

Vibration of Vulcraft Steel Joists with Flush Framed and Flush Bearing Seat Connections

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Introduction

The type of the steel joist end connection to a girder (hot-rolled section, built-up section, or conventionally fabricated truss) or a Joist Girder can significantly affect the natural frequency and the effective mass of floor framing systems associated with motion caused by walking, commonly called vibration. The purpose of this white paper is to explain the different effects on the natural frequency and effective mass for steel joists with traditional and flush framed connections. The manual calculation procedures in the AISC Design Guide 11, 2nd Ed. *Vibrations of Steel-Framed Structural Systems Due to Human Activity*, hereafter referred to as AISC DG11, 2nd Ed. and the Steel Joist Institute Technical Digest 5 *Vibration of Steel Joist – Concrete Slab Floors*, hereafter referred to as SJI TD5, are the basis for showing the differing effects of steel joist end connection configurations.

Where flush framed steel joist connections are used, the steel deck is directly in contact with and attached to the girder. This results in the girder acting in a fully composite condition when subjected to vibrational excitation. This member-to-slab connection is also identical to the connection in systems with W-shape beams and girders. Consequently, where steel joists are used with flush framed end connections, vibration behaviors are the same as for W-shape beam and girder systems.

Recommended methods for computing the girder or Joist Girder natural frequency, f_g , and effective joist panel weights, W_j , for typical beam-to-girder, flush framed steel joist-to-girder, and Ecospan® flush bearing seat-to-girder connections are described in the following sections.

Typical Girder Connections

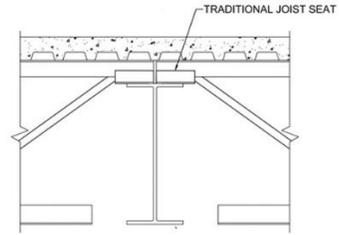
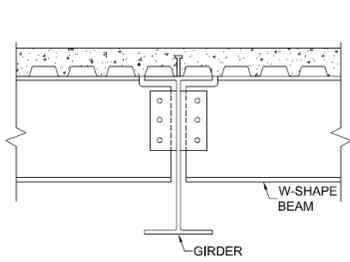
This paper discusses six types of flush framed connections between joists and beams supported by Joist Girders or girders.

Figure 1(a) shows a typical beam to girder web connection and Figure 1(b) shows a traditional joist seat to a girder connection, which may have an optional extended bottom chord connection. There are provisions in AISC DG11, 2nd Ed. for predicting the natural frequency and effective weight associated with floor acceleration due to walking for these connection types. Identical provisions for the joist seat connections are found in SJI TD5.

Figures 2 and 3 show typical flush framed joist connections to a girder and Joist Girder, respectively. Figures 4 and 5 show typical Ecospan® flush bearing seat connection to a girder and Joist Girder, respectively. The flush bearing seat connection can be used for relatively small end reactions. None of the connections shown in Figures 2 through 5 are explicitly covered in AISC DG11, 2nd Ed. or SJI TD5.

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(a) Typical Beam-to-Girder Web Connection

(b) Traditional Joist Seat-to-Girder Flange Connection

Figure 1. Typical Beam and Joist Connections to Girders

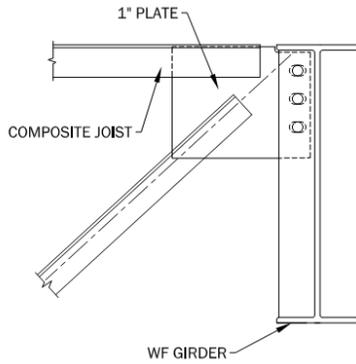


Figure 2. Flush Frame Joist-to-Girder Connection

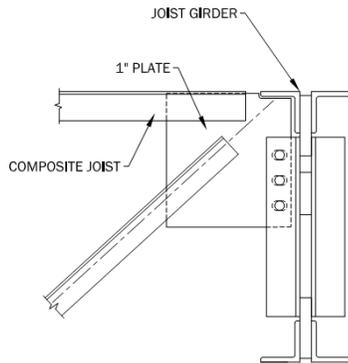


Figure 3. Flush Frame Joist-to-Joist Girder Connection



Figure 4. Ecospan® Flush Bearing Seat-to-Girder Connection



Figure 5. Ecospan® Flush Bearing Seat-to-Joist Girder Connection

Overview of AISC DG 11, 2nd Edition

Following is an overview of the applicable provisions in AISC DG11, 2nd Ed. and summaries of how these provisions apply or can be applied to the connections shown in Figures 1 through 5.

