THE SJI COMPOSITE STEEL JOIST CATALOG
FIRST EDITION 2007
FOR USE BY THE DESIGN PROFESSIONAL

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Abstract:

In 2006 the Steel Joist Institute introduced a new Load and Resistance Factor Design (LRFD) Standard Specification for the design and manufacture of simply-supported open-web composite steel joists. This paper will appraise SJI's new **CJ**-Series Composite Steel Joists from the perspective of the Design Professional. General topics to be covered are: An introduction to Composite Steel Joists that provides the Design Professional with a basic understanding of the background research that was conducted to verify the structural models that have been utilized in the specification's development; a brief overview of the 2007 SJI First Edition Catalog that includes the Standard Specification for Composite Steel Joists, **CJ**-Series, Design Guide Weight Tables and Bridging Tables and Code of Standard Practice for Composite Steel Joists; and a demonstration of how the Catalog can be used for the practical design, use and application of Composite Steel Joists by examining completed projects that incorporate Composite Steel Joists as part of their structural systems.

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INTRODUCTION

The Steel Joist Institute (SJI) has developed a standard specification for the design of composite steel joists, the **CJ-**Series, in response to a growing need to have a consistent design methodology for all SJI member companies. In 2006, the Standard Specification for Composite Steel Joists was ANSI accredited and it is now contained in the 2007 First Edition Composite Steel Joist Catalog shown in Figure 1 (SJI, 2007). This publication contains the following main sections: The Standard Specification for Composite Steel Joists, **CJ-**Series, Code of Standard Practice for Composite Steel Joists, Responsibilities of the Design Professional, Design Guide LRFD Weight Tables and Bridging Tables for Normal Weight (145 pcf) and Light Weight (110 pcf) Concrete, Composite Joist Design Examples, Accessories and Details, Fire-Resistance Ratings for Composite Steel Joists, and OSHA Safety Standards for Steel Erection. The Standard Specification for Composite Steel Joists (subsequently referred to as the Standard Specification) covers the design, manufacture, and use of simply-supported, uniformly loaded open-web composite steel joists. The design methodology adopted by the SJI is based on Load and Resistance Factor Design (LRFD).

Figure 1 Newly released 2007 First Edition Composite Steel Joist Catalog

History of Composite Steel Joists

The first experimental research conducted in the U.S. utilizing open-web steel joists as part of a composite joist system was carried out in the 1960's (Lembeck, 1965; Wang and Kaley, 1967). Composite action in the earlier testing program was achieved by inverting and lowering the top chord angles so that the webs extended above the top chord into the concrete slab. Additional shear connection was created by the use of 1/2 in. diameter filler rods welded to the top chord between the panel points. The tests were compared to conventional joists with the same theoretical design load and the results showed that the composite steel joists were stiffer, having about a 20 percent reduction in deflection at the design load. The composite joists also attained an ultimate moment approximately 14 percent higher than the conventional joists that were tested. In the later experimental program, composite action was achieved by providing a longitudinal shear key along the one-piece top chord of the joists. Supplemental shear connection was provided in some of the tests by adding continuous metal chairs into the top chord that were shaped like a bulb. In both research projects, the results indicated that it was possible to achieve composite action in open-web steel joist construction.

Tide and Galambos (1970) performed tests on five composite steel joists that used 3/8 in. diameter x 2 in. long shear studs welded to the joist top chords. A 3 in. concrete slab was cast over each of the joist specimens. The main purpose of the research was to investigate the degree of composite action that could be obtained by studying the stud shear connector behavior in a composite system comprised of open-web steel joists, a cast-in-place concrete slab, and mechanical shear connectors holding the two together. The researchers varied the type and size of the joist top and bottom chords as well as the number and location of stud shear connectors. The web members were over-designed in all the test specimens to ensure there would be no web failures in the experiments.

It wasn't until the mid 1980's that there was a renewed interest in composite design using open-web steel joists. At the University of Minnesota, Leon and Curry (1987 and Curry, 1988) reported on the testing of two full-scale, 36 ft. long span composite steel joists to failure. Each test specimen was constructed with 2 in. composite steel deck, 3/4 in. diameter headed shear studs, and normal weight concrete with a nominal strength of 4 ksi. Alsamsam (1988) tested another two full-scale specimens to failure. The major result of the four tests was that the composite beam model could be used to predict the ultimate moment capacity of composite steel joists.

The next series of two full-scale tests were conducted at the University of Nebraska - Lincoln by Patras and Azizinimini (1991). The composite steel joists were 36 feet long with a nominal depth of 12 inches. Top and bottom chords of both specimens consisted of two equal leg angles welded back to back. Web members consisted of equal leg angles placed on the outside of the chords. Vulcraft's 2VLI 20 gauge, galvanized deck supported the 4 inch total concrete slab depth. Shear connectors, 3/4 inch diameter x 3 1/2 inches long after welding, were welded through the metal deck to the steel joist top chord angles. Light weight concrete was utilized for both specimens. Test specimen CH-1 was designed for a nominal strength of 3 ksi while CH-2 was designed for a nominal strength of 12 ksi. Crushing of the concrete adjacent to the shanks of the "Weak" position shear studs in CH-1 was observed while there was no noticeable concrete crushing in CH-2 in the vicinity of the shear studs. Test results also showed that the higher strength concrete in CH-2 exhibited a higher stiffness as expected. Ultimate load-carrying capacities were accurately predicted for both test specimens.

For over 35 years, similar research was taking place in Canada to determine whether composite steel joist construction was feasible. Azmi (1972) conducted six tests on composite joists with 50 ft. spans. In addition to the testing, a design model was developed that showed good correlation with the experimental data. The model was based on three levels of shear connection: Under-connected, balanced, and over-connected which related the stud shear strength to the tensile yield force in the bottom chord of the joist. The research continued with Fahmy (1974) who developed a finite difference method to analyze the behavior of composite steel joists in both the elastic and inelastic regimes that considered two different methods for shear connection, puddle welds and shear studs. The method was verified and showed good agreement with the test results of Azmi as well as with two additional experiments conducted as part of this research. The numerical method was later refined by Robinson and Fahmy (1978) for the case of partial composite action between the open-web steel joists and the concrete slab.

