Appendix D Example 31 – Falsework Removal with Winches

This example shows the typical review items for falsework removal with winches. These items include: static stability – winch overturning & sliding, and deck stress analysis. The internal workings of the winch are not reviewed here. It is assumed that the weight of the falsework being removed has been previously calculated.

Winches are typically laid perpendicular to the bridge centerline (not always though, sometimes other configurations are required to accommodate various geometry) and can be supported with one, two, three, or more supports.

Given Information

This example uses a two-support winch as shown here:

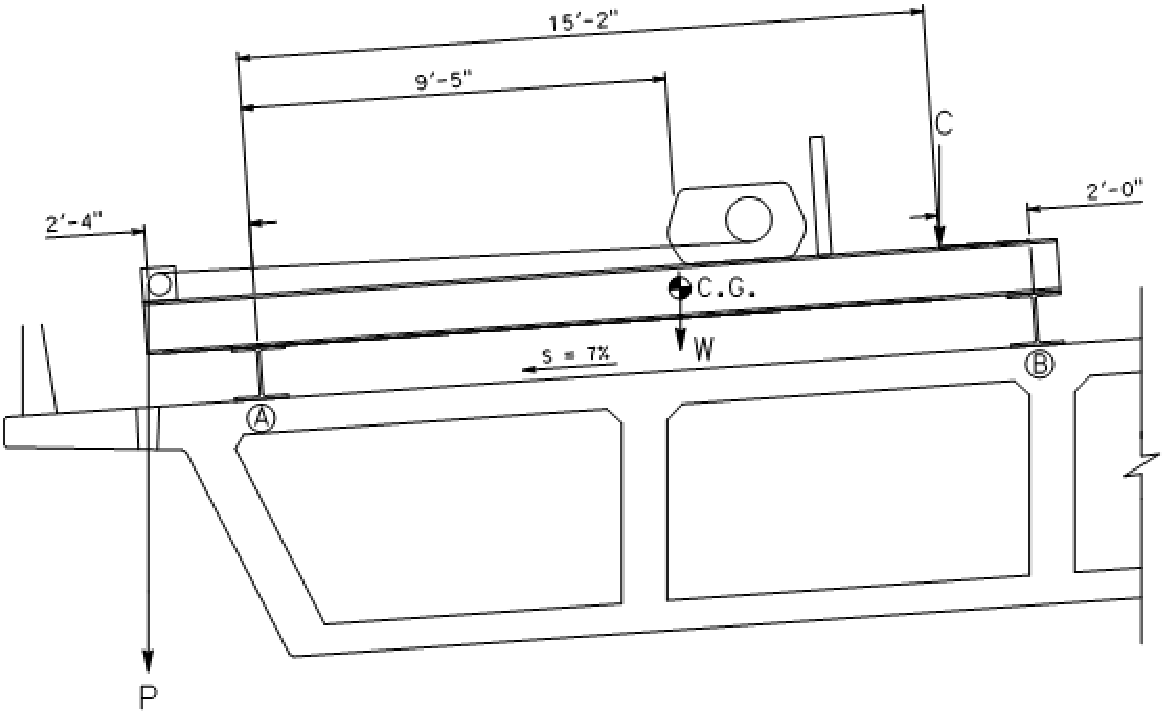

Figure D-31-1. Typical Winch with Two Supports.

Where $\mathrm{P} = \text{design load supported by the winch}$

$\mathrm{W} = \text{weight of winch through the center of gravity}$

$$\mathrm{C = weight\ of\ counterweights}$$

The dimensions and winch weights (C and W) must be provided by the contractor with the submittal. The design load, P, is the weight of the falsework being supported and must be calculated independently by the reviewer for the worst case scenario. For this example the following values are given for the analysis:

$\mathrm{P = 32\ kips}$

$\mathrm{W = 5{,}000\ lbs = 5.0\ kips}$

$\mathrm{For\ C, use\ three\ 4' \ x\ 4' \ x\ 1' reinforced\ concrete\ deadmen\ (\gamma_{concrete} = 150\ pcf)}$

$$\mathrm{C = 3\ (4\ ft * 4\ ft * 1\ ft)(150\ pcf) = 3\ (16\ ft^3)(150\ pcf) = 7{,}200\ lbs}$$

$$\mathrm{C = 7.2\ kips}$$

Check Overturning

The *2018 Standard Specifications,* Section 48-2.02B(1), *Falsework – Materials – Design Criteria – General,* requires that the load used for analysis of the overturning moment and sliding of the winch system must be 150% of the design load (Note: Cross slope is ignored for moment calculations since there is minimal influence on the moments in this example).

