

Appendix D Example 18 – Cable Bracing – Bents

Refer to *Falsework Manual*, Section 5-5, *Cable Bracing Systems*. This example demonstrates the adequacy of internal cable bracing of a falsework bent.

Given Information

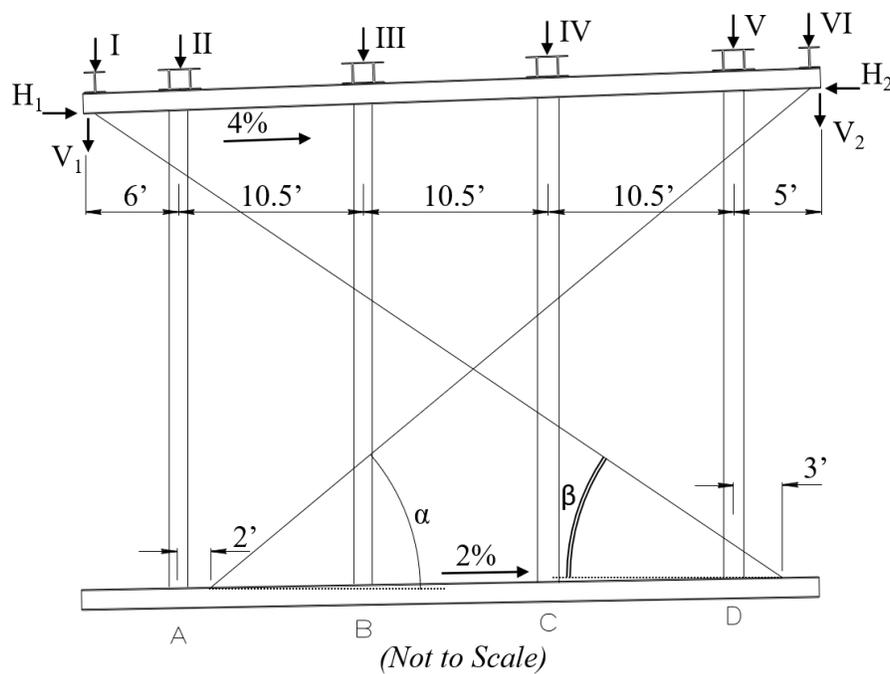


Figure D-18-1. Falsework Bent Cable Bracing

Falsework Bent:

Left Post height: 25 feet (Post A)
 Cap slope: + 4%
 Sill slope: + 2%
 Preload: Cable 1 = 1000 lbs,
 Cable 2 = 1080 lbs
 Cables: 2 each, one per side
 Falsework supporting a box girder bridge
 Falsework bent not adjacent to traffic

Cap & Sill Beams:

W 14 x 53
 $I = 541 \text{ in}^4$
 Weight = 53 plf

Steel Posts:

12" Ø steel pipe
 Wall thickness = 1/4"
 $A = 9.23 \text{ in}^2$
 $S = 26.56 \text{ in}^3$
 $r = 4.16 \text{ in}$

Cable Data from Manufacturer:

New 1/2" Ø IWRC 6 x 19 wire rope
 Breaking strength = 11.50 Tons
 Metallic area of cable = 0.118 in^2
 Cable weight = 0.46 plf
 Modulus of elasticity = $13.5 \times 10^6 \text{ psi}$ ($12.2 \times 10^6 \text{ psi}$ up to 20% of ultimate load)
 Constructional stretch = 0.5%
 Safety factor = 3
 Cable clip efficiency = 80% use (Table 5-2)

Determine if the Bracing System is Adequate

Determine post heights, cable lengths, vertical and horizontal distances between each cable connection