A fundamental reference on the design and construction of composite floor systems was published by Chien and Richie (1984). Contained in the work was a chapter devoted to the design of open-web steel joists. The design criteria was based on ultimate strength methods, but also addressed the issues of serviceability and connections.

More recent research in Canada has dealt with the effect of concrete shrinkage on the behavior of composite steel joists (Kennedy and Brattland, 1992). The authors tested two full-scale 38 ft. specimens to failure, one at 65 days and the other at 85 days. It was found that the majority of the shrinkage occurred in the first 30 days. The failure loads that the specimens attained closely matched predictions based on an ultimate strength method with only the bottom chord in tension.

By far the most extensive research program has been carried out at Virginia Polytechnic and State University. This research, sponsored by Nucor Corporation starting in 1991 (Gibbings and Easterling, 1991), (Nguyen, Gibbings, Easterling, and Murray, 1992), (Sublett and Easterling, 1992), (Lyons, Easterling, and Murray, 1994), (Roddenberry, Easterling, and Murray, 2000 and 2002) and most recently (Avci and Easterling, 2003), have all examined the behavior of composite steel joists. The projects have concentrated on the ultimate strength of the composite joists and the development of better prediction models or the behavior and strength of the stud shear connectors as part of the overall composite system.

EXPERIMENTAL RESEARCH

Bottom Chord Behavior

As load is first applied to a composite joist, the bottom chord elastically strains. Generally, the SJI **CJ**-Series joists (SJI, 2007) have an allowable total composite load that stresses the bottom chord to approximately 60% of the load necessary to yield the bottom chord. Removal of any of the load prior to the bottom chord reaching yield merely results in a linear elastic reduction in the bottom chord strain. As additional load is once again applied to the joist, the bottom chord will eventually reach its yield strength and then continue to elongate inelastically. If the load is reduced after the bottom chord is in the inelastic region, this will result in a linear elastic reduction in the member strain that would be parallel to the elastic strain that occurred during loading. A permanent deflection will be seen when the composite live load is reduced. As can be seen from Figure 2 and from load –deflection curves, composite joists can be designed to behave in a ductile manner.

Top Chord Behavior

When the metal deck, bridging, and concrete slab are applied to a composite joist, the joist is non-composite until such time that the concrete has reached sufficient strength to transfer load from the joist top chord through the shear stud connectors into the concrete slab. Prior to this point in time the joist acts identically to a non-composite joist as shown in the initial portion of the loading curve shown in Figure 3.

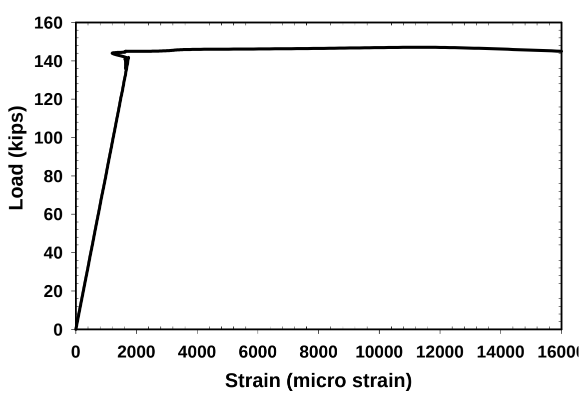

Figure 2 Load versus Strain for a Typical Composite Joist Bottom Chord

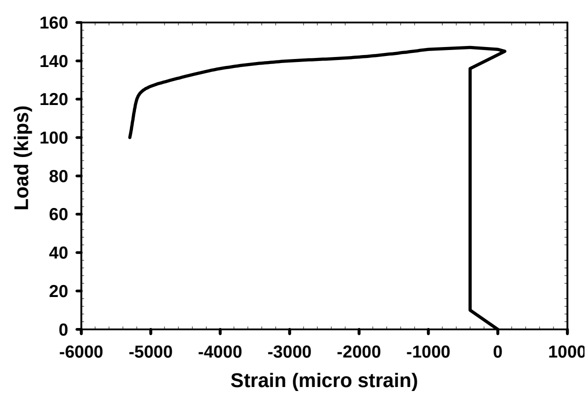

Figure 3 Load versus Strain for Typical Composite Joist Top Chord

After the concrete has cured, additional load is transferred through the shear stud connectors to the concrete slab. The net result is an increase in the compression within the top chord that is very small. Once the bottom chord starts to yield, and if sufficient shear connectors are provided, the top chord will go into tension. Generally, sufficient shear connection is not provided to fully develop the top chord so this may not occur. Once the shear stud connections start to fail, the tension force that has developed within the top chord will start to reduce. Eventually, the top chord continues to develop more and more compression until the composite joist reaches its ultimate moment capacity.

Web Behavior

Full-scale load tests have demonstrated that the webs of a composite joist behave in a similar manner to those found within a non-composite joist. Simply stated, the webs must be capable of transferring the vertical shear from the interior of the joist to the two end reactions. Prior to yielding of the bottom chord, the web members behave linearly elastic. Once the bottom chord starts to yield and shear connection starts to be lost, the forces in the web members reduce accordingly.