$$\mathrm{Analysis\ load = 1.5 * P = 1.5 * 32\ kips = 48\ kips}$$

Estimate overturning moment $\mathrm{M_{OT}}$:

$$\mathrm{M_{OT} = (48\ kips)(2.33\ ft)\ \approx 112^{ft-kip}}$$

Note: The moment is taken at support A in Figure 1 since this is the point of rotation for the winch system.

Estimate the resisting moment $\mathrm{M_r}$:

$$\mathrm{M_r = (5.0\ kips)(9.42\ ft) + (7.2\ kips)(15.17\ ft) \approx 156^{ft-kip}}$$

Check demand vs. capacity:

$$\mathrm{M_{OT}\ \le M_r\ \Rightarrow\ 112\ kip \cdot ft\ < 156^{ft-kip}} \qquad \mathbf{OK}$$

$$\frac{\mathrm{Demand}}{\mathrm{Capacity}} = \frac{\mathrm{M_{OT}}}{\mathrm{M_r}} = \frac{112^{\mathrm{ft-kip}}}{156^{\mathrm{ft-kip}}} \approx 0.72 \le 1.00 \qquad \mathbf{OK}$$

Check Sliding

As with overturning, sliding requires the load for analysis to be increased by 150% per the *2018 Standard Specifications.*

First, determine the driving force for the sliding, $\mathrm{f_s}$:

$$\mathrm{f_s = (1.5P + W + C)\sin\theta, where\ \theta = \tan^{-1}\left(\frac{s}{100}\right) = \tan^{-1}\left(\frac{7}{100}\right) \approx 4^{\circ}}$$

$$\mathrm{f_s = (1.5 * 32\ kips + 5.0\ kips + 7.2\ kips)\sin(4) \approx 4\ kips}$$

The next step in checking the winch sliding is to determine the support reactions at supports A & B to find sliding resistance. Since the supports are where the resistance to sliding occurs, do not apply the 150% analysis increase. The reactions are:

$$\mathrm{R_A = \frac{\overbrace{(32\ kips)}^{P}(19.5\ ft) + \overbrace{(5.0\ kips)}^{W}(7.75\ ft) + \overbrace{(7.2\ kips)}^{C}(2\ ft)}{17.167\ ft}}$$

$$\mathrm{\approx 39\ kips}$$

$$\mathrm{R_B = 32\ kips + 5.0\ kips + 7.2\ kips - 39\ kips \approx 5.2\ kips}$$

The sliding resistance $\mathrm{F_r}$ is:

$$\mathrm{F_r = \mu \sum F_N = \mu(R_A + R_B)\cos\theta}$$

Where: $\mathrm{\mu = coefficient\ of\ friction\ from\ steel\ to\ concrete = 0.45}$

(Note: the coefficient of friction can be as low as 0.10 depending on the condition of the surfaces and the presence of water or lubricants so use caution in determining the coefficient of friction. 0.45 was used here as a typical coefficient of friction between dry, rough concrete and weathered steel.)

$$\mathrm{F_r = \mu(R_A + R_B)\cos\theta = 0.45(39\ kips + 5.2\ kips)\cos(4) \approx 19.8\ kips}$$

Check demand vs. capacity:

$$\mathbf{f_s \leq F_r \Rightarrow 4\ kips < 18\ kips \qquad OK}$$

$$\mathrm{\frac{Demand}{Capacity} = \frac{f_s}{F_r} = \frac{4\ kips}{19.8\ kips} \approx 0.20 \leq 1.00} \qquad \mathbf{OK}$$

Deck Stress Analysis

The bridge deck stress analysis is the next step in the review. The deck stress is reviewed for maximum moment and shear in the slab. Ideally, the winch supports would be placed directly on the girder lines, however this is rarely possible due to bridge geometry, falsework configuration, winch geometry, and skew. It is therefore necessary to examine the moment and shear at various locations to determine the maximum stress induced. Figure 2 shows a typical winch layout pattern with the winch supports on and adjacent to the girder lines as well as in between the girders.

