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Introduction to CJ-Series Steel Joists in Floor Systems

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Introduction to CJ-Series Steel Joists in Floor Systems

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LEARNING OBJECTIVES

At the conclusion of this article, the reader should be able to understand the following:

- What advantages steel joists provide when designing concrete floor systems.
- How one specifies a composite joist and an understanding of a CJ-Series joist designation.
- How one calculates the composite moment capacity for a CJ-Series joist.
- How one can efficiently install welded shear studs through the steel deck to the underlying CJ-Series composite joists.
- How the predicted floor vibration for a joist-supported floor system can be determined utilizing readily available software.
- How SJI's Floor Bay Tool can readily assist the designer to estimate the cost of a joist-supported floor system.

Overview

Composite and noncomposite steel joists are utilized to support concrete floor systems. This article highlights the use of Steel Joist Institute (SJI) CJ-Series composite joists. SJI CJ-Series composite steel joists utilize shear studs welded through the steel deck to the underlying top chord angles of the steel joists (see Figures 1 and 2). Steel joist top chords typically are fabricated utilizing hot-rolled or cold-formed steel angles. A typical 1-inch horizontal gap between the top chord angles requires that the shear studs be welded to the top chord horizontal legs on either side of this gap.

After the concrete is placed on the steel deck and allowed to cure, the concrete slab acts as a compression chord element for the steel joist. Installed welded shear studs transfer the horizontal shear between the concrete slab and steel joist.

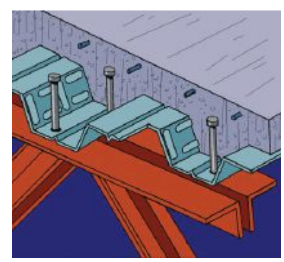

Figure 1. Shear studs are welded through steel deck to a steel CJ-Series composite joist.

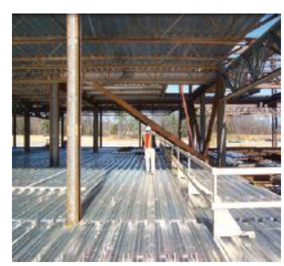

Figure 2. Shear studs are welded through steel deck to underlying steel joists.

Key advantages of SJI's CJ-Series composite joists include the following:

• Composite steel joists provide an efficient and economical floor system.

• Floor-to-floor heights can be reduced when utilizing composite steel joists since mechanical systems can be routed through the open web steel joists.

• When utilizing composite steel joists, large column-free areas can be provided, allowing increased flexibility for laying out floor plans.

• Reductions in building weight have been achieved through use of efficient composite steel joist designs, resulting in savings to the building owner.

Advantages

Primary advantages for SJI's CJ-Series composite steel joists include the following:

1. Mechanical ducts and piping (MEP) can be run through the open webs of the CJ-Series joists (see Figure 3), in lieu of running beneath a beam bottom flange. This permits a reduction in the overall floor-to-floor height of the building structure.

