Appendix A Example 3: Bridge Scaffolding

This appendix provides an example of bridge scaffolding which is suspended from a steel bridge. The calculations illustrated check the demand and adequacy of the scaffold support cables, as well as the available bridge load capacity.

Given Information

- Two span bridge with concrete deck and steel girders
- Column Steel girders are simply supported (span = 135')
- Flexible scaffold system suspended by cables from bridge structure
- Scaffold designed for 25 psf LL

Required

1. Review scaffold submittal for conformance with Standard Special Provisions Section 7-1.02K(6)(e), *Scaffolding*.
2. Verify global scaffold demand does not exceed available capacity.
3. Verify cable loads are less than allowable.
4. Check cable connection at abutment walls.

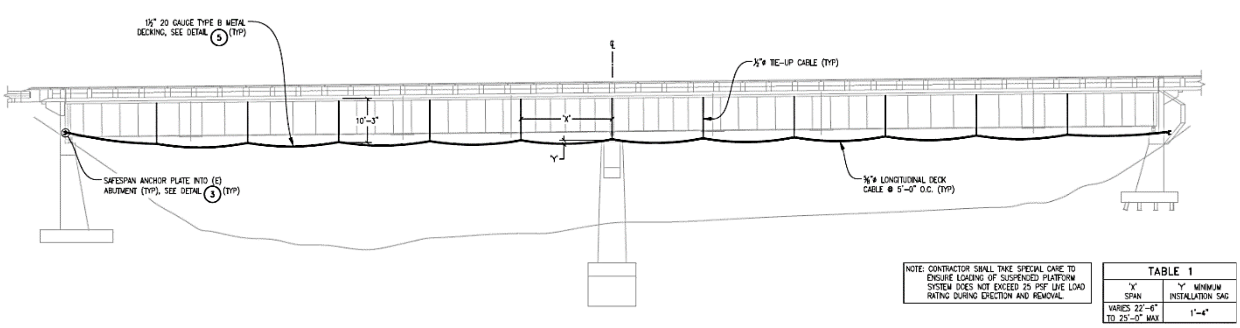

Figure A-3-1. Elevation

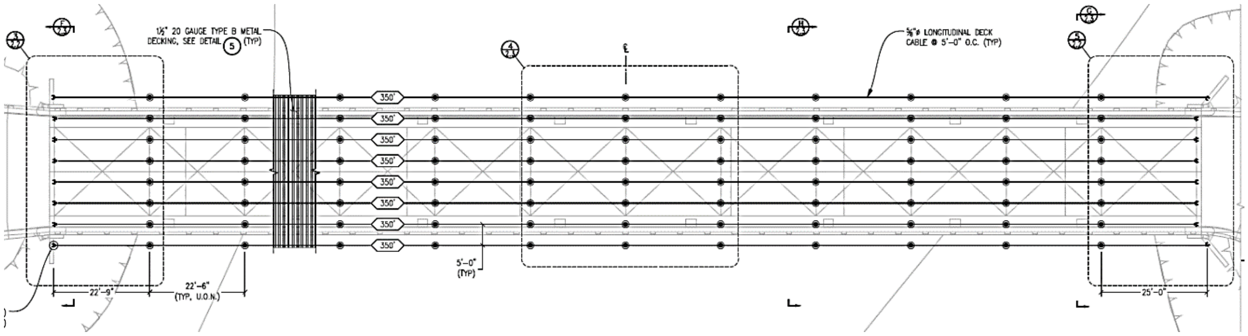

Figure A-3-2. Plan View Scaffold Layout

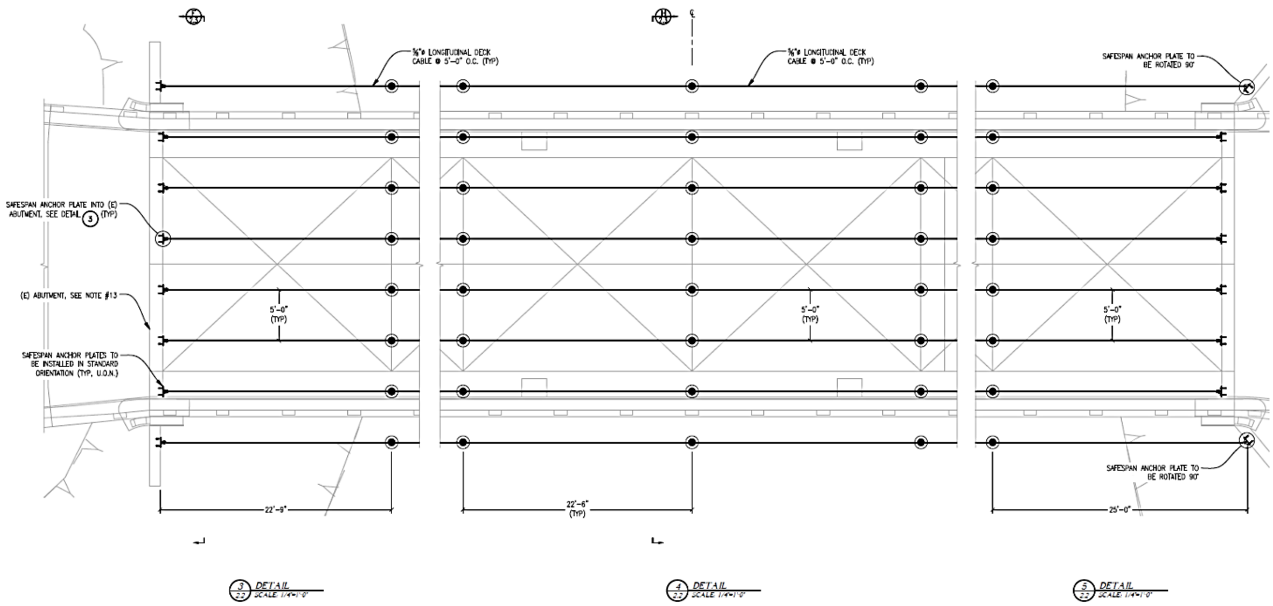

Figure A-3-3. Plan View Center and End Spans

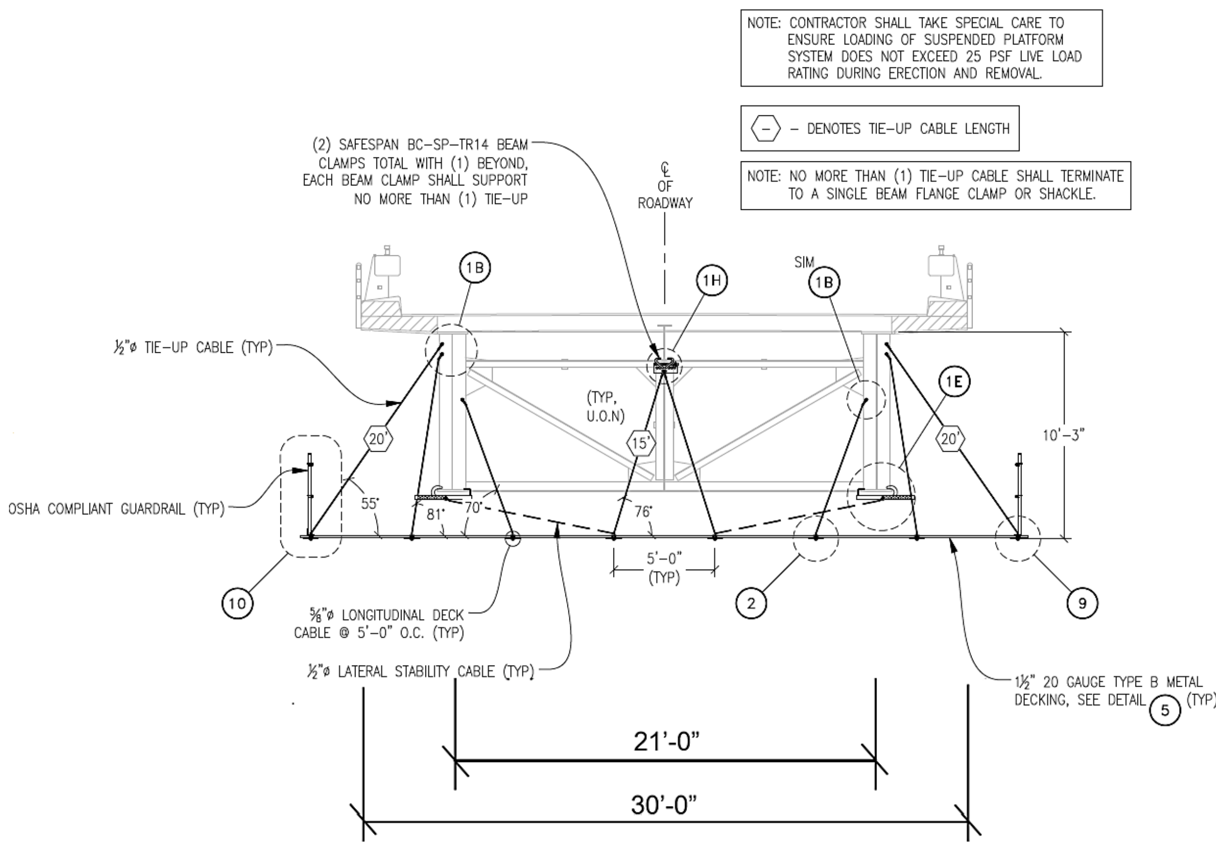

Figure A-3-4. Structure Section

Dead Load

Scaffold deck = 2.06 psf
Tie-up & Longitudinal Cable = 0.72 plf

Live Load

Review General Notes from shop drawings for proposed loading = 25 psf (proposed)

Wind Load

Wind loads calculated using documented method. For this example, the provisions of *AASHTO Guide Design Specifications for Bridge Temporary Works*, Second Edition (GSBTW) with 2020 Interim Revisions were used to calculate wind pressures to be applied to the scaffold structure.

