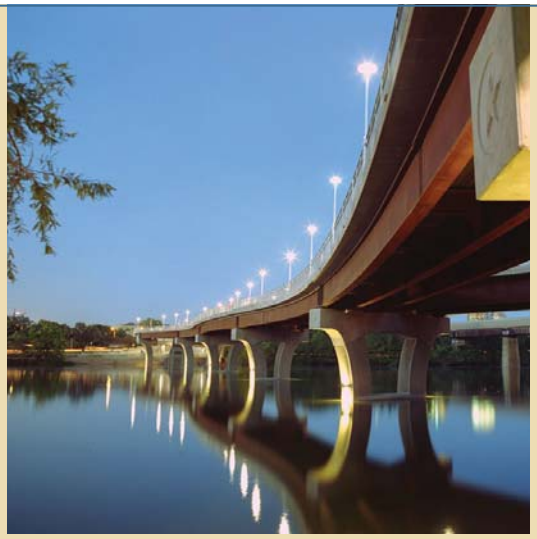
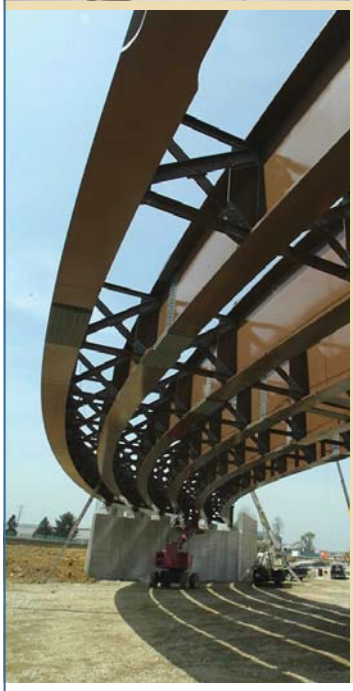








U.S. Department of Transportation
Federal Highway Administration



Steel Bridge Design Handbook

Design Example 3: Three-Span Continuous Horizontally Curved Composite Steel I-Girder Bridge

Publication No. FHWA-HIF-16-002 - Vol. 23

December 2015



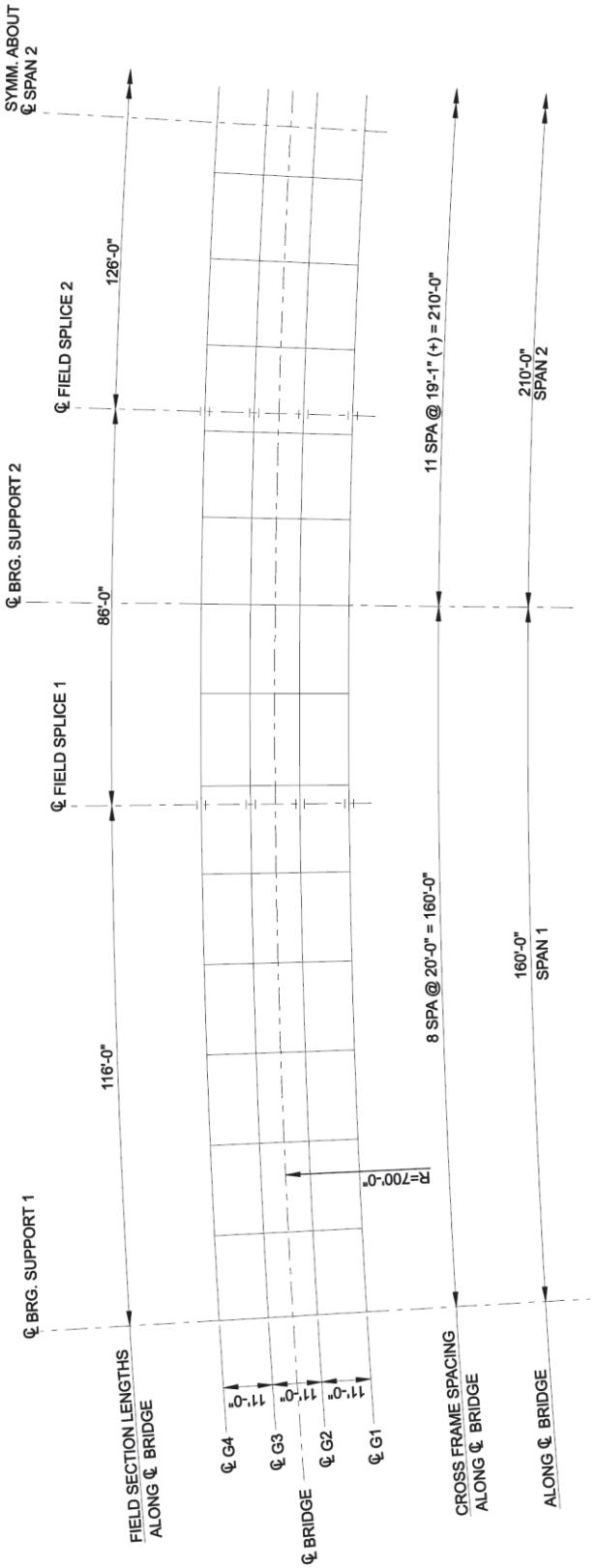


Figure 2: Framing Plan

$$Q_r = \phi_{sc} Q_n \qquad \text{Eq. (6.10.10.4.1-1)}$$

where: Q_n = nominal shear resistance of a single shear connector determined as specified in Article 6.10.10.4.3 (kips)
ϕ_{sc} = resistance factor for shear connectors specified in Article 6.5.4.2

