# Hot Rolled Steel - Composite Beam Design

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Composite beam design of any 'I' shaped section, including full code checking and member optimization, may be performed based on the following codes:

- The 13th Edition of AISC's Steel Construction Manual (LRFD & ASD)
- The 9th Edition of AISC's Steel Construction Manual for Allowable Stress Design (ASD)
- The 2nd and 3rd Editions of AISC's Steel Construction Manual for Load & Resistance Factor Design (LRFD)
- The 2001 Edition of the Canadian code (CAN/CSA-S16)

All beams are assigned a set of Design Rules that may be used to control the beam's geometry, allowable stress / capacity ratios, and deflection. For un-shored construction, the steel shape alone must satisfy these Design Rules when subjected to its construction and pre-composite loads. See the sections on Design Rules and Load Combinations for more information.

## Pre-Composite Design

The maximum allowable stress or moment capacity for the pre-composite beam is based entirely on Chapter F of the AISC Specifications. The capacity of the pre-composite beam is compared to the actual pre-composite loading and stresses to determine the adequacy of the beam. The pre-composite design values can be reviewed in the Non-Composite Bending Capacity section of the Member Detail Report.

**Note**

- Pre-Composite beam design is only performed for load combinations that contain the DL-Pre load category.
- For shored construction, the steel beam is assumed to be fully supported during the construction period and will not be designed for loading in the pre-composite state. Pre-DL loads, such as beam and deck self weight, will be added into the post-composite loads to be resisted by the full composite section.

## Post-Composite Design - ASD (AISC 9th Edition)

There are number of different code checks that are required for composite ASD beams. Unfortunately, this is not very clearly spelled out in the AISC specifications. An excellent explanation of this procedure is given in **Steel Structures: Design and Behavior** by Salmon & Johnson (1990, Harper Collins Publishers).

**Note**

- For ASD design, the transformed moment of inertia used to calculate post-composite stresses is based on normal weight concrete per the requirements in the ASD specification. However, the post composite deflection will be based on the weight of concrete specified by the user or the Elastic modulus entered on the Deck Properties Spreadsheet.

### *Summation of Pre and Post-Composite Steel Stresses vs. Yield*

The first check looks at the sum of pre and post-composite stresses. The pre-composite stresses use the section modulus, S, of the steel beam by itself and the pre-composite loading. The post -composite stresses use the effective section modulus, Seff, of the composite section and the post-composite loading. These stresses are listed as fby (sum of actual stresses) and Fby (allowable stress) on the detail report. Generally, Fby is 0.90*Fy.

fby = M(pre-composite) / S + {M(post-composte)} / Seff

This check is based on the following sentences from the ASD specification: "For composite beams constructed without temporary shoring, stresses in the steel section shall not exceed 0.9Fy. Stresses shall be computed assuming the steel section alone resists all loads applied before the concrete has reached 75% of its required strength and the effective composite section resists all loads applied after that time."

### *All Loads applied to the Composite Section*

The second check looks at the sum of pre and post-composite loads against the full composite section. These stresses are listed as Fb and fb on the detail report. Generally, Fb is 0.66*Fy.

fb = Total Moment / Seff

This check is based on the following sentences from the ASD specification: "When shear connectors are used in accordance with Section I4, the composite section shall be proportioned to support all of the loads without exceeding the allowable stress prescribed in Section F1.1, even when the steel section is not shored during construction."

### *Post Composite Loads vs. Allowable Concrete Stress*

The third check looks at the concrete stresses for the post-composite loads ONLY. These are the fc and Fc values shown on the detail report. Generally, Fc is 0.45*f`c.

fc = M(post-composite) / (Itr / ytop * Es/Ec)

This check is based on the following sentences from the ASD specification: "The actual section modulus of the transformed composite section shall be used in calculating the concrete flexural compression stress and, for construction without temporary shores, this stress shall be based upon loading applied AFTER the concrete has reached 75% of its required strength. The stress in the concrete shall not exceed 0.45f`c."

## Post-Composite Design - LRFD

The code checking for composite beams is a bit simpler for LRFD than it is for ASD. The moment capacity of the composite section is based on the plastic stress distribution and is compared to the moment demand of the total load.

