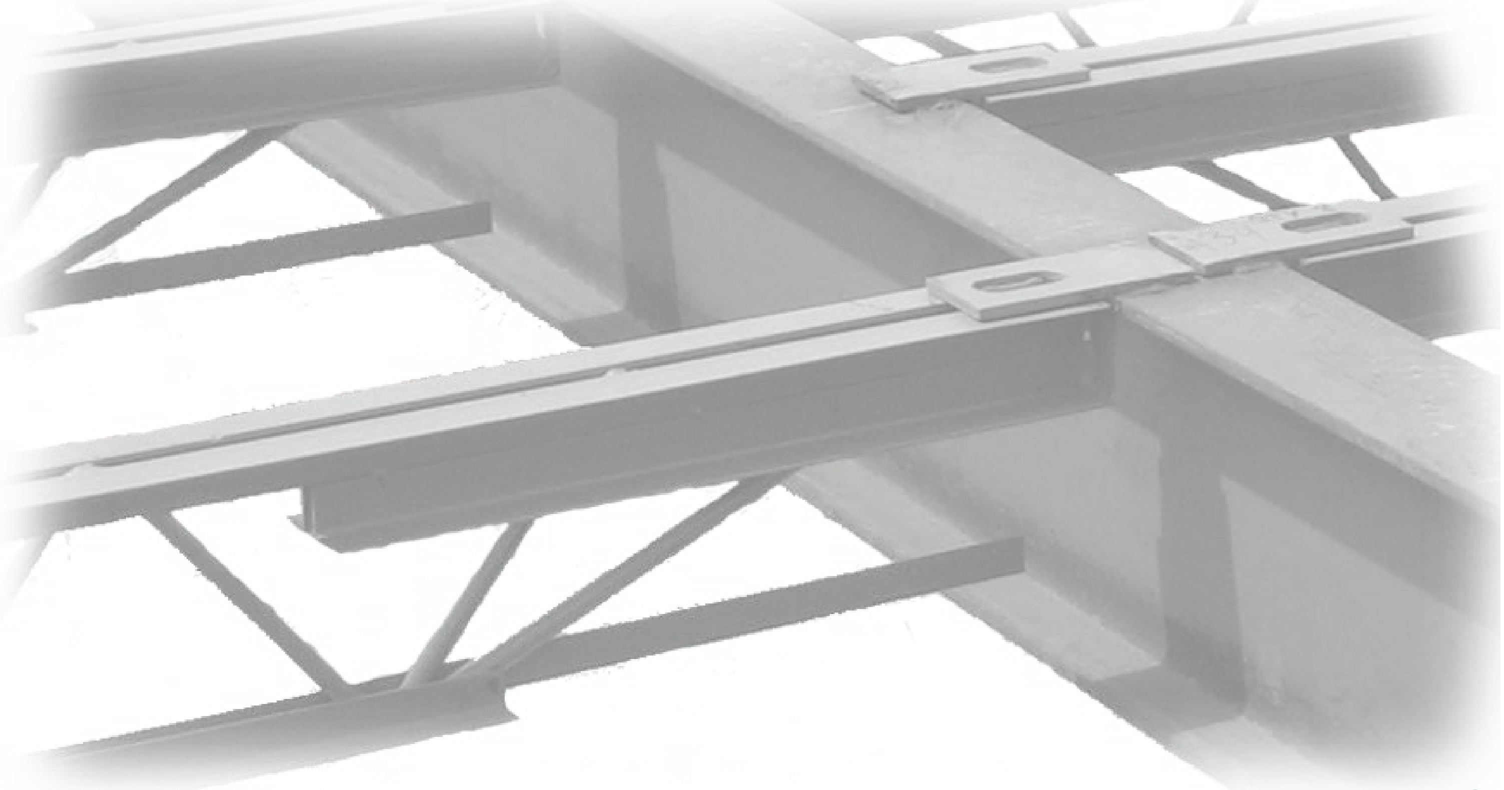
# FLUSH SEAT DESIGN GUIDE FOR USE WITH ECOSPAN® COMPOSITE JOISTS



ECONOMY THROUGH ECOLOGY®

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v1.3

## Nucor-Vulcraft / Verco Group
## Ecospan® Composite Floor System

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## Symbols

| Symbols | Definition |
|---|---|
| A | Horizontal distance from end of the joist top chord angles to centerline of girder, in. |
| $b_f$ | Flange width of the girder, in. |
| $e$ | Eccentricity of bearing reaction from tip of girder flange, in. |
| $f_b$ | Longitudinal bending stress in girder, lb/in$^2$ |
| $F_{y\ girder}$ | Yield strength of the girder, ksi |
| $g$ | Width of flush seat horizontal plate, in. |
| $k_1$ | Fillet dimension of the girder, in. |
| L | Horizontal gap between outside of vertical seat plate and exterior of girder flange, in. |
| $M_p$ | Plastic moment of a one inch width, in-kips |
| $M_{pw}$ | Plastic moment capacity of girder web, in-kips |
| $P_{yl}$ | Nominal joist reaction capacity without interaction effects, kips |
| $Q$ | Reduction factor for slender unstiffened elements |
| $R_{bt}$ | Nominal joist reaction, kips |
| $R_{nyl}$ | Nominal joist reaction capacity, kips |
| $t_f$ | Flange thickness of girder, in. |
| $t_p$ | Horizontal plate thickness, in. |
| $t_v$ | Vertical plate thickness, in. |
| $t_w$ | Web thickness of girder, in. |
| $T_{rf}$ | Flange resistance to twisting, in-kips |
| $\Phi_b$ | LRFD Resistance Factor for flexure |
| $\Phi_b R_{bt}$ | Design joist reaction, kips |
| $\Phi_b R_{nyl}$ | Design joist reaction, kips |
| $\Omega_b$ | ASD strength factor for flexure |

# 1.0 Introduction

## 1.1 General

Open web steel joists have been used for many years as an economical component of concrete slab on steel deck floor systems. Joists have demonstrated many advantages including high strength to weight ratio, low cost, ease of erection, and the ability to run utilities through the webs of the joist. A disadvantage of the conventional joist is the traditional joist seat increases the depth of the structural system at the support. The standard Steel Joist Institute (SJI) K-Series joist has a seat depth of 2 1/2 inches while the standard SJI LH Series joist seat depth is 5 inches.

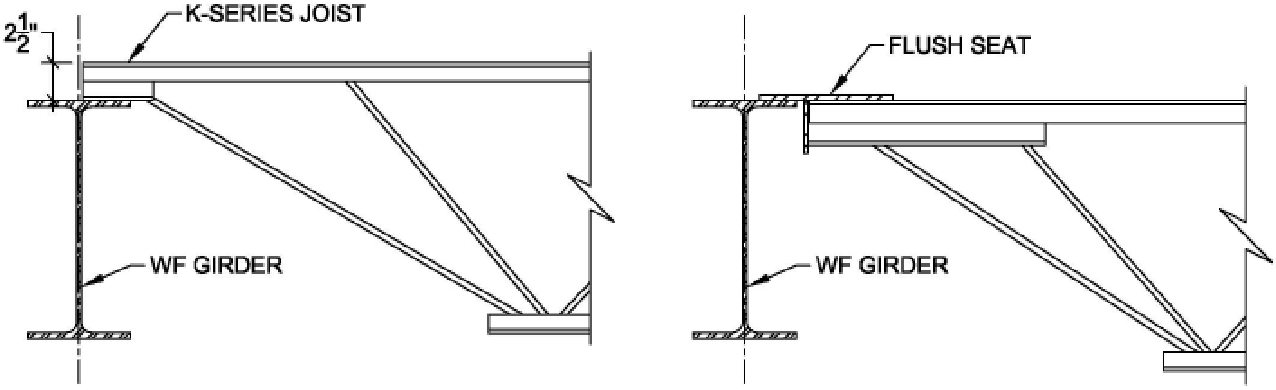

**Figure 1.1 – Standard K-Series Joist and Joist with Flush Seat**

When a standard joist seat is utilized the overall structural depth is increased by the seat depth. Unlike a standard joist seat, the flush joist seat does not increase the structural depth of the floor system. The horizontal top plate of the flush seat does project over the top of the joist and support, however, the floor deck lays over the flush seat horizontal top plate causing no net increase in the floor elevation. The flush seat compared to a standard joist seat can be seen in Figure 1.1.

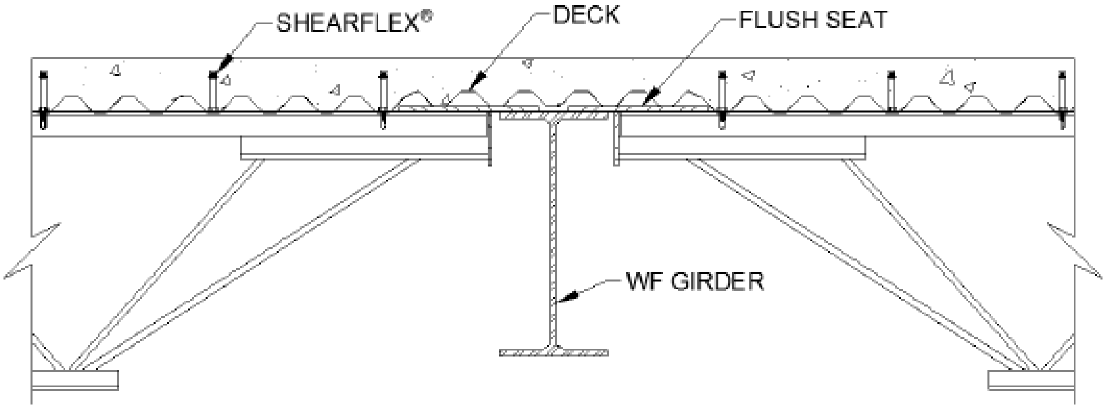

**Figure 1.2 – Flush Seat with Ecospan® Composite Floor System**

The flush seat has been developed for use with the Ecospan® Composite Floor System (Ecospan®). Ecospan® is a composite system offered by Nucor-Vulcraft utilizing a composite slab attached to steel joists with Shearflex® fasteners. Figure 1.2 shows Ecospan® utilizing the flush seat. More information on Ecospan® may be obtained from Nucor-Vulcraft.

