5.27 CURVED CAST-IN-PLACE PRESTRESSED BOX GIRDERS

5.27.1 GENERAL

This BDM addresses cast-in-place prestressed box girders designed with horizontal curvature, which require special consideration due to the presence of lateral prestress forces. In particular, a lateral force approximately equal to the jacking force (P_j) divided by the radius (R) needs to be considered in the girder design.

5.27.2 DEFINITIONS

Duct tie—A u-shaped stirrup that hooks around both legs of the girder stirrup to distribute the lateral forces by engaging the entire rebar cage within the girder.

5.27.3 NOTATIONS

$F_{u\text{-}in}$ = in-plane deviation force effect per unit length of tendon (kips/ft)

f'_{ci} = design concrete compressive strength at time of stressing (ksi)

h_c = clear height of girder measured along the axis of the web (ft)

P_j = jacking force per girder (kips)

P_u = factored jacking force per girder (kips)

R = horizontal radius of the centerline of the girder under consideration (ft)

γ = load factor for prestressing = 1.2

ϕ = resistance factor

5.27.4 APPLICABILITY

This memo applies to girders with horizontal radii of 2,000 ft or less. For bridges with girders having R > 2,000 ft, the issues presented in this memo may still apply if there is an unusually high P_j (say 8,000 kips) and/or for structure depths exceeding 16 feet. Refer to National Cooperative Highway Research Program (NCHRP) Report 620 [1].

5.27.5 LATERAL FORCE DESIGN

The following design elements need to be considered due to lateral prestress forces originating from horizontal curvature:

1. Provide duct ties according to Figure 5.27.5.1.3 “Detail A” if required for containment of tendons. Refer to Figure 5.27.5.1.2.

2. Include the effects of regional transverse bending of the web in the vertical stirrup design. Refer to Figures 5.27.5.2.1 through 5.27.5.2.6.

3. The cable path of the tendons shall account for increased spacing between ducts if “Detail A” is applicable. Refer to BDM 5.22.

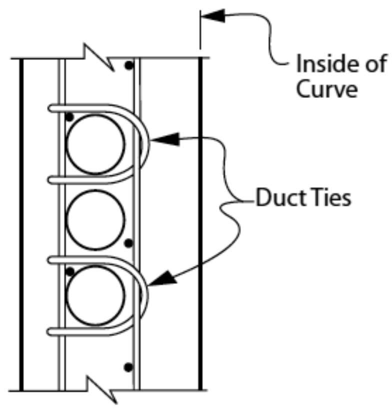

Figure 5.27.5.1 Duct Tie Configuration

5.27.5.1 Determine if “Detail A” Is Needed

Determine if “Detail A” shall be used based upon Figure 5.27.5.1.2. “Detail A” shall be used when the lateral force ($F_{u\text{-}in}$) versus clear height (h_c) is plotted on Figure 5.27.5.1.2 and is larger than the curve value for the specific girder radius. For h_c, see Figure 5.27.5.1.1. The need for “Detail A” should be checked for exterior sloped girders and vertical interior girders separately.

$$F_{u-in} = \frac{P_u \cos\theta}{R} \qquad (5.27.5.1.1)$$

$$F_{u-in} = \gamma P_j \qquad (5.27.5.1.2)$$

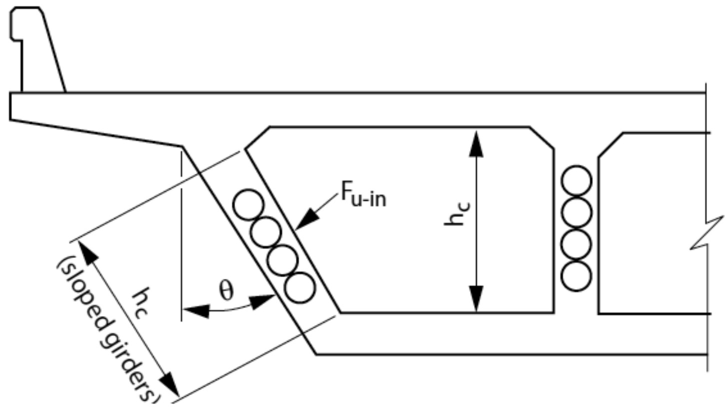

Figure 5.27.5.1.1 Lateral Tendon Force

The need for “Detail A” is a function of the concrete tensile stress adjacent to the tendons. Tensile stress contributions come from the local cover beam over the tendons as well as regional transverse bending of the girder spanning between the top and bottom slabs.

The highest possible girder tendon force is to be used when calculating P_u. Take into account the final force variation between girders. In general, the maximum final force ratio between any two girders is 10:9.