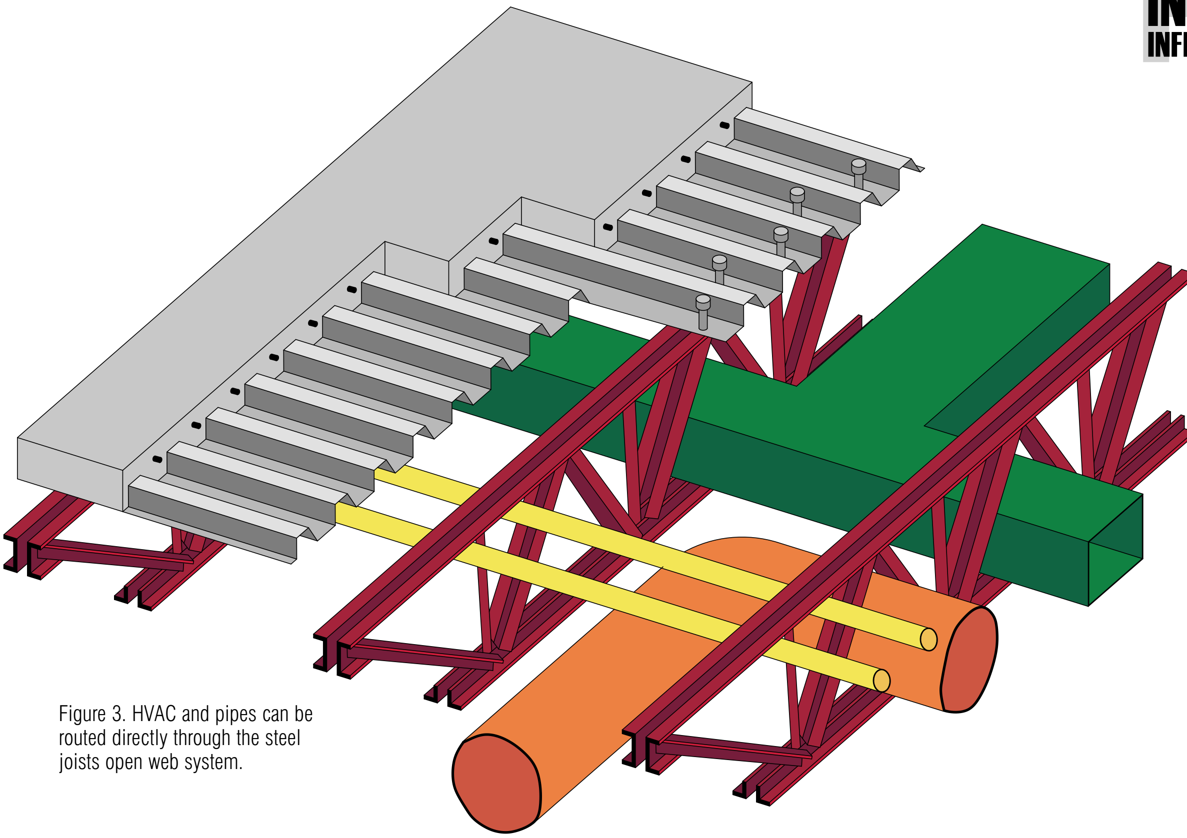

Figure 3. HVAC and pipes can be routed directly through the steel joists open web system.

2. Specially designed panel configurations and web openings can be fabricated, permitting the passage of HVAC, plumbing and electrical conduits. Rectangular vierendeel openings are ideally located near the mid-span of the steel joists for typical uniformly loaded joists. Vertical shear near the mid-span of the joist is at a minimum value at this location, resulting in the lightest CJ-Series joist possible.

3. Maximum span-to-depth ratio of 30 permits the use of shallower CJ-Series joists for any given span.

4. Efficient composite design allows greater-distance spans for a given steel joist depth. These larger spans result in larger column spacing, thereby providing increased options for floor layout. Larger open areas increase the potential rental value of the floor.

5. Live load deflections are reduced as the locking of the concrete slab by the welded shear studs to the steel joist provides a much stiffer floor system.

6. Efficient erection of the CJ-Series joist system minimizes construction time and permits early occupancy of the building.

7. Increased load-carrying capacity and associated wider joist spacing reduces the number of steel joists to be erected and fireproofed.

Composite Steel Joists, CJ-Series Designation

CJ-Series composite steel joists are designated following the standard format as outlined below:

"Joist Depth" CJ "Total Factored Composite Design Load"/"Total Factored Composite Live Load"/"Total Factored Composite Dead Load"

• Joist Depth: 30 inches in this example. The joist depth must be provided in inches (mm). This depth includes the steel joist portion only, not the deck slab.

