SJI First Edition CJ-Series Standard Specifications for Composite Steel Joists, Weight Tables, Bridging Tables and Code of Standard Practice – A Brief Overview

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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 Steel Joist Institute (SJI) member companies. In 2006, the Standard Specifications for Composite Steel Joists was ANSI approved 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 Specifications 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, 2350 kg/m^3) and Light Weight (110 pcf, 1800 kg/m^3) Concrete, Composite Joist Design Examples, Accessories and Details, Fire-Resistance Ratings for Composite Steel Joists, and OSHA Safety Standards for Steel Erection.

The Standard Specifications for Composite Steel Joists (subsequently referred to as the Standard Specifications) cover the design, manufacture, and use of simply-supported, uniformly loaded open-web composite steel joists. The design methodology that was adopted by the SJI is based on Load and Resistance Factor Design (LRFD).

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. 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 (9.5, 12.7, 15.9, or 19 mm) diameter shear studs welded through the steel deck to the top chord members of the underlying steel joist.

The design of **CJ**-Series joist chord sections is based on a yield strength of 50 ksi (345 MPa). Web sections are based on a yield strength of at least 36 ksi (250 MPa), but not greater than 50 ksi (345 MPa). Applicable concrete strengths are either 4 or 5 ksi (27.6 or 34.5 MPa).

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 (610 mm), total factored composite load-carrying capacity of 1400 plf (20.4 kN/m), factored composite live load capacity of 800 plf (11.7 kN/m), and factored composite dead load capacity of 240 plf (3.5 kN/m).

The depth of the bearing seat at the ends of underslung **CJ**-Series joists can vary from 2.5 to 7.5 inches (64 to 191 mm) 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).

FIGURE 1 Newly released First Edition Composite Steel Joist Catalog containing the Standard Specifications for Composite Steel Joists, **CJ**-Series, Weight Tables and Bridging Tables, and the Code of Standard Practice

COMPOSITE JOIST DESIGN REQUIREMENTS

Chord Design

The moment capacity of a composite steel joist can be calculated using the simple model shown in Figure 2. 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.

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

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

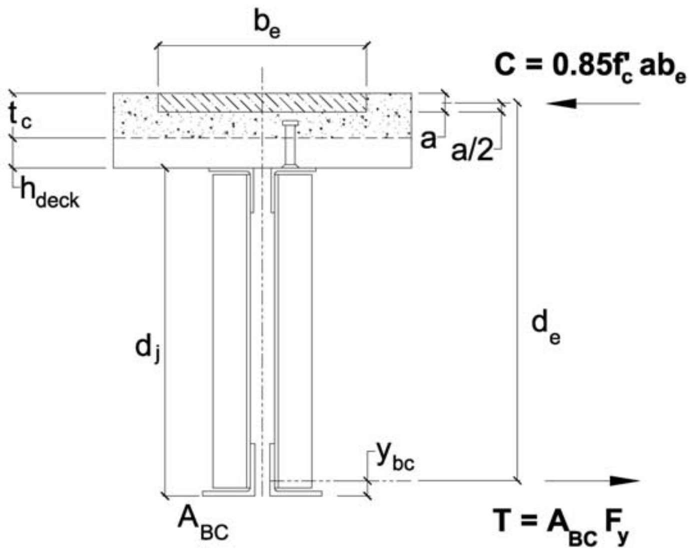

FIGURE 2 COMPOSITE STEEL JOIST FLEXURAL MODEL

Where,

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

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.

$$M_u \le \phi M_n \quad (3)$$

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

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

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. (mm)	Minimum Horizontal Flat Leg Width, in. (mm)	Minimum Leg Thickness, in. (mm)
0.375 (10)	1.50 (38)	0.125 (3.2)
0.500 (13)	1.75 (44)	0.167 (4.2)
0.625 (16)	2.00 (51)	0.209 (5.3)
0.750 (19)	2.50 (64)	0.250 (6.3)

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 (kN/m)

L = design length for the composite steel joist (Span – 0.33 ft., Span – 102 mm)

$V_{c\,min}$= minimum factored compressive design shear in tension web members, lb (kN)

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 (25 mm) between chord angles as shown in Figure 3. 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 Specifications provide 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 4.