Shear connectors that are 6 in. long by 7/8 in. diameter are selected for design. Compute the nominal resistance of one shear connector embedded in the concrete deck using Article 6.10.10.4.3.

$$Q_n = 0.5 A_{sc} \sqrt{f'_c E_c} \le A_{sc} F_u \qquad \text{Eq. (6.10.10.4.3-1)}$$

where: A_{sc} = cross-sectional area of a stud shear connector
E_c = modulus of elasticity of the deck concrete = 3,834 ksi (calculated previously)
F_u = specified minimum tensile strength of a stud shear connector determined as specified in Article 6.4.4 (ksi)

$$A_{sc} = \frac{\pi(0.875)^2}{4} = 0.60 \text{ in.}^2$$

$$Q_n = 0.5(0.60)\sqrt{(4)(3{,}834)} = 37.2 \text{ kips}$$

$$A_{sc} F_u = 0.60(60) = 36 \text{ kips} \quad \text{(controls)}$$

Therefore, use Q_n = 36 kips.

Compute the nominal shear force, P, according to the provisions of Article 6.10.10.4.2. For the shear connector design, Span 1 is divided into two regions: 1) the portion between the end of the span and the location of maximum positive live load moment and 2) the portion between the maximum positive live load moment and the adjacent interior support.

7.14.1.1 End of Span to Maximum Positive Moment Location

Between the end of Span 1 and the location of maximum positive live load plus impact moment, Eq. (6.10.10.4.2-1) is applicable. For this portion of Span 1, the total nominal shear force and required pitch are computed in the following calculations.

The total nominal shear force in this portion of the span is computed as follows:

$$P = \sqrt{P_p^{\,2} + F_p^{\,2}} \qquad \text{Eq. (6.10.10.4.2-1)}$$

where: P_p = total longitudinal force in the concrete deck at the point of maximum positive live load plus impact moment (kips) taken as the lesser of either:

$$P_{1p} = 0.85f'_c\, b_s t_s \qquad \text{Eq. (6.10.10.4.2-2)}$$

or

$$P_{2p} = F_{yw} D t_w + F_{yt} b_{ft} t_{ft} + F_{yc} b_{fc} t_{fc} \qquad \text{Eq. (6.10.10.4.2-3)}$$

F_p = total radial force in the concrete deck at the point of maximum positive live load plus impact moment (kips) taken as:

$$F_p = P_p \frac{L_p}{R} \qquad \text{Eq. (6.10.10.4.2-4)}$$

b_s = effective width of the concrete deck (in.)
L_p = arc length between an end of the girder and an adjacent point of maximum positive live load plus impact moment (ft)
R = minimum girder radius over the length, L_p (ft)

The effective width of the concrete deck, b_s, is calculated according to Article 4.6.2.6.1 for an exterior girder, calculated previously as 111 in. Conservatively, since G4 is an exterior girder with an overhang less than half of the girder spacing, the width of the deck could have been assumed to be equal to the interior girder effective width so that all girders would have the same stud spacing. That approach is not taken here.

$$P_{1p} = 0.85(4)(111)(9) = 3{,}397 \text{ kips}$$

$$P_{2p} = 50(84)(0.5625) + 50(21)(1.5) + 50(20)(1.0) = 4{,}938 \text{ kips}$$

The total longitudinal force in the deck, P_p, is the lesser of P_{1p} or P_{2p}; therefore, P_p is taken to be 3,397 kips.

The arc length, L_p, between the end of the girder and the point of maximum positive live load plus impact moment is 73 feet. The total radial shear force in the concrete deck, F_p, at the point of maximum positive live load plus impact moment is computed as follows.

$$F_p = (3{,}397)\left(\frac{73}{716.5}\right) = 346.1 \text{ kips}$$

Therefore, the total nominal shear force in this portion of the span is:

$$P = \sqrt{3{,}397^2 + 346.1^2} = 3{,}415 \text{ kips}$$

The minimum number of shear connectors, n, over the region under consideration is taken as:

$$n = \frac{P}{Q_r} = \frac{P}{\phi_{sc} Q_n} \qquad \text{Eq. (6.10.10.4.1-2)}$$

$$n = \frac{3{,}415}{0.85(36)} = 112$$

Compute the required pitch, p, with 3 studs per row.

$$\text{No. of rows} = \frac{112}{3} = 37.3\text{, say 38 rows}$$

$$p = \frac{73(12)}{(38-1)} = 23.7 \text{ in.}$$

The shear connector pitch for strength is less critical than for fatigue in this region, which is demonstrated later in this example.