The flush seat has been developed for use with joist girders, wide flange girders, reinforced concrete, cold formed steel framing and other load bearing systems. A pair of opposing flush seats supported on a joist girder can be seen in Figure 1.3.

**Figure 1.3 – Opposing Joists on a Joist Girder**

## 1.2 Seat Configuration

The flush seat at each location must be designed and configured for the maximum joist end reaction. The flush seat components are designed by Nucor-Vulcraft based on the loading and design requirements specified by the design professional. Supporting members, connection materials, and attachment requirements between the flush seat and supporting member are the responsibility of the registered professional and not specified by Nucor-Vulcraft.

The capacity of the flush seat is influenced by the support stiffness, the seat connection to the support, and the seat connection to the joist. Each of these can be broken into the following specific topics; these components mentioned are labeled in Figure 1.4.

- The size and type of the supporting member (wide flange, joist girder, etc.).
- The strength and configuration of the supporting member.
- The width and thickness of the flush seat horizontal plate.
- The location of the flush seat vertical plate relative to the supporting member.
- The connection of the seat to the support.
- The connection of the horizontal and vertical seat plates to the top chord and the E-member.

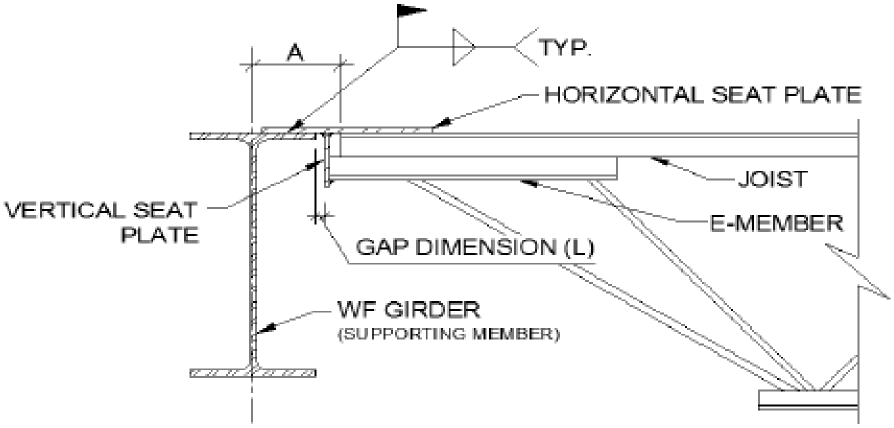

**Figure 1.4 – Flush Seat Component Designations**

Conventional joists are configured with the intersection of the end diagonal and the top chord occurring over the support. With a flush seat as shown in Figure 1.5, it is not possible for the end diagonal to intersect the top chord over the support. Therefore, the work point between the joist end diagonal and the top chord of the joist is eccentric to the support. This results in a bending moment in the top chord of the joist. The top chord is reinforced to provide adequate capacity to resist these moments. This reinforcement consists of angles oriented opposite the top chord angles to create an "I" shaped section and is defined as an E-member.

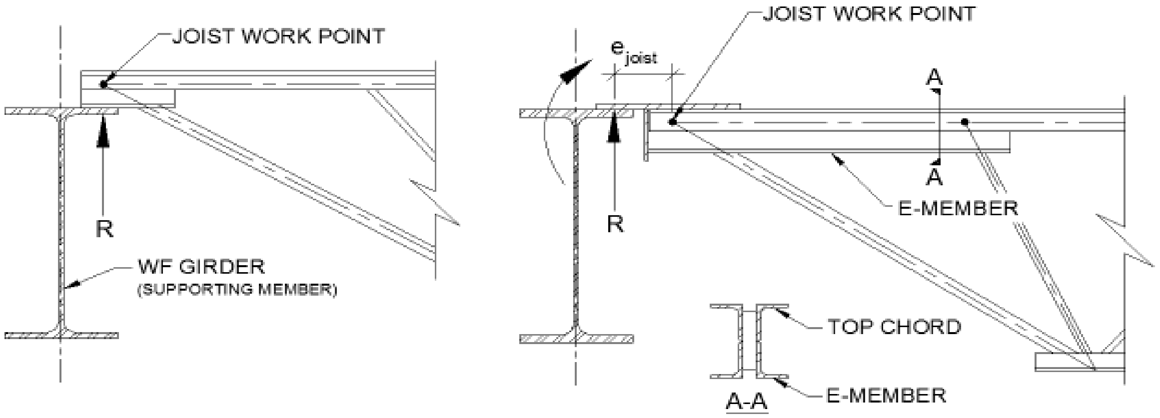

**Figure 1.5 – Flush Seat and Standard Seat Work Points**

It is possible to use many different plate sizes and components to fabricate a flush seat. However, to ensure consistent manufacturing and simplify design, a standardized set of dimensions and component sizes have been developed. For joists supported on steel wide flange girders or joist girders, the typical flush seat horizontal top plate will be 4 to 6 inches wide with a typical thickness of 1/4 inch to 1/2 inch. It also extends a minimum of 3 inches beyond the exterior face of the flush seat vertical plate. For joists supported on masonry, a minimum 5 inch wide plate is used. For masonry supported conditions, the thickness of the top plate may be increased as required to satisfy serviceability limit states.

## 1.3 Limitations

The flush seat has been developed specifically for use with Ecospan®. It is intended to be an alternate seat configuration to the standard seat. It is not intended for use where the joist is sloped relative to the supporting member. The standard seat should be specified by the design professional whenever space requirements allow since the flush seat requires additional material. The joists do not need to be symmetrical with flush seats at both ends. It is recommended that the flush seat be used at interior locations with clearance requirements and standard seats be used at perimeter locations. This proposed configuration is particularly suited for projects with masonry bearing walls.

Testing has shown the configuration of the flush seat does not compromise the overall stiffness or load carrying capacity of the joists. Deflection and end rotation of joists with flush seats are similar to joists with conventional seats. However, flush seats are not designed to transfer axial load through the seat. Therefore, flush seats should not be used as a tie joist in bracing systems. This also includes the transfer of diaphragm forces perpendicular to the length of the joist. Therefore, the design professional will need to design an alternate load transfer system to transfer diaphragm shear forces.

The recommended maximum service load reaction for Ecospan® joists utilizing the flush seat is 10 kips. Contact Nucor-Vulcraft for assistance if higher end reactions are anticipated.

Since most design professionals are familiar with conventional joist seats, various features of the flush seat are compared to standard Steel Joist Institute 'K' or 'LH' Series joist seats. These comparisons are not intended to imply a joist with a flush seat is a SJI standard product. These comparisons are made to provide a point of reference for the design professional.

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# 2.0 Flush Seat Joists Supported on Wide Flange Girders

## 2.1 Introduction and Discussion

When a flush seat is used with wide flange girders, the design of the seat is the responsibility of Nucor-Vulcraft. The design professional is responsible for the other design aspects of the assembly to ensure the joist seat attachment to the supporting girder can transfer the design load. In order to specify flush seats, the design professional needs to evaluate and specify the necessary design requirements for the following:

1. Adequate bearing on the girder flange
2. Adequate joist seat to girder weld or bolts
3. Localized limit states of the girder flange and girder web
4. Serviceability verification (seat deflection)
5. Inspection requirements

Recommendations, design equations, and tabulated capacities have been developed to assist the design professional with performing the required design and evaluation of the appropriate limit states.

## 2.2 Minimum Bearing

A minimum of 2 inches of bearing is required for structural steel supporting members, though, 2 1/2 inches is preferred. Therefore, where joists are opposing each other as shown in Figure 1.2 or Figure 1.3, the minimum flange width of the supporting girder shall be at least 5 inches. Since the flush seat bearing length may be less than required for K-Series joists, the limitations on minimum girder sizes (based on required bearing width) for K-Series joists can be conservatively applied for joists with flush seats.

## 2.3 Seat Dimensions and Detailing

The configuration of the flush seat results in a gap between the flange tip of the supporting girder and the face of the flush seat vertical plate (as shown in Figure 2.1). The width of this gap, “L”, is a critical design parameter when determining the capacity of the flush seat. In order to standardize details, Vulcraft has established critical joist and seat dimensions that are used to determine the gap size.

Vulcraft will detail flush seats with dimension “A” (center of girder to end of top chord) as shown in Figure 2.1. This sets the point from which the joist base length (length of the top chord) is configured for each joist.

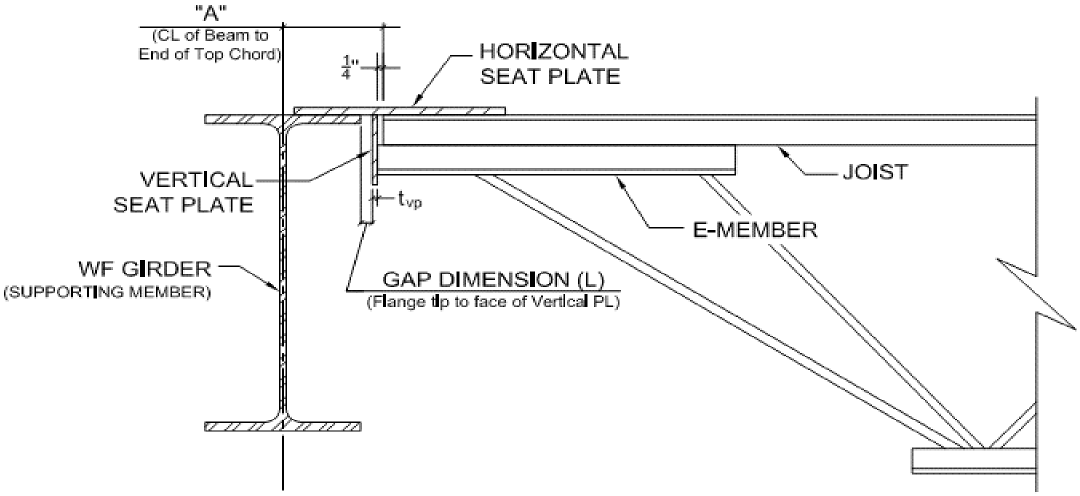


**Figure 2.1 – Ecospan® Flush Seat Joist Seat Components (Wide Flange Girder)**

The E-members on joists with flush seats projects horizontally beyond the end of the top chord to provide clearance for the weld between the vertical and horizontal flush seat plates. The minimum projection of the E-member beyond the top chord is 1/8 inch (1/4 inch is assumed by the detailer to calculate the joist base length). The vertical seat plate will be placed against the end of the E-member as shown in Figure 2.1.