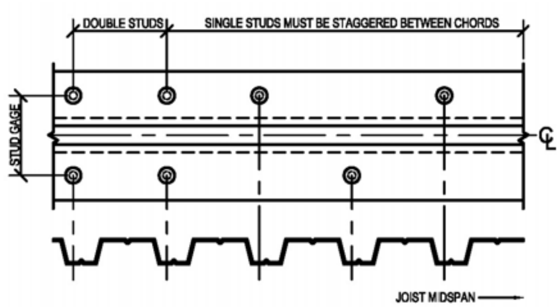

FIGURE 3 SHEAR STUD POSITIONS ON TOP CHORD

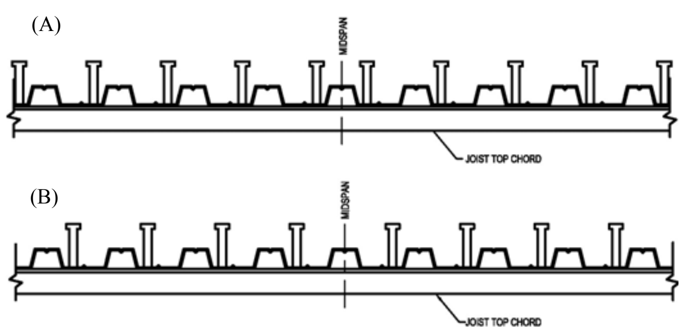

FIGURE 4 SHEAR STUD LAYOUT A) "WEAK" AND B) "STRONG" POSITION

The Standard Specifications limit 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. (38, 51, or 76 mm) deep decks with $d_{stud}/t_{top\,chord} \le 2.7$:

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

For studs in 1.5, 2, or 3 in. (38, 51, or 76 mm) deep decks with $2.7 < d_{stud}/t_{top\,chord} \le 3.0$:

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

$$= \text{Min}\left[0.5A_{stud}\sqrt{f'_c E_c}\ ,\ R_p R_g A_{stud} F_{u\,stud} - 6670\left(\frac{d_{stud}}{t_{top\,chord}} - 2.7\right)\right]\text{(N)} \tag{10}$$

Where,

A_{stud} = cross–sectional area of shear stud, in.^{2} (mm^2)
d_{stud} = diameter of shear stud, in. (mm)
E_c = modulus of elasticity of the concrete, ksi (MPa)
f'_c = specified minimum 28 day concrete compressive strength, ksi (MPa)
$F_{u\,stud}$ = minimum tensile strength of stud, 65 ksi (450 MPa)
Q_n = shear capacity of a single shear stud, kips (N)
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. (mm)

Shear studs, after installation, shall extend not less than 1 1/2 in. (38 mm) above the top of the steel deck and there shall be at least 1/2 in. (13 mm) 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 Specifications 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. (10 mm) Dia. Stud	1/2 in. (13 mm) Dia. Stud	5/8 in. (16 mm) Dia. Stud	3/4 in. (19 mm) Dia. Stud
1 in. (25 mm)	1.9 in. (48 mm)	0.55	0.55	0.50	0.45
1.5 in. (38 mm)	2.1 in. (53 mm)	0.55	0.50	0.45	0.40
1.5 in. (38 mm) Inverted	3.9 in. (99 mm)	0.85	0.60	0.60	0.60
2 in. (51 mm)	6 in. (152 mm)	---	0.55	0.50	0.45
3 in. (76 mm)	6 in. (152 mm)	---	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 (18.3 meters), 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 (18.3 meters), but not greater than 100 feet (30.5 meters), 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 (30.5 meters) hoisting cables shall not be released until all rows of bridging are completely installed. For spans over 60 feet (18.3 meters) 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,

$$\ell_{br} = \left(100 + 0.67\,d_j + 40\frac{d_j}{L}\right) r_y \text{, in. or } = \left(100 + 0.026\,d_j + 0.48\frac{d_j}{L}\right) r_y \text{ (mm)} \tag{11}$$

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

Where,

d_j = steel joist depth, in. (mm)

L = design length for the composite joist, ft. (m)

r_y = out-of-plane radius of gyration of the top chord, in. (mm)

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).

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

$$F_{construction} = \left(\frac{\pi^2 E}{\left(\frac{0.9\,\ell_{br}}{r_y}\right)^2}\right) \geq 12.2\,\text{ksi or} \geq 84.1\,\text{MPa} \tag{14}$$

Where,

n = 8 for horizontal bridging; 2 for diagonal bridging

A_t = cross sectional area of joist top chord, in.^{2} (mm^2)

E = Modulus of Elasticity of steel = 29,000 ksi (200,000 MPa)

$\frac{\ell_{br}}{r_y}$ = is determined from (11) or (12)

$F_{construction}$ = assumed nominal stress in top chord due to construction loads, ksi (MPa)

CODE OF STANDARD PRACTICE FOR COMPOSITE STEEL JOISTS

In addition to the new Standard Specifications 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, located at the back of the Code of Standard Practice, 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 load schedule, load diagram, and load combination 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.

CONCLUSIONS

Composite Steel Joists may be used to provide an economical shallow floor system with reduced floor-to-floor 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.

The Steel Joist Institute has recently published the First Edition Catalog for the **CJ**-Series that contains the Standard Specifications for Composite Joists, Weight Tables, Bridging Tables, and Code of Standard Practice to assist Specifying Professionals with the design and selection of Composite Steel Joists. A copy of this catalog can be obtained from the Steel Joist Institute's website at http://www.steeljoist.org/publications or by contacting the SJI office.

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