7.14.1.2 Maximum Positive Moment Location to Adjacent Interior Support

Between the location of maximum positive live load plus impact moment and the adjacent interior support, Eq. (6.10.10.4.2-5) is applicable. For this portion of Span 1, the total nominal shear force and required pitch are computed in the following calculations.

The total nominal shear force in this portion of the span is computed as follows:

$$P = \sqrt{P_T^{\,2} + F_T^{\,2}} \qquad \text{Eq. (6.10.10.4.2-5)}$$

where: P_T = total longitudinal force in the concrete deck between the point of maximum positive live load plus impact moment and the centerline of an adjacent interior support (kips) taken as:

$$P_T = P_p + P_n \qquad \text{Eq. (6.10.10.4.2-6)}$$

P_n = total longitudinal force in the concrete deck over an interior support (kips) taken as the lesser of either:

$$P_{ln} = F_{yw} D t_w + F_{yt} b_{ft} t_{ft} + F_{yc} b_{fc} t_{fc} \qquad \text{Eq. (6.10.10.4.2-7)}$$

or

$$P_{2n} = 0.45 f'_c\, b_s t_s \qquad \text{Eq. (6.10.10.4.2-8)}$$

F_T = total radial force in the concrete deck between the point of maximum positive live

load plus impact moment and the centerline of an adjacent interior support (kips) taken as:

$$F_T = P_T \frac{L_n}{R} \qquad \text{Eq. (6.10.10.4.2-9)}$$

L_n = arc length between the point of maximum positive live load plus impact moment and the centerline of an adjacent interior support (ft)
R = minimum girder radius over the length, L_n (ft)

The following two terms were computed previously and are applicable here as well:

$P_p = 3{,}397$ kips

$b_s = 111$ in.

Using the plate girder dimensions at Support 2 (Field Section 2), compute P_{1n} as follows:

$$P_{1n} = 50(84)(0.625) + 50(28)(2.5) + 50(27)(3) = 10{,}175 \text{ kips}$$

$$P_{2n} = 0.45(4)(111)(9) = 1{,}798 \text{ kips}$$

The total longitudinal force in the deck over the interior support, P_n, is the lesser of P_{1n} or P_{2n}; therefore, P_n is taken to be 1,798 kips.

Therefore, the total longitudinal force in the concrete deck in the region under consideration is:

$$P_T = 3{,}397 + 1{,}798 = 5{,}195 \text{ kips}$$

Next, compute the arc length, L_n, and the total radial force in the concrete deck, F_T, in the region under consideration. The total arc length along girder G4 in Span 1 is 163.8 ft.

$$L_n = 163.8 - 73 = 90.8 \text{ ft}$$

$$F_T = 5{,}195\left(\frac{90.8}{716.5}\right) = 658 \text{ kips}$$

The total nominal shear force in this portion of the span is:

$$P = \sqrt{5{,}195^2 + 658^2} = 5{,}237 \text{ kips}$$

The minimum number of shear connectors, n, over the region under consideration is taken as:

$$n = \frac{P}{Q_r} = \frac{P}{\phi_{sc} Q_n} \qquad \text{Eq. (6.10.10.4.1-2)}$$

$$n = \frac{5{,}237}{0.85(36)} = 171.1, \text{ say } 172$$

Compute the required pitch, p, with 3 studs per row.

$$\text{No. of rows} = \frac{172}{3} = 57.3, \text{ say 58 rows}$$

$$p = \frac{90.8(12)}{(58-1)} = 19.1 \text{ in.}$$

The shear connector pitch for strength is less critical than for fatigue in this region, which is demonstrated later in this example.

7.14.2 Shear Connector Design for Fatigue – Girder G4, Span 1

To demonstrate the fatigue requirements for shear connectors, fatigue will be checked at the maximum positive moment location and at the first interior support (Support 2).

7.14.2.1 Maximum Positive Moment Location

Determine the required pitch of the shear connectors for fatigue at this section according to the provisions of Article 6.10.10.1.2. The pitch, p, of shear connectors must satisfy the following:

$$p \le \frac{nZ_r}{V_{sr}} \qquad \text{Eq. (6.10.10.1.2-1)}$$

where: n = number of shear connectors in a cross-section
Z_r = shear fatigue resistance of an individual shear connector determined as specified in Article 6.10.10.2 (kips)
V_{sr} = horizontal fatigue shear range per unit length (kips/in.)

The 75-year single lane Average Daily Truck Traffic $(ADDTT)_{SL}$ is assumed to be 1,000 trucks per day. Where the projected 75-year $(ADDT)_{SL}$ is greater than or equal to 960 trucks per day, the fatigue resistance for an individual stud shear connector, Z_r, is defined in Article 6.10.10.2 as follows:

$$Z_r = 5.5d^2 \qquad \text{Eq. (6.10.10.2-1)}$$