Loads:

DL = 2.06 psf & 0.72 plf
LL = 25 psf

WL_{30} (wind at V= 30 mph sustained wind speed requires that workers vacate structure; provided by designer in submittal)

WL_{92} (wind at V= 92 mph site basic wind speed)

Load Combinations (ASD)

1. DL
2. DL+LL
3. DL+0.75LL+0.75WL_{30} (WL_{30} is service load)
4. DL+0.6WL_{92}
5. 0.6DL+0.6WL_{92} (for maximum uplift)

Note:
Wind at 30 mph (WL_{30}) is a service load and wind at 92 mph (WL_{92}) is a factored load. For ASD, the factored wind load is multiplied by 0.6.

Global Check of Existing Structure

Longitudinal cables spaced 5'-0" O.C. (see structure section above)

Overall scaffold width = 5'-0"(7) = 35'-0"

Bridge width = 30'-0"

Vertical supports spaced @ 22'-6" typical (see plan view scaffold layout above)

Available bridge uniform load = 65 psf (from contract specifications below):

2. Bluff Creek Bridge (br. no. 04-0063), Rube Creek Bridge (br. no. 04-0215) and Bluff Creek Bridge (br. no. 04-0225):

Bridge name/number	Available bridge load capacity (lb/sq ft)	Bridge width (ft)	HS-20 design live load		Permit design live load	
			Percentage of HS-20 loading (percent)	No. LL_{HS20} lanes	Permit vehicle	No. LL_{Permit} lanes
Bluff Creek Bridge (br. no. 04-0063)	65	30	100	2.38 for main girders	N/A	N/A

Figure A-3-5. Available Bridge Uniform Load for Bluff Creek Bridge

Girder spacing = 21'-0" (Figure A-3-4)

Available Bridge Load Capacity

Available capacity distributed loading = 30'(65 psf) = 1950 plf

Demand

Scaffold point dead load to bridge = 35'(22.5')(2.06psf)+ 8(22.5')(0.72plf) = 1752 lb

