

Understanding steel joists

The Steel Joist Institute's new CJ-Series Composite Steel Joist catalog

By David Samuelson, P.E.

The Steel Joist Institute (SJI) is introducing the CJ-Series Composite Steel Joists in response to a growing need to have a standard composite steel joist specification for all SJI member companies. The recently published CJ-Series catalog contains standard specifications covering the Load and Resistance Factor Design (LRFD), manufacture, and use of simply supported open-web composite steel joists. Other sections within the new CJ-Series catalog include accessories and details, responsibilities of the design professional, code of standard practice, weight tables and bridging tables for normal weight (145 pcf) and lightweight (110 pcf) concrete, composite joist design examples, and a composite joist floor design parameters checklist.

Definition of composite steel joists

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-millimeter) diameter shear studs welded through the steel deck to the top chord members of the underlying steel joist, as shown in Figure 1.

The design of CJ-Series joist chord sections is based on a yield strength of



Composite steel joists with a depth of 44 inches, spacing of 9 feet, and span of 60 feet provide a very efficient floor system at Owens and Minor Inc., in Atlee Station, Va. A concrete slab having a total depth of 6 inches is supported by the 3-inch composite steel deck.

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 ksi (27.6 MPa) or 5 ksi (34.5 MPa).

History of composite steel joists

Hundreds of projects similar to the one shown above utilizing composite steel joists have been constructed across the United States and Canada during the last 40 years. With SJI's recent standardization of a design method for composite steel joists (i.e., the CJ-Series), the structural engineer of record now has the assurance that multiple SJI member companies will be able to provide composite steel joists for their specific projects. At the same time, there will be greater consistency between composite steel joist designs, as all SJI member companies approved to manufacture CJ-Series joists will

be required to follow the same design specifications.

Advantages of CJ-Series composite steel joists

CJ-Series joists provide a number of advantages, including the following:

- Reductions in overall floor-to-floor height of the structure.
- Mechanical ducts and piping (see Figure 2) can be run through the open webs of the CJ-Series joists instead of running beneath the joist bottom chords. Specially designed panel configurations and web openings can be provided when necessary.
- Maximum span-to-depth ratios of L/30 permit the use of shallower joists for any given span.
- Larger spans result in larger column spacing, increasing useable floor space.
- CJ-Series steel joists are very efficient, allowing a reduction in the joist weight for any given joist depth.

Lighter weight joists translate into potentially lighter weight columns and reduced foundation costs.

- Live-load deflections are significantly reduced due to composite action.
- Efficient erection of the CJ-Series joist system reduces construction time. Wider joist spacing reduces the number of joists to be erected and, when required, the number to be fireproofed.

Designations for CJ-Series composite steel joists

The 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 24CJ 1400/800/240 composite joist has a steel joist depth of 24 inches (610 mm), a total factored composite load-carrying capacity of 1,400 plf (20.4 kN/m), a factored composite live-load capacity of 800 plf (11.7 kN/m), and a factored composite dead-load capacity of 240 plf (3.5 kN/m).

Camber

All CJ-Series composite steel joists are manufactured with camber. Typical

composite joist bearing seats provide negligible rotational restraint. Therefore, CJ-Series joists are modeled as pin-ended members when manufactured with the typical underslung bearing seats. CJ-Series joists are cambered for 100 percent of the non-composite dead load. This is in contrast to composite wide-flange beams where connections at the ends of the beams may only permit approximately 85 percent of the camber to be removed under the full non-composite dead load.

Composite moment capacity theory

The moment capacity of a composite steel joist can be calculated using the simple model shown in Figure 3.

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:

- one-eighth of the joist span, center-to-center of supports;
- one-half the distance to the centerline of the adjacent joist; and
- the distance to the edge of the slab.

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

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

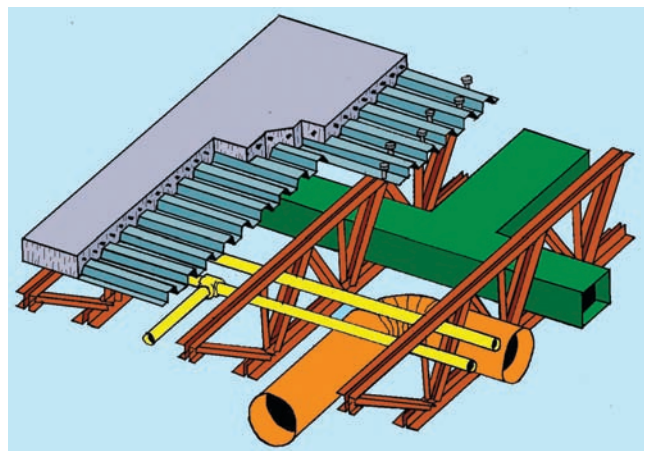
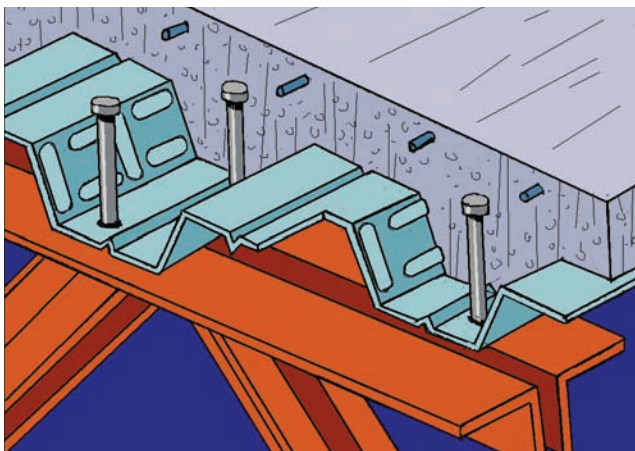
where,

- 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)

The contribution of the steel joist top chord to the moment capacity of the composite system is ignored. The first top chord end panel member is designed for the full-factored load requirements as a non-composite member.

$$M_u \leq \phi M_n \quad (\text{Equation 3})$$

Figure 1 (left): Shear studs are welded through the steel deck to the top chord of the CJ-Series joist. Note that the shear studs are alternately installed on both joist top chord angles. Figure 2 (right): The CJ-Series composite steel joists permit passage of HVAC, plumbing, and electrical conduit through the open webs of the joist system. This makes it possible to reduce floor-to-floor heights.