• Total Factored Composite Design Load: 2,188 plf in this example

• Total Factored Composite Live Load: 1,168 plf in this example

• Total Factored Composite Dead Load: 420 plf in this example

In this example, the CJ-Series composite steel joist designation shown on the structural plans would be **30 CJ 2188/1168/420**.

30	CJ	2188	1168	420
Depth (in.)	Composite Joist	Total Factored Composite Load (plf)	Total Factored Composite Live Load (plf)	Total Factored Composite Dead Load

1 Total Factored Composite Design Load = Total Factored Composite Live Load + Total Factored Composite Dead Load + Total Factored Noncomposite Dead Load. The "SJI Composite Joist Floor Required Design Parameters Checklist (Nominal Uniform Loads)" provides a form that can be utilized for organizing loading information. See also SJI CJ COSP-2015, Section 6.6.1, Design Input Required for Composite Steel Joists.

Rectangular Vierendeel Openings

SJI's CJ-Series composite joists frequently are designed with vierendeel openings to permit the passage of large heating, ventilation, air conditioning (HVAC) ducts run through the CJ-Series open web system (see Figures 4, 5 and 6). Doing so reduces the required floor-to-floor height, as large HVAC ducts can be run through the vierendeel opening as opposed to beneath the joist bottom chord. It's advantageous if the vierendeel opening is located near the minimum vertical shear across the steel joist (typically near the joist mid-span for a uniformly loaded joist). Doing so reduces the combined vertical shear forces required to be carried by the joist top and bottom chords, thereby resulting in the greatest CJ-Series joist weight savings. The maximum width of the vierendeel opening is commonly no greater than two times the depth of the CJ-Series steel joist.

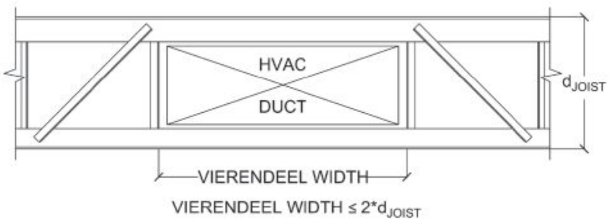

Figure 4. Vierendeel opening detail.

Figure 5. HVAC duct running through vierendeel opening.

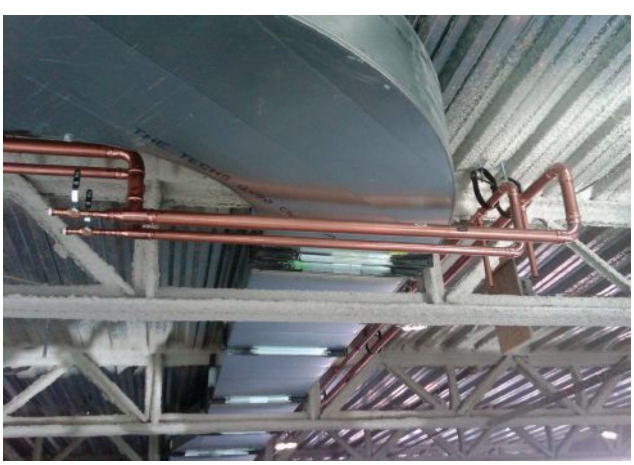

Figure 6. HVAC duct passing through vierendeel openings at the joist mid-span.

Composite Design Moment Capacity

The ultimate strength model for a composite joist is no different than the ultimate strength model for a composite wide-flange beam (see Figure 7). At ultimate strength, the tension force in the bottom chord is simply the area of the steel joist bottom chord times the yield strength of the bottom chord (typically 50 ksi). This tensile force is assumed to act at the centroid of the bottom chord.

The compression in the concrete is simply $0.85f'_c\ a\ b_{eff}$ where f'_c is the 28-day concrete compressive strength, a is the depth of the concrete compressive block, and b_{eff} is the concrete effective width. The compressive force is assumed to act at $a/2$. In this model, we're ignoring any forces in the joist top chord (i.e., sufficient shear connection has been installed to fully yield the joist bottom chord). If less shear connection had been installed (i.e., partial shear connection), there would be a compressive force in the top chord. The concrete effective depth, b_{eff}, shall be calculated identical to that assumed for a composite wide-flange beam.