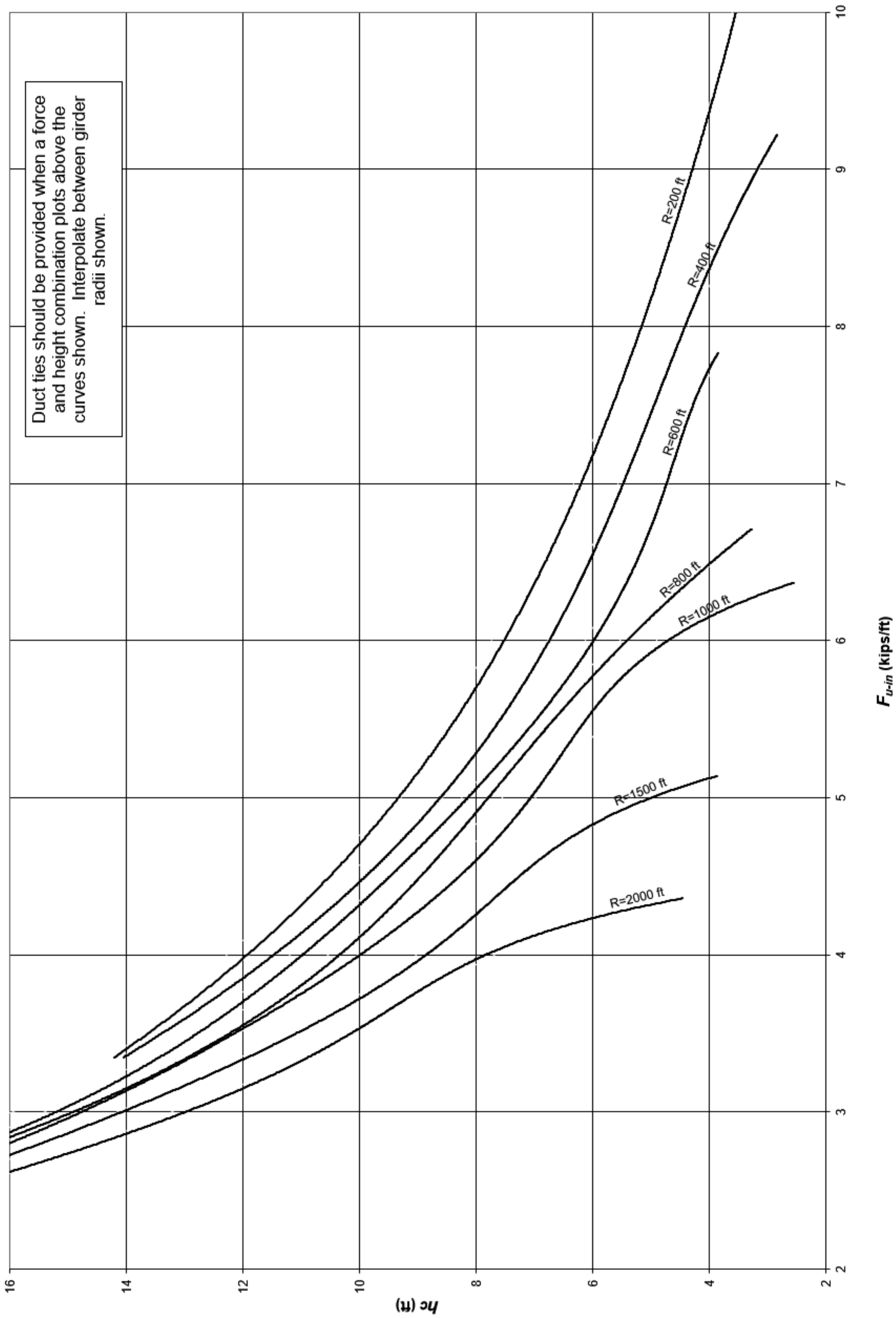

Figure 5.27.5.1.2 Need for “Detail A”

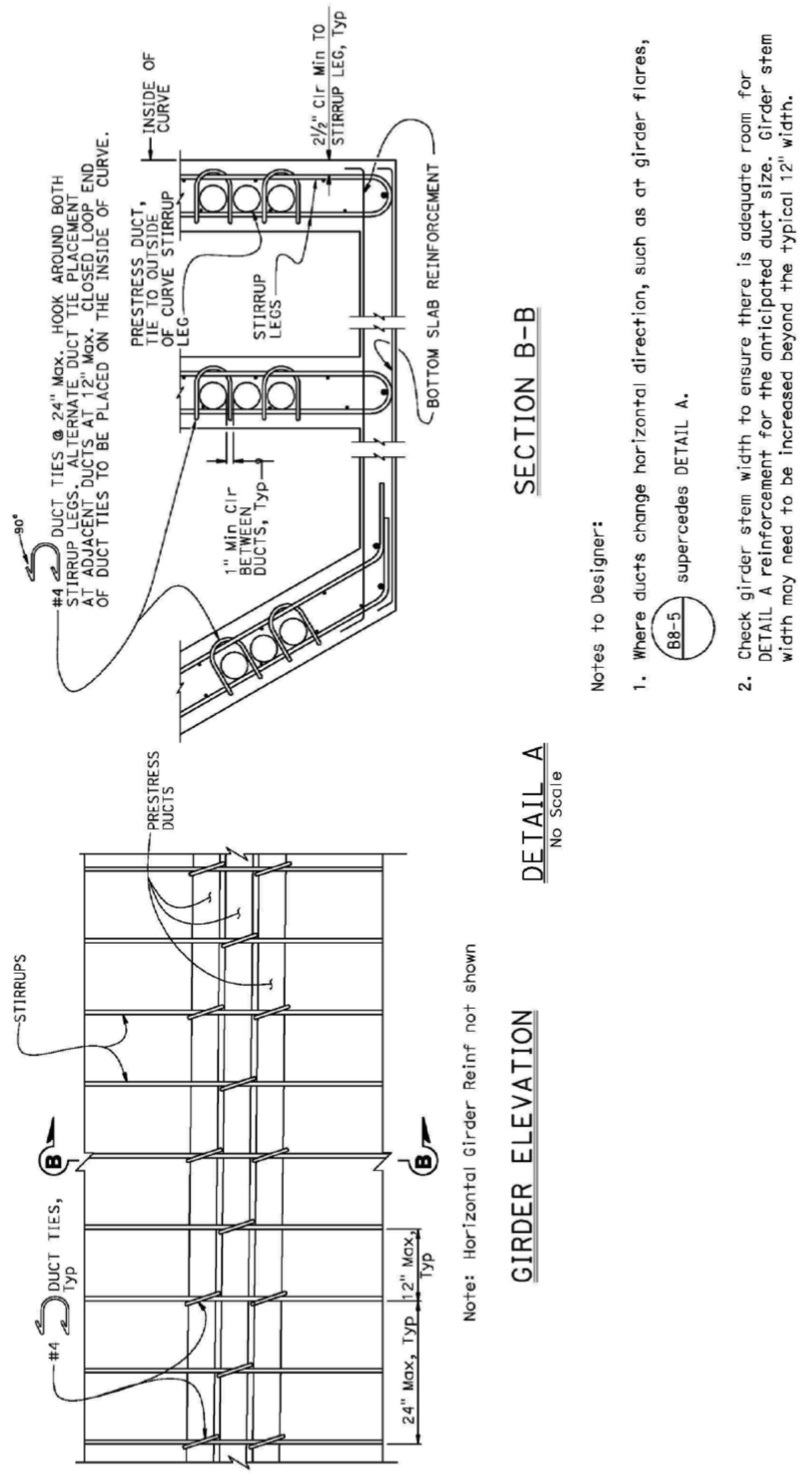

Figure 5.27.5.1.3 "Detail A"

5.27.5.2 Girder Stirrup Spacing

Determine the stirrup spacing that should be used due to lateral tendon flexural effects utilizing Figures 5.27.5.2.1 through 5.27.5.2.6. This stirrup requirement is in addition to what is needed to resist other loads. Interpolation is necessary for bridges with radii between those shown in these six figures. Spacing for other stirrup sizes can be determined by using an equivalent area of steel.

Stirrup spacing requirements were determined using a combination of three different force effects. A strut and tie model was used to capture the interaction of the duct ties with the inside-of-curve stirrup leg. Local beam flexural effects were then added to this. The local beam is the cover concrete adjacent to the duct stack with the stirrup leg acting as the reinforcement within that local beam. Finally, regional flexural effects were added assuming the girder acts as a beam spanning between the deck and soffit slabs.