Use geometry to find the necessary information

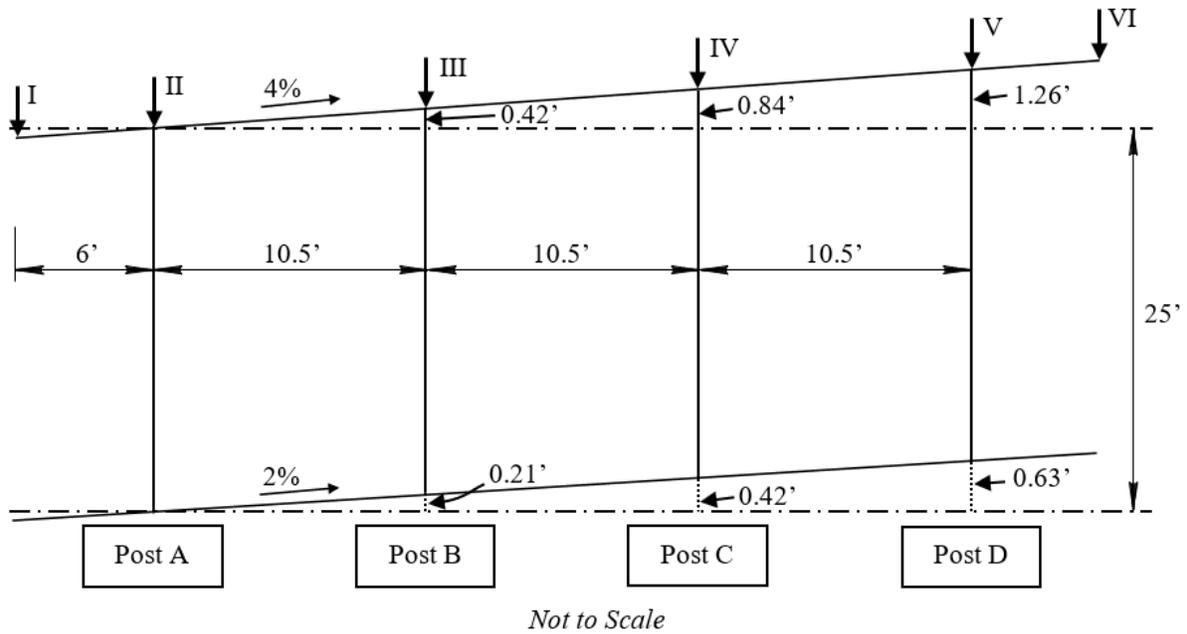


Figure D-18-2. Dimensional Analysis of Post Heights

Post Heights:

$$A = 25.00 \text{ ft}$$

$$B = 25 + 0.42 - 0.21 = 25.21 \text{ ft}$$

$$C = 25 + 0.84 - 0.42 = 25.42 \text{ ft}$$

$$D = 25 + 1.26 - 0.63 = 25.63 \text{ ft}$$

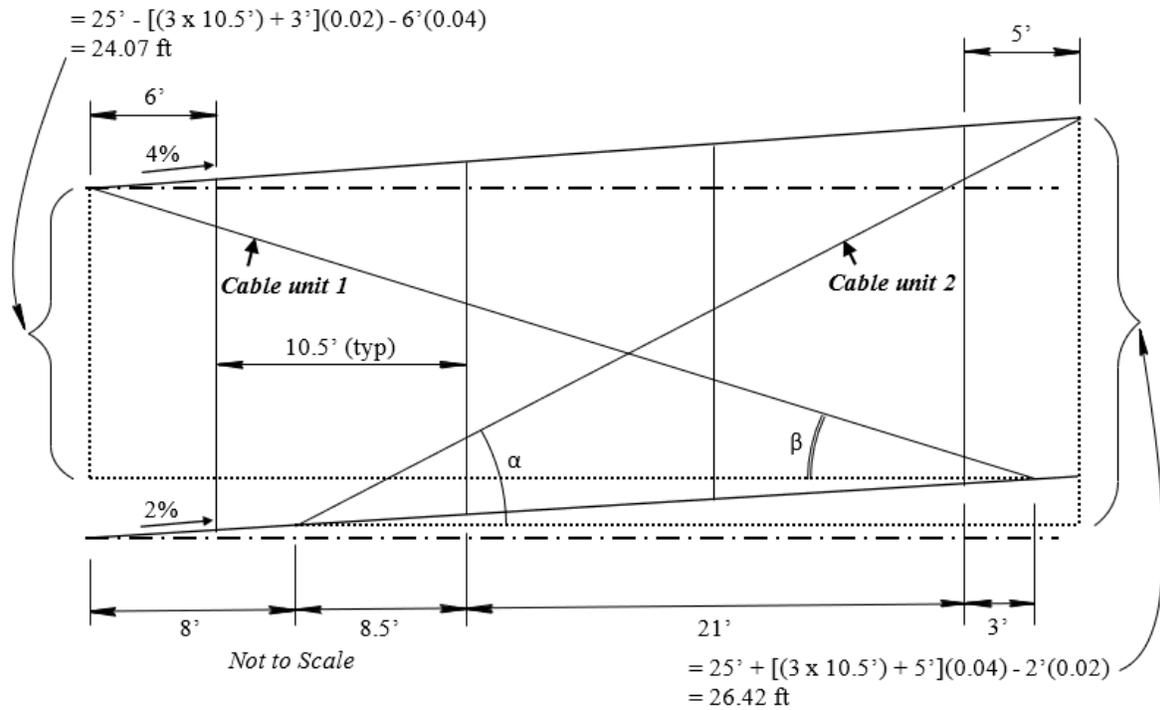


Figure D-18-3. Dimensional Analysis of Cable Bracing

Cable Angles:

Cable Unit 1: (using known post height = 25 ft)

$$\tan \beta = \frac{25 - [(3 \times 10.5) + 3](0.02) - 6(0.04)}{6 + 3(10.5) + 3} = \frac{24.07}{40.5}$$

$$\beta = 30.72^\circ$$

Cable Unit 2: (using known post height = 25 ft)

$$\tan \alpha = \frac{25 + [(3 \times 10.5) + 5](0.04) - 2(0.02)}{8.5 + 2(10.5) + 5} = \frac{26.42}{34.5}$$

$$\alpha = 37.44^\circ$$

Cable Lengths (assuming no drape):

$$L_1 = \sqrt{24.07^2 + 40.5^2} = 47.11 \text{ ft}$$

$$L_2 = \sqrt{26.42^2 + 34.5^2} = 43.45 \text{ ft}$$

Calculate the horizontal design load

Table 1 – Loads from Stringers

Loading Condition	Stringer Loads (kips)					
	Stringer I	Stringer II	Stringer III	Stringer IV	Stringer V	Stringer VI
Total DL + LL	20	73	76	90	69	19
Total DL Only	17	61	64	75	59	16
Soffit Slab & Stem DL + LL	13	51	46	55	42	11

Assume the 2% loading controls (from Table 1)

Total DL only = 17+61+64+75+59+16 = 292 kips

Horizontal load = 2% of total dead load = (292,000)(0.02) = 5840 lbs

Calculate the capacity of the cable units

The cable capacity is determined for static loading conditions by using the breaking (ultimate) strength divided by an appropriate factor of safety, in this case the safety factor = 3 (Ref. 5-5.06 *Factor of Safety*).

$$\text{Cable working capacity} = \frac{\text{Strength}}{\text{Safety factor}} = \frac{(11.5 \text{ Tons}) \left(2,000 \frac{\text{lbs}}{\text{Ton}} \right)}{3} = 7667 \text{ lbs}$$

Working load = (80%)(7667) = 6134 lbs (with Crosby clips efficiency applied)

Check the cable preload values

Check that the horizontal component of the Cable Unit 2 preload balances that of Cable Unit 1:

Cable Unit 1 designated preload = 1000 lbs

Preload the individual cables of Cable Unit 2 to:

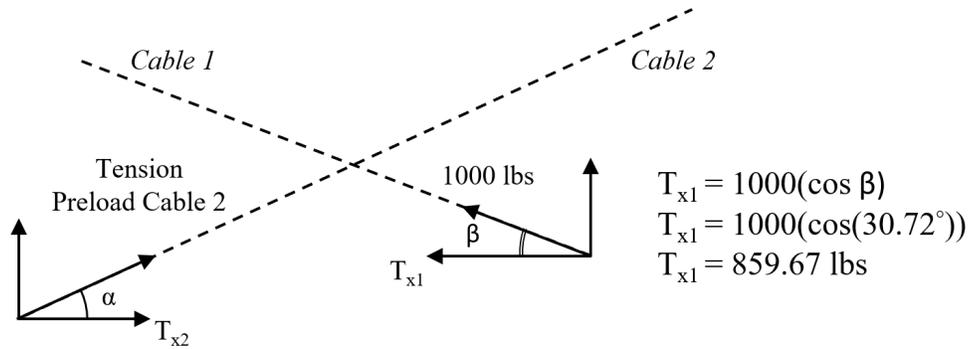


Figure D-18-4. Cable Bracing Geometry

$$T_2 = \frac{859.67}{\cos(37.44)} = 1083 \text{ lbs} \approx 1080 \text{ lbs} = \text{Cable Unit 2 designated preload}$$

Preload value of Cable Unit 2 balances Cable Unit 1. **OK**

Additionally, check that the cable drape after preload doesn't exceed the maximum drape:

Use the equation found in Figure 5-18, *Cable Drape Formula* to determine the distance from the chord to the loaded cable and compare to the maximum drape found in Table 5-5, *Maximum Cable Drape*.

Maximum Cable Drape for 1/2" diameter cable = 2 in

$$\text{Cable Unit 1 A} = \frac{(0.46)(40.5)^2}{8(1000)(\cos(30.72))} = 0.11 \text{ ft} = 1.33 \text{ in}$$

1.33 in < 2 in allowable **OK**

$$\text{Cable Unit 2 } A = \frac{(0.46)(34.5)^2}{8(1080)(\cos(37.44))} = 0.079 \text{ ft} = 0.96 \text{ in}$$

0.95 in < 2 in allowable **OK**

Calculate the cable unit design loads and compare with the cable unit capacity

Use the horizontal design load to calculate the cable unit design load:

$$\text{Cable Unit 1 } P = \frac{5840}{2(\cos 30.72)} = 3397 \text{ lbs} < 6134 \text{ lbs} \quad \text{OK}$$

$$\text{Cable Unit 2 } P = \frac{5840}{2(\cos 37.44)} = 3678 \text{ lbs} < 6134 \text{ lbs} \quad \text{OK}$$

Calculate the cable unit elongations

The cable will experience two stretch conditions, elastic stretch and constructional stretch.

Elastic stretch:

Check if cable design load for both cables exceeds 20% of minimum breaking force.

$$20\% \text{ of minimum breaking force} = (0.20)(11.5 \text{ tons})(2000 \text{ lbs/ton}) = 4600 \text{ lbs}$$

$$\text{Cable Unit 1 Design Load} = 3397 \text{ lbs} < 4600 \text{ lbs}$$

$$\text{Cable Unit 2 Design Load} = 3678 \text{ lbs} < 4600 \text{ lbs}$$

Design loads of both cables do not exceed 20% minimum breaking force; therefore, use equation 5-5.09C(1)-2 to find elastic stretch (if design loads had exceeded 20% minimum breaking force, equations 5-5.09C(1)-3 and 5-5.09C(1)-4 would have been used to find the total elastic stretch).