Frequency

Girder or Joist Girder natural frequency is estimated using the fundamental natural frequency equation of a simply supported beam with uniform mass:

$$f_n = \frac{\pi}{2} \left[\frac{gE_s I_t}{wL^4} \right]^{1/2} \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 3-1})$$

where

- f_n = fundamental natural frequency, Hz
- g = acceleration of gravity, 386 in./sec.²
- E_s = modulus of elasticity of steel, 29,000 ksi
- I_t = transformed moment of inertia; effective transformed moment of inertia if shear deformation is included; reduced transformed moment of inertia to account for joist seat flexibility, in.⁴
- w = uniformly distributed weight per unit length (actual, not design, dead and live loads) supported by the member, kip/in.
- L = member span, in.

AISC DG11, 2nd Ed., Eqn. (3-1) can be rewritten as

$$f_n = 0.18 \sqrt{\frac{g}{\Delta}} \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 3-3})$$

where

Δ = mid-span deflection of the member relative to its supports due to the supported weight, that is,

$$\Delta = 5wL^4 / (384E_s I_t), \text{ in.}$$

Human-induced loads typically cause mid-bay displacement amplitudes smaller than 0.01 in., implying very low horizontal shear force between the steel framing members and the slab. When the deck is in direct contact with the top of the member, deck fasteners, including spot welds and screws, provide enough slip resistance to warrant using the full composite transformed moment of inertia in vibration analyses. Members with physical separations between the member and the slab, e.g., a girder or Joist Girder supporting open-web steel joists with traditional seats, behave as partially composite members with an effective moment of inertia somewhat-to-significantly less than the full composite moment of inertia of the girder or Joist Girder.

Traditional joists seats fall into the second category, so the effective moment of inertia of Joist Girders supporting traditional joist seats is estimated using

$$I_g = C_r I_{chords} + \frac{I_e - C_r I_{chords}}{4} \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 3-10})$$

where

C_r = coefficient from AISC DG11, 2nd Ed., Eqn. 3-9a or 3-9b shown below

I_{chords} = moment of inertia of the chord areas, in.⁴

I_e = effective composite moment of inertia from AISC DG11, 2nd Ed., Eqn. (3-7), in.⁴ shown below

For joists or Joist Girders with single – or double angle web members with $6 \leq L/D$

$$C_r = 0.90 \left(1 - e^{-0.28 \left(\frac{L}{D} \right)^{2.8}} \right) \leq 0.90 \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 3-9a})$$

For joists with continuous round web members with $10 \leq L/D$

$$C_r = 0.721 + 0.00725 \left(\frac{L}{D} \right) \leq 0.9 \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn 3-9b})$$

where

D = nominal depth of joist or Joist Girder, in.

L = joist or Joist Girder span, in.

$$I_e = \frac{1}{\frac{\gamma}{I_{chords}} + \frac{1}{I_{comp}}} \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn 3-7})$$

where

I_{chords} = moment of inertia of the chord areas, in.⁴

I_{comp} = fully composite moment of inertia of the slab and girder areas, in.⁴

and

$$\gamma = \frac{1}{C_r} - 1 \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn 3-8})$$

Similarly, the effective moment of inertia of hot-rolled or built-up girders supporting traditional joist seats is estimated using

$$I_g = I_x + \frac{I_{comp} - I_x}{4} \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 3-11})$$

where

I_x = moment of inertia of the girder, in.⁴

I_{comp} = fully composite moment of inertia of the slab and girder areas, in.⁴

Effective Weight

The recommended criterion for low frequency building floors in AISC DG11, 2nd Ed., states that the floor system is satisfactory if the peak acceleration, a_p , due to walking excitation as a fraction of the acceleration of gravity, g , determined from

$$\frac{a_p}{g} = \frac{P_o e^{-0.35 f_n}}{\beta W} \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 4-1})$$

does not exceed the tolerance acceleration limit, a_o/g , shown in Table 4-1 for the appropriate occupancy, where