Scaffold point live load to bridge = 35'(22.5')(25psf) = 19688 lb

Total = 21440 lb

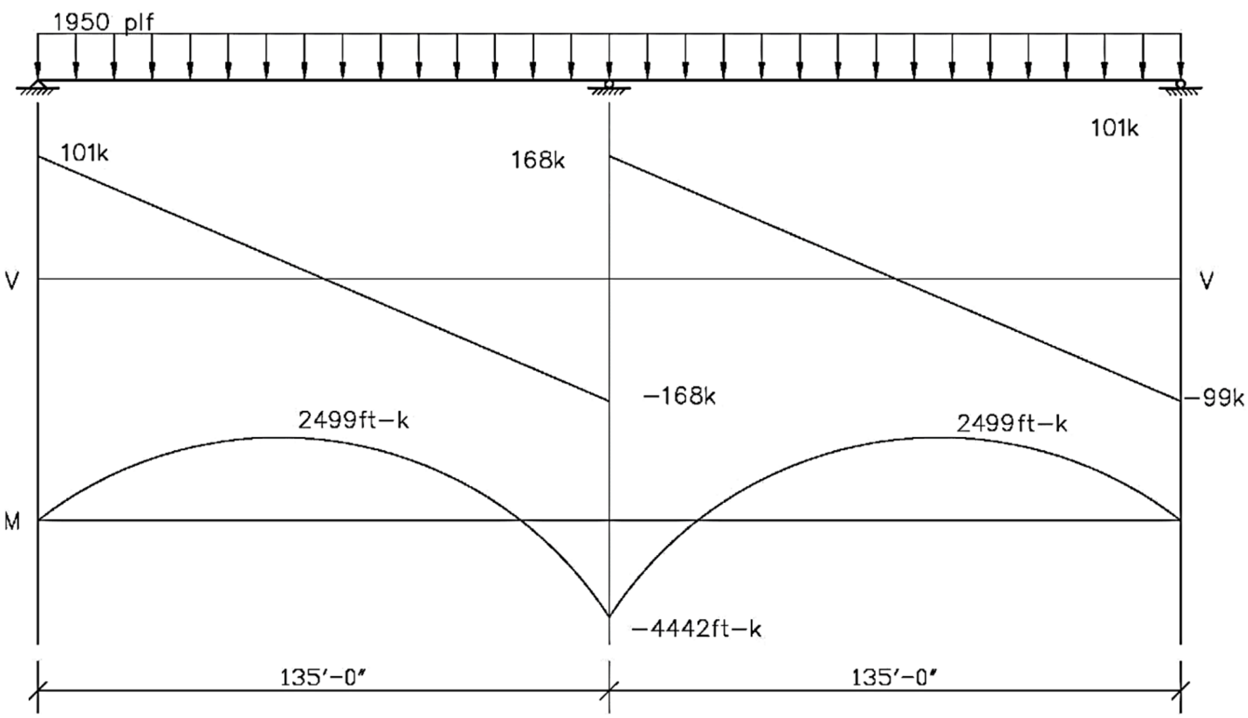

Figure A-3-6. Girder Capacity Shear and Moment Envelope

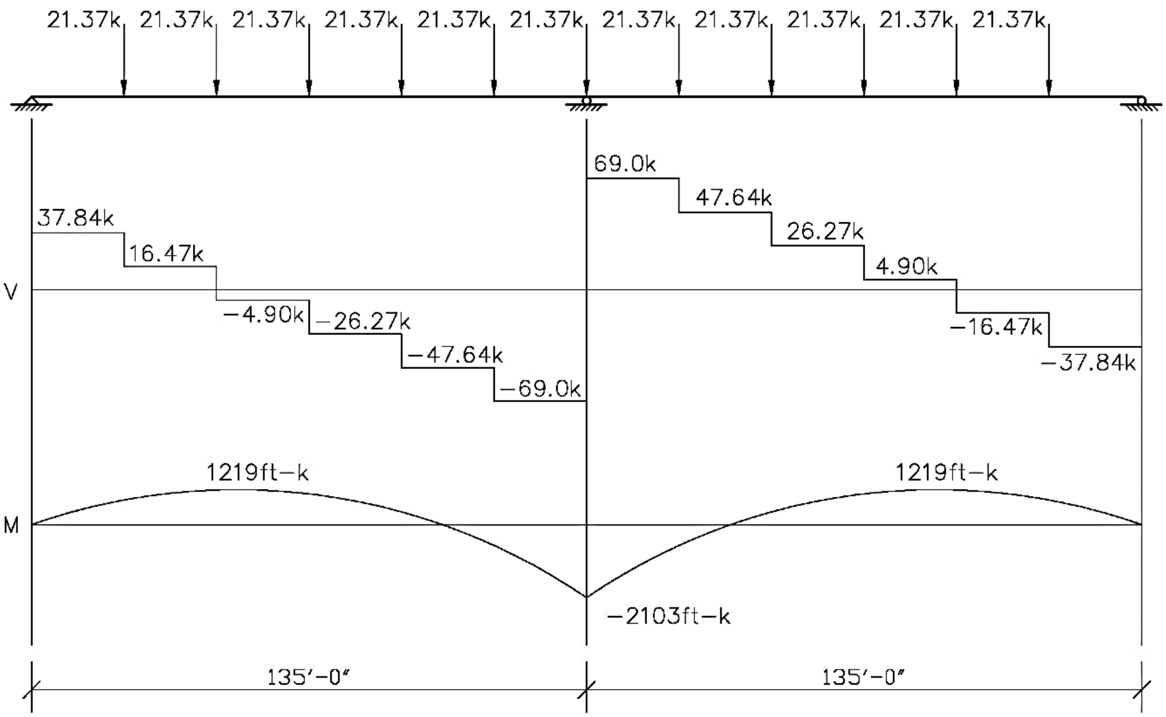

Figure A-3-7. Girder Demand Shear and Moment Envelope Full Live Load

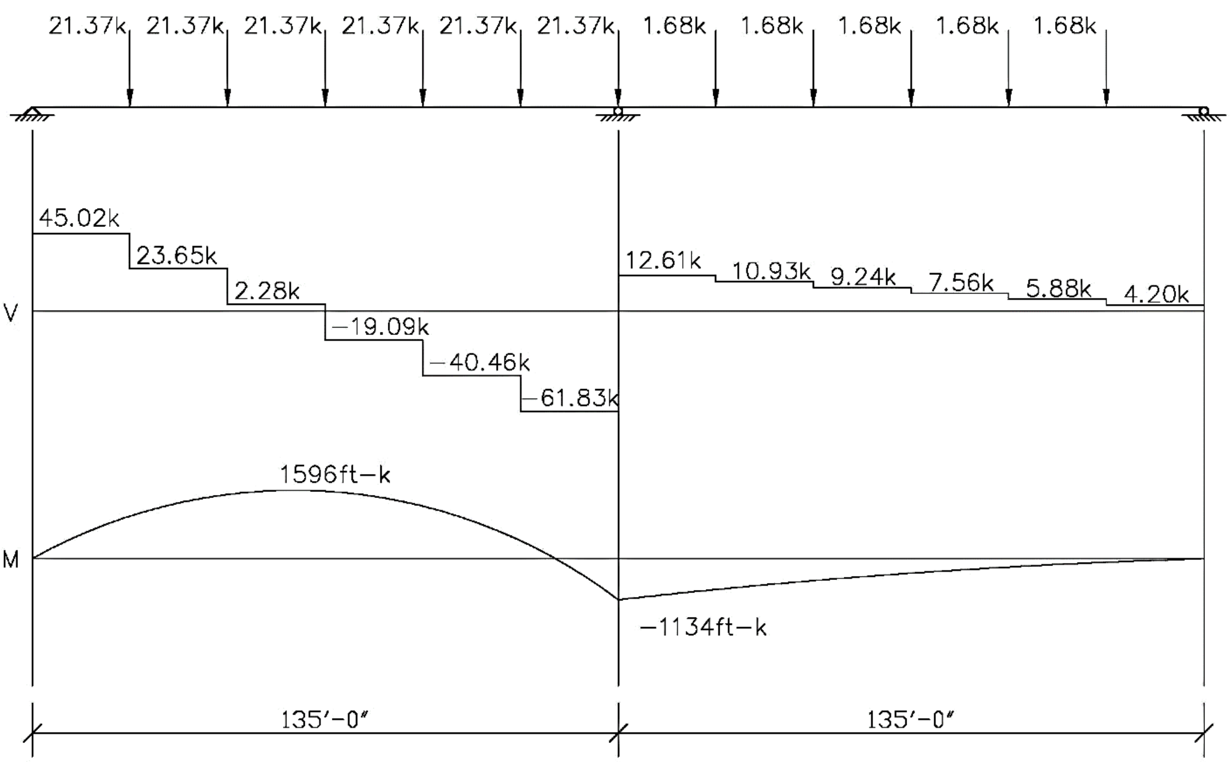

Figure A-3-8. Girder Demand Shear and Moment Envelope Alternate Span Live Load

Taking the highest demands from Figure A-3-7 and A-3-8:

Shear demand ends = 45.02 k < 101 k capacity ⟸ OK

Shear demand center = 69.00 k < 168 k capacity ⟸ OK

Moment demand Positive = 1596 ft-k < 2499 ft-k capacity ⟸ OK

Moment demand Negative = 2103 ft-k < 4442 ft-k capacity ⟸ OK

Longitudinal Cables (analyzed per typical cable)

Cable span	=	25'-0" max per shop drawings
Cable sag installed	=	1'-4" (75% of design sag per shop drawings)
Cable sag design	=	1'-9" (1.33x1'-4" = 1'-9" Includes construction and elastic stretch per shop drawings)
Cable load (**q**)	=	[2.06 psf +(25 psf)](5')+(0.72 plf) = 136 plf (interior condition) [2.06 psf +(25 psf)](2.5')+(0.72 plf) = 68 plf (25' ext. condition)