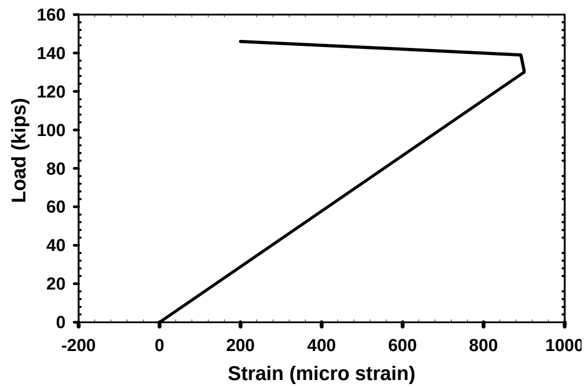

Figure 4 Web Behavior

Shear Stud Behavior

One thing noted in the initial full-scale composite joist tests (Gibbings and Easterling, 1991) was that the location of the shear studs within the deck rib influenced the ultimate load-carrying capacity of the test specimens. When 2 or 3 inch composite deck is utilized, these deck profiles typically have a stiffening rib at the center of each bottom rib. This requires that the shear stud be located on either one side or the other of the deck stiffening rib. For shear studs located on the side of the deck stiffening rib closest to the center of the joist span (typically referred to as the "Weak" position) lower shear stud capacities were noted. Conversely, when the shear studs were located on the side of the deck stiffening rib closest to the ends of the joists (typically referred to as the "Strong" position) increases in shear stud capacity of approximately 20 – 30% were usually obtained (Roddenberry, Easterling, and Murray, 2002).

BASIC DESCRIPTION OF PRODUCT

The term "Composite Steel Joists" refers to open web, parallel chord, load-carrying members suitable for direct support of one-way floor or roof systems. Members may consist of hot-rolled or cold-formed steel, including cold-formed steel whose yield strength has been attained by cold working. **CJ**-Series joists are lightweight, shop-manufactured steel trusses. The design of **CJ**-Series joist chord sections is based on a yield strength of 50 ksi. Web sections are based on a yield strength of at least 36 ksi, but not greater than 50 ksi. Applicable concrete strengths are either 4 or 5 ksi. Shear connection between the joist top chord and overlying concrete slab allows the steel joist and slab to act together as an integral unit after the concrete has adequately cured. Shear connection typically consists of 3/8, 1/2, 5/8, or 3/4 inch diameter shear studs welded through the steel deck to the top chord members of the underlying steel joist.

A composite steel joist designation is determined by its nominal depth, the letters "**CJ**", followed by the total factored uniform composite load, factored uniform composite live load, and finally the factored uniform composite dead load. For example, a 24**CJ**1400/800/240 has a nominal depth measured from the upper surface of the steel top chord to the underside of the bottom chord of 24 inches, total factored composite load-carrying capacity of 1400 plf, factored composite live load capacity of 800 plf, and factored composite dead load capacity of 240 plf.

The depth of the bearing seat at the ends of underslung **CJ-**Series joists can vary from 2.5 to 7.5 inches depending on the joist span, depth, or load-carrying capacity. A suggested bearing depth for a given composite steel joist designation is included in the *Design Guide LRFD Weight Table for Composite Steel Joists, **CJ**-Series* for NORMAL WEIGHT CONCRETE as well as for LIGHT WEIGHT CONCRETE. Composite Steel Joist products can be furnished as underslung (top chord bearing) or with square ends (bottom chord bearing).

COMPOSITE JOIST DESIGN REQUIREMENTS

Chord Design

The moment capacity of a composite steel joist can be calculated using the simple model shown in Figure 5. The distance between the centroid of the tension bottom chord and the centroid of the concrete compressive stress block, d_e, is computed using a concrete stress of $0.85f'_c$ and an effective concrete width, b_e, taken as the sum of the effective widths for each side of the joist centerline, each of which shall be the lowest value of the following:

1. one-eighth of the joist span, center-to-center of supports;
2. one-half the distance to the center-line of the adjacent joist;
3. the distance to the edge of the slab.

$$a = M_n / (0.85\, f'_c\, b_e\, d_e) \le t_c, \text{ in.} \quad (1)$$

$$d_e = d_j - y_{bc} + h_{deck} + t_c - a/2, \text{ in.} \quad (2)$$

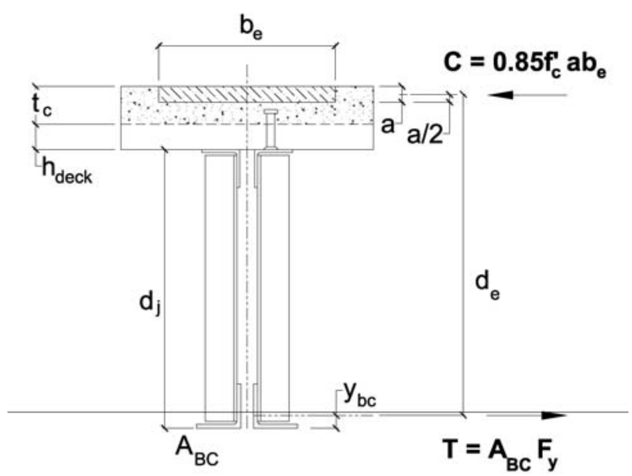

Figure 5 Composite Steel Joist Flexural Model

Where,

- a = depth of concrete compressive stress block, in.
- b_e = effective width of concrete slab over the joist, in.
- d_j = steel joist depth, in.
- f'_c = specified minimum 28 day concrete compressive strength, ksi
- h_{deck} = height of steel deck, in.
- M_n = nominal moment capacity of the composite joist, kip-in.
- t_c = thickness of concrete slab above the steel deck, in.
- y_{bc} = vertical distance to centroidal axis of bottom chord measured from the bottom of the bottom chord, in.