$$\Delta = \frac{(\text{Cable Design Load} - \text{Preload})(L)}{A (0.90E)}$$

$$\text{Cable Unit 1 } L = 47.11 \text{ ft}$$

$$\text{Cable Unit 2 } L = 43.45 \text{ ft}$$

$$\text{Metallic area of cable} = 0.118 \text{ in}^2$$

$$\text{Modulus of elasticity} = 13.5 \times 10^6 \text{ psi (12.2} \times 10^6 \text{ psi up to 20\% of ultimate load)}$$

$$\text{Cable Unit 1 } \Delta = \frac{[(3397 - 1000)](47.11)}{(0.118)(.90)(13.5 \times 10^6)} = 0.079 \text{ ft}$$

$$\text{Cable Unit 2 } \Delta = \frac{[(3678 - 1080)](43.45)}{(0.118)(.90)(13.5 \times 10^6)} = 0.079 \text{ ft}$$

Constructional Stretch:

Assume that the total constructional stretch comes out at 65% of the ultimate load and that the stretch is proportional to the load applied. Use the following formula for constructional stretch:

$$\Delta_{CS} = \left(\frac{\text{Cable Design Load}}{.65 \text{ Min. Breaking Force}} \right) (\text{Constructional Stretch})(L)$$

65% of minimum breaking force = (0.65)(11.5 tons)(2000 lbs/ton) = 14,950 lbs
Constructional Stretch = 0.5%

$$\text{Cable Unit 1 } \Delta_{CS} = \left(\frac{3397}{14950} \right) (0.005)(47.11) = 0.054 \text{ ft}$$

$$\text{Cable Unit 2 } \Delta_{CS} = \left(\frac{3678}{14950} \right) (0.005)(43.45) = 0.053 \text{ ft}$$

Total stretch:

$$\text{Cable Unit 1 } L \text{ (after stretch)} = 47.11 + 0.079 + 0.054 = 47.24 \text{ ft}$$

$$\text{Cable Unit 2 } L \text{ (after stretch)} = 43.45 + 0.079 + 0.053 = 43.58 \text{ ft}$$

Note that the effects of cap or sill bending can generally be ignored for short cantilever conditions.

Calculate the horizontal cap movement and compare with the allowable horizontal displacement

- a** = vertical distance between the cable connection at the cap and the point on the sill directly below it.
- b** = cable length before stretch
- b'** = cable length after stretch
- c** = slope distance between the point on the sill described for a, and the cable connection on the sill.

Cable Unit 1 Loaded:

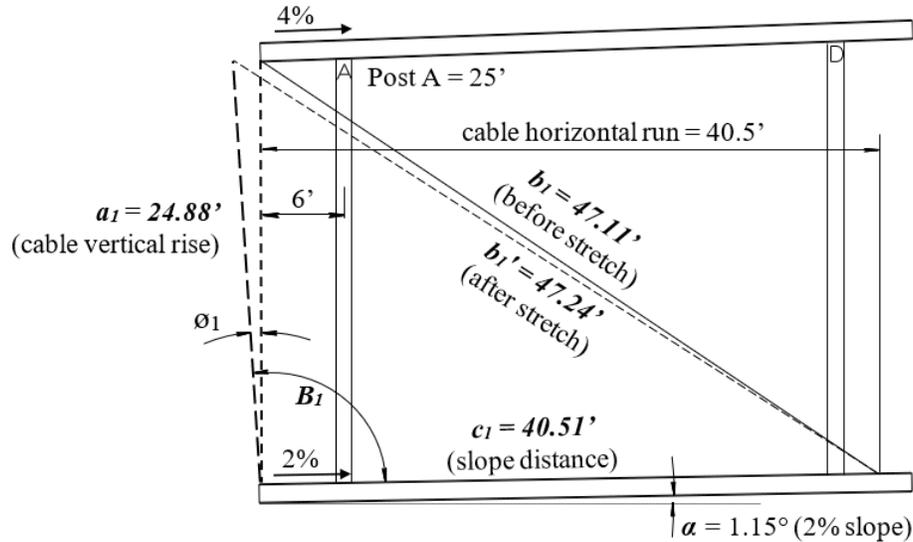


Figure D-18-5. Cap Movement with Cable Unit 1 Loaded

$$a_1 = 25.00 - (6)(0.04) + (6)(0.02) = 24.88 \text{ ft}$$

$$c_1 = \frac{40.5}{\cos \alpha} = \frac{40.50}{\cos 1.15^\circ} = 40.51 \text{ ft}$$