## Deflection Design

### *Total Deflection Design and Beam Camber*

The total beam deflection is a summation of the pre-composite deflection (minus beam camber) and the post composite deflection. The pre-composite deflection is based on the unfactored pre-composite loads and the **non-composite** beam properties. The post composite deflection is based on the additional post composite loads and the **composite** beam properties.

Beams are cambered to reduce a portion of the **pre-composite dead load deflection** of the beam. This percentage and the other various camber controls are specified by the user in the Global Parameters screen. See Global Parameters for more information.

**Note:**

- The self-weight column here is what is used to assign camber. None of the load defined in the PreDL load category will be considered when cambering members.

## Studs and Stud Distribution

You can specify composite beams with uniform or segmented stud distributions using the Global Parameters. Both methods of stud distribution will satisfy both the minimum stud spacing and the required composite action due to the moments in the beam. These moments include both the maximum moments in the beam for each load combination and the moments at concentrated load locations.

**Note**

- The maximum moment will not always result in the maximum required stud density. For this reason, the program calculates the required stud distribution for **each** load combination and retains the maximum requirement for its design values.

**Uniform Studs** – When a uniform stud distribution is used, the program will calculate the maximum stud density required in the beam and apply that stud density to the entire beam.

**Segmented Studs** – When a segmented stud distribution is allowed, the program first fills the segments at the ends of the beam. The studs in these segments see a greater percentage of the total shear than the studs towards the mid-span of the beam.

The program will use the fewest number of stud rows possible. Once the number of studs in a segment reaches the number that can be fit into one row, the program will begin to add studs to the next beam segment. This continues until all the beam segments resisting the applied moment are filled. If necessary another row of studs will be added, starting again with the outer segments.

**Note**

- The maximum number of segments used for stud distribution is five. If a composite beam has more than five segments it will be designed using a uniform stud distribution.

## Deck Ranking

RISAFloor allows different composite slabs on either side of a beam. The slab properties are "left" and "right" where the beam is oriented such that its start point is at the bottom and its end point is at the top. When there are multiple decks on one side of a beam span, the program finds the deck with the most conservative design properties for each side of the beam. This will be based on the deck orientation (parallel or perpendicular), the thickness of the slab, the elastic modulus of the concrete, and the distance from beam flange to slab centroid. Since perpendicular decks receive no additional stiffness from the concrete filled ribs and control stud placement, they are always assumed to control over parallel ones.

**Note**

- By default a deck that makes an angle to the beam of 10 degrees or less is considered parallel to the beam. This default may be changed on the **Global Parameters** screen.

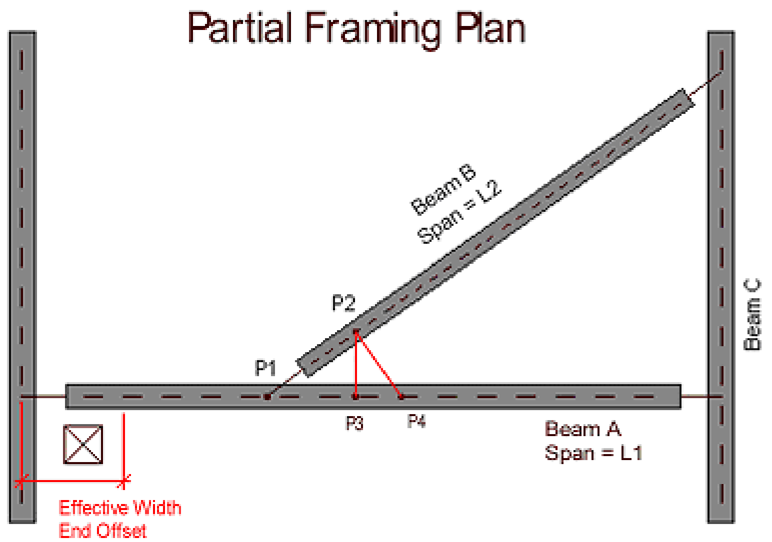
## Effective Width Calculation

The effective width is calculated for each side of the composite beam, and will be the lesser of one-eighth of the beam span, one-half of the distance to an adjacent support (a parallel beam or wall), or the distance to the slab edge. In addition, there are two **Global Parameters** settings that help determine the way that the effective width is determined.

