
- When filling in the form regarding the joist chord and web member properties, it is recommended that the field measurements be taken with a micrometer rather than a tape measure, since chord thicknesses can vary by as little as 1/64 inch and web diameters can vary by 1/32 inch.
- Sending pictures or sketches of the joist profiles is also recommended when the member cross-sections seem to be of a proprietary nature. When you submit the form below and want to submit photographs or sketches to go along with it, please email them to sji@steeljoist.org

The next step in the evaluation process is to determine all of the existing loads on the joist system. The existing and new loading criteria are then used to establish the shear and moment envelope of the individual joist. This information is then used to compare to the allowable shear and moment envelope based on either the historical data provided by SJI or an independent analysis of the member as a simple truss. If the SJI historical data is used for comparison to the actual loading on joists that were not fabricated with a uniform shear and moment capacity over the entire span length (i.e. not KCS joists) then in addition to confirming that the applied shear and moment do not exceed the joist capacity it is also necessary to compare the location of the maximum imposed moment to the mid-span of the joists.



Typically if the location of the maximum moment is less than or equal to one foot from the mid-span and the maximum applied moment is less than the joist moment capacity, the joist is capable of safely supporting the imposed loads. However, if the location of the maximum moment is greater than one foot from the mid-span, the capacity of the joist may not be sufficient even if the applied moment is less than the specified capacity. This latter situation can occur for two reasons. First the moment capacity envelope of the joist may actually be less in regions of the span other than plus or minus one foot from the mid-span. Secondly, a shift in the moment envelope from that normally associated with a uniformly loaded simple span (and the prerequisite shear envelope) may result in stress reversals in the web members (i.e. from tension to compression) that the original member was not designed or manufactured for. A similar, although typically more advantageous, condition also can occur with J or H-Series joists because of variations in the uniform shear capacity of these same members as was discussed previously.

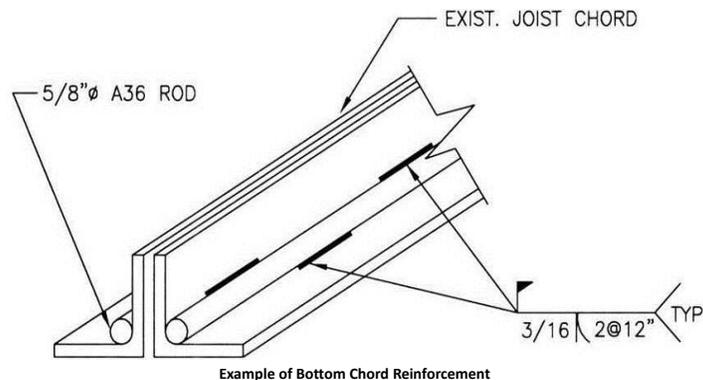


In situations in which it has been confirmed that the existing joists do not have sufficient capacity to support the new loads; there are three methods that can be used to rectify the condition:

1. **Load Redistribution.**
2. **Adding new joists or beams.**
3. **Reinforcing existing joists.**



Load redistribution involves the installation of a sufficiently stiff member perpendicular to the span of the joist as required to distribute the applied load to enough adjacent joists such that no one joist is overstressed as a result of the new loading. Adding new joists or beams typically involves the installation of a new framing member parallel to the joist span such that all or most of the new applied load is supported by the new framing. New self-supporting beams can also be installed perpendicular to the joist span as required to reduce the original span length of the member. Finally, new independent, self-supporting beam and column frames can also be installed to circumvent the imposition of any new loads on the existing joist framing system. Reinforcing involves the installation of supplemental material to the original joist as required to increase the load carrying capacity of the member.