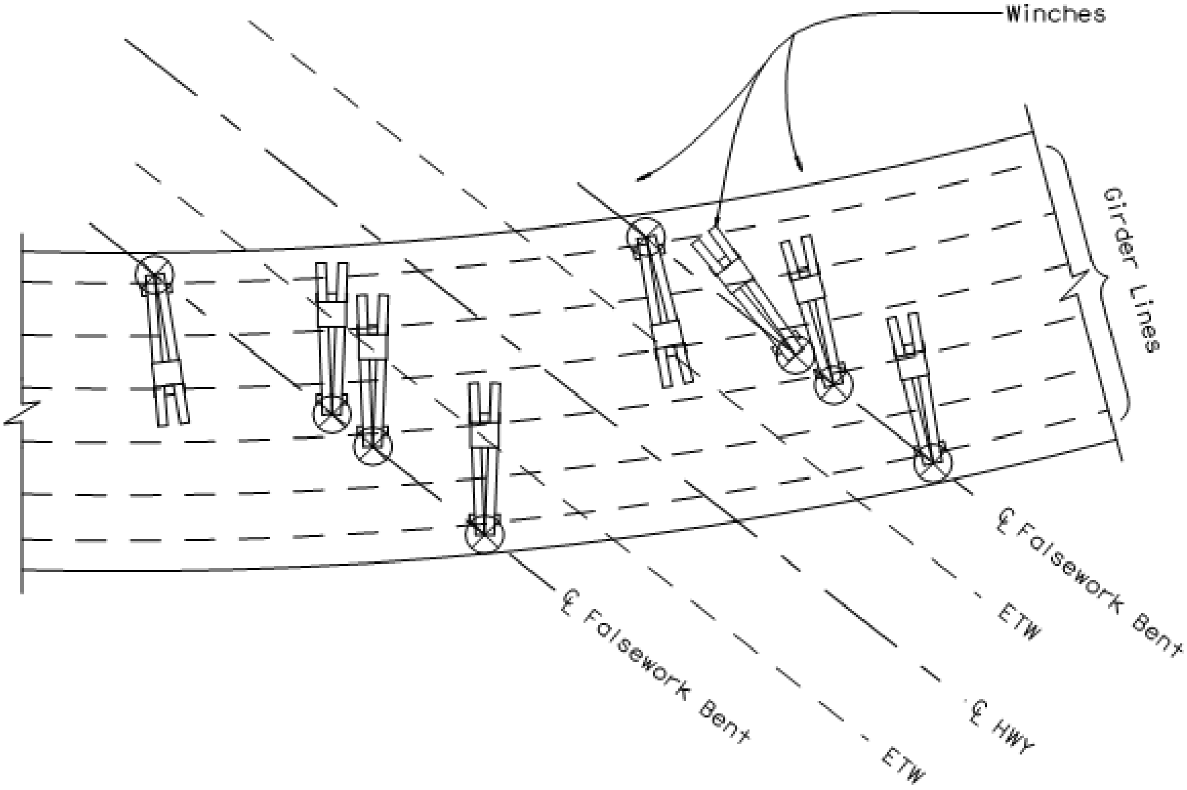

Figure D-31-2. Typical Winch Layout Plan.

Given the part bridge typical section shown in Figure 3, find design strength of the bridge deck for flexure and shear then compare to loads applied from winch system. The design code used for this analysis is the Bridge Design Specifications, LFD Version, April 2000 (BDS, LFD 2000). (A similar analysis can be performed using AASHTO LRFD Design Specifications or concrete design textbook).