P_o = amplitude of the driving force, 65 lb

f_n = fundamental natural frequency of a beam or joist panel, a girder panel, or a combined panel, as applicable, Hz

β = damping ratio

W = effective weight supported by the beam or joist panel, girder panel or combined panel, as applicable, lb

From AISC DG11, 2nd Ed., the effective panel weight is estimated by determining the effective panel weights for the beam or joist panel (W_j) and girder panel (W_g) modes separately and then combining them in proportion to their flexibilities. The effective panel weights for the beam or joist and girder panel modes are estimated from

$$W = wBL \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 4-2})$$

where

w = supported weight per unit area, psf

L = member span, ft

B = effective panel width, ft

For the beam or joist panel mode, the effective width is

$$B_j = C_j (D_s / D_j)^{1/4} L_j \leq 2/3 \times \text{Floor Width} \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 4-3})$$

where

- C_j = 2.0 for joists or beams in most areas
= 1.0 for joists or beams parallel to a free edge (edge of balcony, mezzanine, or building edge if cladding is not connected)
- D_s = slab transformed moment of inertia per unit width, in.⁴/ft
= approximately $12d_e^3 / (12n)$ in.⁴/ft, or from a deck manufacturer's catalog
- d_e = effective depth of the concrete slab, taken as the depth of the concrete above the deck plus one-half the depth of the deck, in.
- n = dynamic modular ratio
= $E_s / 1.35E_c$
- E_s = modulus of elasticity of steel, 29,000 ksi
- E_c = modulus of elasticity of concrete, ksi
- D_j = joist or beam transformed moment of inertia per unit width, I_j / S , in.⁴/ft
- I_j = transformed or effective moment of inertia of the beam or joist, in.⁴
- S = joist or beam spacing, ft
- L_j = joist or beam span, ft

Floor width is the distance perpendicular to the span of the beams or joists in the bay under consideration over which the structural framing (beam or joist and girder size, spacing, length, etc.) is identical or nearly identical in adjacent bays.

For the girder panel mode, the effective width, except for edge girders, is

$$B_g = C_g (D_j / D_g)^{1/4} L_g \leq 2/3 \times \text{Floor Length} \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 4-4})$$

where

- C_g = 1.6 for girders supporting joists connected to the girder flange with joist seats
= 1.8 for girders supporting beams connected to the girder web
- D_g = girder transformed moment of inertia per unit width
= I_g divided by the average span of the supported beams or joists, in.⁴/ft
- I_g = transformed moment of inertia of the girder
- L_g = girder span, ft

Floor length is the distance perpendicular to the span of the girders in the bay under consideration over which the structural framing (beam or joist and girder size, spacing, length, etc.) is identical or nearly identical in adjacent bays.

Where beams, joists or girders are continuous over their supports and an adjacent span is greater than 0.7 times the span under consideration, the effective panel weight, W_j or W_g , can be increased by 50%. This liberalization also applies to rolled sections shear-connected to girder webs, but not to joists connected only at their top chord. When joist bottom chord extensions are installed and connected before concrete is placed, the effective weight of the joist mode can be increased by 30%. Since continuity effects are not generally realized when girders frame directly into columns, either shear or moment connected, this increase does not apply to such girders. If the girder passes over a column top, the increase is applicable.