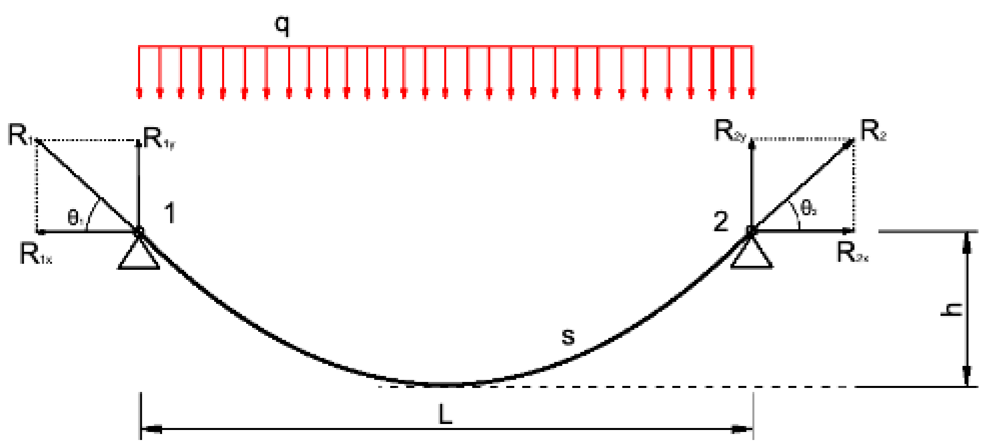

Figure A-3-9. Uniformly Loaded Cable

Horizontal support reaction **R_{1x}**: .

$$R_{1x} = R_{2x} = \frac{qL^2}{(8h)} = \frac{136(22.5)^2}{(8(1.75))} = 4918 \text{ lbs} \qquad \text{(A-3-1)}$$

Vertical support reaction **R_{1y}**:

$$R_{1y} = R_{2y} = \frac{qL^2}{2} = \frac{136(22.5)}{2} = 1530 \text{ lbs} \qquad \text{(A-3-2)}$$

Resultant (cable tension):

$$\sqrt{{R_{1x}}^2 + {R_{1y}}^2} = \sqrt{{R_{2x}}^2 + {R_{2y}}^2} = \sqrt{4918^2 + 1530^2} = 5150 \text{ lbs} \qquad \text{(A-3-3)}$$

For 5/8" 6x19 IWRC cable:

Minimum breaking strength (**MBF**) = 20.60 tons = 41,200 lbs

Min required factor of safety (**FS**) = 6 (applied to the live load per Cal/OSHA and applies to rope/wire rope only per CSO § 1658)

Factor of safety (**FS**) = 41,200/5150 = 8 > 6 ⟸ OK

Connection: 3 wire rope clips (Crosby):

Connection efficiency (**CE**) = 80% (*Falsework Manual*, Table 5-2)

Allowable cable load:

$$\frac{\text{MBF(CE)}}{\text{FS}} = \frac{41{,}200(0.80)}{6} = 5493 \text{ lbs} > 5150 \text{ lbs} \quad \Longleftarrow \quad \text{OK} \qquad \text{(A-3-4)}$$

