PDHonline Course S117 (1 PDH)

The Analysis of Open Web Steel Joists in Existing Buildings

Instructor: D. Matthew Stuart, P.E., S.E., F.ASCE, F.SEI, SECB, MgtEng

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088
www.PDHonline.org
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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.

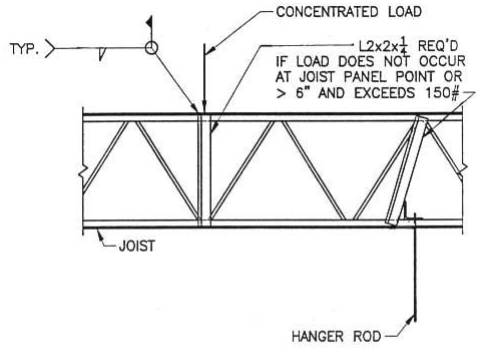
ASD

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	26K5	26K6	26K7	26K8	26K9	26K10	26K12
Depth (in.)	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
Approx. Wt. (lbs./ft.)	7.8	7.9	8.5	9.0	9.4	10.3	11.7	13.5	8.1	8.6	9.0	9.7	10.4	11.8	13.7
Span (ft.)															
23	660	660	660	660	660	660	660	660							
	660	660	660	660	660	660	660	660							
24	620	660	660	660	660	660	660	660							
	516	644	644	644	644	644	644	644							
25	479	540	600	660	660	660	660	660	650	650	650	650	650	650	650
	466	611	620	620	620	620	620	620	650	650	650	650	650	650	650
26	442	499	643	660	660	660	660	660	642	650	650	650	650	650	650
	406	493	493	439	439	439	439	439	639	641	641	641	641	641	641
27	410	462	503	550	660	660	660	660	602	647	650	650	650	650	650
	361	404	439	479	479	479	479	478	477	619	622	622	622	622	622
28	381	429	467	521	660	660	660	660	466	608	650	650	650	650	650
	323	362	393	436	466	466	466	466	427	464	601	601	601	601	601
29	364	400	435	485	636	660	660	660	434	473	627	650	650	650	650
	290	326	364	392	429	436	436	436	364	417	463	479	479	479	479
30	331	373	406	453	600	644	660	660	405	441	492	644	650	650	650
	262	293	319	353	387	419	422	422	346	377	417	467	468	468	468
31	310	349	380	424	468	510	660	660	379	413	460	609	650	650	650
	237	266	289	320	350	379	410	410	314	341	378	413	444	444	444
32	290	327	357	397	439	478	649	649	356	387	432	477	619	649	649
	216	241	262	290	318	344	393	393	286	309	343	376	407	431	431
33	273	308	336	373	413	449	632	632	334	364	406	448	488	632	632
	196	220	239	266	289	313	368	368	269	292	312	342	370	404	404
34	267	290	315	351	388	423	602	616	315	343	382	422	469	616	616
	179	201	218	242	264	286	337	344	237	267	288	312	338	378	378
35	242	273	297	331	366	399	473	601	297	323	360	398	433	601	601
	164	184	200	221	242	262	308	324	217	236	261	286	310	366	366
36	229	258	281	313	346	377	447	487	280	306	340	376	409	486	487
	150	169	183	203	222	241	283	305	199	216	240	263	284	334	334
37	216	244	266	296	327	356	423	474	264	289	322	356	387	460	474
	136	155	169	187	206	222	260	290	183	199	221	243	262	308	316

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.