The first setting is the **Effective Width End Offset** which allows you to ignore elements at the end of the beam.

**End Off Set Example 1** - In looking at Beam A in the following figure, the opening beneath the beam does not limit its effective width if it falls within this end offset distance.

**End Off Set Example 2** - In looking at Beam B, the effective width beneath Beam B is half the distance between points P2 and P4. This is because point P2 is the offset distance from the end of Beam B, and point P4 is the point on beam A normal to beam B at the offset distance.




The second parameter used to control effective width calculations is the **Orthogonal Beam Angle** which lets you define what angle constitutes orthogonal framing and therefore does not encroach on the effective width. In the figure above, Beam A and Beam C truly are orthogonal and therefore have no affect on each other's effective widths. Beam B, however, is skewed to its supports and may or may not be considered orthogonal. For example, if the **Orthogonal Beam Angle** is set to 45 degrees then the Beam B – Beam C connection, which forms a 60 degree angle, is considered orthogonal. However, the Beam B –

Beam A connection forms a 30 degree angle and therefore is not considered orthogonal and effective width calculations will not be performed there (i.e. the effective width above Beam A is zero). If you would like to override this effective width calculation you may do so by entering a value in the **B-eff Left** or **B-eff Right** columns on the **Hot Rolled** tab of the **Beams** spreadsheet.

## General Limitations

**Negative Moments -** All beams with negative moments will be designed as non-composite beams. Typically these will be continuous beams and cantilevers.

**Beams with Slender Webs –** Beams that have slender webs will be designed as non-composite beams.

**Long Term Deflections –** No calculations are performed to account for additional deflections due to the creep or shrinkage of the concrete slab.

**Neutral Axis within Slab -** RISAFloor assumes that the entire concrete slab will be on the compression side of the neutral axis. When the neutral axis is within the slab, the program does NOT adjust the composite section properties to neglect the portion of the concrete slab that is in tension.

## Limitations / Assumptions for Canadian Composite

### *Longitudinal Stud Spacing:*

Longitudinal stud spacing is assumed to be the greater of the 6 times the stud diameter or the value of min spacing given in the global parameters. This value is **not** calculated based on the number of studs on the individual beam. Refer to CSA S16-01 (clause 17.7.2.2 (b)) for more information.

### *Non-Standard Rib Heights for Metal Deck*

No provision is given in the code for when deck rib height (hd) is not equal to 75 mm or 38 mm. Therefore, in cases where hd is not equal to one of the above values, the qrr will be taken as equal to qrs. This may not be a conservative assumption. Refer to CSA S16-01 (clause 17.7.2.3) for more information.

### *Concrete Pull Out Area for Shear Studs*

Refer to CSA S16-01 (clause 17.7.2.3) for more information.

- No subtraction for the pull-out area is being done for beams adjacent to slab edges (i.e. spandrel beams).
- No provisions is given for pull-out area in cases with more than two rows of studs.Therefore, the maximum number of stud rows is limited to two for beams with perpendicular decks.
- The c/c spacing between two rows of studs is taken as 4 times the diameter of the studs for calculating the additional pull-out area in case of two rows.

### *Limits on Composite Action*

The minimum limit for composite action is taken as 0.4 for both stress and deflections. The minimum value is taken as the maximum of 0.4 and the ‘Min Percent Composite’ value entered on the Global Dialog.

## Troubleshooting Composite Design

Remember, it is possible for a composite beam to be designed as non-composite. This can occur for a number of reasons as described below.

Frequently, a beam member may be designated as composite, but the final design will end up being non-composite. There are still a number of reasons why this may happen.