Cable angle to horizontal (**θ**):

$$\theta = \tan^{-1}\left(\frac{R_{1y}}{R_{1x}}\right) = \tan^{-1}\left(\frac{R_{2y}}{R_{2x}}\right) = \tan^{-1}\left(\frac{1530}{4918}\right) = 17.28° \qquad \text{(A-3-5)}$$

3/4" Shackle working load (per provided data sheet) assumed = 9500 lbs

9500 lbs > 5150 lbs ⟸ OK

Vertical Support Cables

Middle cable reactions = 5'(22.5')(2.06 psf+25 psf) + (22.5')(0.72 plf) = 3060 lbs

For 1/2" 6x19 IWRC cable:

Minimum breaking strength (**MBF**) = 13.30 tons = 26,600 lbs

Min required Factor of safety (**FS**) = 6 (applied to the live load per Cal/OSHA and applies to rope/wire rope only per CSO § 1658)

Factor of safety (**FS**) = 26,600/3060 = 8.7 > 6 ⟸ OK

Connection: 3 wire rope clips (Crosby):

Connection efficiency (**CE**) = 80% (*Falsework Manual*, Table 5-2)

Allowable cable load:

$$\frac{\text{MBF(CE)}}{\text{FS}} = \frac{26{,}600(0.80)}{6} = 3547\ \text{lbs} > 3060\ \text{lbs} \Longleftarrow \text{OK} \qquad \text{(A-3-6)}$$

SafeSpan beam flange clamp (verify capacity with manufacturer's instructions)

3/4" Shackle Working Load (per provided data sheet) assume = 4.75 ton
4.75 ton x 2000 lbs/ton = 9500 lbs > 3060 lbs $\Longleftarrow$ OK

Cable Attachment at Abutment

Cable tension = 5150 lbs (previously calculated)
Angle to horizontal = 17.28º (previously calculated)

SafeSpan end anchor plate (verify capacity with manufacturer's instructions)

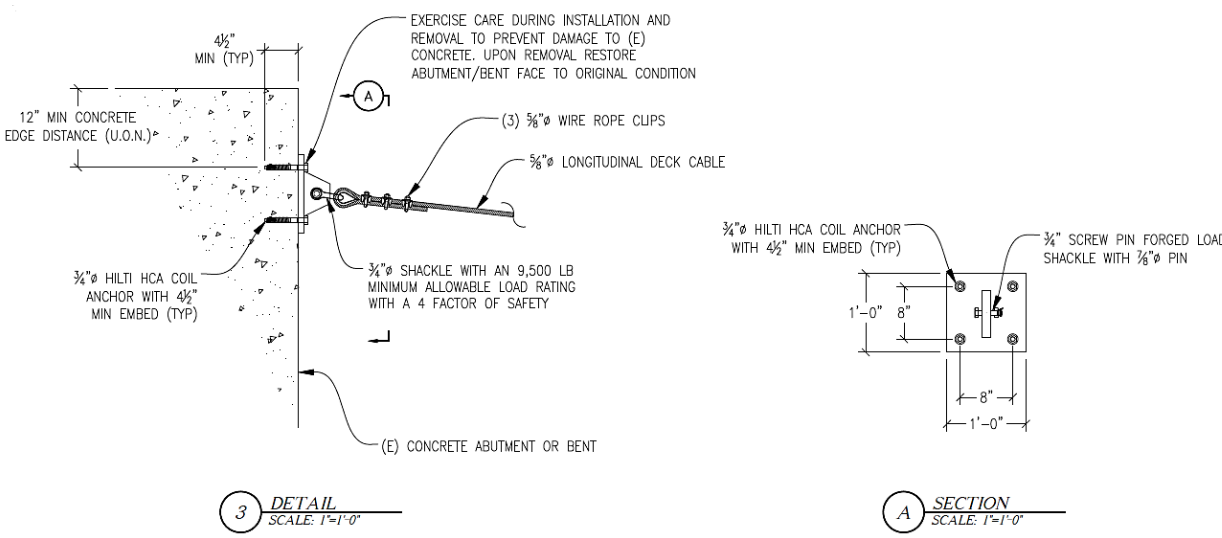

Figure A-3-10. Cable Attachment at Abutment

Anchor Analysis

For four ¾" Hilti HCA coil anchors:

Spacing	=	8" o.c.
Nominal embedment	=	4.5" min.
Edge distance	=	12" min.
Assume **f'_c**	=	3000 psi
Vertical load	=	1530 lb (previously calculated)
Horizontal load	=	4918 lb (previously calculated)

Anchor Manufacturer's Instructions

MATERIAL SPECIFICATIONS

1/4-in. HCA manufactured from case hardened AISI 1038 carbon steel with a minimum tensile strength of 100 ksi (690 MPa).

3/8-, 1/2-, 5/8- and 3/4-in. HCA meet the chemical requirements of AISI 1035 carbon steel and are heat treated for a minimum tensile strength of 120 ksi (830 MPa).

Coil is manufactured from carbon steel.