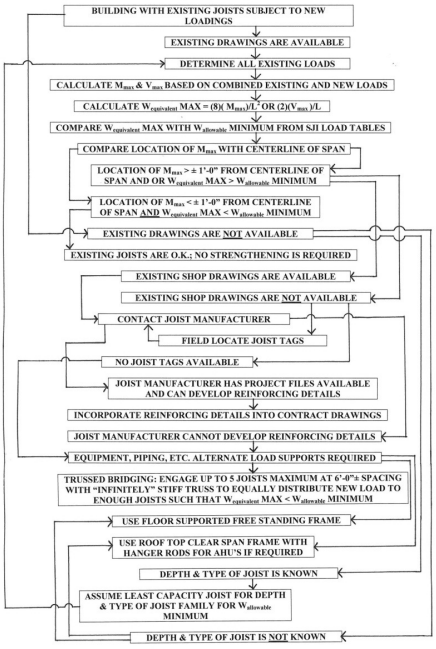


TYPICAL CONCENTRATED LOAD ON JOIST DETAIL

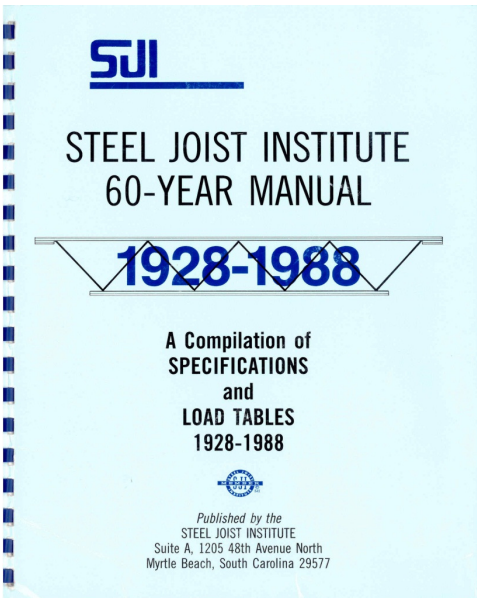
The reason for this position is as follows. Although it is possible to analyze individual component members of joists or joist girders for increased loads, it is very difficult if not impossible to document the capacity of existing welds at the panel points. Although bottom chord panel point welds can 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 measurers 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.

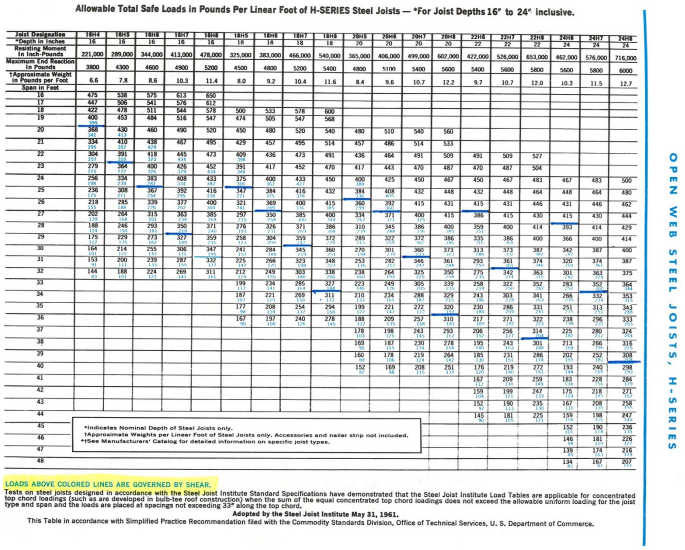


When analyzing older structures, it is common to come across members that are no longer produced. It is often difficult to locate allowable load tables for these members. An excellent publication is available however from SJI for determining the load carrying capacity of older members. Even though this slide shows a copy of the 60-Year manual, the title of the latest reference book is the SJI 75-Year Manual, which covers most joists and joist girders manufactured between 1928 and 2005.



Source: Steel Joist Institute

It is also helpful when reviewing the allowable load tables for older joists to have an understanding of how to properly interpret the tables. To provide an example of how to interpret an older load table, a partial copy of SJI's allowable joist load table (circa. 1961) for a H-Series joist is provided on this slide.



Allowable Total Safe Loads in Pounds Per Linear Foot of H-SERIES Steel Joists — *For Joist Depths 16" to 24" inclusive.