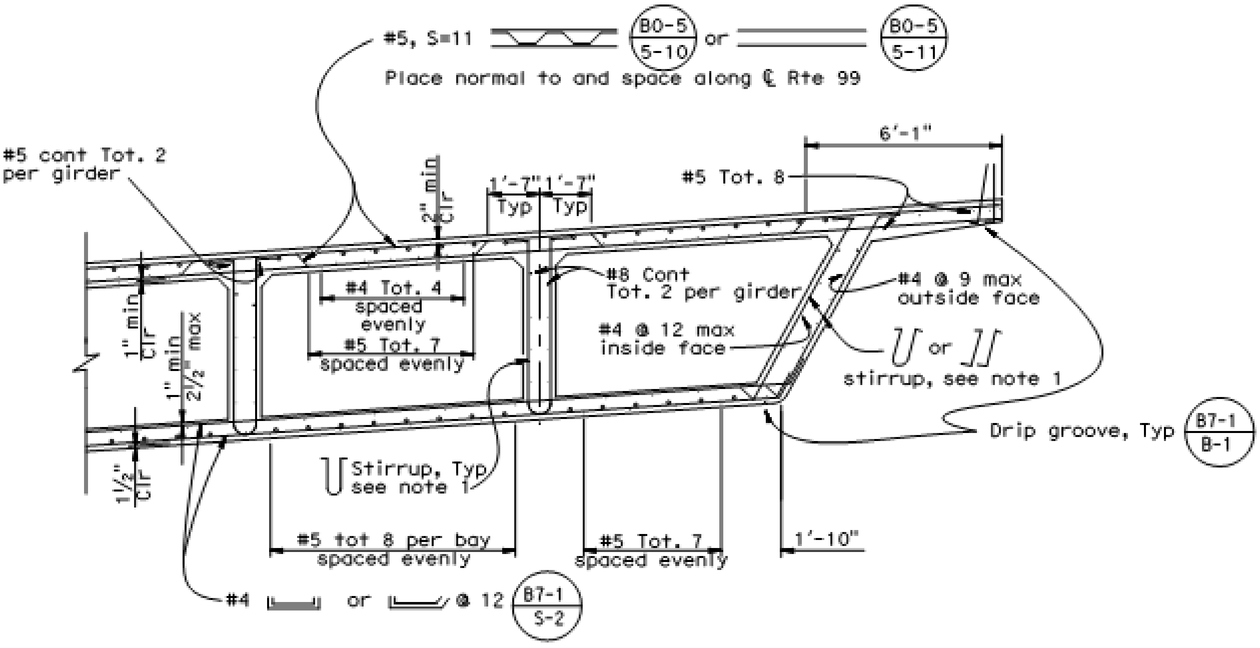

Figure D-31-3. Part typical section used in this example.

Flexural Strength

Given the following values:

$f'_c = 4{,}000 \text{ psi}$

$f_y = 60{,}000 \text{ psi}$

$A_s = 0.31 \text{ in}^2 \text{ for \#5 transverse reinforcement}$

$\text{Transverse reinforcement spacing}, s = 11 \text{ in}$ (Standard Plan B0-5 Detail 5-10 used in this example)

$\text{Deck thickness}, t = 9 \text{ in}$

$\text{Girder centerline spacing} = 9 \text{ ft}$

Find the factored flexural strength φM_n:

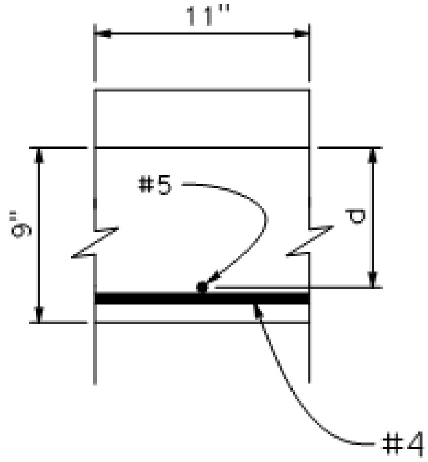

Figure D-31-4. Deck Transverse Strip Section (truss and top bar not shown for clarity).

As shown in Figure 4, a deck strip of width of 11 inches was used for this example. The 11 inches were taken from the typical section "s" value for the transverse rebar as shown. Only the bottom #5 tension reinforcement was used in these calculations. The capacity added by the truss bars is ignored but could be included in a more refined analysis.

