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Specification and Design of Composite Steel Joists

TECHNICAL DIGEST THIRTEEN



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Federal Regulations Governing Erection of Joist Products

Steel joists and Joist Girders must be erected in accordance with the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor- 29 CFR Part 1926 Safety Standards for Steel Erection. The erection of Open Web Steel Joists is governed by Section 1926.757 of this Federal Regulation.

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**SPECIFICATION AND DESIGN
OF COMPOSITE STEEL JOISTS**



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FOREWORD

This first edition is the culmination of many years of research and testing that demonstrates the applicability, economy, efficiency, serviceability, and versatility in the use of composite steel joists. The Technical Digest is another addition to the series of Steel Joist Institute publications designed to give the reader information regarding the application and usage of composite steel joists.

This and other SJI Technical Digests serve to highlight specific areas of design and/or application for the benefit of architects, building inspectors, building officials, designers, engineers, erectors, students, and others.



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BACKGROUND AND PURPOSE

The purpose of this digest is to present information to the specifying professional and the joist manufacturer for the design of composite steel joists in response to a growing need to have a consistent design methodology for all Steel Joist Institute (SJI) member companies. This joist type 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 term “composite steel joist” refers to an open web, parallel chord, load-carrying member suitable for direct support of one-way floor or roof systems. Members that make up a composite steel joist may consist of hot-rolled or cold-formed steel, including cold-formed steel whose yield strength has been attained by cold working. The design of the joist chord sections is based on a yield strength of 50 ksi while the web sections are based on a yield strength of at least 36 ksi, but not greater than 50 ksi. Applicable concrete strengths are typically either 4 or 5 ksi. Composite steel 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 consists of 3/8 in., 1/2 in., 5/8 in., or 3/4 in. diameter shear studs welded through the steel deck to the top chord members of the underlying steel joist.

The first Standard Specifications for Composite Steel Joists, **CJ-Series**, was ANSI approved in 2006 and was included in the 2007 First Edition Composite Steel Joist Catalog published by the SJI. 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 is based on Load and Resistance Factor Design (LRFD). In addition to the Standard Specifications, the Catalog contains Weight Tables, Bridging Tables, and Code of Standard Practice for Composite Steel Joists to assist specifying professionals with their design and proper selection. The Standard Specifications for Composite Steel Joists, **CJ-Series** have been updated in 2010 and again in 2015 where it was formally identified as the ANSI/SJI 200–2015 *Standard Specification for Composite Steel Joists, CJ-Series*. The most recent Composite Steel Joist Catalog was published in 2020.

GLOSSARY

Accessories Structural components related to the design, fabrication and erection of joists and *Joist Girders* including, but not limited to sloped *end bearings*, *extended ends*, *ceiling extensions*, *bridging* and *bridging anchors*, *headers*, and bottom chord lateral bracing for *Joist Girders*.

Allowable Strength Nominal strength divided by the safety factor, R_n/Ω .

Available Strength *Design strength* or *allowable strength* as appropriate.

Applicable Building Code (ABC) Building code under which the structure is designed.

Bay Width The distance between the main structural frames or walls of a building.

Bearing The distance that the bearing shoe or seat of a *joist* or *Joist Girder* extends over its masonry, concrete or steel support.

Bearing Length The distance that the bearing shoe or seat of a *joist* or *Joist Girder* extends over its support.

Bearing Depth Depth of the joist at the bearing point or bearing seat.

Bearing Plate The steel plate used for a *joist* or *Joist Girder* to bear on when it is supported by masonry or concrete supports. The plate is designed by the *specifying professional* to transfer the *joist* reaction to the supporting structure.

Bridging In general, a member connected to a joist to brace it from lateral movement.

Bundle The banding together of joist products, *bridging*, and/or *decking* into certain sizes, weights, pieces, lengths, etc. to expedite shipping, unloading and storage, and erection at a job site.

Buyer The entity that has agreed to purchase *material* from the manufacturer and has also agreed to the terms of sale.

Camber An upward curvature of the chords of a *joist* or *Joist Girder* induced during shop fabrication. Note, this is in addition to the pitch of the top chord.

Cantilever The portion of a *joist* product that extends beyond its structural support. A row of *X-bridging* may need to be provided at the end of the *cantilever* and at the structural support to ensure it is stable during erection and under load.

Ceiling Extension A *bottom chord extension* except that only one angle of the *joist* bottom chord is extended from the first bottom chord panel point towards the end of the joist.

Chords The top and bottom members of a *joist* or *Joist Girder*. When a chord is comprised of two angles there is usually a gap between the members.