Joist Designation	16H4	16H5	16H6	16H7	16H8	18H5	18H6	18H7	18H8	20H5	20H6	20H7	20H8	22H6	22H7	22H8	24H6	24H7	24H8
*Depth in Inches	16	16	16	16	16	18	18	18	18	20	20	20	20	22	22	22	24	24	24
Resisting Moment In Inch-Pounds	221,000	295,000	344,000	413,000	478,000	325,000	383,000	466,000	540,000	365,000	406,000	499,000	607,000	422,000	526,000	653,000	462,000	576,000	716,000
Maximum End Reaction In Pounds	3800	4300	4600	4900	5200	4500	4800	5000	5400	4800	5100	5400	5600	5400	5600	5800	5600	5800	6000
†Approximate Weight in Pounds per Foot	6.6	7.8	8.6	10.3	11.4	8.0	9.2	10.4	11.6	8.4	9.6	10.7	12.2	9.7	10.7	12.0	10.3	11.5	12.7
Span in Feet																			
16	475	538	575	613	650														
17	447	506	541	576	612														
18	422	478	511	544	578	500	533	578	600										
19	400	453	484	516	547	474	505	547	568										
20	368	430	460	490	520	450	480	520	540	480	510	540	560						
21	334	410	438	467	495	429	457	495	514	457	486	514	533						
22	304	391	418	445	473	409	436	473	491	436	464	491	509	491	509	527			
23	279	358	400	426	452	391	417	452	470	417	443	470	487	470	487	504			
24	256	330	383	408	433	375	400	433	450	400	425	450	467	450	467	483	467	483	500
25	236	308	367	392	416	347	384	416	432	384	408	432	448	432	448	464	448	464	480
26	218	285	339	377	400	321	369	400	415	360	392	415	431	415	431	446	431	446	462
27	202	264	315	363	385	297	350	385	400	334	371	400	415	386	415	430	415	430	444
28	188	246	293	350	371	276	326	371	386	310	345	386	400	359	400	414	393	414	429
29	175	229	273	327	359	258	304	359	372	289	322	372	386	335	386	400	366	400	414
30	164	214	255	306	347	241	284	345	360	270	301	360	373	313	373	387	342	387	400
31	153	200	239	287	332	225	266	323	348	253	282	345	361	293	361	374	320	374	387
32	144	188	224	269	311	212	249	303	338	238	264	325	356	275	342	363	301	363	375
33						199	234	285	327	223	249	305	339	258	322	352	283	352	364
34						187	221	269	311	210	234	288	329	243	303	341	266	332	353
35						177	208	254	294	199	221	272	320	230	286	331	251	313	343
36						167	197	240	278	188	209	257	310	217	271	322	238	296	333
37										178	198	243	293	206	256	314	225	280	324
38										169	187	230	278	195	243	301	213	266	316
39										160	178	219	264	185	231	286	202	252	308
40										152	169	208	251	176	219	272	193	240	298
41														167	209	259	183	228	284
42														159	199	247	175	218	271
43														152	190	235	167	208	258
44														145	181	225	159	198	247
45																	152	190	236
46																	146	181	226
47																	139	174	216
48																	134	167	207

*Indicates Nominal Depth of Steel Joists only.
†Approximate Weights per Linear Foot of Steel Joists only. Accessories and nailer strip not included.
††See Manufacturers' Catalog for detailed information on specific joist types.

LOADS ABOVE COLORED LINES ARE GOVERNED BY SHEAR.

Tests on steel joists designed in accordance with the Steel Joist Institute Standard Specifications have demonstrated that the Steel Joist Institute Load Tables are applicable for concentrated top chord loadings (such as are developed in built-tee roof construction) when the sum of the equal concentrated top chord loadings does not exceed the allowable uniform loading for the joist type and span and the loads are placed at spacings not exceeding 33" along the top chord.

Adopted by the Steel Joist Institute May 31, 1961.

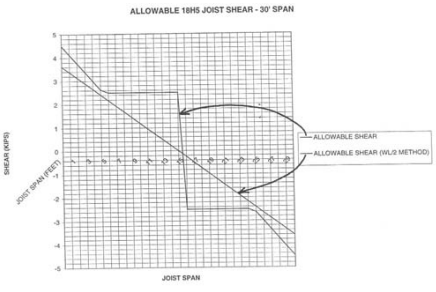
This Table in accordance with Simplified Practice Recommendation filed with the Commodity Standards Division, Office of Technical Services, U. S. Department of Commerce.