$$\cos B_1 = \left[\frac{a_1^2 + c_1^2 - b_1'^2}{2a_1c_1} \right] \text{ (Law of Cosines)}$$

$$B_1 = \cos^{-1} \left[\frac{(24.88)^2 + (40.51)^2 - (47.24)^2}{(2)(24.88)(40.51)} \right] = 89.19^\circ$$

$$\theta_1 = B_1 - (90^\circ - \alpha) = 89.19^\circ - (90^\circ - 1.15^\circ) = 0.34^\circ$$

$$\text{Horizontal deflection limit (Ref. 5-5.07)} = \frac{25 \text{ ft}}{8} = 3.125 \text{ in} \leq \frac{12 \text{ in}}{4} = 3 \text{ in}$$

$$\text{use } \Delta_{\max} = 3 \text{ in}$$

$$\text{Upper Cap Displacement} = 24.88(\sin(0.34^\circ)) = 0.148 \text{ ft} = 1.77 \text{ in}$$

$$1.77 \text{ in} \leq 3 \text{ in allowable} \quad \mathbf{OK}$$

Cable Unit 2 Loaded:

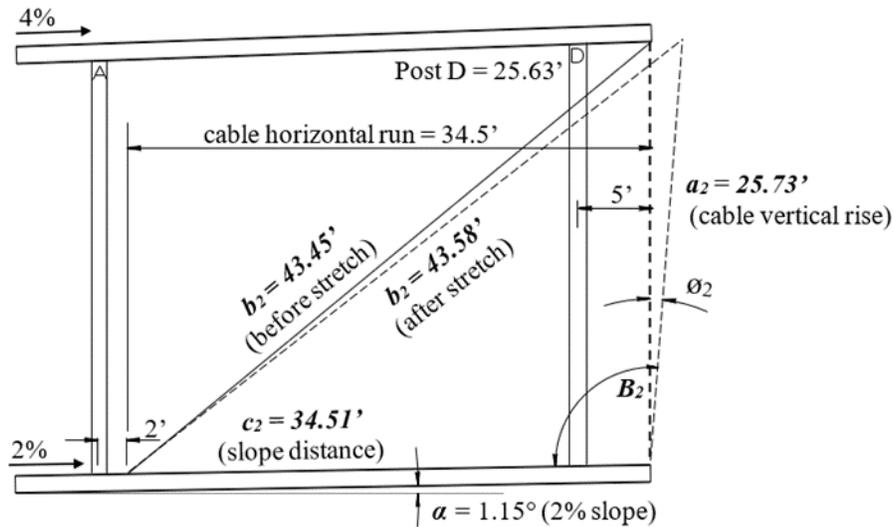


Figure D-18-6. Cap Movement with Cable Unit 2 Loaded

$$a_2 = 25.63 + (5)(0.04) - (5)(0.02) = 25.73 \text{ ft}$$

$$c_2 = \frac{34.5}{\cos \alpha} = \frac{34.5}{\cos(1.15^\circ)} = 34.51 \text{ ft}$$

$$\cos B_2 = \left[\frac{a_2^2 + c_2^2 - b_2'^2}{2a_2c_2} \right] \text{ (Law of Cosines)}$$

$$B_2 = \cos^{-1} \left[\frac{(25.73)^2 + (34.51)^2 - (43.58)^2}{(2)(25.73)(34.51)} \right] = 91.49^\circ$$

$$\theta_2 = B_2 - (90^\circ + \alpha) = 91.49^\circ - (90^\circ + 1.15^\circ) = 0.34^\circ$$

$$\text{Upper Cap Displacement} = 25.73 ((\sin(0.34^\circ)) = 0.153 \text{ ft.} = 1.84 \text{ in.}$$

$$1.84 \text{ in} \leq 3 \text{ in allowable} \quad \mathbf{OK}$$

Determine Post Adequacy

For cable bracing systems supporting box girder structures, check for post adequacy for the two loading conditions provided in the [Contract Specifications](#), Section 48-2.02B(2), *Loads*.