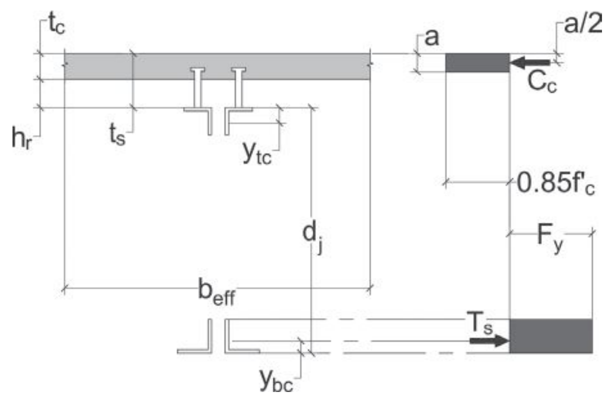

Figure 7. Flexural model for a composite steel joist.

Shear Stud Installation

Table 1 defines suggested minimum horizontal top chord leg lengths and thicknesses for installing welded shear studs. Installation of welded shear studs becomes increasingly difficult as the horizontal leg length and leg thickness of the steel joist top chord decrease.

Table 1. Minimum Top Chord Size 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

AISC requires $\left[\frac{d_{stud}}{t_{top\ chord}}\right] \leq 2.5$

SJI testing supports $\left[\frac{d_{stud}}{t_{top\ chord}}\right] \leq 3.0$

but with a reduction in the welded shear stud capacity.

Where d_{stud} = diameter of welded shear stud and $t_{top\ chord}$ = thickness of top chord horizontal angle.

Given the typical 1-inch gap between the joist top chord angles, one must avoid placing shear studs over this 1-inch gap. This is typically done by 1) chalk-lining the longitudinal centerline of the joist and offsetting each shear stud from this single line; or 2) providing two chalk lines—one chalk line over the center of each top chord horizontal leg.

Figure 8. A layout shows welded studs and ceramic ferrules prior to installation.

Two chalk lines were made on this joist: one over the center of each top chord horizontal leg.

To facilitate the welding of the shear studs, the steel deck must be tight against the joist top chord. It's typical practice to provide composite joists unpainted. Paint is a nonconductive coating that hinders electrical contact between the underside of the steel deck and joist top chord, making it more difficult to strike an electrical arc between the tip of the shear stud and grounded steel joist.

It's recommended that welded shear studs be alternately placed on each horizontal leg of the top chord angles. Doing so results in a more-uniform transfer of shear force from the concrete slab into the top chord of the CJ-Series steel joist.

As a composite joist is loaded, the concrete slab wants to slip relative to the joist top chord toward each end of the steel joist (see Figure 9).

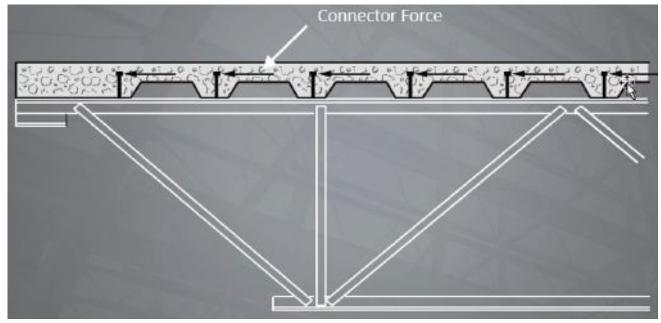

Figure 9. Shear stud connector force.

Many steel composite decks contain a stiffening rib located at the center of the bottom deck rib, requiring the welded shear stud be placed on either side of this stiffening rib. The strongest position for a welded shear stud (see Figure 11) occurs when the shear stud is located as far as possible from the mid-span of the steel joist (see Figure 10).