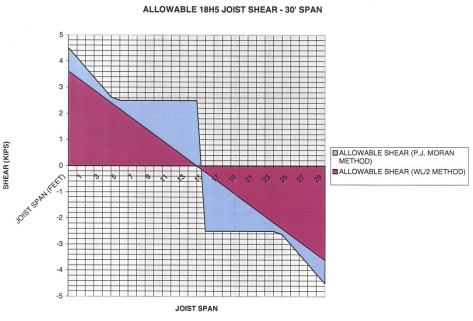
OPEN WEB STEEL JOISTS, H-SERIES

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).

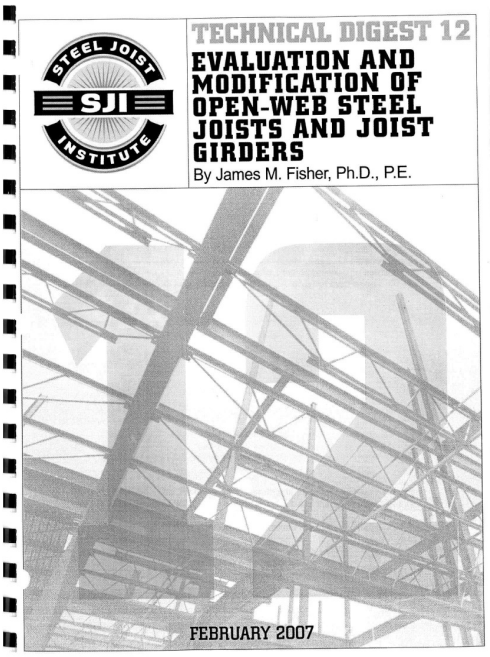
These differences in shear capacities result from the following. On the allowable load tables, each joist column has a horizontal blue line separating where the allowable uniform loading of the joists is controlled by the shear capacity of the joist and where the allowable uniform loading of the joist 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 given 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.



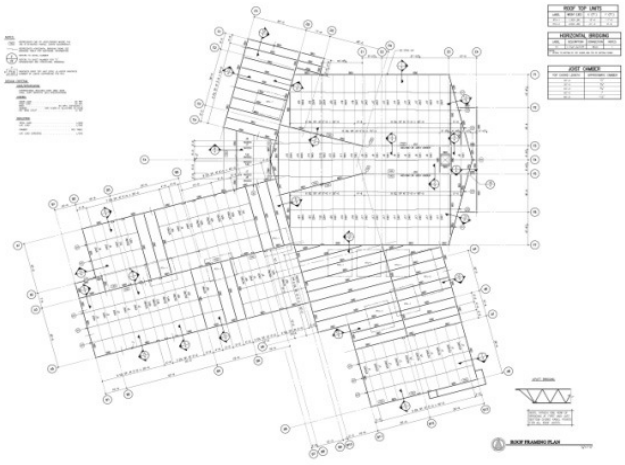


The evaluation and strengthening of existing open web steel joists and joist girders is often required as a result of equipment upgrades or new installations, and adaptive reuse or change in use of a facility. The SJI provides an excellent resource for the evaluation and modification of existing joists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