Based on the standard dimension “A” from the center of the support girder to the end of the top chord, the location of the vertical seat plate relative to the supporting girder flange tip can be determined. The resulting dimension is designated as the gap dimension, “L”. Table 2.1 lists the resulting gap dimensions based on various girder flange sizes. The gap dimension in Table 2.1 includes an allowance of 1/4 inch for tolerances in manufacturing and erection at each joist end. Assuming the joist is centered in the bay results in a possible variation of 1/8 inch at each end. The remaining 1/8 inch tolerance is allocated to the steel structural support.

The AISC Code of Standard Practice (COSP) tolerances define the maximum variation of the location of the steel frame after the erection process, not the location of the components during the erection process. Therefore, the tolerance allowance in Table 2.1 is to provide a reasonable amount of adjustment for the steel frame, including the joists, during erection which will allow the erector to meet the intended AISC COSP tolerances for the completed project.

**Table 2.1 – Seat Detailing Dimensions for Wide Flange Girders**

| Girder Size | Girder Flange Width | “A” Dimension* | Gap Dimension (L)** |
|---|---|---|---|
| W8x10-15, W10x12-19, W12x14-22 | 4” | 3” | 3/4” |
| W14x22-26 | 5” | 3 1/2” | 3/4” |
| W8x18-21 | 5 1/4” | 3 5/8” | 3/4” |
| W16x26-31 | 5 1/2” | 3 3/4” | 3/4” |
| W10x22-30 | 5 3/4” | 3 7/8” | 3/4” |
| W18x35-46 | 6” | 4” | 3/4” |
| W8x24-28, W12x26-35 | 6 1/2” | 4 1/4” | 3/4” |
| W14x30-38 | 6 3/4” | 4 3/8” | 3/4” |
| W16x36-57, W24x55-62 | 7” | 4 1/2” | 3/4” |
| W18x50-71 | 7 1/2” | 4 3/4” | 3/4” |
| W8x31-67, W10x33-45, W12x40-50, W14x43-53 | 8” | 5” | 3/4” |
| W21x48-93 | 8 1/8” | 5 1/8” | 7/8” |
| W24x68-103 | 9” | 5 1/2” | 3/4” |
| W10x49-68, W12x53-58, W14x61-82, W27x84-129 | 10” | 6” | 3/4” |
| W10x77-112, W16x67-100 | 10 1/4” | 6 1/8” | 3/4” |
| W30x90 | 10 3/8” | 6 1/4” | 7/8” |

***Utilizes ½ the girder flange width, a ½” gap, ¼” vertical plate, and ¼” E-member projection.**
****Assumes a ½” gap with a ¼” total tolerance for manufacturing and erection.**

## 2.4 Flush Seat to Wide Flange Girder Connection

Per the SJI specifications, a typical K-Series joist to support girder weld is not considered to be under stress due to gravity loading. In the flush seat application, localized deformations in the flush seat horizontal plate result in stresses at the field weld attachment to the supporting girder.

The flush seat testing program included loading the joists beyond the allowable load to yield of the flush seat, releasing the load, and reloading the joists beyond yielding of the flush seat through multiple load cycles. The typical field weld used during testing was a 1/8 inch x 1 1/2 inches long fillet weld on each side of the horizontal plate. The testing program was augmented using independent Finite Element Method (FEM) analysis to evaluate force development and load paths in the flush seat.

Analytical FEM models of the flush seat and the weld show that under gravity loading, the force in the weld is transverse to the axis of the field weld. This force is generated as the top flange of the support girder dishes perpendicular to the joist and the vertical plate on the flush seat restrains this dishing effect.

The recommended minimum flush seat weld to wide flange girders and joist girders for gravity load transfer consists of two 1/8 inch x 1 1/2 inches long fillet welds located on both sides of the horizontal plate, 1/4 inch to 1/2 inch from the tip of the girder flange (see Figure 2.2). This weld forces deflection compatibility at the top flange of the girder and the flush seat horizontal plate.

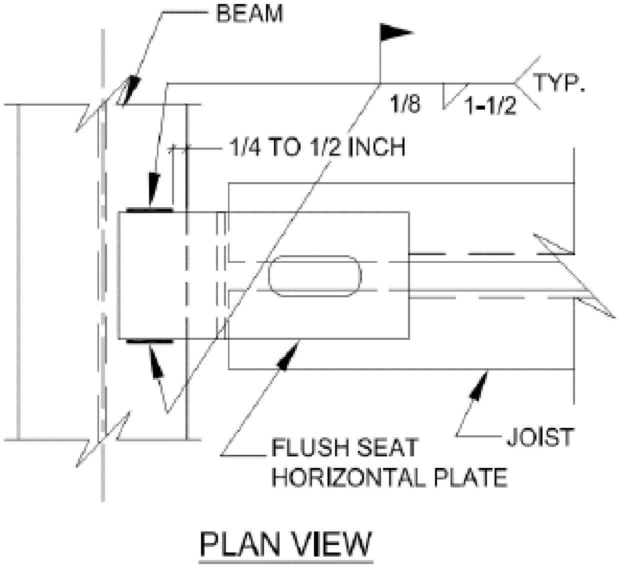


**Figure 2.2 – Flush Seat to Wide Flange Girder - Welded**

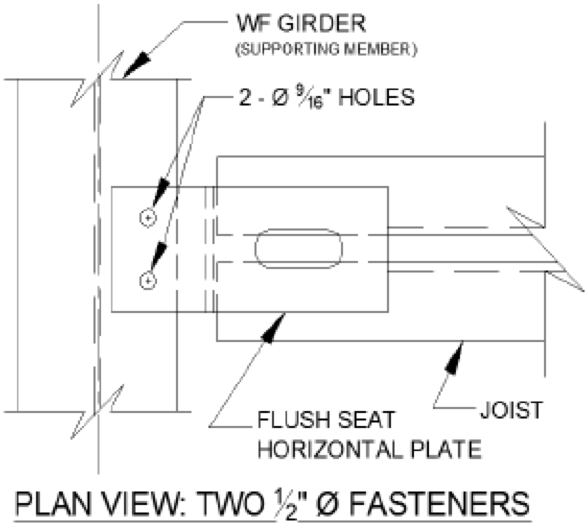


**Figure 2.3 – Flush Seat to Wide Flange Girder - Bolted**

Tests have shown when the weld is located at the end of the horizontal flush seat plate over the "k" region of the wide flange girder, the weld is forced to deform over the web of the girder and may result in premature weld failure at ultimate loads.

The testing program and analytical studies have also shown (2) 1/2 inch diameter bolts (minimum A325) behave similarly to the recommended fillet welds. Therefore, bolts are considered an acceptable option for attaching the flush seat to the wide flange girders. Figure 2.3 shows a two bolt configuration.

## 2.5 Wide Flange Girder Design

The design of wide flange girders supporting joists with flush seats is very similar to designing wide flange girders supporting joists with standard seats. The design professional needs to evaluate all localized bending of the girder flange or web. These limit states are discussed in detail in Sections 2.6 and 2.7.

ANSI/AISC 360 provisions regarding the design of wide flange girders for flexure assume the load is applied at the neutral axis of the wide flange girder. In practice, loads are often eccentrically applied to wide flange girders. As shown in Figure 1.6, the configuration of the flush seat places the joist end diagonal work point outside of the center of bearing for the flush seat. The reinforced top chord (E-member), flush seat, and local bending behavior of the supporting flange act to deliver the end reaction to the bearing point on the girder flange.

Testing and analytical studies have shown that the flush seat does provide a reliable mechanism to deliver the joist reaction to wide flange girders in a manner consistent with conventional joist seats when loaded from both sides. For single sided loading conditions, the effect on the girder is consistent with having the load applied eccentrically to the girder at the center of bearing of the flush seat horizontal plate. In addition to the design criteria provided in this design guide, the girder must be designed to account for this eccentric loading.

## 2.6 Localized Girder Flange Bending

Wide flange girders need to be checked for a localized flange bending limit state at the supporting joist with a flush seat. The strength of the girder flange to resist this localized bending can be evaluated using yield line theory. The yield line solution was proposed by Galambos (2001) to evaluate localized bending in joist girder top chords due to standard joist seat loadings.

The appropriateness of the yield line solution, for wide flange sections, was verified through tests and analytical studies. A yield line forms in the girder flanges at high loads as shown in Figure 2.4. Finite element studies also indicated the formation of yield lines along the top flange of the girder. A plot of the yield lines from a finite element study with loads on both sides can be seen in Figure 2.5.

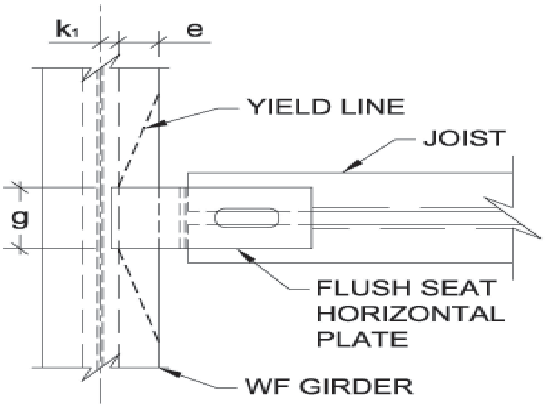


**Figure 2.4 – Yield Line Formation**

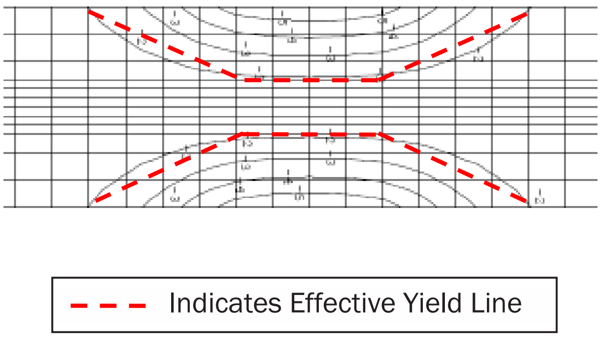


**Figure 2.5 – Plot of FEM Analysis of Flange Bending Behavior**

The solution of the yield line equations for a given configuration is based on plastic analysis. The internal work is set equal to the external work and the resulting equation is solved for the least work solution. The internal work is the sum of the moment rotations of the flange plate along the yield lines. The external work is equal to the joist reaction multiplied by the vertical deflection of the joist seat at the point of load application to the girder flange.