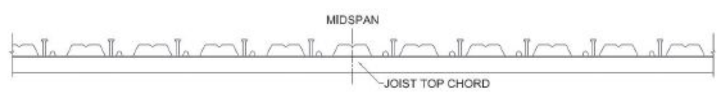

Figure 10. Shear Stud Layout in "Strong" Position.

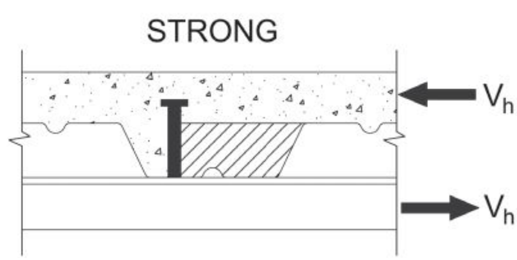

Figure 11. Strong-side stud position.

Welded shear studs placed on the side of the deck-stiffening rib closest to the mid-span of the joist will develop a reduced shear stud capacity. Concrete between the shank of the stud and steel deck rib can be crushed, hence permitting the stud to plow through the edge of the deck rib (see Figure 12).

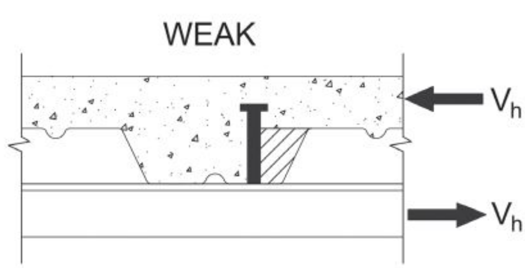

Figure 12. Weak-side shear stud location.

Suggested SJI shear stud capacities and quantity of shear studs in SJI's Weight Tables conservatively assume that the shear studs have been installed in the "Weak" position.

Noncomposite Load Case

SJI's CJ-Series joists must be designed to support the weight of the steel joists, steel deck, wet concrete, concrete placing workers and power trowels with the joists acting noncompositely (see Figures 13 and 14). It's a common practice for the joist manufacturer to camber the CJ-Series joist for 100 percent of the assumed dead load of the steel joists, steel joist bridging, steel deck and concrete. This results in a level floor prior to application of any composite loading to the concrete floor slab.

Figure 13. Concrete is pumped over the steel deck and supporting steel joists.

Figure 14. Concrete is placed over steel deck and supporting steel joists with a bucket.

UL Fire Ratings

Fire testing of SJI's CJ-Series composite joists has been completed at Underwriter's Laboratory (UL) in Northbrook, Ill. In this testing, Underwriter's Laboratory conducted full-scale fire endurance tests of SJI's CJ-Series joists that adhered to the requirements of ASTM E119, "Standard Test Methods for Fire Tests of Building Construction and Materials."

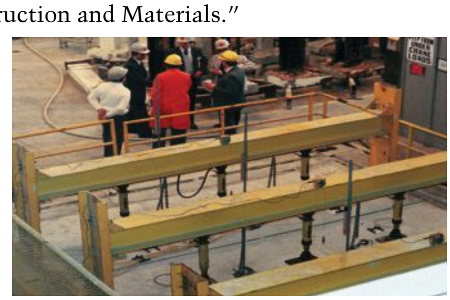

Figure 15. Underwriter's Laboratory fire tests CJ-Series joists.

Tables are provided in SJI's CJ-Series catalog showing UL Fire Resistance Ratings for Floor Ceiling Assemblies protected with membrane or spray-applied fire-resistive materials for 1-, 1.5-, 2-, 3- and 4-hour ratings (see Table 2, below).

Figure 16. Spray-applied fire-proofing on a CJ-Series joist.

Table 2. UL Design Numbers.