Find dimension d from extreme compression fiber (top of deck) to tension bar c.g.:

$$\mathrm{d} = 9\ \mathrm{in} - 1\ \mathrm{in} - 0.5\ \mathrm{in} - \frac{0.625\ \mathrm{in}}{2} \approx 7.19\ \mathrm{in}$$

The design moment strength for rectangular sections with tension reinforcement only per BDS, LFD 2000 Section 8.16.3.2 Equation 8-16 is:

$$\varphi \mathrm{M_n} = \varphi \left[\mathrm{A_s f_y}\left(\mathrm{d} - \frac{\mathrm{a}}{2}\right)\right]$$

where:

$$\varphi = 0.90 \quad \text{(BDS, LFD 2000 8.16.1.2.2 strenth reduction for flexure)}$$

$$\mathrm{a} = \frac{\mathrm{A_s f_y}}{0.85\mathrm{f_c'b}} = \frac{(0.31\ \mathrm{in^2})(60{,}000\ \mathrm{psi})}{0.85(4{,}000\ \mathrm{psi})(11\ \mathrm{in})} = 0.4973\ \mathrm{in} \approx 0.5\ \mathrm{in}$$

$$\mathrm{b} = \text{width of strip} = 11\ \mathrm{in}$$

Calculate the factored flexural strength $\varphi \mathrm{M_n}$:

$$\varphi M_n = 0.90\left[(0.31\ \text{in}^2)(60{,}000\ \text{psi})\left(7.19\ \text{in} - \frac{0.5\ \text{in}}{2}\right)\right] \approx 116{,}176^{\text{in-lb}} \approx 9.7^{\text{ft-kip}}$$

Maximum moment occurs when the winch support is placed at the center of a girder bay (mid-span of transverse deck slab). In this case, treat the maximum winch support load as a point load and assume the span is simple (divide moment by 5 for the support width and multiply by 11/12 to get the equivalent load on an 11 inch strip to compare to capacity). A diagram of the 11-inch strip, support load, and the distribution of the moment is shown in Figure 5.

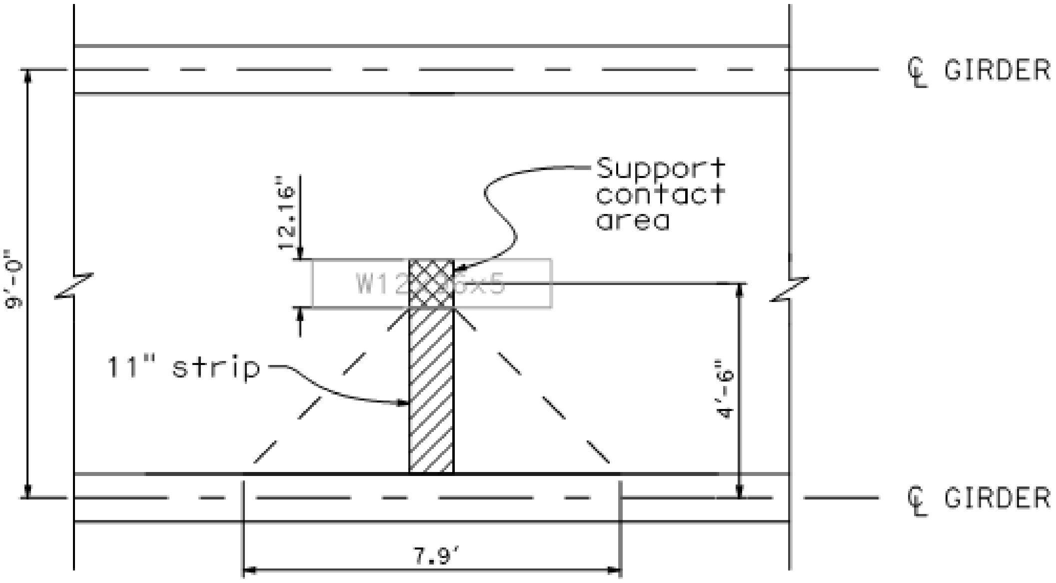

Figure D-31-5. Strip used for Flexure Analysis and Distribution of Moment.

$$M_{\max} = \frac{R_A l}{4} = \frac{(39\ \text{kips})(9\ \text{ft})}{4} \approx 87^{\text{ft-kip}} \quad \Rightarrow \quad \frac{87^{\text{ft-kip}}}{5\ \text{ft}}\left(\frac{11}{12}\right) \approx 16.0^{\text{ft-kip}}$$