For the yield line solution used by Galambos for standard joist seats, the joist reaction was assumed to be located at the center of bearing. Based on testing and finite element analysis, it was determined the flush seat bearing location should be at the flange tip of the wide flange girder. For a standard seat, the bearing width is taken as the full width of the joist seat. The flush seat vertical plate stiffens the horizontal plate across its full width. Thus the full width of the flush seat is also the effective bearing width.

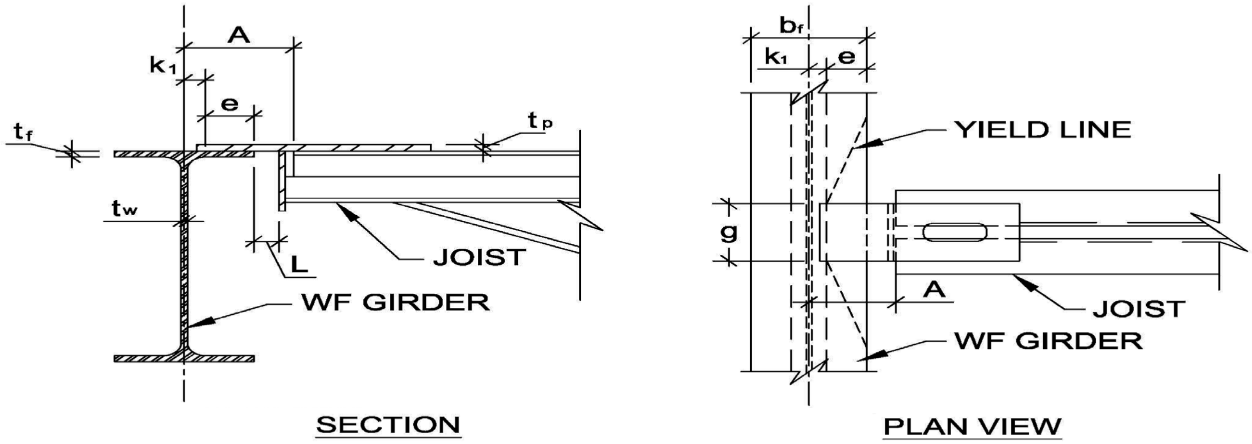


**Figure 2.6 – Localized Girder Flange Bending – Equation Designations**

The following equations are used to check the transverse flange bending limit state. The yield line based derivation for these equations can be found in Appendix B. The variables for these equations are shown again in Figure 2.6.

$$P_{yl} = \left(\frac{M_p}{e}\right) * (g + 5.66e) \qquad \text{(kips) (Eqn. 1)}$$

$$R_{nyl} = P_{yl}\left(1.6 - \frac{f_b}{0.6QFy\ girder}\right) \leq P_{yl} \qquad \text{(kips) (Eqn. 2)}$$

Where:

$P_{yl}$ = Nominal Joist Reaction Capacity without Interaction Effects

$M_p$ = Plastic moment of a one inch width $- \left(\frac{t_f^2}{4}\right) * F_{y\,girder}$ (in – kips)

$t_f$ = Flange thickness of the girder (inch)

$F_{y\,girder}$ = Yield stress of the girder (ksi)

$e = \frac{b_f}{2} - k_1$ = Bearing eccentricity (inch)

$b_f$ = Flange width of the girder (inch)

$k_1$ = Fillet dimension of the girder (inch)

$g$ = Width of flush seat horizontal plate (inch)

$R_{nyl}$ = Nominal Joist Reaction Capacity (kips)

$\Phi_b R_{nyl}$ = Design Joist Reaction (kips)

$\Phi_b$ = LRFD Resistance Factor; $\Phi_b = 0.9$

$R_{nyl}/\Omega_b$ = Allowable Joist Reaction (kips)

$\Omega_b$ = ASD Safety Factor; $\Omega_b = 1.67$

$f_b$ = Longitudinal bending stress of the girder (ksi)

$Q$ = Full reduction factor for slender compression elements

Equations 1 and 2 are used for single sided or double sided loading. The nominal reaction is the end reaction for one joist on one side of the girder web. Equation 1 provides the nominal reaction capacity at a given joist without consideration for the longitudinal bending stresses in the flange of the girder. Equation 2 reduces the nominal reaction capacity to account for the longitudinal bending stresses in the girder. Since these equations are derived from standard engineering principles, the appropriate AISC Resistance Factor ($\Phi$) or Safety Factor ($\Omega$) for flexure is applicable.

The results for Equations 1 and 2 have been calculated and tabulated for standard wide flange girders which are shown in Appendix A. The tabular values reported for the flange bending limit state are nominal reaction capacity, $R_{nyl}$. For ultimate strength design, the values are multiplied by $\Phi$. For allowable strength design, the values are divided by $\Omega$.

## 2.7 Localized Wide Flange Girder Web Bending

Wide flange girders supporting a joist with a flush seat need to be evaluated for a combined web bending plus flange twisting limit state. This limit state was observed during the development and testing program. An example of this limit state can be seen in Figure 2.7.

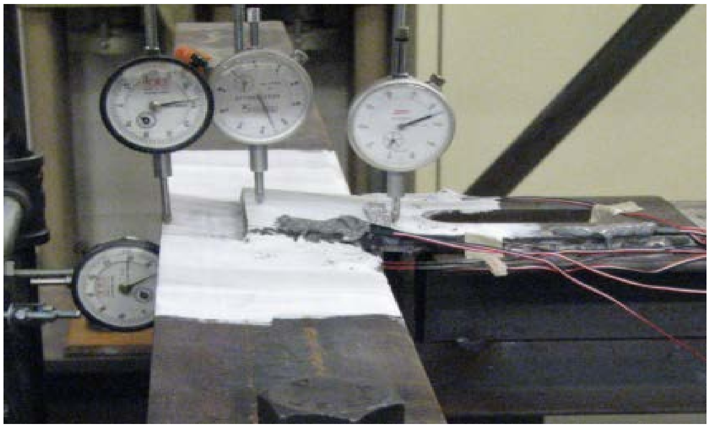


**Figure 2.7 – Web Bending and Flange Twisting of W12x16 with 8k Reaction**

The effective bending width of the web can be calculated as the width of the flush seat "g" plus the distance created by allowing the load to spread out from the bearing seat in both directions at an angle of 3 to 1 from the flange tip to the edge of the girder web fillet as illustrated in Figure 2.8.

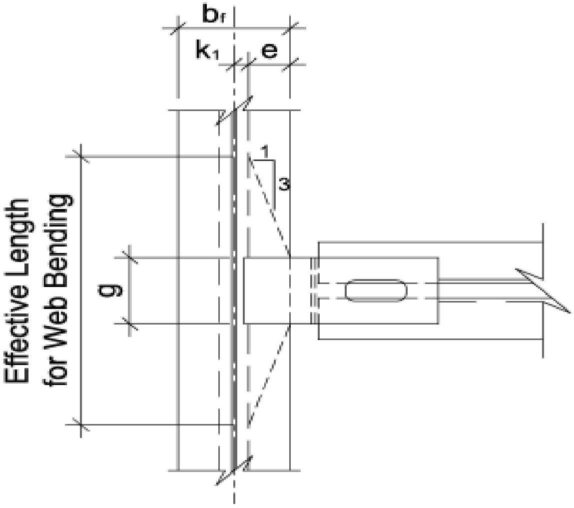


**Figure 2.8 – Effective Length for Web Bending**

This proposed effective length of the girder web in bending is consistent with the failure mode observed during testing. The girder top flange also contributes to resisting the effects of the seat eccentricity in this limit state. The top flange resistance is quantified by the torsional strength of the top flange.

Based on the strengths of the components (flange and web); Equations 3 through 5 can be used to evaluate the limit state of web bending and flange twisting for girders subjected to loads on only one side. When girders are subjected to unequal loads (i.e. shorter bays on one side), the web bending limit state can be checked for the net difference between the joist reactions.

<u>Where:</u>

$$R_{bt} = \frac{(M_{pw} + 2T_{rf})}{e} \qquad \text{(kips) (Eqn. 3)}$$

$$M_{pw} = \frac{F_{y\,girder}\left(g + 6\left({}^{b_f}\!/_{2} - k_1\right)\right)t_w^{\,2}}{4} \qquad \text{(in - kips) (Eqn. 4)}$$

$$T_{rf} = 0.6F_{y\ girder} * \frac{b_f\ t_f^{\,2}}{3} \qquad \text{(in - kips) (Eqn. 5)}$$

<u>Where:</u>

$R_{bt}$ = Nominal Joist Reaction (kips)

$\Phi_b R_{bt}$ = Design Joist Reaction; $\Phi_b = 0.9$ (kips)

${}^{R_{bt}}\!/_{\Omega_b}$ = Allowable Joist Reaction; $\Omega_b = 1.67$ (kips)

$e$ = Eccentricity of bearing reaction from tip of girder flange

$e = \frac{b_f}{2} - k_1$ (inch)

$b_f$ = Flange width of the girder (inch)

$k_1$ = Fillet dimension of the girder (inch)

$F_{y\,girder}$ = Yield stress of the girder (ksi)

$g$ = Width of flush seat horizontal plate (inch)

$t_w$ = Web thickness of the girder (inch)

$t_f$ = Flange thickness of the girder (inch)

## 2.8 Serviceability Requirements

Testing confirmed the assembly consisting of the flush seat to wide flange girder connection is very ductile. In fact, the seat can safely resist loads beyond initial yielding and recover after unloading to resist additional higher loads. This ductile behavior is desirable, however the localized bending may result in undesirable deformations. Since the seat can safely carry load at high deformations, a serviceability based limit for the seat capacity has been developed.