Clear Span The actual clear distance or opening between supports for a *joist* that is the distance between walls or the distance between the edges of flanges of beams.

Cold-Formed Steel Structural Member Shape manufactured by press-braking blanks sheared from sheets, cut lengths of coils or plates, or by roll forming cold- or hot-rolled coils or sheets; both forming operations being performed at ambient room temperature, that is, without addition of heat such as would be required for hot forming.

Collateral Load All additional dead loads other than the weight of the building, such as sprinklers, pipes, ceilings, floor covering, and mechanical or electrical components.

Composite Condition in which steel and concrete elements and members work as a unit in the distribution of internal forces.

Composite Steel Joist Open web, parallel chord, load-carrying member 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. 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.

Concrete Compressive Strength Compressive strength of concrete typically measured after 28 days of curing time.

Concrete Unit Weight Weight of a volume of concrete, typically 145 lb/ft.³ (2300 kg/m³) for normal weight or 110 lb/ft.³ (1760 kg/m³) for lightweight aggregate.

Connection Combination of structural elements and *joints* used to transmit forces between two or more members. See also *splice*.

Constructability The ability to erect structural members in accordance with Subpart R without having to alter the over-all structural design.

Construction Joint A *joint* where two placements of concrete start and stop.

Construction Load (for joist erection only) Any *load* other than the weight of the employee(s), *joists*, and the *bridging bundle* (see OSHA Regulations 1926.757(d)(1), (d)(2) and (d)(3); and ASCE 37).

Deck A floor or roof covering made out of gage metal attached by welding or mechanical means to *joists*, beams, purlins, or other structural members and can be galvanized, painted, or unpainted.

Design Length The length of a joist used in the structural analysis.

Design Load Applied *load* determined in accordance with *LRFD load combinations*.

Diagonal Bridging Two angles or other structural shapes connected from the top chord of one *joist* to the bottom chord of the next joist to form an 'X' shape. These members are always connected at their point of intersection.

Design Strength *Resistance factor* multiplied by the *nominal strength*, ϕR_n .

Effective Length Length of an otherwise identical column with the same strength when analyzed with pin-ended boundary conditions.

End Anchorage The proper attachment of the ends of a *joist* product to its support.

End Support The masonry, structural concrete, or structural steel that supports the ends of *joist* products and is capable of carrying the loads transmitted to it by the joist products.

Erection Bridging The bolted *diagonal bridging* that is required to be installed prior to releasing the *hoisting cables* from the steel *joists*.

Erector The entity that is responsible for the safe and proper erection of the *materials* in accordance with all applicable codes and regulations.

Extended End The extended part of a *joist* top chord with the seat angles also being extended from the end of the joist extension back into the joist and maintaining the standard end *bearing* depth or joist top chord depth over the entire length of the extension.

Factored Load Product of a *load factor* and the *nominal load*.

Ferrule Ceramic ring placed at base of the *shear stud* which shields the arc between welding equipment and steel *deck*.

Filler A short piece of round bar, plate or angle welded between a two angle *chord* member or a two angle *web* member to tie them together, usually located at the midpoint of the member between *joints*.

Flexural Buckling *Buckling* mode in which a compression member deflects laterally without twist or change in cross-sectional shape.

Flexural-Torsional Buckling *Buckling* mode in which a compression member bends and twists simultaneously without change in cross-sectional shape.

Gravity Load *Load*, such as that produced by dead and live loads, acting in the downward direction.

Header A structural member located between two joists or between a joist and a wall or girder which carries another joist or joists. It is usually made up of an angle, channel, or beam with saddle angle *connections* on each end for bearing.

Horizontal Bridging A continuous angle or other structural shape connected to the top and bottom chord of a *joist*.

Inspector An independent person hired to verify that the erection of a structure is in accordance with the *Site-Specific Erection Plans* including the *Joist Placement Plans* and the *deck* placement drawings.

Joint Area where two or more ends, surfaces or edges are attached. Categorized by type of fastener or weld used and the method of force transfer.

Joist A structural load-carrying member with an open web system which supports floors and roofs utilizing hot-rolled or cold-formed steel and is designed as a simple span member. Currently, the SJI has the following joist designations: **K-Series** including **KCS**, **LH-Series** and **DLH-Series**, and **CJ-Series**.

Joist Girder A primary structural load-carrying member with an open web system designed as a simple span usually supporting equally spaced concentrated loads of a floor or roof system acting at the panel points of the member and utilizing hot-rolled or cold-formed steel.