For a one-way slab, this moment can be distributed approximately 45° to the supports. Which is:

$$= \ 11\ \text{in} * \frac{1\ \text{ft}}{12\ \text{in}} + 2\left(4.5\ \text{ft} - \frac{1\ \text{ft}}{2} - \frac{12.16\ \text{in}}{2}\frac{1\ \text{ft}}{12\ \text{in}}\right) \approx 7.9\ \text{ft}$$

$$M_{\max} = \frac{16.0^{\text{ft-kip}}}{7.9\ \text{ft}} \approx 2^{\text{ft-kip}}$$

Check demand vs. capacity:

$$\mathbf{M_{max} \leq \varphi M_n \Rightarrow 2 < 9.7} \qquad\qquad \textbf{OK}$$

$$\frac{\text{Demand}}{\text{Capacity}} = \frac{M_{max}}{\varphi M_n} = \frac{2\ \text{kip} \cdot \text{ft}}{9.7\ \text{kip} \cdot \text{ft}} \approx 0.21 \leq 1.00 \qquad \textbf{OK}$$

Shear Strength

Reference: BDS, LFD 2000 Section 8.16.6 – Shear.

Per Section 8.16.6.1, the nominal shear strength V_n is:

$$V_n = V_c + V_s \qquad \text{Equation 8-47}$$

where:

$$V_c = 2\sqrt{f_c'}b_w d \qquad \text{Equation 8-49 (Nominal shear strength of concrete)}$$

$$V_s = 0 \text{ since there is no shear reinforcement in slab}$$

First, the two-way punching shear of the winch support acting at the mid span of the transverse deck slab is checked. The punching shear perimeter for the W12 x 96 x 5 winch support is illustrated in Figure 6.

Calculate the effective perimeter, b_o, and use this value for b_w:

$$b_o = 2\overbrace{\left\{2\left(\frac{d}{2}\right) + b_f\right\}}^{\text{effective width}} + 2\overbrace{\left\{2\left(\frac{d}{2}\right) + l\right\}}^{\text{effective length}}$$

where

$b_f = \text{width of support} = 12.16\ \text{in}$

$l = \text{length of support} = 5\ \text{ft} = 60\ \text{in}$

$d = 7.19\ \text{in (see page 6 of 10 for calculations)}$

$$b_o = 2\left\{2\left(\frac{7.19\ \text{in}}{2}\right) + 12.16\ \text{in}\right\} + 2\left\{2\left(\frac{7.19\ \text{in}}{2}\right) + 60\ \text{in}\right\} \approx 173.1\ \text{in}$$

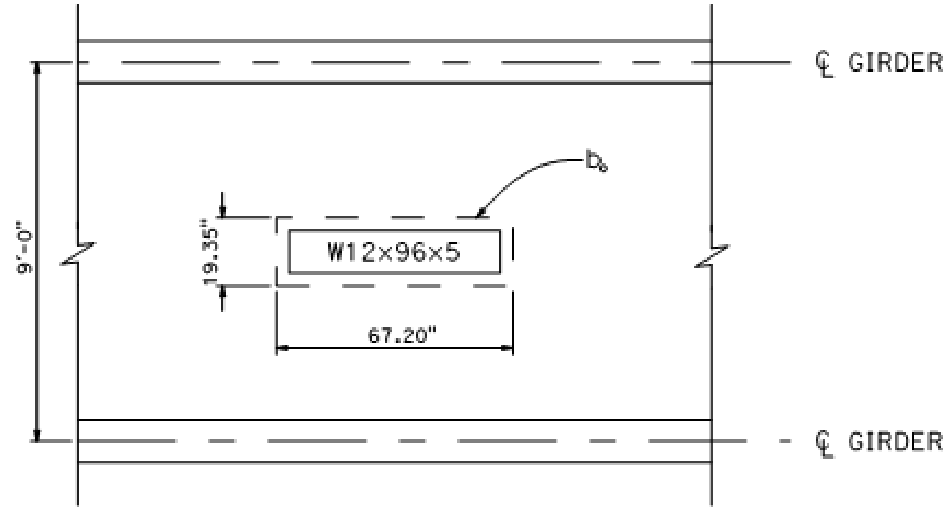

Figure D-31-6 – Two-Way Punching Shear at Mid-Span of Transverse Deck Slab.