A number of different criteria could be used to evaluate the deformation of the seat. For convenience, the deformation measurement adopted is the vertical displacement of the seat at the center of the flush seat vertical plate, relative to the center of the supporting girder flange. The deformation measurement of the vertical plate can be seen in Figure 2.9.

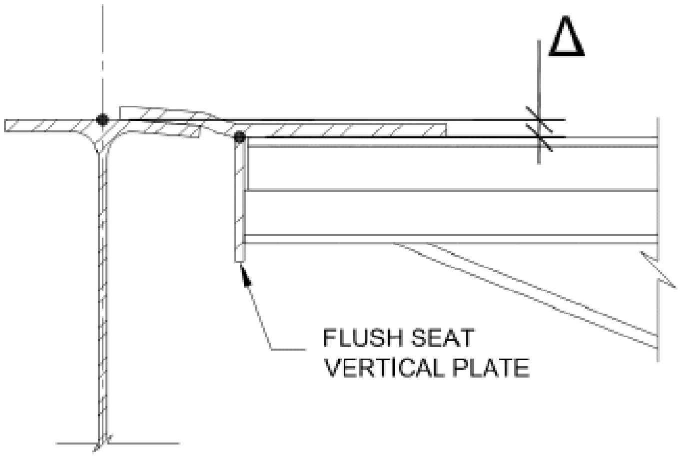


**Figure 2.9 – Deformation Measurement of Vertical Plate**

The deflection limit has been set to keep seat deformations below a level that is considered to be visibly objectionable. The recommendations in this design guide are based on a total deflection limit of 1/4 inch. This total limit is equally divided between the loads in the pre-composite and composite state and are 1/8 inch each. In this case, composite load is defined as all loads applied after the concrete is placed. The design professional shall evaluate the serviceability requirements for each project and set the appropriate deflection limits.

The composite load limit is intended to limit the size of cracks in the concrete slab. It is recommended the design professional specify adequate reinforcement in the slab over the supports to control the size of longitudinal cracks in the concrete that may occur due to seat deformation. At high service loads deflection cracks may be visible. However, with proper reinforcement, should be no more objectionable than ordinary shrinkage cracks. Transverse reinforcing minimizes concrete crack widths and allows for a larger potential deflection allowance if needed.

The flush seat deformation was studied in the testing program and was validated using finite element models of the joist seat with various support girders and loads. A partial view of the single-sided finite element model is illustrated in Figure 2.10.

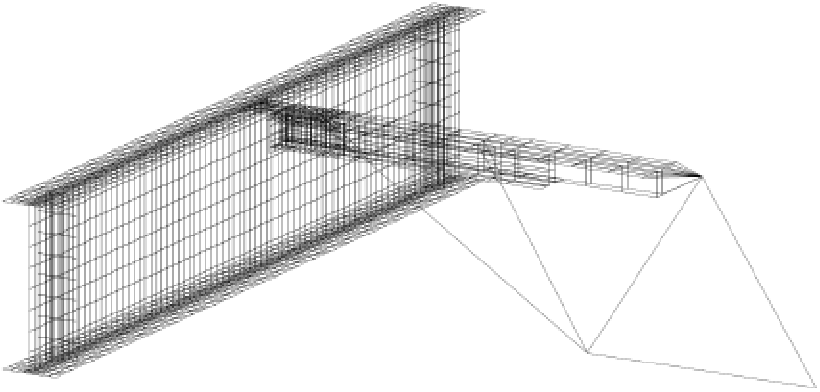


Figure 2.10 – Single-Sided Finite Element Model (WF Girder)

To evaluate vertical deflection of the flush seat and vertical plate, Equation 6 was developed. It provides reasonable correlation with the finite element models and tests for loads under the strength based limits. The variables for Equation 6 are shown in Figure 2.11.

Where:

$$\Delta = \frac{P_1 * (A - k_1)^3}{B * E * I} * \left(0.4 + 0.6\left(\frac{P_1 - P_2}{P_1}\right)\right) \qquad \text{(inch) (Eqn. 6)}$$

Where:

$P_1$ = Larger joist reaction on one side of girder web (kips)

$P_2$ = Smaller joist reaction on far side of girder web (kips)

$$A = \left(\frac{b_f}{2}\right) + L + t_{vp} + 1/4 \qquad \text{(inch)}$$

$b_f$ = Flange width of the girder (inch)

$k_1$ = Fillet dimension of the girder (inch)

$L$ = Gap length measured to the outside of the vertical plate (inch)

$$B = \left(\frac{b_f}{10}\right) + L \geq 1.0 \qquad \text{(dimensionless)}$$

$E$ = Modulus of elasticity = 29,000 (ksi)

$$I = \frac{g * t_f^3}{12} \qquad (\text{inch}^4)$$

$g$ = Width of flush seat horizontal plate (inch)

$t_f$ = Flange thickness of the girder (inch)

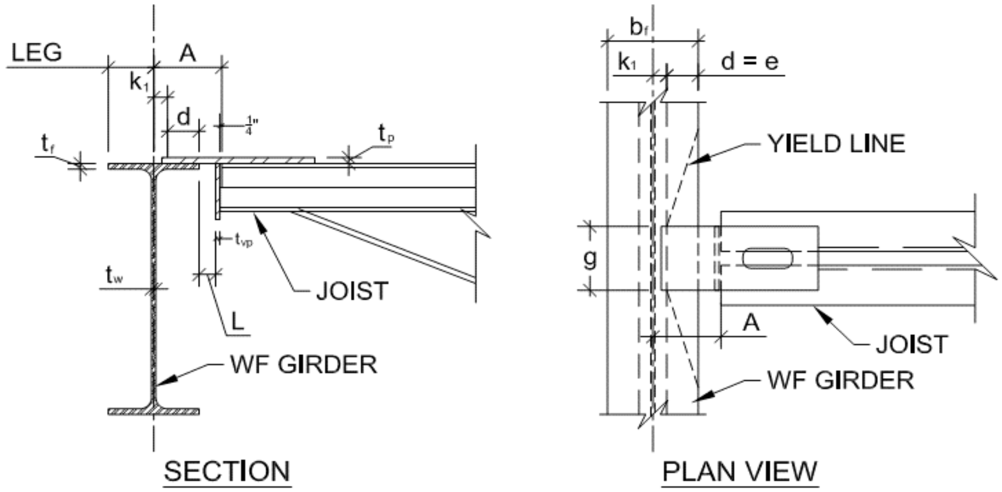


**Figure 2.11 – Flush Seat Vertical Plate Deflection - Equation Designation**

The finite element studies show the flange deflection of the flush seat on a wide flange girder with equally loaded joists on either side of the girder web is approximately 40% of the deflection of the same sized girder with the joist applied to one side only. When a wide flange girder has loading on one side, overall rotation of the girder can occur, and must be evaluated by the design professional. Conversely, if a wide flange girder supports two sided flush seats with equal end reactions, overall global rotation of the girder does not occur. Equation 6 provides a straight line interpolation between the single sided case and the case with equal joist reactions on each side of the support girder.

Localized wide flange girder capacities supporting joists have been tabulated in Appendix A based on the recommended total load deflection limit and gap dimensions for a 4" wide flush seat. The tabulated values include the single sided case and the symmetrically loaded case. Straight line interpolation may be used for cases with unequal loading.

Additional testing of the flush seat with concrete cover has shown that an increase in capacity is available due to the added stiffness provided by the composite system. Wide flange girder flange deflections were decreased compared to similar loads without concrete. Currently, the increase in capacity associated with these same deflection limits have not been quantified.

# 3.0 Flush Seat Joists Supported on Joist Girders

## 3.1 Introduction and Discussion

When a flush seat is used with joist girders, the design of the actual seat and the joist girder is the responsibility of Vulcraft. The design professional is responsible for designing the attachment of the joist to the joist girder. Recommendations in this design guide have been developed to assist the design professional to specify the required weld of the flush seat to the joist girder.

## 3.2 Minimum Bearing

For consistency with the testing program, a minimum of 2 inches (2-1/2 inches recommended) of bearing on steel supports is required. Therefore, a minimum joist girder chord angle leg of 2-1/2 inches is recommended. This is equivalent to the minimum bearing length required for a K-series joist.

## 3.3 Seat Dimensions and Detailing

The dimensions of the flush seat for each application are determined based on minimum bearing, the joist girder top chord angle leg size, detailing, fabrication, and erection considerations. Refer to Chapter 2 for gap size, "A" dimension, and tolerances.

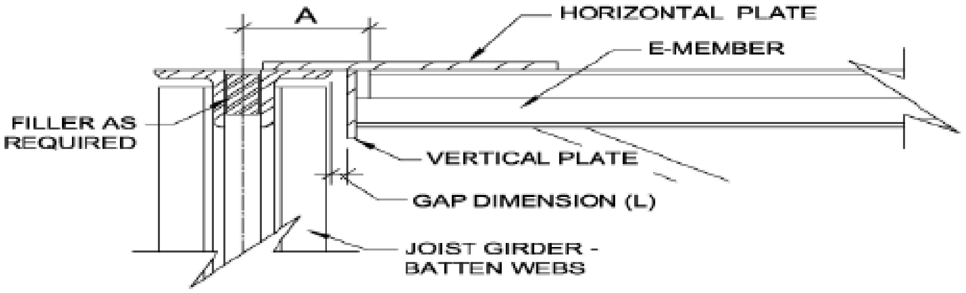


**Figure 3.1 – Flush Joist Seat Components (Joist Girder)**

Based on the standard dimensions from the center of the joist girder to the end of the top chord, the location of the vertical plate relative to the outstanding angle tip can be determined. Vulcraft will design the flush seat with the distance from center of joist girder to the end of the joist top chord dimension, "A", as provided in Table 3.1 and shown in Figure 3.1 (Table 3.1 assumes a 1/4 inch thick vertical plate).