When the steel deck ribs are perpendicular to the steel joists, the concrete below the top of the steel deck is neglected when determining section properties and in calculating the concrete compressive stress block. The contribution of the steel joist top chord to the moment capacity of the composite system is ignored. With the centroid of the top chord being close to the center of the compressive stress block in the overlying concrete slab, the top chord develops a small moment couple. If one includes the top chord in the total moment capacity this would result in a large increase in shear connection requirements that generally is not economical for the small gain in moment capacity. The first top chord end panel member is designed for the full factored load requirements as a non-composite member.

$$M_u \leq \phi M_n \tag{3}$$

ϕM_n = minimum design flexural strength of composite section (from Equations 4, 5, 6, and 7, kip-in.)
M_u = required flexural strength determined from applied factored loads, kip-in.

The design flexural strength of the composite section, ϕM_n, shall be computed as the lowest value of the following limit states: Bottom Chord Tensile Yielding, Bottom Chord Tensile Rupture, Concrete Crushing, and Shear Connector Strength.

a) Bottom Chord Tensile Yielding: $\phi_t = 0.90$

$$\phi M_n = \phi_t A_b F_y d_e \tag{4}$$

b) Bottom Chord Tensile Rupture: $\phi_{tr} = 0.75$

$$\phi M_n = \phi_{tr} A_n F_u d_e \tag{5}$$

c) Concrete Crushing: $\phi_{cc} = 0.85$

$$\phi M_n = \phi_{cc} 0.85 f'_c \, b_e t_c d_e \tag{6}$$

d) Shear Connector Strength: $\phi_{stud} = 0.90$

$$\phi M_n = \phi_{stud} \, N Q_n d_e \geq 0.50 \phi_t A_b F_y d_e \tag{7}$$

Where,

A_{bc} = cross-sectional area of steel joist bottom chord, in.^{2}
A_n = net cross-sectional area of the steel joist bottom chord, in.^{2}
b_e = effective width of concrete slab over the joist, in.
d_e = vertical distance from the centroid of steel joist bottom chord to the centroid of resistance of the concrete in compression, in.
F_u = tensile strength of the steel joist bottom chord, ksi
F_y = specified minimum yield stress of steel joist bottom chord, ksi
N = number of shear studs between the point of maximum moment and zero moment
Q_n = nominal shear capacity of one shear stud, kips
t_c = minimum thickness of the concrete slab above the top of the metal deck, in.

In addition to the chord requirements specified above, the minimum horizontal flat leg width and minimum thickness of top chord shall be as specified in Table 1. This will allow the proper installation of headed steel shear studs in accordance with AWS D1.1 Sections 7 and C7, Stud Welding (AWS, 2004).

Table 1 Minimum Top Chord Sizes For Installing Welded Shear Studs

Shear Stud Diameter, in.	Minimum Horizontal Flat Leg Width, in.	Minimum Leg Thickness, in.
0.375	1.50	0.125
0.500	1.75	0.167
0.625	2.00	0.209
0.750	2.50	0.250

Web Design

Testing has verified that the web members of a composite steel joist behave in essentially the same manner as web members found within a ‘traditional’ non-composite steel joist. Webs must be designed so that they have sufficient strength to transfer the vertical shear from the applied loads to the ends of the composite joist. Webs of **CJ**-Series joists are designed for a minimum vertical shear equal to 25% of the factored end reaction. In addition, tension webs that are controlled by the above minimum shear requirement are also checked for a stress reversal (compressive force) resulting from a half-span live load applied to the joist. Equation (8) was introduced into the Standard Specifications to satisfy this requirement.

$$V_{c\ min} = \frac{(1.6\,w_L)L}{8} \tag{8}$$

Where,

w_L = unfactored live load due to occupancy and moveable equipment, plf
L = design length for the composite steel joist (Span – 0.33 ft.)
$V_{c\ min}$ = minimum factored compressive design shear in tension web members, lbs

Interior vertical web members used in modified Warren type joist configurations are designed to resist the gravity loads supported by the member plus 2.0 percent of the composite bottom chord axial force.

Shear Stud Design

Shear transfer between the concrete slab and a **CJ-**Series joist is typically accomplished by the installation of headed shear studs welded through the steel deck to the underlying steel joist top chord. The typical steel joist top chord consists of double angles with a horizontal gap of 1 inch between chord angles as shown in Figure 6. Shear studs are ideally installed on alternating top chord angles versus installing all shear studs on the same top chord angle. This will result in a more uniform shear transfer into both joist top chord angles.

The Standard Specification provides a shear stud capacity, Q_n, conservatively assuming that all shear studs are placed on the "Weak" side of the deck center stiffening rib, i.e. on the side of the deck stiffening rib closest to the point of maximum bending moment for the joist span. Therefore, the Specifying Professional does not need to be concerned as to which side of the deck center stiffening rib the shear studs are being welded. The definition of "Weak" and "Strong" shear stud position can be found in the 2005 AISC *Commentary on the Specification for Structural Steel Buildings*, Fig. C-I3.4 (AISC, 2005) and illustrated in Figure 7.

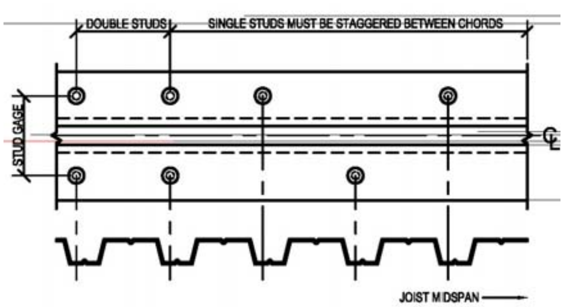

Figure 6 Shear Stud Positions on Top Chord

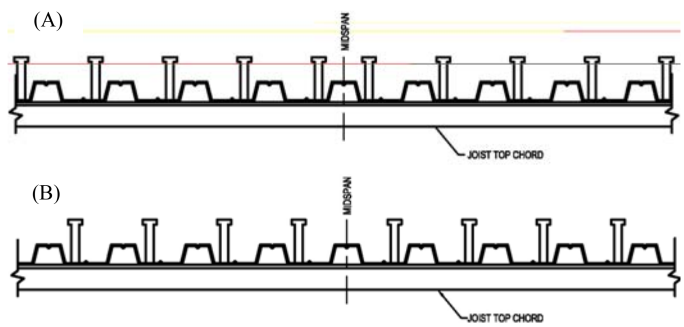

Figure 7 Shear Stud Layout a) "Weak" and b) "Strong" Position

The Standard Specification limits the ratio of the shear stud diameter/flange thickness to a maximum of 3.0, but requires a reduction in shear stud capacity when the stud/top chord thickness ratio falls in between 2.7 – 3.0. Prior testing of shear studs on thin flanges (Goble, 1968) indicated that when the ratio of the diameter of the stud/flange thickness exceeds 2.7, shear studs do not develop their full shear capacity.