Joist Placement Plans Drawings that are prepared depicting the interpretation of the Contract Documents requirements for the *material* to be supplied by the *Seller*. These floor and/or roof plans are approved by the *Specifying Professional*, *Buyer* or *Owner* for conformance with the design requirements. The *Seller* uses the information contained on these drawings for final *material* design. A unique piece mark number is typically shown for the individual placement of *joists*, *Joist Girders*, and *accessories* along with sections that describe the *end bearing* conditions and minimum attachment required so that *material* is placed in the proper location in the field.

Joist Substitute A structural member who's intended use is for very short spans (10 feet or less) where open web steel *joists* are impractical. They are usually used for short *spans* in skewed bays, over corridors or for outriggers. It can be made up of two or four angles to form channel sections or box sections.

Lateral Buckling *Buckling* mode of a flexural member involving deflection normal to the plane of bending.

Lateral-Torsional Buckling *Buckling* mode of a flexural member involving deflection normal to the plane of bending occurring simultaneously with twist about the shear center of the cross section.

Limit State Condition in which a structure or component becomes unfit for service and is judged either to be no longer useful for its intended function (*serviceability limit state*) or to have reached its ultimate *load-carrying capacity (strength limit state)*.

Load Force or other action that results from the weight of building materials, occupants and their possessions, environmental effects, differential movement, or restrained dimensional changes.

Load Effect Forces, stresses, and deformations produced in a *structural component* by the applied loads.

Load Factor Factor that accounts for deviations of the *nominal load* from the actual *load*, for uncertainties in the analysis that transforms the *load* into a *load effect*, and for the probability that more than one extreme *load* will occur simultaneously.

Local Buckling *Limit state of buckling* of a compression element within a cross section.

LRFD (Load and Resistance Factor Design) Method of proportioning structural components such that the *design strength* equals or exceeds the *required strength* of the component under the action of the LRFD load combinations.

LRFD Load Combination Load combination in the applicable building code intended for strength design (load and resistance factor design).

Material *Joists, Joist Girders* and *accessories* as provided by the seller.

Nominal Load Magnitude of the *load* specified by the *applicable building code*.

Nominal Strength Strength of a structure or component (without the *resistance factor* or *safety factor* applied) to resist the load effects, as determined in accordance with the *Standard Specifications*.

Non-composite Condition in which steel and concrete elements and members do not work as a unit in the distribution of internal forces. The bare steel *joist* carries all applied *loads* including the wet weight of the concrete.

OSHA The Occupational Safety and Health Administration is the federal government agency whose purpose is to save lives, prevent injuries, and protect the health of the workers of America.

Owner The entity that is identified as such in the Contract Documents.

Permanent Load *Load* in which variations over time are rare or of small magnitude. All other *loads* are *variable* loads.

Placement Plans See “*Joist Placement Plans.*”

Quality Assurance System of shop and field activities and controls implemented by the *owner* or his/her designated representative to provide confidence to the *owner* and the building authority that quality requirements are implemented.

Quality Control System of shop and field controls implemented by the *seller* and *erector* to ensure that contract and company fabrication and erection requirements are met.

Required Strength Forces, stresses, and deformations produced in a structural component, determined by either *structural analysis*, for the LRFD or ASD load combinations, as appropriate, or as specified by the *Standard Specifications*.

Resistance Factor, ϕ Factor that accounts for deviations of the actual strength from the *nominal strength*, deviations of the actual *load* from the nominal load, uncertainties in the analysis that transforms the *load* into a load effect and for the manner and consequences of failure.

Safety Factor, Ω Factor that accounts for deviations of the actual strength from the *nominal strength*, deviations of the actual *load* from the nominal load, uncertainties in the analysis that transforms the *load* into a load effect and for the manner and consequences of failure.

Seller A company certified by the Steel Joist Institute engaged in the manufacture and distribution of *joists*, *Joist Girders*, and *accessories*.

Service Load *Load* under which serviceability *limit* states are evaluated

Serviceability Limit State Limiting condition affecting the ability of a structure to preserve its appearance, maintainability, durability, or the comfort of its occupants or function of machinery, under normal usage.

Shear Stud Headed shear connector specifically designed for use on a steel *joist* or beam, which permits *composite* action between concrete *slab* and *joist* or beam.

Shear Stud Welder Machine used to weld headed *shear studs* through the steel *deck* to the steel *joist*.

Slab Concrete placed to form a *deck* to a specified thickness. A portion of the *slab* serves as part of the *composite joist* system as well as sub-floor or finished floor.

Slenderness Ratio The ratio of the effective length of a column to the radius of gyration of the column about the same axis of bending.

Span The centerline-to-centerline distance between structural steel supports such as a beam, column or *Joist Girder* or the *clear span* distance plus four inches onto a masonry or concrete wall.