**Table 3.1 – Seat Detailing Dimensions for Joist Girders**

| Joist Girder Top Chord Angle Size | Joist Girder Width | Center of Joist Girder to end of joist top chord (A) | Resulting design gap dimension (L) |
|---|---|---|---|
| L 2 1/2 X 2 1/2 | 6" | 4 1/4" | 3/4" |
| L 3 X 3 | 7" | 4 3/4" | 3/4" |
| L 3 1/2 X 3 1/2 | 8" | 5 1/4" | 3/4" |
| L 4 X 4 | 9" | 5 3/4" | 3/4" |
| L 5 X 5 | 11" | 6 3/4" | 3/4" |
| L 6 X 6 | 13" | 7 3/4" | 3/4" |

## 3.4 Flush Seat to Joist Girder Weld

The conditions, criteria, and recommendations that apply to welding the flush seat to a wide flange girder are applicable to welding the flush seat to a joist girder as discussed in Chapter 2 and shown in Figure 3.2.

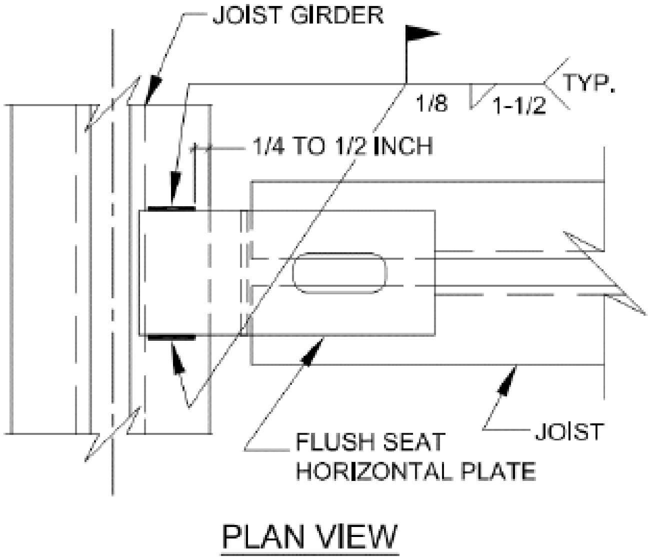


**Figure 3.2 – Flush Seat to Joist Girder Weld**

## 3.5 Joist Girder Design

The Vulcraft Design Engineer must design the joist girder to meet the requirements of the design professional. As with typical joist connections, the design professional must provide the desired spacing, loads, girder depth, and web configuration limitations. The design professional must also indicate that the connections are to be Ecospan® flush seat connections.

## 4.0 Flush Seat Joists Supported on Masonry, Concrete, or ICF

For flush seats supported by masonry, concrete, or Insulated Concrete Forms (ICF), contact the Ecospan® office of Nucor-Vulcraft for more information. Special design modifications must be made to utilize the flush seat on masonry, concrete or ICF.

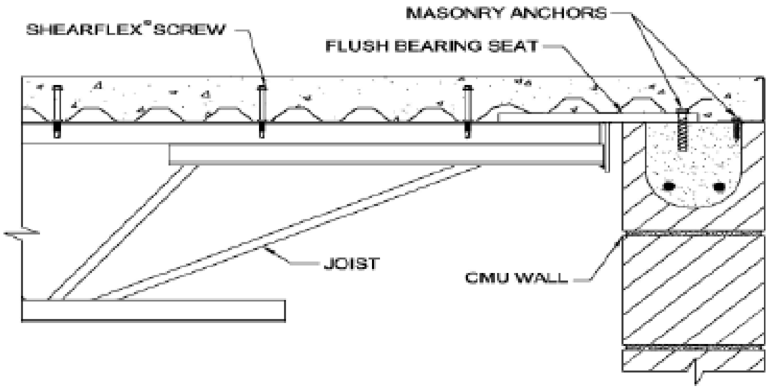
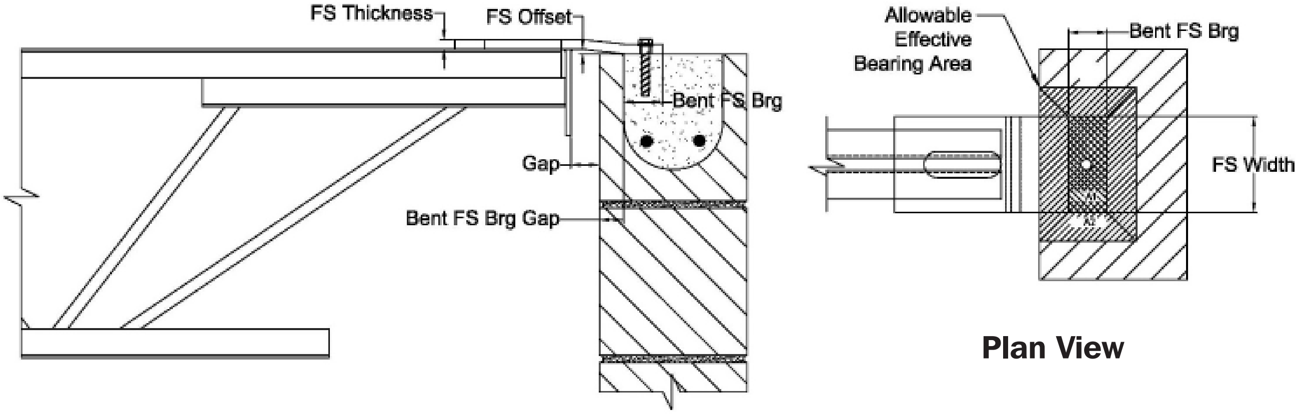


**Figure 4.1 – Standard Flush Seat to CMU Wall**



Plan View

**Figure 4.2 – Bent Flush Seat to CMU Wall**

The modifications may consist of a bent horizontal plate. A bent horizontal plate will apply the bearing pressure near the center of the masonry wall. This can be beneficial in reducing inside face shell cracking of the masonry wall. The bent plate may increase concrete longitudinal cracking at the top surface of the floor slab necessitating concrete reinforcing at this location. As such, the use of this detail needs to be evaluated with Vulcraft on a case by case basis.

## 5.0 Flush Seat Joists Supported on Cold Formed Bearing

It is recommended that flush seats not be supported directly on the top track of CFS walls without a load distribution member (LDM) intermediately placed as shown in Figure 5.1. Alternatively, Figure 5.2 illustrates a standard joist seat with a concrete LDM, which is usually a more cost effective method. Flush seats supported on Hollow Structural Sections (HSS) must be analyzed for additional gap width and additional eccentricity into the end of the steel joist (See Appendix C).

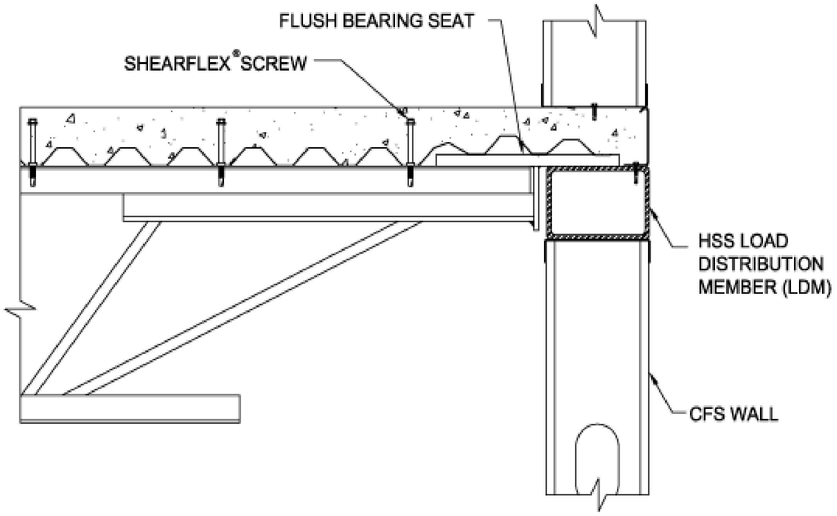


Figure 5.1 – Flush Seat to Cold Formed Steel with HSS LDM

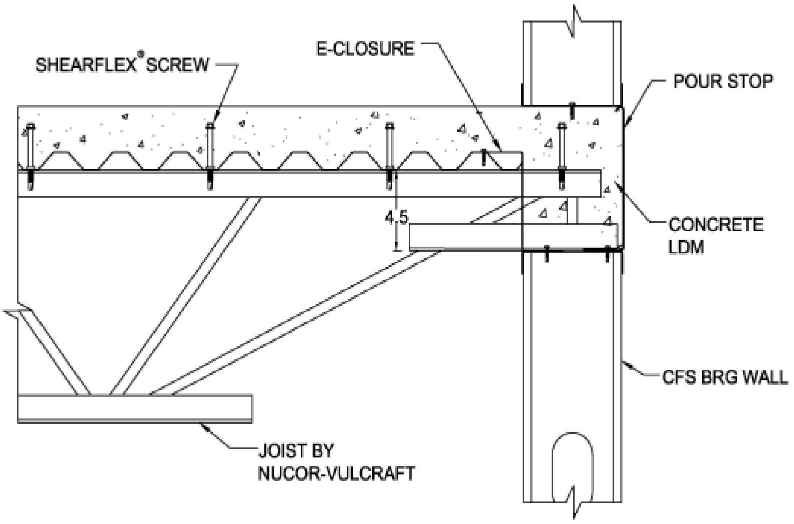


Figure 5.2 – Preferred Alt. - Standard Seat to Cold Formed Steel with Concrete LDM