The key to the successful use of load redistribution involves the installation of a structural member that can adequately and predictably distribute the applied load to enough adjacent joists to justify the safe support of the load. A method of calculating the relative stiffness of a distribution member is available in "Designing With Steel Joists, Joist Girders, Steel Deck" by Fisher, West & Van De Pas and is illustrated below:

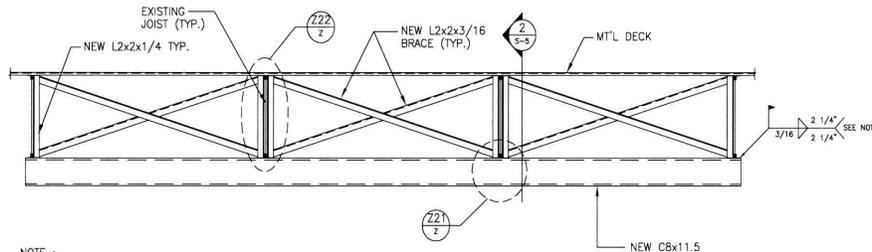
$$\beta = \sqrt[4]{\left(\frac{K}{S}\right) / (4EI)}$$

Where: K = Stiffness of the joist, kips/inch
 S = Spacing of the joists
 E = Modulus of Elasticity of beam
 I = Moment of Inertia of beam

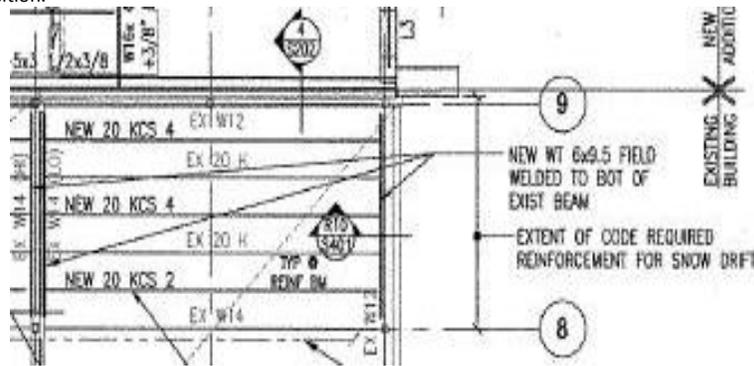
If $S < \pi/4\beta$ the beam on elastic support calculations are applicable. If the spacing limit is not exceeded and the length of the beam is less than $1/\beta$, the beam may be considered to be rigid with respect to the supporting joists and the reaction of the joists may be determined by static equilibrium.

In general, if the spacing of the joists is less than approximately 78% of the calculated stiffness of the distribution member and the length of the distribution member is less than the inverse of the calculated stiffness, then the distribution member may be considered as rigid enough to statically calculate the load reactions to the affected joists.

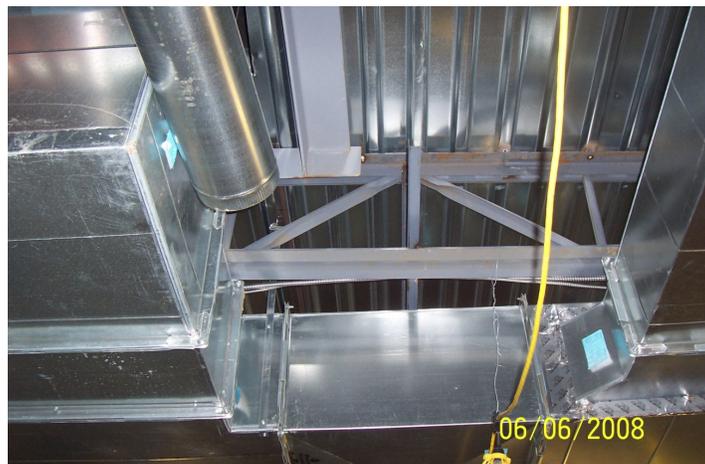
For load redistribution solutions it is my preference to use trussed distribution members rather than individual beams to assure the adequate transfer of the applied load. By trussed the author means continuous members located perpendicular to both the existing joist bottom and top chords in conjunction with diagonal web members connected to the continuous members at the intersection of the joist chords. The resulting configuration looks like a truss and provides greater stiffness than an individual beam connected to either the joist bottom or top chords. The author also recommends that no more than five joists be engaged by a distribution member. In addition, the use of pipes for the continuous distribution truss chord members can also be advantageous as this type of section fits neatly through the V shaped panel point openings created at the intersection of the existing chords and web members. Load redistribution solutions may be difficult to install depending on accessibility and the presence of existing MEP systems, ceilings or other appurtenances.