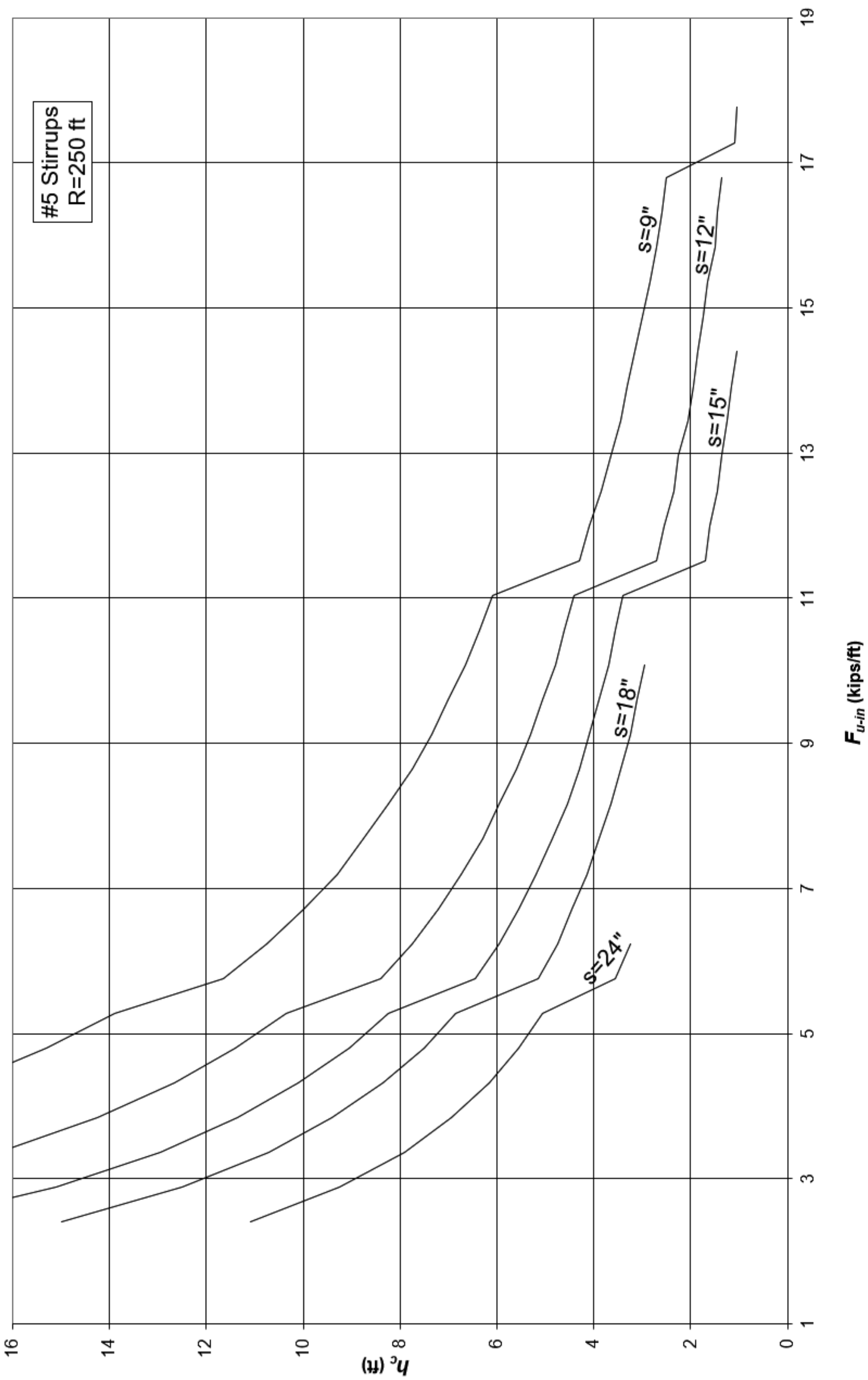

Figure 5.27.5.2.1 Stirrup Spacing R = 250 ft

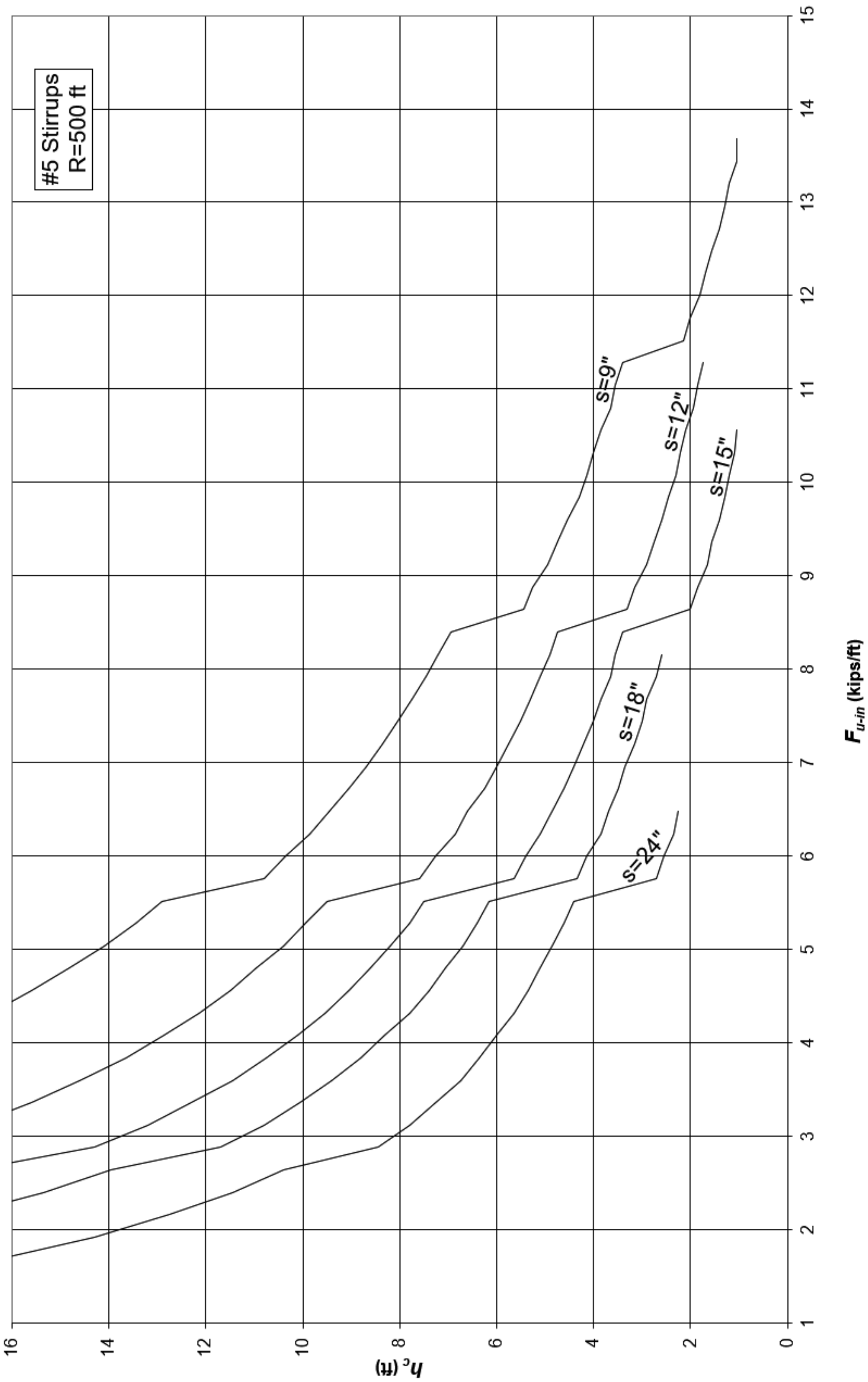

Figure 5.27.5.2.2 Stirrup Spacing R = 500 ft

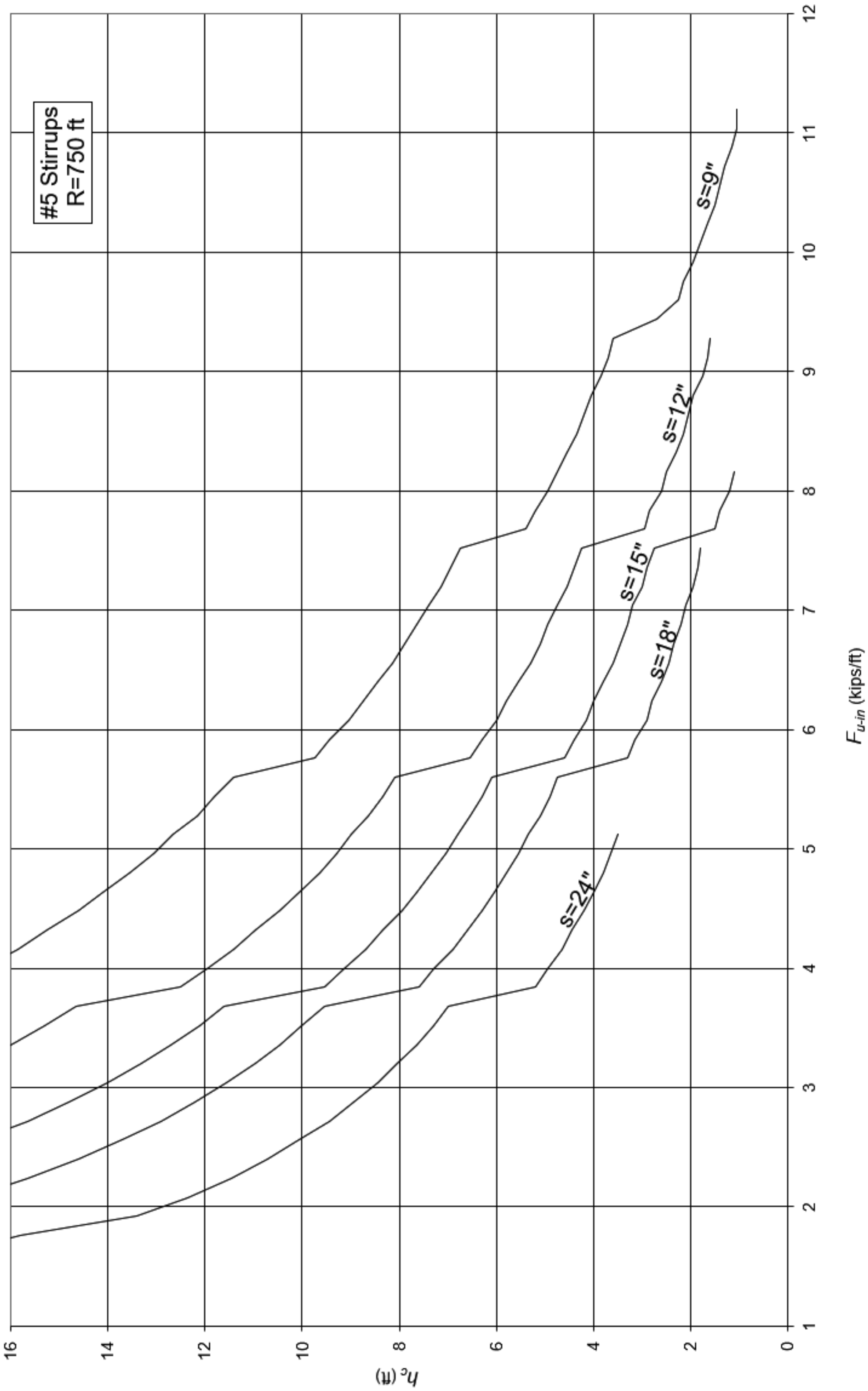

Figure 5.27.5.2.3 Stirrup Spacing R = 750 ft

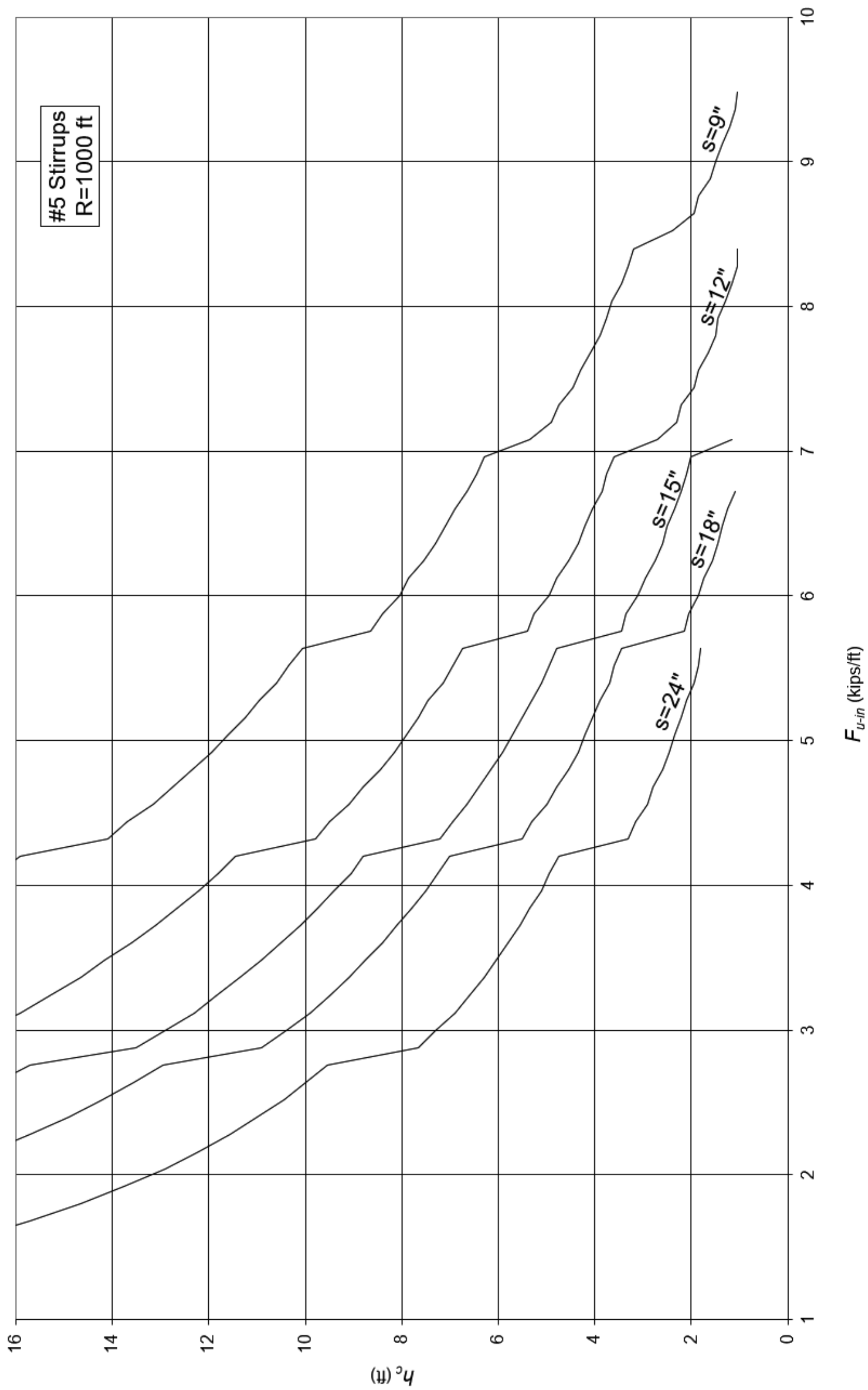

Figure 5.27.5.2.4 Stirrup Spacing R = 1000 ft