For studs in 1.5, 2, or 3 in. deep decks with $d_{stud}/t_{top\,chord} \leq 2.7$:

$$Q_n = \mathrm{Min}\left[0.5A_{stud}\sqrt{f'_c E_c}\ ,\ R_p R_g A_{stud} F_{u\ stud}\right], \text{kips} \tag{9}$$

For studs in 1.5, 2, or 3 in. deep decks with $2.7 < d_{stud}/t_{top\,chord} \leq 3.0$:

$$Q_n = \mathrm{Min}\left[0.5A_{stud}\sqrt{f'_c E_c}\ ,\ R_p R_g A_{stud} F_{u\ stud} - 1.5\left(\frac{d_{stud}}{t_{top\ chord}} - 2.7\right)\right], \text{kips} \tag{10}$$

Where,

A_{stud} = cross–sectional area of shear stud, in.^{2}
d_{stud} = diameter of shear stud, in.
E_c = modulus of elasticity of the concrete, ksi

f'_c = specified minimum 28 day concrete compressive strength, ksi
$F_{u\ stud}$ = minimum tensile strength of stud, 65 ksi
Q_n = shear capacity of a single shear stud, kips
R_p = shear stud coefficient from Table 2
R_g = 1.00 for one stud per rib or staggered position studs
= 0.85 for two studs per rib side-by-side; 0.70 for three studs per rib side-by-side
$t_{top\ chord}$= thickness of top chord horizontal leg or flange, in.

Shear studs, after installation, shall extend not less than 1 1/2 in. above the top of the steel deck and there shall be at least 1/2 in. of concrete cover above the top of the installed studs.

Since paint may potentially hinder the installation of welded shear studs to the joist top chord, the Standard Specification for Composite Steel Joists states that the standard shop practice is to supply composite steel joists unpainted.

Table 2 Values For R_p

Deck Height	$Wr_{@\ mid\text{-}height}$	3/8 in. Dia. Stud	1/2 in. Dia. Stud	5/8 in. Dia. Stud	3/4 in. Dia. Stud
1 in.	1.9 in.	0.55	0.55	0.50	0.45
1.5 in.	2.1 in.	0.55	0.50	0.45	0.40
1.5 in. Inverted	3.9 in.	0.85	0.60	0.60	0.60
2 in.	6 in.	---	0.55	0.50	0.45
3 in.	6 in.	---	0.50	0.50	0.50

Notes: 1) $Wr_{@\ mid\text{-}height}$ = Average deck rib width of deck rib containing the shear stud.
2) The deck is assumed to be oriented perpendicular to the joists.

CAMBER

All **CJ-**Series composite steel joists are cambered for 100% of the unfactored non-composite dead load during manufacturing. This amount of camber will be completely removed during construction with the application of the dead loads from the joists, bridging, steel deck, and concrete slab. Typical composite joist bearing seats provide negligible rotational restraint at the ends of the joist, hence, **CJ-S**eries joists are modeled as pin-ended members when manufactured with typical underslung bearing seats. This is in contrast to composite wide flange beams where connections at the ends of the beams may only permit approximately 85% of the camber to be removed under the full non-composite dead load.

BRIDGING

Top and bottom chord bridging is required for the support of all composite steel joists. This bridging may be horizontal, diagonal, or a combination of both depending on the span, depth, and load-carrying capacity of the **CJ-**Series joists. For spans up through 60 feet, welded horizontal bridging may be used except where the row of bridging nearest the center is required to be bolted diagonal bridging as indicated on the SJI joist manufacturer’s joist placement plans. When the span of the composite steel joist is over 60 feet, but not greater than 100 feet, hoisting cables shall not be released until the two rows of bridging nearest the third points are completely installed. When the span exceeds 100 feet, hoisting cables shall not be released until all rows of bridging are completely installed. For spans over 60 feet all rows of bridging shall be diagonal bridging with bolted connections at the chords and intersections. The number of rows of bottom chord bridging shall not be less than the number of top chord rows. Rows of bottom chord bridging are permitted to be spaced independently of rows of top chord bridging.

Bridging must be properly spaced and anchored to support the decking and the employees prior to the attachment of the deck to the top chord. The maximum spacing of lines of bridging, ℓ_{br} shall be the lesser of,

$$\ell_{br} = \left(100 + 0.67\,d_j + 40\frac{d_j}{L}\right) r_y \text{, in.} \tag{11}$$

$$\ell_{br} = 170\,r_y \tag{12}$$

Where,

d_j = steel joist depth, in.
L = design length for the composite joist, ft.
r_y = out-of-plane radius of gyration of the top chord, in.