Check Case I:**Calculate post loads**

Compute the post loads resulting from the soffit and stem reactions (Table 1) along with the vertical component of Cable 1 loading (use moment distribution or other acceptable means). Use the design horizontal load and appropriate cable angle to find the vertical component. Repeat the calculations for Cable 2 loading.

$$P_{\text{vertical}} (\text{Cable Unit 1}) = (5,840) (\tan (30.72^\circ)) = 3470 \text{ lbs}$$

$$P_{\text{vertical}} (\text{Cable Unit 2}) = (5,840) (\tan (37.44^\circ)) = 4471 \text{ lbs}$$

Table 2 Post Loads – Case I: Live Load, Soffit and Stems (No Deck Load) + Cable Loads

Loading Condition	Post Loads (lbs)			
	Post A	Post B	Post C	Post D
Case I + Cable 1 Only	79,695	33,531	50,933	59,570
Case I + Cable 2 Only	73,572	37,549	46,758	66,819

Investigate each post

$$\frac{f_a}{F_a} \leq 1$$

Where:

$$f_a = \frac{P}{A}$$

$$F_a = 16,000 - 0.38 \left(\frac{L}{r} \right)^2 \text{ psi (Contract Specifications, Section 48-2.02B(3)(c) unidentified steel)}$$

Sample calculation for stress in Post A with Cable Unit 1 loaded:

$$P = 79,695 \text{ lbs (from Table 2)}$$

$$f_a = \frac{P}{A} = \frac{79,695}{9.23} = 8634 \text{ psi}$$

$$F_a = 16,000 - 0.38 \left(\frac{(25)(12)}{4.16} \right)^2 = 14,024 \text{ psi}$$

$$\frac{8634}{14,024} = 0.62 < 1 \quad \text{OK}$$

Perform the combined stress calculations for all four posts for both directions of horizontal loadings. Table 3 lists the results of these calculations.

Table 3 Summary of Stresses – Case I: Live Load, Soffit and Stems (No Deck Load) + Cable Loads

	Post A	Post B	Post C	Post D
F_a (psi)	14,024	13,990	13,957	13,923
Case I + Cable 1 Only				
f_a (psi)	8,634	3,633	5,518	6,454
Stress ratio	0.62	0.26	0.40	0.46
Case I + Cable 2 Only				
f_a (psi)	7,971	4,068	5,066	7,239
Stress ratio	0.57	0.29	0.36	0.52

The stress ratio for each post is less than 1.0 for both directions of horizontal loading; therefore, all four posts are satisfactory.

Check Case II:

Calculate post loads

Compute the post loads resulting from entire superstructure cross section reactions (Table 1) without cable loading.

Table 4 Post Loads – Case II: Live Load, Total Dead Load, (No Cable Loads)

	Post Loads (lbs)			
Loading Condition	Post A	Post B	Post C	Post D
Case II	107,527	61,827	80,645	99,262

Investigate each post by using the combined stress expression (axial and bending stresses)

Perform the combined stress calculations for all four posts for both directions of horizontal loadings. Table 5 lists the results of these calculations.

Table 5 Summary of Stresses – Case II: Live Load, Total Dead Load, (No Cable Loads)

	Post A	Post B	Post C	Post D
F_a (psi)	14,024	13,990	13,957	13,923
f_a (psi)	11,650	6,698	8,737	10,754
Stress ratio	0.83	0.48	0.63	0.77

The stress ratio for each post is less than 1.0 for both directions of horizontal loading; therefore, all four posts are satisfactory.