FLOOR – CEILING ASSEMBLIES WITH SPRAY APPLIED FIRE RESISTIVE MATERIALS

Restrained Assembly Rating	Protection Material	Minimum Joist Size[1]	Concrete		Unrestrained Beam Rating	UL Design Number[3]
			Minimum Thickness[2] (in.)	Type		
2 Hr.	SAFRM	N825	2.5	LW, NW	1½ Hr.	D703
		N825	2.5	LW, NW	2 Hr.	D712
		N825	2.5	LW, NW	1½, 2 Hr.	D716
		N825	2.5	LW, NW	1, 1½, 2 Hr.	D722
		N736	2.5	LW, NW	1, 1½, 2, 3, 4 Hr.	D739
		N825	2.5	NW	1, 1½ Hr.	D742
		N825	2.5	LW, NW	1, 1½, 2 Hr.	D745
		N736	2.5	LW	1, 1½, 2, 3 Hr.	D746
		N825	2.5	LW, NW	1½, 2 Hr.	D750
		N825	2.5	LW	1, 1½, 2 Hr.	D752
		N736	2.5	LW, NW	1, 1½, 2, 3 Hr.	D755
		N736	2.5	LW, NW	1, 1½, 2, 3 Hr.	D759
		N736	2.5		1, 1½, 2, 3, 4 Hr.	D760
		N736	2.5		1, 1½, 2, 3, 4 Hr.	D779
		N736	2.5		1, 1½, 2, 3 Hr.	D780
		N736	3.25	LW	1½, 2, 3, 4 Hr.	D782
		N825	2.5	LW, NW	1 Hr.	D822
		N825	2.5	LW, NW	1, 1½, 2 Hr.	D825
		N825	3.25	LW	1, 1½, 2 Hr.	D826
		N825	2.5	LW, NW	1, 1½, 2 Hr.	D831
		N736	2.5	LW, NW	1, 1½, 2, 3 Hr.	D832
		N825	2.5	LW, NW	1½ Hr.	D833
		N825	3.25	LW	1, 1½ Hr.	D840
		N736	2.5	LW, NW	1, 1½, 3 Hr.	D847
		N736	2.5	LW, NW	1, 1½, 2, 3, 4 Hr.	D858
		N736	2.0	LW, NW	1, 1½, 2, 3 Hr.	D859
		N825	3.25	LW	1, 1½, 2 Hr.	D860
		N825	2.5	LW, NW	1, 1½ Hr.	D861
		N825	2.5	LW	1 Hr.	D862

Optimal CJ-Series Joist Spacing

Ideally, CJ-Series joists are spaced 8-12 feet on center. Wider joist spacing results in the following advantages:

- Fewer joists to erect
- Fewer joists to fireproof
- Larger joist members make it easier to add spray-applied fireproofing
- Larger joist top chord members facilitate shear stud installation
- Reduced installed cost of CJ-Series joists and composite steel deck at wider joist spacings

Floor Vibration

Noncomposite and composite joists both behave compositely under walking excitation, because attaching the steel deck to the top chord via puddle welding or screw/pin fastenings creates composite action between the concrete slab and joist top chord.

Modern floors should be analyzed for walking-induced vibration utilizing the recommendations in SJI's *Technical Digest 5, Vibration of Steel Joist—Concrete Slab Floors* and AISC's *Design Guide 11: Vibrations of Steel-Framed Structural Systems Due to Human Activity, 2nd Edition* (see Figure 17).

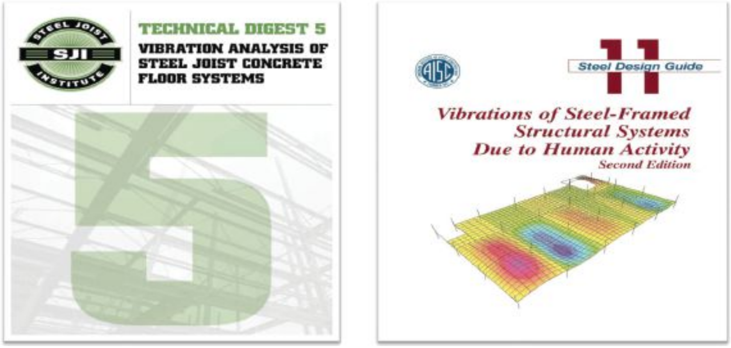

Figure 17. Covers from SJI's Technical Digest 5 and AISC's Design Guide 11, 2nd Edition.