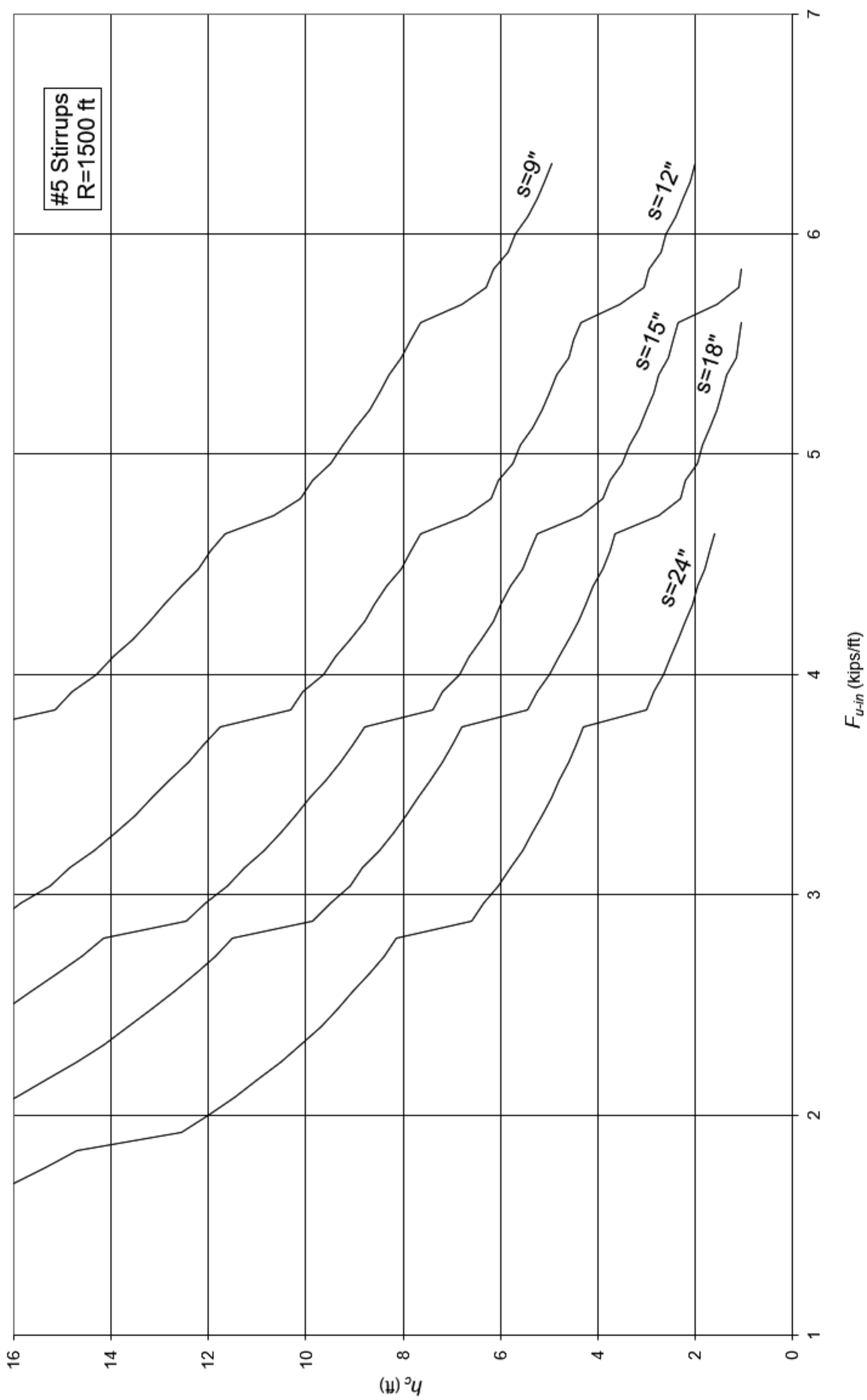

Figure 5.27.5.2.5 Stirrup Spacing R = 1500 ft

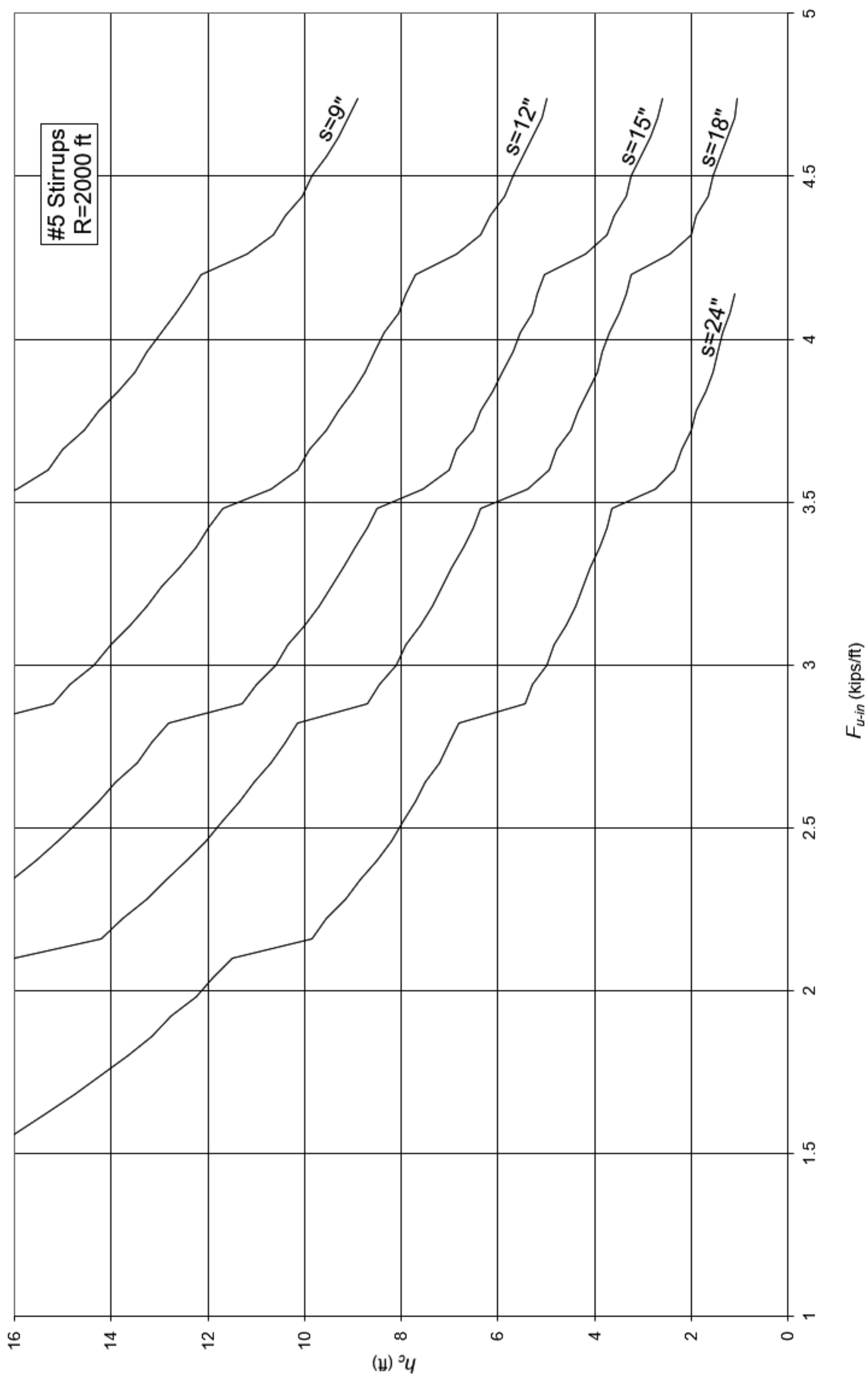

Figure 5.27.5.2.6 Stirrup Spacing R = 2000 ft

The following assumptions were used to develop Figures 5.27.5.1.2, 5.27.5.1.3, and 5.27.5.2.1 through 5.27.5.2.6:

- There is 4 inches of cover between the duct and the girder face on the inside of curve. There is only one vertical or sloped column of tendons.
- Exterior girders are assumed as they control regional flexural effects with the higher continuity factor of 0.7.
- There is a 1-inch vertical gap between tendons.
- Cracking potential is determined from the combination of regional and local beam flexural effects.
- Stem thickness is 12 inches. The stem thickness can be increased to effectively reduce the cracking potential due to lateral tendon forces. However, this should be balanced against the resulting increase in dead load and prestressing force.
- f'_{ci} = 3.5 ksi
- ϕ = 0.85 for cracking stress capacity
- Concrete tensile stress limit = $\phi \times 0.24\sqrt{f'_{ci}}$ (ksi)

5.27.6 EXAMPLE

Consider the following example bridge:

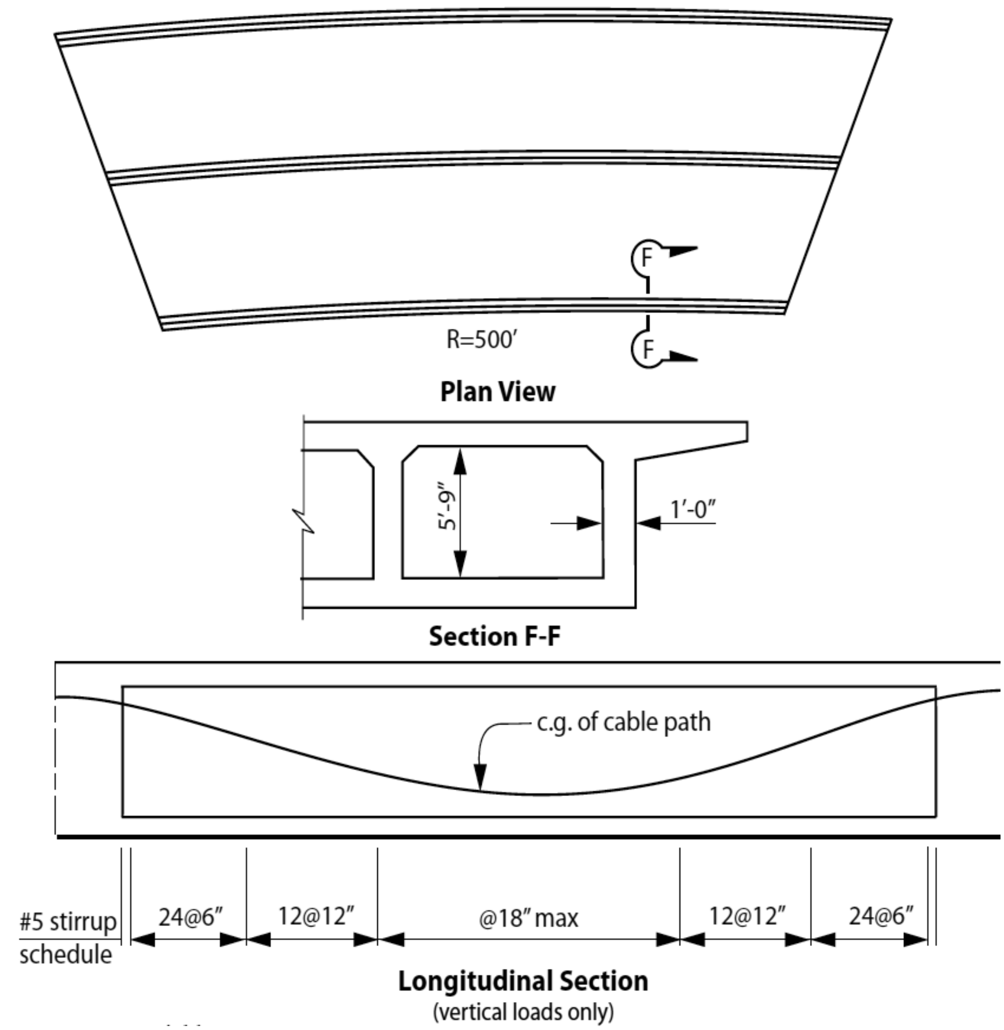

Figure 5.27.6.1 Example Bridge Details

Key variables:

P_j = 2917 kips/girder

h_c = 5.75 ft

$F_{u\text{-}in}$ = 1.2 x 2917/500 = 7.0 kips/ft

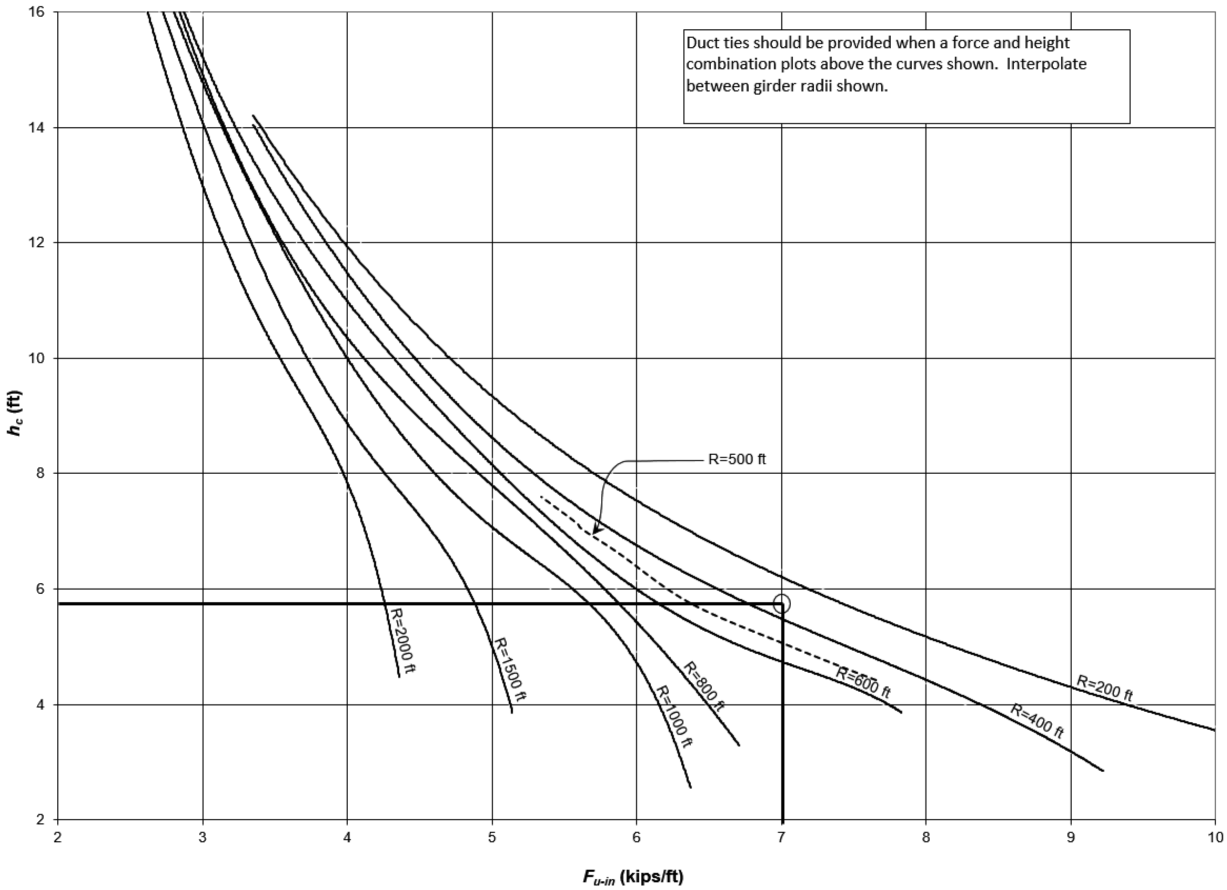

Figure 5.27.6.2 Check if "Detail A" Is Needed

Figure 5.27.6.2 shows the plot of point (7, 5.75). Since this point plots above the curve for R=500 feet (see dashed line), "Detail A" is needed.

Additionally, the vertical girder stirrup design needs to include the effects of lateral tendon forces. Figure 5.27.5.2.2 applies as R = 500 feet.