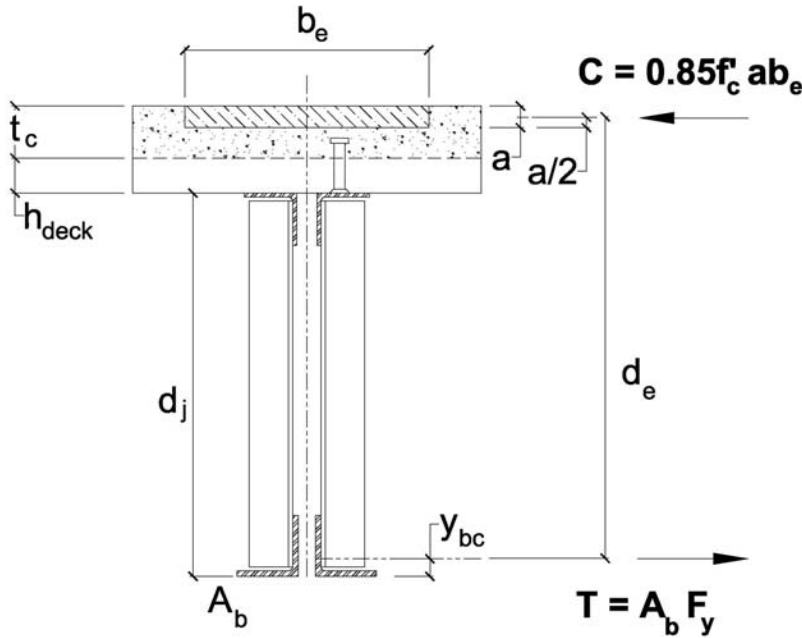


Figure 3: Composite steel joist flexural model

where,

- 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.

- Bottom Chord Tensile Yielding:
 $\phi_t = 0.90$
 $\phi M_n = \phi_t A_b F_y d_e$ (Equation 4)
- Bottom Chord Tensile Rupture:
 $\phi_{tr} = 0.75$
 $\phi M_n = \phi_{tr} A_n F_u d_e$ (Equation 5)
- Concrete Crushing:
 $\phi_{cc} = 0.85$
 $\phi M_n = \phi_{cc} 0.85 f'_c b_e t_c d_e$ (Equation 6)
- Shear Connector Strength:
 $\phi_{stud} = 0.90$
 $\phi M_n = \phi_{stud} N Q_n d_e \geq 0.50 \phi_t A_b F_y d_e$ (Equation 7)

where,

- A_b = cross-sectional area of steel joist bottom chord, in.² (mm²)
- A_n = net cross-sectional area of the steel joist bottom chord, in.² (mm²)
- 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 steel deck, in. (mm)

Web design requirements

Testing has verified that the web members of a composite steel joist behave in the identical manner as web members found within a non-composite joist. Webs must be designed so that



Figure 4: The newly released First Edition Catalog contains standard specifications for composite steel joists, weight tables, bridging tables, and code of standard practice.

they have sufficient strength to transfer the vertical shear from the applied loads to the ends of the composite joist. The CJ-Series webs are designed for a minimum vertical shear equal to 25 percent of the factored end reaction. Conversely, all tension webs are also checked for stress reversals resulting from a half-span live load applied to the joist. 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 studs

Shear transfer between the concrete slab and CJ-Series joist is typically accomplished by installation of 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 millimeter) between chord angles, as shown in Figure 1. Shear studs are ideally installed so that they are installed on alternating top chord angles versus installing all shear studs on the same top chord angle. This will result in a more uniform transfer of shear load into both joist top chord angles.

The CJ-Series Standard Specifications provide a shear stud capacity table that conservatively assumes that all shear studs are placed on the “weak” side of the steel 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. This being the case, one 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.

Prior testing of shear studs on thin flanges (G.G. Goble, “Shear Strength of Thin Flange Composite Specimens,” *AISC Engineering Journal*, Vol. 5, No. 2, April 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. To maximize chord efficiency, the CJ-Series Standard Specifications limits the shear stud diameter/flange thickness to a maximum of 3.0, but requires a reduction in the shear stud capacity when the ratio falls between 2.7 and 3.0.

Conclusion

Composite steel joists facilitate the routing of HVAC ducts, plumbing, and electrical conduits through the open webs of the joists, thereby allowing reductions in the overall floor-to-floor height. Building tenants value the increased flexibility available for laying out floor plans unhindered by closely spaced columns. Composite steel joists have been extensively studied during the last 40 years. Current design practices allow the accurate prediction of the load-carrying capac-

ity to meet serviceability and strength requirements.

To assist designers with design and selection of composite steel joists, the Steel Joist Institute recently published the First Edition Catalog for the CJ-Series that contains standard specifications for composite steel joists, weight tables, bridging tables, and code of standard practice, as shown in Figure 4. A copy of this catalog can be obtained from the SJI’s website at www.steeljoist.org or by contacting the SJI office. ▼

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