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# APPENDIX A: Wide Flange Girder Capacities for Flush Seat (10 kips Maximum)

| **Wide Flange Girder Capacities for Flush Seat<br>$F_y$ = 50 ksi, Horizontal Plate Width = 4 inches** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Wide Flange Girder Size** | **Yield Line, $R_{nyl}$ [kip]** | | **Web Bending & Flange Torsion, $R_{bt}$ [kip]** | ***Total Vertical Deflection, $P_{\Delta}$ [kip] (Max. Δ = 1/4”)*** | | | | | |
| | | | | **Service Loads** | | | | | |
| | $\Phi = 0.9$ | | | **Load on One Side of Girder** | | | **Equal Load on Each Side of Girder** | | |
| | $\Omega = 1.67$ | | | | | | | | |
| | ***$R_{nyl}$ ($f_b = 0$)*** | ***$R_{nyl}$ ($f_b = .6F_y$)*** | $\Phi = 0.9$<br>$\Omega = 1.67$ | 1/2” Gap | 1” Gap | 1-1/2” Gap | 1/2” Gap | 1” Gap | 1-1/2” Gap |
| W30X90 | 30.82 | 18.49 | 37.94 | 8.47 | 8.25 | 7.78 | 21.17 | 20.63 | 19.44 |
| W27X84 | 34.18 | 20.51 | 39.36 | 10.88 | 10.53 | 9.85 | 27.19 | 26.32 | 24.63 |
| W24X104 | 45.07 | 27.04 | 48.07 | 9.12 | 9.13 | 8.87 | 22.81 | 22.83 | 22.17 |
| W24X68 | 29.21 | 17.53 | 33.37 | 11.20 | 10.61 | 9.72 | 28.00 | 26.53 | 24.31 |
| W21X55 | 23.41 | 14.05 | 26.26 | 8.30 | 7.89 | 7.23 | 20.74 | 19.73 | 18.07 |
| W21X48 | 15.92 | 9.55 | 20.31 | 4.76 | 4.52 | 4.13 | 11.90 | 11.29 | 10.32 |
| W21X50 | 26.09 | 15.65 | 29.02 | 16.58 | 14.86 | 12.90 | 41.45 | 37.16 | 32.26 |
| W21X44 | 18.48 | 11.09 | 22.50 | 9.99 | 8.95 | 7.76 | 24.98 | 22.36 | 19.39 |
| W18X76 | 37.92 | 22.75 | 38.51 | 10.10 | 9.93 | 9.44 | 25.25 | 24.81 | 23.60 |
| W18X35 | 16.79 | 10.08 | 18.38 | 9.81 | 8.65 | 7.39 | 24.53 | 21.62 | 18.47 |
| W16X40 | 22.79 | 13.67 | 21.99 | 11.53 | 10.55 | 9.33 | 28.83 | 26.38 | 23.31 |
| W16X36 | 16.45 | 9.87 | 17.53 | 6.74 | 6.22 | 5.52 | 16.86 | 15.54 | 13.81 |
| W16X31 | 18.50 | 11.10 | 18.17 | 13.63 | 11.66 | 9.73 | 34.07 | 29.16 | 24.33 |
| W16X26 | 11.40 | 6.84 | 12.80 | 6.67 | 5.70 | 4.74 | 16.67 | 14.24 | 11.86 |
| W14X99 | 48.23 | 28.94 | 49.95 | 8.73 | 8.73 | 8.51 | 21.82 | 21.82 | 21.26 |
| W14X90 | 40.00 | 24.00 | 41.34 | 6.71 | 6.70 | 6.53 | 16.76 | 16.76 | 16.31 |
| W14X61 | 34.63 | 20.78 | 33.11 | 10.67 | 10.38 | 9.74 | 26.69 | 25.94 | 24.36 |
| W14X43 | 24.56 | 14.73 | 23.51 | 10.91 | 10.12 | 9.08 | 27.27 | 25.30 | 22.70 |
| W14X34 | 18.59 | 11.15 | 18.29 | 8.76 | 8.00 | 7.05 | 21.91 | 20.01 | 17.64 |
| W14X30 | 13.32 | 7.99 | 14.49 | 5.35 | 4.88 | 4.30 | 13.38 | 12.21 | 10.75 |
| W14X22 | 11.15 | 6.69 | 11.89 | 7.98 | 6.55 | 5.29 | 19.94 | 16.38 | 13.23 |

Notes:

1. The design professional must evaluate overall girder capacity limit states including bending, shear, and torsion.
2. Tabulated capacities must be reduced for interaction with beam bending stresses, refer to section 2.6.
3. Multiply values by Φ for LRFD design and divide by Ω for ASD design.
4. The lowest capacity based on yield line, web bending, flange torsion, deflection, and girder capacity is to be used.
5. $R_{nyl}$ must be reduced per equation 2 based on the axial stress in the girder.

## Wide Flange Girder Capacities for Flush Seat
## $F_y$ = 50 ksi, Horizontal Plate Width = 4 inches

| **Wide Flange Girder Size** | **Yield Line, $R_{nyl}$ [kip]** | | **Web Bending & Flange Torsion, $R_{bt}$ [kip]** | ***Total Vertical Deflection, $P_\Delta$ [kip] (Max. $\Delta$ = 1/4")*** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **Service Loads** | | | | | |
| | $\Phi = 0.9$ | | | **Load on One Side of Girder** | | | **Equal Load on Each Side of Girder** | | |
| | $\Omega = 1.67$ | | | | | | | | |
| | ***$R_{nyl}$ ($f_b = 0$)*** | ***$R_{nyl}$ ($f_b = .6F_y$)*** | $\Phi = 0.9$<br>$\Omega = 1.67$ | 1/2" Gap | 1" Gap | 1-1/2" Gap | 1/2" Gap | 1" Gap | 1-1/2" Gap |
| W12X79 | 43.64 | 26.18 | 44.99 | 9.93 | 9.88 | 9.52 | 24.83 | 24.70 | 23.81 |
| W12X72 | 36.31 | 21.78 | 37.56 | 7.69 | 7.64 | 7.36 | 19.21 | 19.10 | 18.39 |
| W12X65 | 29.56 | 17.73 | 30.50 | 5.47 | 5.45 | 5.26 | 13.67 | 13.63 | 13.15 |
| W12X58 | 34.02 | 20.41 | 31.48 | 10.01 | 9.77 | 9.20 | 25.01 | 24.41 | 23.01 |
| W12X53 | 27.46 | 16.48 | 26.67 | 7.26 | 7.08 | 6.67 | 18.14 | 17.70 | 16.68 |
| W12X40 | 23.00 | 13.80 | 21.49 | 8.98 | 8.44 | 7.65 | 22.45 | 21.10 | 19.13 |
| W12X30 | 17.55 | 10.53 | 16.47 | 8.70 | 7.86 | 6.87 | 21.74 | 19.66 | 17.18 |
| W12X26 | 13.11 | 7.87 | 12.54 | 5.67 | 5.12 | 4.47 | 14.18 | 12.81 | 11.17 |
| W12X19 | 12.91 | 7.75 | 12.87 | 14.14 | 9.96 | 7.73 | 35.34 | 24.91 | 19.33 |
| W12X16 | 7.42 | 4.45 | 9.23 | 6.23 | 4.37 | 3.39 | 15.58 | 10.93 | 8.47 |
| W12X14 | 5.36 | 3.22 | 7.23 | 3.87 | 2.71 | 2.09 | 9.69 | 6.76 | 5.23 |
| W10X33 | 16.32 | 9.79 | 16.94 | 4.97 | 4.72 | 4.32 | 12.42 | 11.80 | 10.79 |
| W10X26 | 18.10 | 10.86 | 16.77 | 11.30 | 9.93 | 8.46 | 28.24 | 24.83 | 21.15 |
| W10X22 | 12.05 | 7.23 | 12.22 | 5.83 | 5.17 | 4.44 | 14.57 | 12.93 | 11.09 |
| W10X17 | 11.48 | 6.89 | 12.37 | 11.85 | 8.35 | 6.48 | 29.62 | 20.88 | 16.20 |
| W10X15 | 7.69 | 4.62 | 9.86 | 6.54 | 4.60 | 3.57 | 16.35 | 11.50 | 8.91 |
| W10X12 | 4.68 | 2.81 | 6.44 | 3.17 | 2.21 | 1.71 | 7.94 | 5.53 | 4.27 |
| W8X40 | 27.05 | 16.23 | 27.44 | 10.75 | 10.19 | 9.30 | 26.88 | 25.47 | 23.24 |
| W8X35 | 21.17 | 12.70 | 21.00 | 7.55 | 7.14 | 6.51 | 18.87 | 17.85 | 16.27 |
| W8X31 | 16.30 | 9.78 | 16.66 | 4.90 | 4.66 | 4.27 | 12.26 | 11.66 | 10.67 |
| W8X28 | 19.39 | 11.63 | 18.32 | 9.01 | 8.30 | 7.35 | 22.54 | 20.75 | 18.37 |
| W8X24 | 14.30 | 8.58 | 13.36 | 5.49 | 5.09 | 4.53 | 13.73 | 12.72 | 11.32 |
| W8X21 | 15.18 | 9.11 | 14.33 | 9.33 | 8.14 | 6.88 | 23.33 | 20.36 | 17.19 |
| W8X18 | 10.34 | 6.21 | 10.79 | 5.29 | 4.61 | 3.89 | 13.23 | 11.53 | 9.72 |
| W8X15 | 10.46 | 6.28 | 12.10 | 10.31 | 7.26 | 5.64 | 25.76 | 18.16 | 14.09 |
| W8X13 | 6.86 | 4.12 | 9.43 | 5.51 | 3.87 | 3.00 | 13.77 | 9.68 | 7.51 |
| W8X10 | 4.40 | 2.64 | 5.40 | 2.72 | 1.93 | 1.51 | 6.81 | 4.81 | 3.76 |

Notes:

1. The design professional must evaluate overall girder capacity limit states including bending, shear, and torsion.
2. Tabulated capacities must be reduced for interaction with beam bending stresses, refer to section 2.6.
3. Multiply values by Φ for LRFD design and divide by Ω for ASD design.
4. The lowest capacity based on yield line, web bending, flange torsion, deflection, and girder capacity is to be used.
5. $R_{nyl}$ must be reduced per equation 2 based on the axial stress in the girder.