Calculate the factored shear φV_n where $\varphi = 0.85$ per BDS LFD 2000 Section 8.16.1.2.2:

$$\varphi V_n = \varphi(V_c) = \varphi\left(2\sqrt{f'_c}\,b_o d_{eff}\right) = 0.85\left(2\sqrt{4000}\text{ psi} * 173.1\text{ in} * 7.19\text{ in}\right) \approx 133{,}815\text{ lbs} = 133.8\text{ kips}$$

Compare the two-way punching shear capacity to the maximum support load:

$$\mathbf{R_A \le \varphi V_n \Rightarrow 39\ kips} < 133.8\text{ kips} \qquad \mathbf{OK}$$

$$\frac{\text{Demand}}{\text{Capacity}} = \frac{R_A}{\varphi V_n} = \frac{39\text{ kips}}{133.8\text{ kips}} \approx 0.29 \le 1.00 \qquad \text{OK}$$

Next, calculate the one-way shear with the support at mid-span and 1 foot from girder centerline shown in Figure D-31-7.

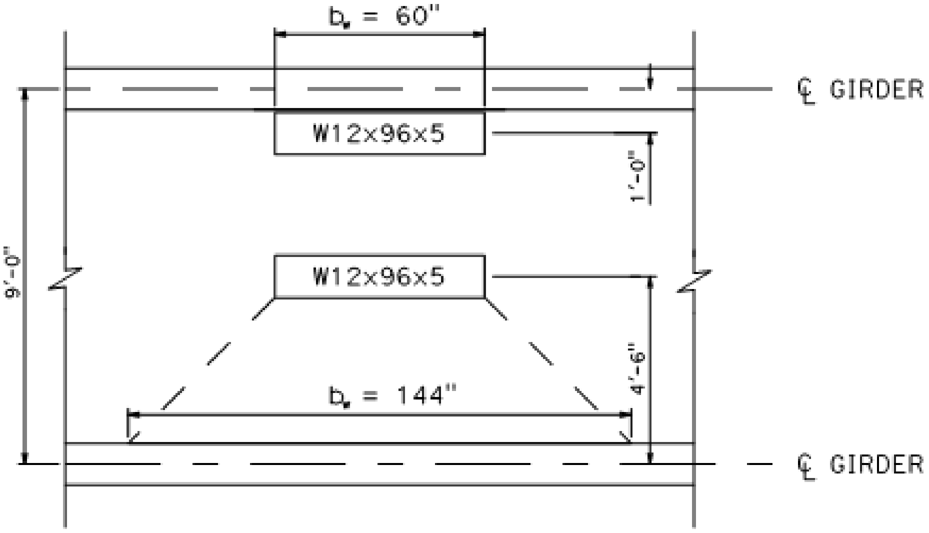

Figure D-31-7. One-Way Shear at Mid-Span and Near Girder of Transverse Deck Slab.

Mid-span one-way shear capacity:

$$\varphi V_n = \varphi\left(2\sqrt{f_c'}b_w d\right) = 0.85\left(2\sqrt{4000}\ \text{psi} * 144\ \text{in} * 7.19\ \text{in}\right) \approx\ 111{,}319\ \text{lbs}$$
$$\approx 111.3\ \text{kips}$$

$$\mathbf{R_A \leq \varphi V_n \Rightarrow 39\ kips\ < 111.3\ kips} \qquad \mathbf{OK}$$

$$\frac{\text{Demand}}{\text{Capacity}} = \frac{R_A}{\varphi V_n} = \frac{39\ \text{kips}}{111.3\ \text{kips}} \approx 0.35 \leq 1.00 \qquad \mathbf{OK}$$

Capacity adjacent to girder:

$$\varphi V_n = \varphi\left(2\sqrt{f_c'}b_w d\right) = 0.85\left(2\sqrt{4000}\ \text{psi} * 60\ \text{in} * 7.19\ \text{in}\right) \approx 46{,}383\ \text{lb} \approx 46\ \text{kips}$$

$$\mathbf{R_A \leq \varphi V_n \Rightarrow 39\ kips\ < 46\ kips} \qquad \mathbf{OK}$$

$$\frac{\text{Demand}}{\text{Capacity}} = \frac{R_A}{\varphi V_n} = \frac{39\ \text{kips}}{46\ \text{kips}} \approx 0.85 \leq 1.00 \qquad \mathbf{OK}$$