A simple way for expediting the vibrational calculations for a CJ-Series-supported concrete floor system is via FloorVibe 3.0 (*www.floorvibe.com/wp*) authored by Dr. Tom Murray, Ph.D., P.E., Montague-Betts Professor of Structural Steel Design, Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, Va. Users identify the type of criterion that the floor will be evaluated for (i.e., Walking, Rhythmic or Sensitive Equipment) and then select the type of floor occupancy (i.e., Paper Office, Electronic Office, Residence, Church/Assembly Area, Quiet Spaces, Shopping Mall, Indoor Footbridge or Outdoor Footbridge).

Based on the identified criterion and occupancy, FloorVibe offers a suggested acceleration limit and damping ratio in addition to assumed dead, live and collateral loading on the floor. Users then input the total concrete depth, concrete f'c, concrete unit weight, steel deck height, CJ-Series joist depths, joist spans, joist spacing, joist loading, girder depths, girder spans and girder loading. FloorVibe calculates the predicted combined floor bay acceleration and frequency, which can be compared against specified vibration tolerance limits for human comfort.

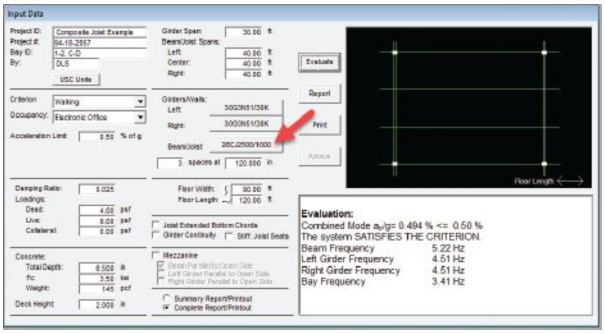

Figure 18. A screenshot from FLOORVIBE 3.0.

SJI Floor Bay Tool

The total cost of a CJ-Series joist floor system can be readily estimated via SJI's Floor Bay Tool (see Figure 19), an Excel-based tool available for free download from *https://steeljoist.org/product-category/design-tools/*. With user-defined unit costs for the CJ-Series steel joists, welded shear studs, joist girders, steel deck, concrete and concrete-reinforcing steel, a total cost/square foot of floor area can be determined. Users can readily compare the economics of differing CJ-Series joist spans, varying joist depths, different joist spacings, different concrete slab depths, different steel deck types, etc., to arrive at an optimal floor-framing solution. Each particular composite joist design can be saved in a table to directly compare the total cost/square foot for the specific design parameters assumed.

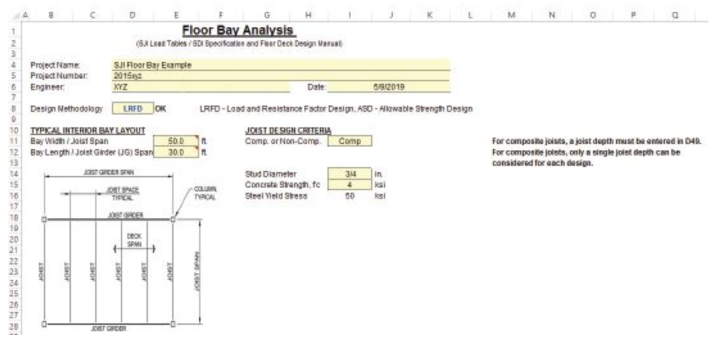

Figure 19. SJI Floor Bay Tool.

Author

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