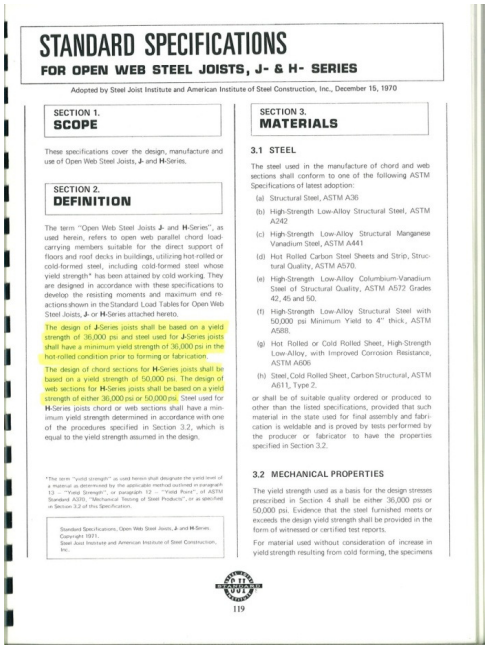
Source: Steel Joist Institute

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 end 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 joists 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 level of a material as determined by the applicable method outlined in paragraph 13 — "Yield Strength", or paragraph 12 — "Yield Point", of ASTM Standard A370, "Mechanical Testing of Steel Products", or as specified 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 A441
(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 to 4" thick, ASTM A588.
(g) Hot Rolled or Cold Rolled Sheet, High-Strength Low-Alloy, with Improved Corrosion Resistance, ASTM A606
(h) Steel, Cold Rolled Sheet, Carbon Structural, ASTM A611, Type 2.

or shall be of suitable quality ordered or produced to other than the listed specifications, provided that such material in 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 prescribed 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 witnessed or certified test reports.

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

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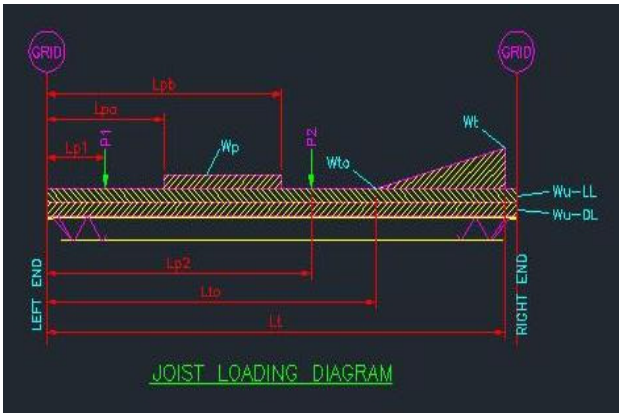
Source: Steel Joist Institute

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.

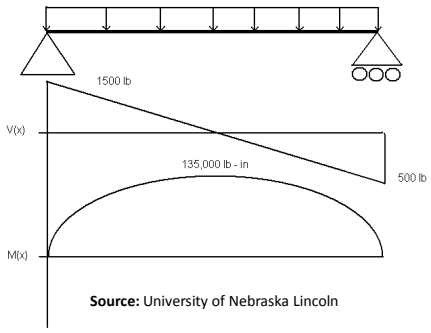
Joist Investigation Form: http://www.steeljoist.org/investigation

- 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 where 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 later 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.

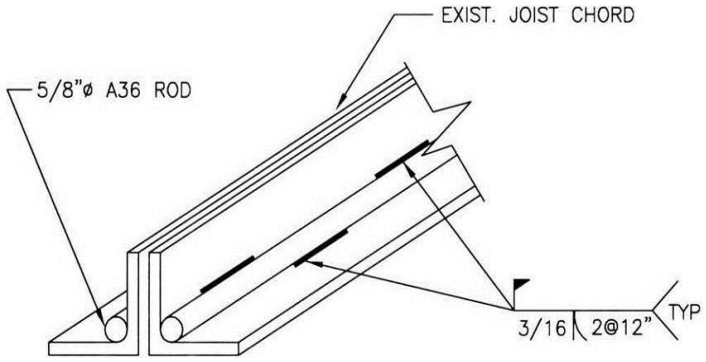


Source: University of Nebraska Lincoln

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.