Specified Minimum Yield Stress Lower limit of *yield stress* specified for a material as defined by ASTM.

Specifying Professional The licensed professional who is responsible for sealing the building Contract Documents, which indicates that he or she has performed or supervised the analysis, design and document preparation for the structure and has knowledge of the load-carrying structural system.

Splice Connection between two structural members joined at their ends by either bolting or welding to form a single, longer member.

Spreader Bar A specially designed structural steel member attached to *hoisting equipment* that may be used to lift *joist, bridging, or decking bundles* at two points.

Square End Bottom chord bearing condition of a parallel chord *joist* where the end web is perpendicular to the chord members.

Standard Specifications Documents developed and maintained by the Steel Joist Institute for the design and manufacture of open web steel joists and Joist Girders. The term “SJI Standard Specifications” encompasses by reference the following:

ANSI/SJI 100–2020 *Standard Specification for K-Series, LH-Series, and DLH-Series Open Web Steel Joists and for Joist Girders*

ANSI/SJI 200–2015 *Standard Specification for Composite Steel Joists, CJ-Series*

Strength Limit State Limiting condition affecting the safety of the structure, in which the ultimate *load-carrying* capacity is reached.

Structural Analysis Determination of load effects on members and *connections* based on principles of structural mechanics.

Structural Drawings The graphic or pictorial portions of the Contract Documents showing the design, location, and dimensions of the work. These documents generally include plans, elevations, sections, details, *connections*, all loads, schedules, diagrams, and notes.

Stud Installation Layout Drawing Plan provided by *Seller to Buyer* showing size, quantity, and location of all shear connectors to be installed on the *composite steel joists*.

Tensile Strength (of material) Maximum tensile stress that a *material* is capable of sustaining as defined by ASTM.

Top Chord Extension (TCX) The extended part of a *joist* top chord. This type of extension only has the two top chord angles extended past the *joist* seat.

Torsional Buckling *Buckling* mode in which a compression member twists about its shear center axis.

Unbraced Length Distance between braced points of a member, measured between the centers of gravity of the bracing members.

Variable Load *Load* not classified as *permanent load*.

Webs The vertical or diagonal members joined at the top and bottom *chords* of a *joist* or *Joist Girder* to form triangular patterns.

Yield Point First stress in a material at which an increase in strain occurs without an increase in stress as defined by ASTM.

Yield Strength Stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain as defined by ASTM.

Yield Stress Generic term to denote either *yield point* or *yield strength*, as appropriate for the material.

1

CHAPTER 1 INTRODUCTION

A truss is one of the most efficient structural members. The designer can proportion each truss element in direct relationship to the required forces. When trusses are used to span horizontal distances, the ability to adjust the depth of the truss is a crucial element to its overall efficiency. The steel joist industry has long recognized the advantages of the efficiency of the truss form. Steel trusses, or open-web steel joists as they are more commonly known, are widely used in roof and floor systems in steel-framed buildings. A relatively recent extension to the use of steel joists is the incorporation of benefits associated with steel-concrete composite construction. The design guide focuses on composite steel joists used in building floor systems.

The benefits of open, essentially column-free floor spaces in buildings are well recognized. Such a configuration provides maximum flexibility in leasable space arrangements and thus gives an owner the ability to easily accommodate the requests of new tenants. Composite steel joists are one structural system that provides these large open areas. In addition to the benefits of column-free space, the open web configuration of the joist permits easy access for mechanical and service systems without necessarily increasing the floor-to-floor heights in the building. These characteristics are significant benefits and make composite steel joists an economical structural system.

Composite steel joists consist of a steel truss and concrete slab connected by some means of shear connection. Both proprietary and non-proprietary shear connectors are available. However, the only shear connectors considered in this design guide are steel-headed stud anchors, which are non-proprietary. In practice, the joists are specifically designed for composite application and are not selected from standard load tables, such as those developed by the Steel Joist Institute (SJI) and member companies of the SJI (SJI 2020). The associated composite slabs are constructed using a steel deck, topped with normal or lightweight concrete.

COMPOSITE STEEL JOIST BEHAVIOR

The behavior of a composite steel joist, subjected to gravity load, reflects the behavior of its individual components. Specifically, the behavior of the bottom chord, top chord, web members, shear connectors, and composite slab dictate the overall composite steel joist behavior. Although not a requirement in current U.S. steel specifications (AISC 2016a), (SJI 2015a), it is generally desirable to have a gravity load-carrying joist respond to load in a ductile manner (ASCE 1996). In the case of composite steel joists, this means that