## APPENDIX B: Derivation of the Collapse Load for a Girder Flange or Chord Angle

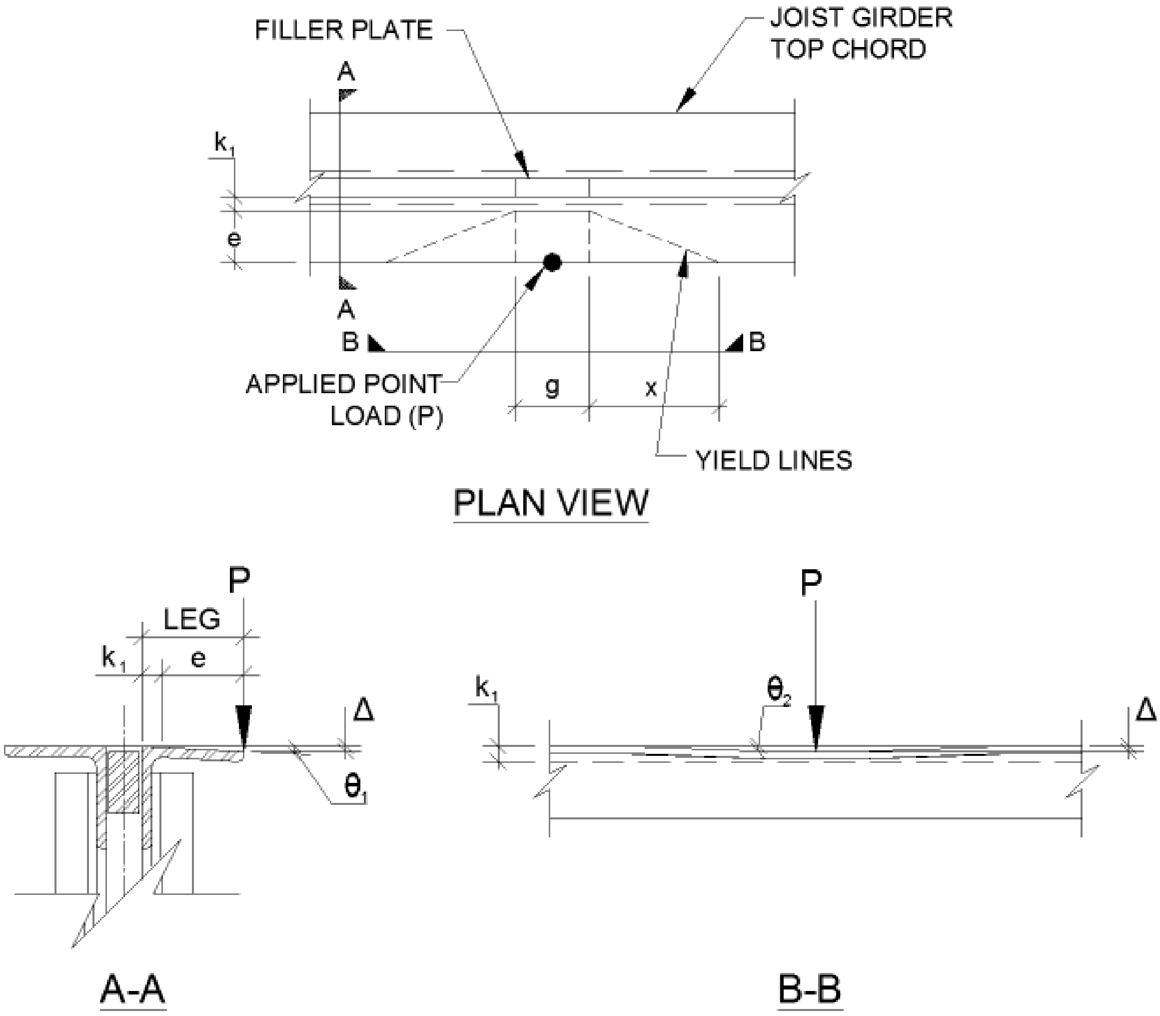

**Figure B.1 – Details for Derivation of Collapse Load**

Set internal work equal to external work. The internal work is equal to the plastic moment per unit length of yield line times the rotation at each yield line. The external work is simply the applied load times the deflection of the plate:

$\sum$ Internal Work = $\sum$ External Work

The rotations and moments acting on the diagonal yield lines are projected onto the parallel and perpendicular lines:

$$M_p\,[\theta_1\,(g + 2x) + \theta_2\,(4e)] = P * \Delta$$

Based on the geometry of the mechanism, it can be seen that:

$$\theta_1 = \frac{\Delta}{\mathbf{e}} \text{ and } \theta_2 = \frac{\Delta}{\mathbf{e}}$$

Using substitution and rearrangement of the variables results in the following equation for P:

$$M_p\left[\frac{\Delta}{\mathbf{e}}\,(g + 2x) + \frac{\Delta}{\mathbf{e}}(4e)\right] = P * \Delta$$

$$M_p\left[\frac{1}{\mathbf{e}}\,(g + 2x) + \frac{4\mathbf{e}}{\mathbf{x}}\right] - P = 0$$

Taking the partial derivative and setting it equal to zero provides the value for x corresponding to the least work solution:

$$\frac{\partial y}{\partial x} = 0$$

$$\left[\frac{2}{e} - \frac{4e}{x^2}\right] = 0 \text{ and } x = \sqrt{2} * e$$

The least work solution for x is substituted back into the equation for P and simplified:

$$M_p\left[\frac{1}{e} * (\,-g + 2\sqrt{2} * e) + \frac{4e}{\sqrt{2} * e}\right] = P$$

$$\frac{M_p}{e}\left[g + 2\sqrt{2} * e\ + 2\sqrt{2} * e\right] = P$$

$$\frac{M_p}{e}\left[g + 4\sqrt{2} * e\right] = P$$

$$\frac{M_p}{e}\ (g + 5.66 * e)\ = P$$

Where:

*P = Joist end reaction* *(kips)*

*$M_p$ = The plastic moment* *(in - kips)*

*e = Eccentricity of bearing reaction* *(inch)*

*g = Width of bearing seat plate* *(inch)*

## APPENDIX C: Flush Seat on HSS

While standard seats are encouraged for E-Series joists supported by cold-formed wall studs (CFS), occasional projects arise where flush seats bear on CFS. In those instances it quite common for a steel load distribution member to be placed between the joist seat and CFS to distribute the concentrated joist reactions. Either steel angles or HSS as shown in Figure 5.1 typically act as the steel load distribution member.

When designing a flush seat supported by a HSS, special consideration needs to be given to the increased unsupported gap length, ”L”, and additional eccentricity induced into the end of the joist.

A HSS having a 5/8 inch wall thickness will have an outside tube radius of 2.25t = 2.25 x 0.625 inches = 1.41 inches. With a typical horizontal gap between the vertical face of the tube and outside face of the vertical flush seat plate of 3/4 inch (assumed 1/2” gap +1/8” joist fabrication length + 1/8” CFS wall panel vertical alignment) the below gap length is determined:

Gap length, L = 1.41 inches + 0.75 inches = 2.16 inches

It should be noted that there is no testing with flush seats having gap lengths greater than 1.5 inches. As the gap length is increased, for example, from 3/4 inch to 1.5 inches, significant reductions in the capacity of the flush seats were noted. It is suggested that one utilize increased conservatism for any gap lengths exceeding 3/4 inch.

The horizontal plate bears on the flat portion of the HSS a minimum of 2.5 inches as suggested by Section 3.2 and that the centroid of the joist web intersects the centroid of the joist top chord 2 inches from the end of the joist top chord, the below joist eccentricity is determined:

Total joist eccentricity, $e_{joist}$ = 1.25 +2.16 + 0.25 + 0.25 +2 = 5.91 inches

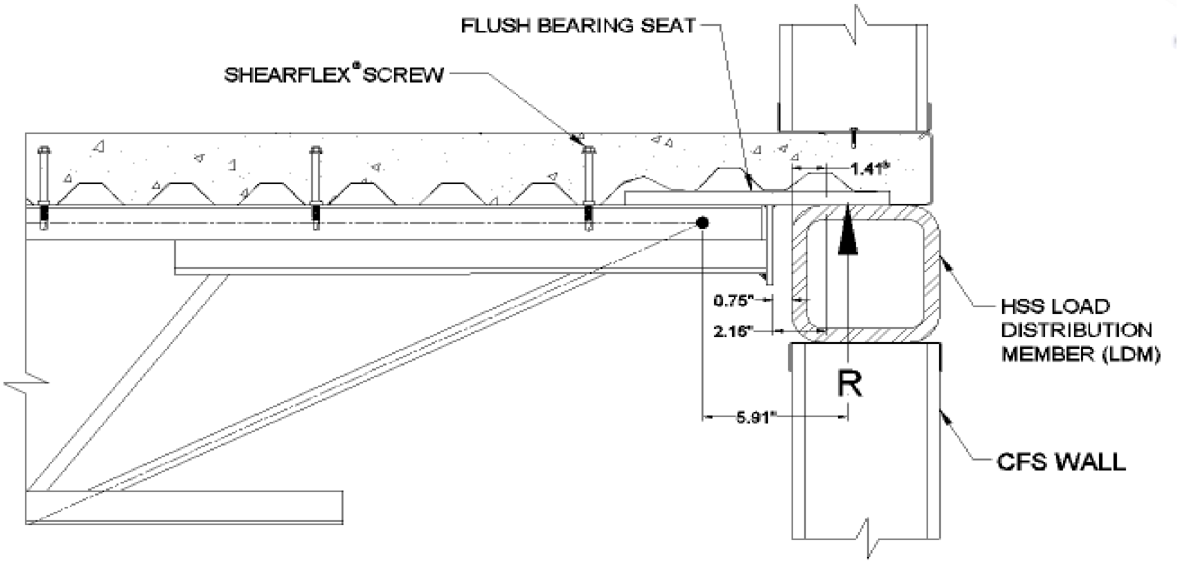

Figure C.1 – Flush Seat to Cold Formed Steel with HSS LDM

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## APPENDIX D: References

Dranger, Thomas S., (1977), “Yield Line Analysis of Bolted Hanging Connections”, Engineering Journal/American Institute of Steel Construction, Third Quarter, pp 92-97.

Galambos, Theodore V., (2001), “The Performance and Design Checking of Chord-Angle Legs in Joist Girders”, Engineering Journal, Third Quarter, pp 119-126.

ASTM D7147, “Standard Specification for Testing and Establishing Allowable Loads of Joist Hangers”.

AISC - Manual of Steel Construction, 14th Edition, American Institute of Steel Construction, 2012

SJI - Standard Specifications for Open Web Steel Joists, K-Series, American National Standard SJI-K-1.1, Steel Joist Institute, 2010

SJI - Standard Specifications for Longspan Steel Joists, LH-Series and Deep Longspan Steel Joists, DLH-Series, American National Standard SJI-LH/DLH-1.1, Steel Joist Institute, 2010

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