Example of Bottom Chord Reinforcement

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 in "Designing With Steel Joists, Joist Girders, Steel Deck" by Fisher, West & Van De Pas and is illustrated below:

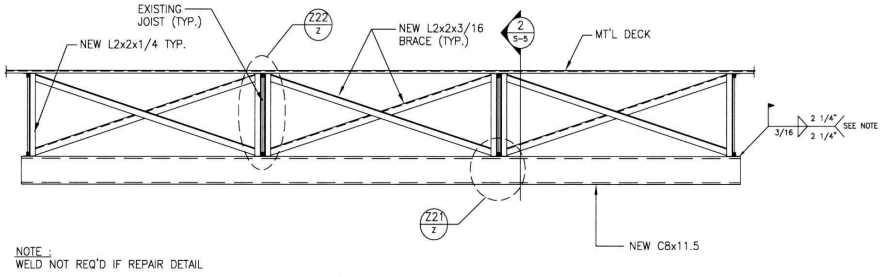
$$\beta = \sqrt[4]{((\frac{K}{S})/(4EI)}$$

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

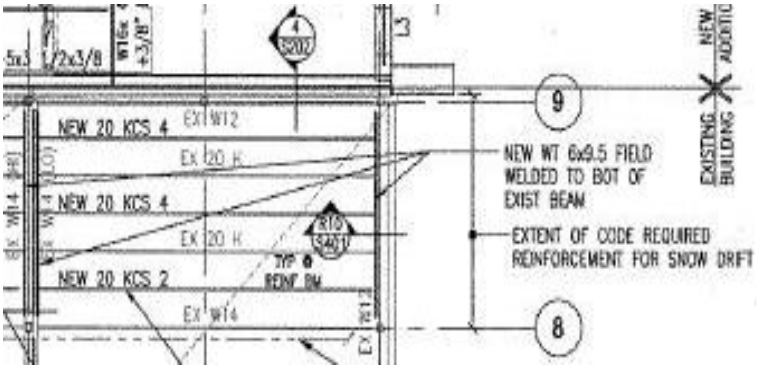
If $S < \pi/4\beta$ the beam on elastic support calculations are applicable. If the spacing limit is not exceeded and the length of the beam is less than $1/\beta$, the beam may be considered to be rigid with respect to the supporting joists and the reaction of the joists may be determined by static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

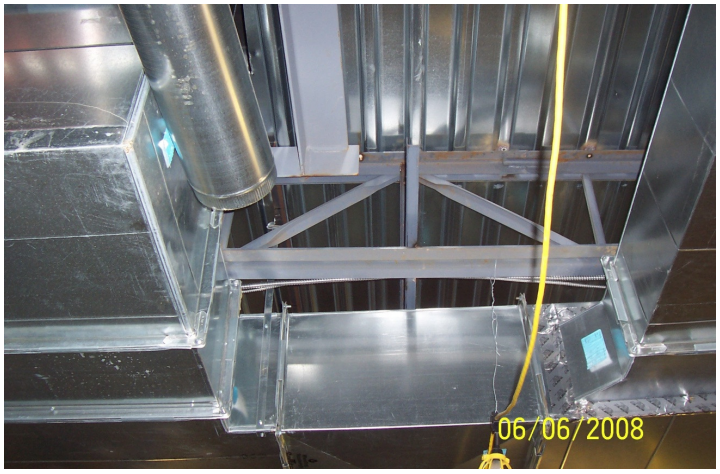
For load redistribution solutions it is my preference to use trussed distribution members rather than individual beams to assure the adequate transfer of the applied load. By trussed the author means continuous members located perpendicular to both the existing joist bottom and top chords in conjunction 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.

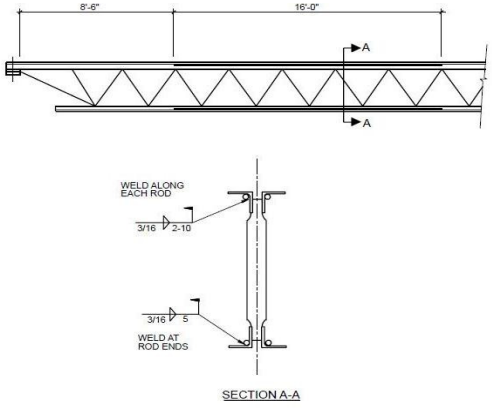


New framing that involves the installation of independent standalone beam and column frames is intended to provide direct support of the new loads such that there is no impact on the existing joist framing. This type of new framing can involve beams (located either beneath or above the impacted existing 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.