1. The Deck properties may not be sufficient for composite behavior. Some of these requirements are:
    a. Thickness of Slab must be at least 2.0 in (per ASD I5.1-5 or LRFD I3.5a)
    b. Height of Studs must extend at least 1.5 in into slab above deck (per I5.1-4 or LRFD I3.5a)
    c. Diameter Of Studs should not exceed 3/4 of an inch (per I5.1-3 or LRFD I3.5a)
    d. Rib Width must be greater than 2 in (per I5.1-2 or LRFD I3.5a)

   e. Weight of Concrete must be greater than 90 pcf (per ASD table I4.2 or LRFD I5.1)
   f. Strength of Concrete must be greater than 3 ksi (per ASD table I4.1)
2. There may not be enough room to add the required number of studs to achieve composite behavior. This may happen when a deck forms a relatively steep angle with the beam and there are ribs available for stud placement. The minimum composite behavior may designated on the Global Parameters.
3. Load combinations that use a "DLpre" load are considered to be **pre-composite** load combinations. If you do not have a "shored" deck, then you should have at least one pre-composite load combination.
4. Load Combinations that do NOT use a DLpre load, are considered to be **post-composite** load combinations. You MUST have at least one post-composite load combination to get composite behavior.
5. Beams with negative bending are not currently designed for composite behavior.
6. The beam alone may satisfy the loading and deflection requirements without needing any help from composite behavior. In this case, you may force a composite design by clearing the **Use Non-Composite if Optimum** option in the Global Parameters.

## Detail Reports for Composite Design

The detail report information for composite beams has the following information that only exists when a member has been designed for composite behavior.

**Composite Bending: 64.9% Capacity at 14.1667ft for LC 4 (ASCE 2 Post)**

**Deck:**

| | Deck | Height (in) | Wr_top (in) | Wr_bot (in) | Pitch (in) | Direction |
|---|---|---|---|---|---|---|
| Left: | Composite Deck | 3 | 7.25 | 4.75 | 12 | Perpendicular |
| Right: | Composite Deck | 3 | 7.25 | 4.75 | 12 | Perpendicular |

**Concrete:**

| | Thickness (in) | f'c (ksi) | wt (k/ft^3) | E (ksi) | b_eff (in) |
|---|---|---|---|---|---|
| Left: | 3.25 | 3 | .11 | 2085 | 42.5 |
| Right: | 3.25 | 3 | .11 | 2085 | 42.5 |

**Studs:**

| Diameter (in) | Height (in) | Rows | Qn (k) | Quantity | Total Q (k) | % Composite |
|---|---|---|---|---|---|---|
| .75 | 5 | 1 | 15.904 | 14 | 111.33 | 40.27 |

**Composite Section:**

| Y Top (in) | Cf (k) | Cf' (k) | Itr (in^4) | I-eff (in^4) | | |
|---|---|---|---|---|---|---|
| 5.102 | 276.48 | 111.33 | 1179.71 | 858.597 | | |
| Mu (k-ft) | Phi | Mn (k-ft) | T max (k) | C max (k) | PNA Y1 (in) | conc a (in) |
| 135.636 | .9 | 232.188 | 276.48 | 704.438 | 1.66 | .514 |

### *Deck*

This section will display the deck type that controlled on each side of the beam. along with the deck properties (Height, Wr_top, Wr_bot, and pitch).

### *Concrete*

This section will display the concrete information for the controlling deck as well as the calculated effective width for each side of the beam.

### *Studs*

This section displays the input stud information along with the following calculated values:

Shear Capacity of each stud, **Qn**.

The total number of studs on the beam, **Quantity,**

The **Total Q** shear force transferred between beam and slab.

The percent of full composite behavior.

### *Composite Section*

This section displays the information used to calculate much of the composite properties and is very useful for comparison to hand calculations. Items that are reported include:

The distance from the Elastic Neutral Axis to the extreme top concrete fiber, **YTop.**

The Compressive force in the concrete flange required to achieve full composite behavior, **Cf**, along with the actual flange compression force, **Cf'.** For ASD 9th edition, these values will be reported as **Vh** and **Vh'.**

The full transformed moment of inertia, **Itr**, as if the beam were fully composite along with the effected moment of inertia based on the partial composite behavior, **Ieff.**

The Distance from the Plastic Neutral Axis to the top of the steel section, **PNA Y1.**

The moment demand, **Mu** versus the nominal moment capacity, **Mn.**

The depth of the effective compression block, **a,** in the concrete versus the compression capacity of the full concrete slab, **Cmax**.

The tension capacity of the full steel section in yield, **Tmax**.

For ASD 9th edition, there will be other actual stress and allowable stress values reported as describe in the sections on Pre and Post Composite design.