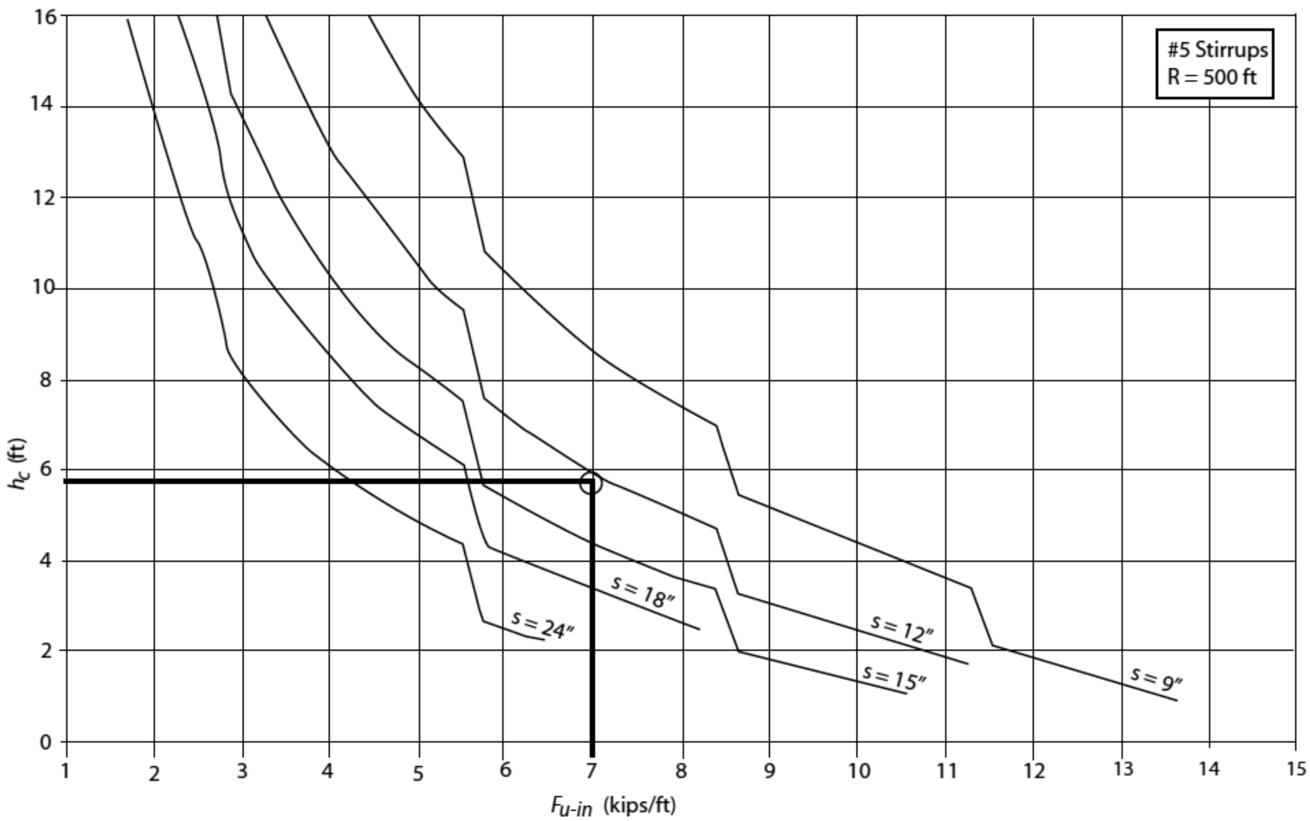

Figure 5.27.6.3 Lateral Loads Stirrup Spacing

Using Figure 5.27.6.3, plot the point (7, 5.75). This point lies just below the curve for s =12 inches. Therefore, the stirrup schedule will need to incorporate this stirrup requirement of #5 @ 12 = 0.31 in^2/ft.

The interaction between lateral loads and other loads on stirrup requirements is not simply additive. Therefore, one method to combine the requirements was proposed by Podolny and Muller [3].

Using this combination method, a final stirrup design is shown in Table 5.27.6.1 (values are in in^2/ft for one stirrup leg):

Table 5.27.6.1 Design Stirrup Spacing

Region	(a) $(A_s)_{OL}$	(b) $(A_s)_{LB}$	(c) (a)+ ½(b)	(d) ½(a)+(b)	(e) 0.7(a+b)	Max c,d,e Design A_s	Design spacing
24@6"	0.62	0.31	0.775	0.620	0.651	0.775	@4"
12@12"	0.31	0.31	0.465	0.465	0.434	0.465	@8"
@18" max	0.207	0.31	0.362	0.413	0.362	0.413	@9"

OL = Other Loads; LB = Lateral Bending

Revised stirrup schedule (combination of other loads and lateral tendon force):

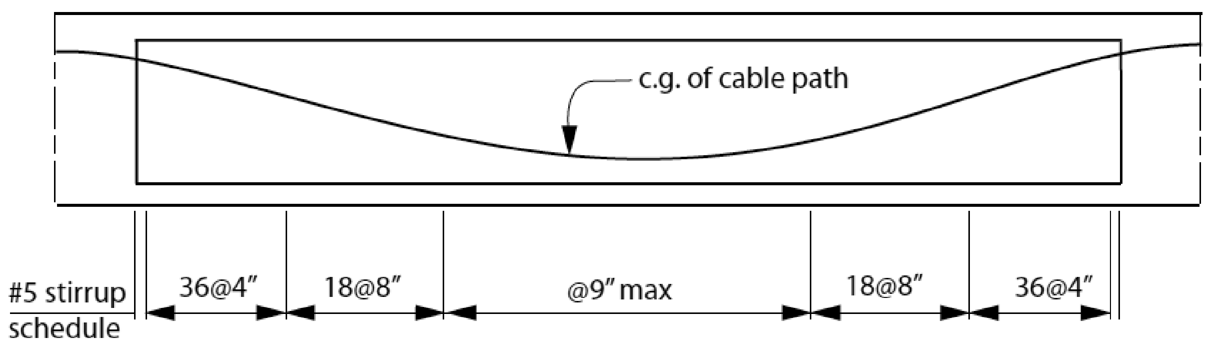

Figure 5.27.6.4 Longitudinal Section/Stirrup Schedule

Note that the revised stirrup spacing in the middle of the span assumes that the spacing required for other loads is 18 inches. Generally, the spacing required in this region due to the strength limit state will be greater than 18 inches. In practice, one should use the actual demand stirrup spacing required in this region before combining with lateral tendon shear demand. The combination should then be limited to 18 inches maximum spacing or 12" maximum if "Detail A" is used.

5.27.7 CONSTRUCTABILITY

When P_j results in a tall duct stack (more than 3 tendons), special attention should be paid to ensuring well-consolidated concrete around each duct. The designer may want to consider a girder design with a thicker stem width. A designer may also want to investigate a concrete mix design that limits the aggregate size to ensure reliable concrete placement. It is recommended to add a note in the RE Pending File to ensure careful inspection and quality assurance during concrete placement around the ducts.

5.27.8 REFERENCES

1. Nutt, Redfield and Valentine, David Evans and Assoc., Zocon Consulting Engineers. NCHRP Report 620. (2008). "*Development of Design Specifications and Commentary for Horizontally Curved Concrete Box-Girder Bridges*".
2. AASHTO. (2017). *AASHTO LRFD Bridge Design Specifications*, 8th Edition, American Association of State Highway and Transportation Officials, Washington DC.
3. Podolny, W. and Muller, J. (1982) "*Construction and Design of Prestressed Concrete Segmental Bridges*". Wiley-Interscience.