Connection of bridging to the chords of a composite steel joist shall be made by positive mechanical means or by welding. Ends of all bridging lines terminating at walls, beams, or double joists boxed by diagonal bridging shall be anchored. Connection of the horizontal and diagonal bridging to the joist chord or bridging terminus point shall be capable of resisting the nominal top chord horizontal force, P_{br} given in (13).

$$P_{br} = 0.0025\ n\ A_t\ F_{construction}\text{, lbs} \tag{13}$$

$$F_{construction} = \left(\frac{\pi^2 E}{\left(\frac{0.9\,\ell_{br}}{r_y}\right)^2}\right) \geq 12.2\,\text{ksi} \tag{14}$$

Where,

n = 8 for horizontal bridging; 2 for diagonal bridging
A_t = cross sectional area of joist top chord, in.^{2}
E = Modulus of Elasticity of steel = 29,000 ksi
$\frac{\ell_{br}}{r_y}$ = is determined from (11) or (12)
$F_{construction}$ = assumed nominal stress in top chord due to construction loads, ksi

CODE OF STANDARD PRACTICE FOR COMPOSITE STEEL JOISTS

In addition to the new Standard Specification for Composite Steel Joist, **CJ**-Series, the Steel Joist Institute has also published an ANSI approved Code of Standard Practice for Composite Steel Joists (COSP). The COSP has been developed with good engineering practice and industry standards in mind as the governing standard interpretation of contracts that include the purchase of Composite Steel Joists.

In general, the Plans used for bidding purposes shall have sufficient information to allow for an accurate estimate, and shall show the following:

- Designation, locations, and elevations of all the materials.
- Joist depth and sizes, including any special design and configuration requirements.
- Type and depth of floor deck.
- Concrete unit weight, nominal compressive strength, and total depth of concrete slab.
- Loads and their locations.
- Locations of all partitions and openings.
- No paint on the joist.

The Estimate for the Composite Steel Joists shall include:

- Composite Steel Joists.
- Joist extended ends, ceiling extensions, and extended bottom chords used as struts.
- Bridging and bridging anchors.

Although not required as part of a standard bid estimate, an approved SJI member company may also quote and identify additional items such as headers, stud shear connectors, centering materials and attachments, erection bolts, moment plates, etc.

The joist manufacturer awarded with a particular contract shall furnish Composite Steel Joist placement plans to show the materials as specified in the contract documents, and to be utilized for field installation of the materials in accordance with the specific project requirements. The Composite Steel Joist placement plans shall include the following:

- Listing of all applicable loads used in the design of the Composite Steel Joists.
- Connection requirements for joist supports, field splices, and bridging attachments.
- Deflection criteria and design camber for each of the composite joists.
- Shear stud installation plans with sizes, quantity, and locations of all shear connectors on the Composite Steel Joists.
- Size, locations, and connections of all bridging.
- Joist headers.

Composite Joist Floor Design Parameters Checklist

As an aid the Specifying Professional, the COSP includes the "SJI Composite Joist Floor Design Parameters Checklist". This form can be used to convey all the required standard design information for the Composite Steel Joists to the joist manufacturer. The form identifies all the composite joist geometry requirements, concrete and steel deck requirements, nominal loadings, and the corresponding factored loadings, as well as any camber and deflection requirements.

The Checklist covers most of the basic loading requirements for the structure and the load combination cases. If there is loading criteria that is too complex to be placed on the form, the Specifying Professional needs to effectively communicate these loading requirements by means of a load schedule and/or load diagram that includes all load combinations to be used. The Specifying Professional shall show on the structural drawings and give due consideration to the following special loads and load effects:

- Snow drift loads.
- Type and magnitude of axial loads. Due consideration shall be given to supply a transfer plate/angle to avoid resolving this force through joist seats.
- Type and magnitude of end moments. Due consideration shall be given to extend the column length and allow a moment plate connection between top of the joist top chord and the column, since joists have a limited capacity for resolving this force through the joist bearing seat connection.
- Structural bracing loads.
- Ponded rain water.
- Wind uplift.
- Concentrated loads.

RECENT COMPOSITE STEEL JOIST PROJECTS

Kohl's Department Stores headquartered in Menomonee Falls, WI began in 1962 with one store. Today, it has over 900 department stores nationwide. Since 1994, over 650 new stores, including 35 two-story stores and four structural slabs, one distribution center, and three phases of their corporate headquarters have been constructed utilizing composite steel joists.

Steel Composite Joist Selection and Advantages

There are three basic prototypical sized stores, an 88,000 square foot one-story store plus an 8,000 square foot storage mezzanine, a 101,475 square foot two-story store, and a 68,000 square foot one-story store without a mezzanine. The exterior walls are prototypically load-bearing masonry or tilt-up concrete walls.

Prior to 1994, the storage mezzanines were constructed of precast concrete planks and steel beams, pre-engineered steel, 3 in. concrete slab and form deck over 12 in. **K**-Series joists spaced at 2'-6" on-center and spanning 15'-0" typically. The second floor construction was 3 in. concrete slab and form deck over 28 in. **K**-Series joists also spaced at 2'-6" on-center and spanning 40'-0" typically. The precast concrete plank mezzanines were costly and provided time delays in the construction, the pre-engineered steel mezzanines had column interferences with operations and office layout flexibility and the **K**-Series joist mezzanine also had column interferences in order to provide the required clearance. The second floor concrete slab and form deck over **K**-Series joists was very susceptible to vibration perceptibility.

In 1994 the mezzanine construction was revised to a 4 in. concrete slab and 1-1/2 in. composite deck over 12 in. composite steel joists spaced at 6'-0" on-center, spanning 30'-0" and supported by exterior masonry or tilt-up concrete load-bearing walls and interior steel beams and columns. The composite steel joist construction provided the following advantages:

- Reduced joist depth
- Over 50% fewer joists and bearing plates
- Utilities located within and through the structure
- Joist compatibility with the load bearing wall
- Reduced in-place cost

Also in 1994 the second floor construction was revised to a 5 in. concrete slab and 1-1/2 in. composite deck over 28 in. composite joists spaced at 6'-8" on-center, spanning 40'-0" and supported by either load bearing exterior precast or tilt-up concrete walls or exterior Joist Girders and columns and interior Joist Girders and columns. The composite steel joist construction provided the following advantages:

- Reduced vibration perceptibility
- Over 50% fewer joists
- Utilities located within and through the composite joists and Joist Girders
- Reduced in-place cost

Steel Composite Joists Lessons Learned

The composite steel joist depth, layout and details that were originally specified were based on recommendations from the "Nucor-Vulcraft Steel Composite and Non-Composite Floor Joists" catalog. Initially, the steel sub-contractors and steel erectors were unfamiliar with composite steel joists and the following conditions were occurring:

- Steel erectors unfamiliarity with stud size and quantity to bid
- Steel erectors unfamiliarity with welding studs to joists
- Insufficient camber in joists

The steel sub-contractors and steel erectors were able to resolve these conditions with the following revisions to the project documents:

1. Structural drawings and specifications require the joist supplier to provide estimated stud size and quantities to the steel erector prior to bidding.
2. Structural drawings and specifications require the joist supplier to design and specify on composite joist shop drawings appropriate stud size and layout compatible with joist top chord.
3. Structural drawings and specifications require the joist supplier to specify the design camber on the final composite joist shop drawing and the joist camber is specified to be field inspected prior to pouring the slab.

Kohl's Department Store, Rapid City, SD structure and site was completed in October 2004 at a cost of $3.15 million. The store has 80,000 square feet of retail space, 8,000 square feet of office and receiving dock and 8,000 square feet of mezzanine storage. The building was located on a site that had grades at one end 12'-8" below finished floor and also had highly expansive fills. The project architect was Korsunsky, Krank and Erickson from Minneapolis, MN and Ambrose Engineering from Cedarburg, WI was the structural engineer. Because the site would have required over 170,000 cubic yards of fill to support a slab on grade and the underlying soils were highly expansive fills, the first floor was designed as a structural slab.

The first floor was constructed of a 5 in. concrete slab and 1-1/2 in. composite deck over 28 in. composite steel joists spaced at 6'-8" on-center, spanning 38'-0" to 40'-0" and designed for a live load of 75 psf for retail stores and a live load of 125 psf at the receiving dock. The first floor composite joists were supported by exterior concrete grade beams and interior Joist Girders and columns. The mezzanine was constructed of 4 in. concrete slab and 1-1/2 in. composite deck over 12 in. composite joists spaced at 6'-0" on-center, spanning 30'-0" and designed for a live load of 125 psf storage load. The mezzanine joists were supported by exterior masonry load-bearing walls and interior steel beams and columns.

The first floor composite steel joists and Joist Girders were exposed to a crawl space overlying the expansive soils and were specified to be painted to protect the steel from exposure to moisture. The horizontal leg of the joist top chord was not painted to allow the studs to be welded through the deck to the top chord. Figure 8 shows some of the design details for the composite steel joists.

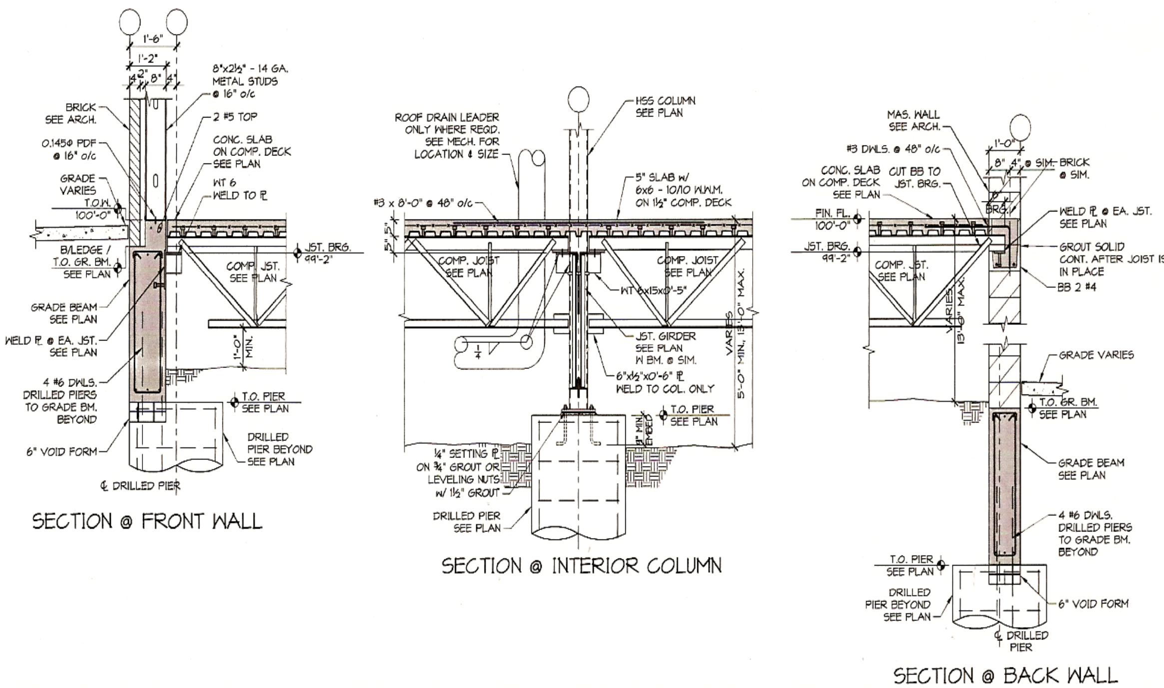

Figure 8 Design Details of the Composite Steel Joists

A composite structural steel beam and structural steel girder was considered as the first floor's structural slab and the cost savings of using the composite steel joists and steel Joist Girders was estimated to be $134,000. The overall cost savings of utilizing a structural floor with a crawl space compared to over-excavating the highly expansive fill, replacing and filling the site to the finished floor elevation was estimated to be over $2.5 million.