Anchor and coil are zinc plated in accordance with ASTM B633, SC 1.

Figure 1 - HCA specifications

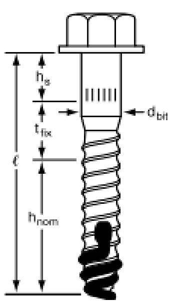

Table 1 - Hilti HCA Coil Anchor specifications

Setting information		Symbol	Units	Nominal anchor diameter				
				1/4	3/8	1/2	5/8	3/4
Nominal bit diameter		d_o	in.	1/4	3/8	1/2	5/8	3/4
Embedment mark[1]		h_s	in.	3/8	5/8	5/8	3/4	1
Anchor Length	min.	ℓ	in.	1-3/4	2-1/4	3	3-1/2	4-1/2
	max.	ℓ	in.	3-1/2	5	7	8	10
Fixture hole diameter		d_h	in.	5/16	7/16	9/16	11/16	13/16
Installation torque		T_{inst}	ft-lb	10	40	80	130	180
Minimum base material thickness		h	in.	the greater of 3 or 1.3 times h_{nom}				

1 Maximum fixture thickness $t = \ell - (h_{nom} + h_s)$

Combined shear and tension loading

$$\left(\frac{N_d}{N_{rec}}\right) + \left(\frac{V_d}{V_{rec}}\right) \leq 1.0$$

Figure A-3-11. Anchor Manufacturer's Instructions

Table 2 - Hilti HCA allowable concrete and steel capacity (lb)[1]

Nominal anchor diameter in.	Nominal embedment in.	f'_c = 2,000 psi		f'_c = 4,000 psi		f'_c = 6,000 psi		Allowable steel strength[2]	
		Tension[3]	Shear	Tension[3]	Shear	Tension[3]	Shear	Tension	Shear
1/4	3/4	230	230	325	330	400	400	1,620	835
	1	355	380	500	535	615	655		
3/8	1-1/2	650	850	920	1,205	990	1,475	4,375	2,255
	2	1,005	1,390	1,420	1,965	1,740	2,410		
1/2	2	1,005	1,515	1,420	2,145	1,740	2,625	7,775	4,005
	3	1,845	3,020	2,605	4,270	3,190	5,230		
5/8	2-3/8	1,300	2,175	1,835	3,075	2,250	3,765	12,150	6,260
	3-7/8	2,705	5,000	3,825	7,070	4,685	8,660		
3/4	3-1/4	2,080	3,915	2,940	5,540	3,600	6,780	17,495	9,010
	4-1/2	3,385	6,810	4,790	9,630	5,865	11,705		

1 Allowable concrete capacities based on a safety factor of 4.
2 Steel strength calculated using 0.33 f_{uta} $A_{nominal}$ for tension and 0.17 f_{uta} $A_{nominal}$ for shear.
3 Reduce tension capacity by 20% for HCA Hex Head Bolts that are reused. Coils may not be reused.

Figure A-3-12. Hilti HCA Allowable Concrete and Steel Capacity

Table 4 - Hilti HCA edge distance and anchor spacing guidelines[1,2]

	Load Direction	Critical	Minimum	Influence factor[3]
Spacing	Tension	3.0 h_{nom}	1.0 h_{nom}	f_{AN} = 0.70
	Shear	2.0 h_{nom}	1.0 h_{nom}	f_{AV} = 0.70
Edge distance	Tension	1.5 h_{nom}	0.8 h_{nom}	f_{RN} = 0.75
	Shear ⊥ toward edge[4]	2.5 h_{nom}	1.0 h_{nom}	f_{RV1} = 0.25
	Shear ll or ⊥ away from edge[4]	2.5 h_{nom}	1.0 h_{nom}	f_{RV2} = 0.50

1 For edge and spacing distances between critical and minimum spacing/edge distances, use linear interpolation.
2 Influence factors are cumulative.
3 Influence factor at minimum spacing/edge distance. Influence factor at critical equals 1.0.
4 For shear loads in between perpendicular toward edge and parallel with edge, use the following equation, $f_{RV3} = 0.25 / (\cos \beta + 0.5 \sin \beta)$ for $55° \le \beta < 90°$. For $0° \le \beta < 55°$, use influence factor for shear perpendicular toward edge. See Figure 2.

Figure A-3-13. Hilti HCA Edge Distance and Anchor Spacing Guidelines

Tension and Shear

Maximum anchor plate thickness (**t**), assuming anchor length of 6 inches:

$$t = \boldsymbol{l} - (H_{nom} + h_s) = 6" - (4.5" + 1") = 0.5" \qquad \text{max (table 1)}$$ A-3-7)

Note:
Verify anchor plate thickness less than or equal to maximum ½" in field

Critical spacing tension	= 3(h_{nom}) = 3(4.5") = 13.5" > 8" (Reduction for spacing required)
Critical edge Dist. tension	= 1.5(h_{nom}) = 1.5(4.5") = 6.75" < 12" (No reduction for edge Dist.)
Critical spacing shear	= 2(h_{nom}) = 2(4.5") = 9" > 8" (Reduction for spacing required)
Critical edge Dist. shear	= 2.5(h_{nom}) = 2.5(4.5") = 11.25" < 12" (No reduction for edge Dist.)