For the combined mode, the effective panel weight is estimated using

$$W = \frac{D_j}{D_j + D_g} W_j + \frac{D_g}{D_j + D_g} W_g \quad (\text{AISC DG11, 2}^{\text{nd}} \text{ Ed., Eqn. 4-5})$$

where

- Δ_j and Δ_g = mid-span deflections of the beam or joist and girder, respectively, due to the weight supported by the member, in.
- W_j and W_g = effective panel weights from AISC DG11, 2nd Ed., Eqn. (4-2) shown above for the beam or joist and girder panels, respectively, lb

Beam to Girder Web Connection

The beam-to-girder web connection, shown in Figure 1(a) is the basic connection in AISC DG11, 2nd Ed. For this connection:

- The girder is considered to be fully composite because the deck-to-girder top flange connection at the steel deck-to-top beam flange interface provides adequate resistance to the horizontal shear force shown in Figure 6. The connection can be puddle welds, ShearFlex[®] screws or standard steel studs.
- $C_g = 1.8$ when determining the girder panel mode effective width using AISC DG11, 2nd Ed., Eqn. 4-4 shown above.
- If an adjacent beam or joist span is greater than 0.7 times the span, effective joist panel weight, W_j , from AISC DG11, 2nd Ed., Eqn. (4-2) shown above can be increased 50%.

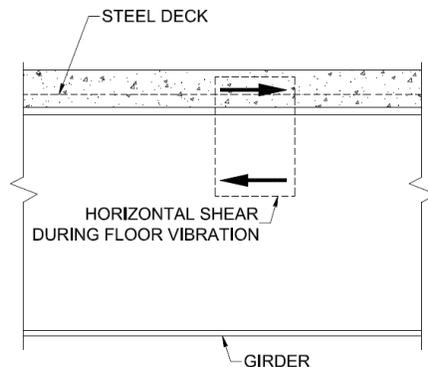


Figure 6. Horizontal Shear Force at Deck-to-Girder Flange

Traditional Seated Connection of Steel Joists to a Girder or Joist Girder

Figure 1(b) shows the traditional open web joist to girder connection in which the joist is supported by a seat on the girder top flange. As shown in Figure 7, this support detail provides much less horizontal shear continuity than if the

slab is directly connected to the top flange. If bottom chord extensions are not installed, due to the lack of flexural continuity between the joists in adjacent bays, there is no participation of the mass of adjacent bays in resisting walker-induced vibration.

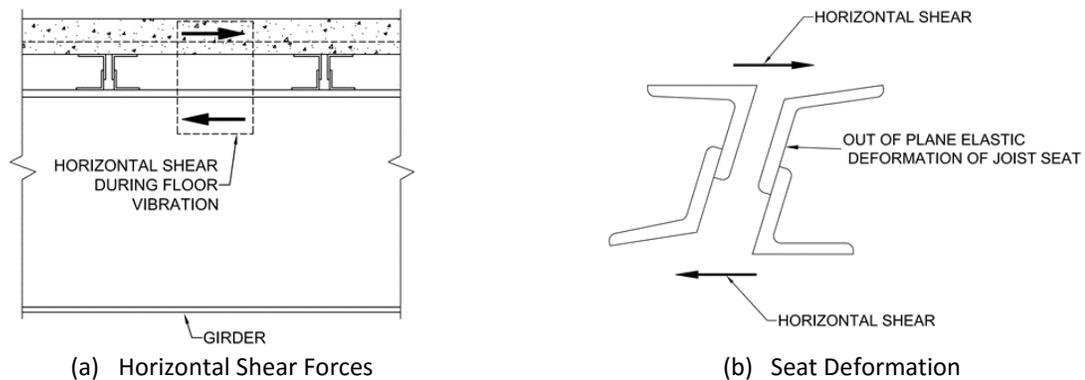


Figure 7. Traditional Joist Seat Connection Deformation

These effects are accounted for as follows:

1. The separation of the concrete slab and the girder top flange or Joist Girder top chord results in partial composite action and the moment of inertia of the girder of Joist Girder supporting joist seats is determined using AISC DG11, 2nd Ed., Eqn. 3-10 or Eqn. 3-11 as shown above, respectively. The primary result is a reduction in the natural frequency of the girder mode.
2. The reduced bending stiffness requires that the coefficient $C_g = 1.8$ in AISC DG11, 2nd Ed., Eqn. 4-4 shown above, be reduced to 1.6 when traditional joist seats are present, resulting in a slight reduction in the girder mode effective weight, W_g .
3. The non-participation of mass in adjacent bays means that an increase in effective joist panel weight, W_j , is not considered, that is, the 50% increase in joist panel weight, as recommended for shear-connected beam-to-girder connections in AISC DG11, 2nd Ed., Section 4.1.2 shown above, is not applicable.
4. If the bottom chord extensions are installed and connected before the concrete slab is placed and if an adjacent joist span is greater than 0.7 times the joist span, the effective joist panel weight, W_j from AISC DG11, 2nd Ed., Eqn. 4-2 shown above can be increased 30% as stated in AISC DG11, 2nd Ed., Section 4.1.2.

Flush Frame Steel Joist to Girder Connection

The flush frame steel joist to girder connection shown in Figure 2 is equivalent to the typical beam-to-girder web connection shown in Figure 1(a). For this connection:

- The girder is considered to be fully composite.
- $C_g = 1.8$ when determining the girder panel mode effective width using AISC DG11, 2nd Ed., Eqn. 4-4.
- If an adjacent joist span is greater than 0.7 times the joist span, the effective joist panel weight W_j from AISC DG11, 2nd Ed., Eqn. 4-2 can be increased 50%, even if the joist bottom chords have not been extended.

Flush Framed Steel Joist to Joist Girder Connection

The flush frame steel joist to Joist Girder connection shown in Figure 3 is equivalent to the typical beam-to-girder web connection shown in Figure 1(a). For this connection:

- The Joist Girder is considered to be fully composite.
- $C_g = 1.8$ when determining the girder panel mode effective width using AISC DG11, 2nd Ed., Eqn. 4-4.
- If an adjacent joist span is greater than 0.7 times the joist span, the effective joist panel weight W_j from AISC DG11, 2nd Ed., Eqn. 4-2 can be increased 50%, even if the joist bottom chords have not been extended.

Ecospan® Flush Bearing Seat to a Girder or to a Joist Girder Connection

For the Ecospan® flush bearing seat connection to a girder or Joist Girder shown in Figures 4 and 5:

- The girder or Joist-Girder is considered to be fully composite because the slab is directly connected to the top flange or top chord.
- Because of the lack of flexural stiffness of the joist-to-girder or Joist Girder connection, $C_g = 1.6$ when determining the girder panel mode effective width using AISC DG11, 2nd Ed., Eqn. 4-4 shown above.
- The 50% increase in joist panel weight, as recommended for shear-connected beam-to-girder web connections in AISC DG11, 2nd Ed., Section 4.1.2, is not applicable because there is no rotational connection to the girder or Joist Girder.
- If the bottom chord extensions are installed and connected before the concrete slab is placed and if an adjacent joist span is greater than 0.7 times the joist span, the effective joist panel weight, W_j from AISC DG11, 2nd Ed., Eqn. 4-2 shown above can be increased 30% as stated in AISC DG11, 2nd Ed., Section 4.1.2.

Summary

AISC DG11, 2nd Ed. has provisions for predicting the natural frequency and effective panel weight for floors with beam-to-girder web connections. Both AISC DG11, 2nd Ed. and SJI TD5 contain provisions for predicting the natural frequency and effective panel weight for floor framing with traditional seated joist to girder or Joist Girder connections.

For the flush framed joist connection, the floor slab is in contact with the top chord of the girder or Joist Girder, therefore the girder or Joist Girder can be considered fully composite. This is identical to what occurs with a beam-to-girder web connection as noted in AISC DG 11 2nd Ed. and SJI TD5. Also, because of the rotational restraint provided by the flush framed joist connection, the provisions for determining the effective joist panel weight used for the beam-to-girder web connection apply as well.

When the Ecospan® flush bearing seat-to-girder or Joist Girder is used, the fully composite girder or Joist Girder behavior is also valid. However, the effective panel weight cannot be increased because of the lack of rotation strength at the connection unless extended bottom chords are installed before the slab concrete is placed. Because the Ecospan® connection is only to the top of the girder or Joist Girder, C_g is taken as 1.6.