The general contractor for this project was Witcher Construction, Eden Prarie, MN, the steel fabricator was American Structural Metals, Somerset, WI and the manufacturer of the composite joists, joists, Joist Girders and metal deck was Nucor Vulcraft, Norfolk, NE.

CONDOMINIUM /RESORT CONSTRUCTION USING COMPOSITE STEEL JOISTS

Kalahari Indoor Water Park Resort, Sandusky, OH constructed an addition to the existing condominium wing to provide additional support of their indoor and outdoor water park operations. The new addition is a $22 million, six-story, 288 unit, steel framed facility utilizing composite steel joists with concrete topping on steel deck for the floor framing system. Construction reached substantial completion in December, 2007. PLANNING Design Build, Inc.

from Madison, WI provided the architectural and engineering services for the project and Rudolph Libbe from Toledo, OH served as general contractor. The six-story facility utilizes 20 in. deep composite steel joists spaced at 8’-6” to 9’-3” on center with spans of 27 feet. A floor-to-floor height of 11’-0” was required to match existing conditions, which created floor-to-ceiling heights of 8’-8” within the individual units. The composite joists are designed for a total uniform load of 100 psf consisting of a 60 psf dead load and a 40 psf live load. Bridging was provided per SJI requirements and manufacturer’s recommendations. A total slab thickness of 5 in. consisted of 2 in. composite steel deck with a 3 in. concrete topping. The composite steel deck had a specified design thickness of 0.0348 inches (20 gage). Type-B headed studs with a 1/2 in. diameter and 3 1/2 inches long were specified for the composite connectors to the joists. Normal weight concrete with a specified compressive strength of 4,000 psi was utilized for the concrete topping. Synthetic fiber reinforcing was provided in the concrete topping slab for crack control.

The existing condominium wing utilized hollow core pre-cast plank and steel beam construction, which was designed and constructed by PLANNING Design Build, Inc. The composite steel joist system offered multiple benefits over the original pre-cast plank and steel beam system of the existing facility. Some of those benefits were:

- Utilization of one erector during construction instead of separate pre-cast and steel erectors.
- Reduced erection time due to fewer pieces to erect.
- Crane’s capacity requirements are reduced due to weight savings between plank and joists.
- Reduced foundation sizes due to reduction in building dead load.
- Elimination of water infiltration issues resulting from core-drilling in hollow core plank.
- Steel framing allowed for tighter construction tolerances over pre-cast concrete.
- Interior build-out issues experienced as a result of plank camber and gypsum topping installation were eliminated.

Overall, the composite steel joist system allowed for a faster, less expensive, and smoother construction process to be realized over the existing pre-cast plank option. Construction tolerances were tighter, product quality issues were eliminated, and the final product performed at a level equal to or better than the original system utilizing pre-cast plank.

Key Lime Cove Resort, Gurnee, IL consists of a 60,000 square foot indoor water park with retail and restaurant amenities connected to a 422 unit hotel facility. The hotel facility consists of two steel framed four-story hotel wings utilizing composite steel joist framing. Construction cost of the hotel wings is a combined $34 million. Construction will reach substantial completion in March, 2008. PLANNING Design Build, Inc. from Madison, WI provided full single source services consisting of architectural, engineering, and construction services for the project. The four-story hotel wings utilize 24 in. deep composite steel joists spaced 9’-5” on center with spans of 27 feet. A floor-to-floor height of 11’-4” is utilized to match masonry coursing used to construct the elevator and stair shafts. A floor-to-ceiling height of 8’-7” is provided in the individual hotel room units. The composite joists are designed for a total uniform load of 100 psf consisting of a 60 psf dead load and a 40 psf live load. Bridging was provided per SJI requirements and manufacturer’s recommendations. A total slab thickness of 4 1/2 in. consisted of a 2 in. composite steel deck with 2 1/2 in. concrete topping. The composite steel deck had a specified design thickness of 0.0348 inches (20 gage). Type-B headed studs with a 1/2 in. diameter and 4 inches long were specified for the composite connectors to the joists. Normal weight concrete with a specified compressive strength of 4,000 psi was utilized for the concrete topping. Synthetic fiber reinforcing was provided in the concrete topping slab for crack control.

Based on the lessons learned from the Kalahari Resort condominium project and the pre-cast system used for the original facility, the composite steel joist system utilized was compared to conventional steel joist systems and conventional wide-flange composite beam systems, and the pre-cast system was discarded as a competitive option. The primary benefits of the composite joist system over the other systems were varied, though some of the benefits that were noted are:

- The composite joist system offers significant weight savings over the other two options.
- The composite joist system utilizes approximately 50% fewer joists than the conventional joist system.
- Unit costs of composite steel joists are approximately 30% lower than wide-flange framing per ton.

The composite joist system is a faster and less expensive system than conventional steel framing systems. Weight savings can range anywhere from 30 to 50 percent and fewer pieces allows for faster erection time. The reduction in erection time also allows the contractor to realize savings in crane usage over conventional systems.

CONCLUSIONS

A significant amount of data has been accumulated from testing that has been performed on composite steel joists over the past 40 years. The results of these experimental and analytical research projects have been reviewed by the Steel Joist Institute's Composite Joist Committee and the committee determined that it is possible to accurately predict the load-carrying capacities and deflection behavior of composite steel joists. The committee also found that the ultimate strength models that were originally developed for composite wide flange beams are applicable to composite steel joists. Based on all the available information to date on the behavior of composite steel joists, the committee was able to develop the new Standard Specification for Composite Steel Joists, **CJ**-Series that has been published by SJI in the First Edition 2007 Composite Steel Joist Catalog.

Through several case studies that have been described Composite Steel Joists have been shown to provide an economical shallow floor system with reduced floor-to-floor or floor-to-ceiling heights, increased flexibility in laying out floor plans uninterrupted by closely spaced columns, and allow the routing of HVAC ducts, plumbing, electrical conduits, and telecommunications through the open-web system of the joists.

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