Spacing influence factor for tension:

$$0.7 + 0.3\left(\frac{8 - 4.5}{13.5 - 4.5}\right) = 0.817 \tag{A-3-8}$$

Spacing influence factor for shear:

$$0.7 + 0.3\left(\frac{8 - 4.5}{9 - 4.5}\right) = 0.933 \tag{A-3-9}$$

Allowable loads determined using linear interpolation from manufacture's tables:

Allowable tension load:

$$4\left(\frac{3385 + 4790}{2}\right)(0.817) = 13{,}360 \text{ lbs} > 4918 \text{ lbs} \quad \Longleftarrow \quad \text{OK} \tag{A-3-10}$$

Allowable shear load:

$$4\left(\frac{6810 + 9630}{2}\right)(0.933) = 30{,}676 \text{ lbs} > 1530 \text{ lbs} \quad \Longleftarrow \quad \text{OK} \tag{A-3-11}$$

Combined loading:

$$\left(\frac{4918}{13360}\right) + \left(\frac{1530}{30676}\right) = 0.42 < 1 \quad \Longleftarrow \quad \text{OK} \tag{A-3-12}$$

Existing Bridge Members

Analysis of all individual bridge members is beyond the scope of this example and has not been included.

In accordance with Standard Special Provisions Section 7-1.02K(6)(e), scaffold loads must not exceed the load-carrying capacity of existing bridge members. Member moment and shear demand comparison showing that the scaffolding load demand does not exceed the member moment and shear demands of the available uniform load must be submitted. Members that the available uniform load cannot be applied to, must be analyzed under *AASHTO LRFD Bridge Design Specifications with California Amendments*, latest addition.

The analysis of the existing bridge members using LRFD and LFD may require the assistance of the Bridge Design PE for Bridge Design projects. If the project is a Structure Maintenance and Investigation (SM&I) project, then SM&I would provide support.

Wind Loading Procedure

Wind loads calculated using the provisions of the GSBTW. This structure is a conventional bridge, so the provisions of section 2.3.5.2.1 are used.

Design wind speed when full enclosure is in place = 30 mph (designer service load per submittal).

Design wind speed when scaffold has been vacated = 92 mph (AASHTO LRFD BDS figure 3.8.1.1.2-1).

Wind exposure category C used for this structure.

Wind Pressure

$$\mathrm{P_z} = 2.56 \times 10^{-3} \mathrm{V^2 K_Z G C_D K_d} \qquad \text{(A-3-13)}$$

V = 30 mph (enclosed structure)

Structure height (**Z**) = 25'

$$\mathrm{K_z(C)} = \frac{\left[2.5 \ln\left(\frac{Z}{0.0984}\right) + 7.35\right]^2}{478.4} = \frac{\left[2.5 \ln\left(\frac{25}{0.0984}\right) + 7.35\right]^2}{478.4} = 0.9389 \qquad \text{(A-3-14)}$$

(AASHTO LRFD-BDS 3.8.1.2.1-3)

Gust factor (**G**) = 0.85 (LRFD-BDS 2.3.5.2.3b)

Drag coefficient (**C_D**) = 2.0 (LRFD-BDS table 2.3.5.2.3b-2)

Wind directionality factor (**Kd**) = 0.95 (LRFD-BDS 2.3.5.2.3b)

P_{Z30} = $2.56x10^{-3}(30)^2(0.9389)(0.85)(2.0)(0.95)$ = <u>3.49 psf</u>

Area =10.25 sq ft/ft

Force = (3.49 psf)(10.25sq ft/ft)/2 = 17.91 plf (half containment attached to structure)

V = 92 mph (vacated structure)

P_{Z92} = $2.56x10^{-3}(92)^2(0.9389)(0.85)(2.0)(0.95)$ = <u>32.82 psf</u>

Area =1 sq ft/ft

Force = 0.6(32.82 psf)(1sq ft/ft) = 19.69 plf $\Longleftarrow$ Governs (Factored load)

Load to ½"Ø lateral stability cable = 25'(19.69 plf) = 492 lbs

For 1/2" 6x19 IWRC cable:

Minimum breaking strength (**MBF**)	=	13.30 tons = 26,600 lbs
Min Factor of safety (**FS**)	=	6 (applied to the live load per Cal/OSHA and applies to rope/wire rope only per CSO 1658)
Factor of safety (**FS**)	=	26,600/492 = > 54 $\Longleftarrow$ OK

Connection: 3 wire rope clips (Crosby)

Connection efficiency (**CE**)	=	80% (*Falsework Manual,* Table 5-2, Wire Rope Connections)

Allowable cable load:

$$\frac{\text{MBF(CE)}}{\text{FS}} = \frac{26{,}600(0.80)}{6} = 3457 \text{ lbs} > 492 \text{ lbs} \quad \Longleftarrow \text{OK} \qquad \text{(A-3-15)}$$