As indicated above, adding new joists or beams to an existing system can also be used to provide solutions to new loads on a joist structure. When new members are added parallel to the existing joists the new framing can be used to either reduce the tributary area of the existing joists or provide direct support of the new loads such that there is no impact on the existing joist framing. Methods used to install new parallel framing often involve the need to manufacture, ship and erect the new members using field splices. However, it is possible to install new full length manufactured joists via the use of loose end bearing assemblies. In this later scenario the joists are first erected on a diagonal to allow the top chord to be lifted above the bearing elevation. The joist is then rotated into an orthogonal position with the lower portion of the bearing assembly then dropped and welded into place. Typically in this situation, a shallower bearing seat is also provided for ease of installation and then shimmed once the new joist is in its proper position.



When new beams or other similar members are added perpendicular to the joist span the new framing serves to reduce the span of the existing members thereby increasing the load carrying capacity of the joists. However, in this scenario it is still necessary to analyze the existing joists to assure that no load reversals have occurred in tension only web members and that the actual applied moment falls within the remaining existing moment capacity envelope of the joist. As with load redistribution solutions, both of the above new framing approaches may be difficult to install depending on accessibility and the presence of existing MEP systems, ceilings or other appurtenances.



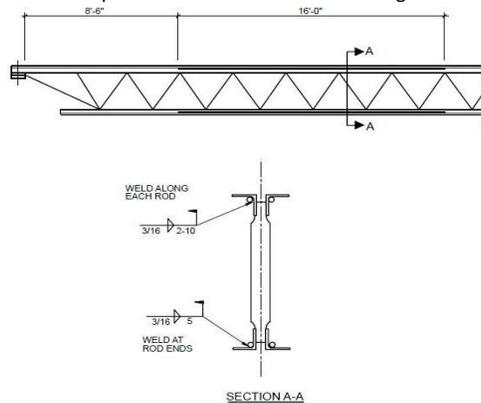
New framing that involves the installation of independent standalone beam and column frames is intended to provide direct support of the new loads such that there is no impact on the existing joist framing. This type of new framing can involve beams (located either beneath or above the impacted existing framing) supported by new columns and foundations or beams that frame between existing columns. This type of solution can also involve new beam frames supported from posts located directly above existing beams or columns. The above solutions are typically less susceptible to the presence of existing MEP systems, ceilings or other appurtenances as the other new beam or joist framing solutions.



Procedures for reinforcing joists are expertly described in the SJI Technical Digest No. #12 and involve two basic approaches:

1. Ignore the strength of the existing member and simply design the new reinforcement to carry all of the applied load, or...
2. Make use of the strength of the existing members when designing the reinforcing.

Both of the recommended approaches typically involve significantly more labor costs than material costs because of the expense associated with field welding.



I prefer to avoid the use of field reinforcement for the following reasons. A manufactured open web steel joist is basically a pre-engineered product, however, when an engineer involved with the modification of an existing joist specifies new field installed reinforcement, that same engineer assumes the responsibility for the overall adequacy of the joist. This liability extends to not only the reinforcing modifications but also inherently to any pre-existing, unknown conditions or deficiencies in the joist. In addition, field welding associated with the installation of reinforcement also poses concerns for the design engineer. Problems associated with field welding are also discussed in Technical Digest No. #12 and include; temporary localized loss of the material strength of the existing steel due to heat generated by the weld, induced eccentricities, inadequate load path mechanisms, and lack of access particularly at the top chord.

