11-31 CURVED POST-TENSIONED BRIDGES

General

Cast-in-place post-tensioned girders designed with horizontal curvature will require special consideration due to the presence of lateral prestress forces. In particular, a lateral force approximately equal to the jacking force (P_{jack}) divided by the radius (R) will need to be part of the girder design loads.

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_{jack} per girder (say 8,000 kips) and/or for structure depths exceeding 16 feet. Refer to National Cooperative Highway Research Program (NCHRP) Report 620.

Scope

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

1. Duct ties are to be provided if required for containment of tendons. Refer to Figures 1 through 4.
2. Vertical stirrup designs shall be modified to include the effects of regional transverse bending of the web according to Figures 5 through 10.
3. The cable path of the tendons shall be adjusted to account for increased spacing between ducts if "Detail A" is applicable. Refer to MTD 11-28.

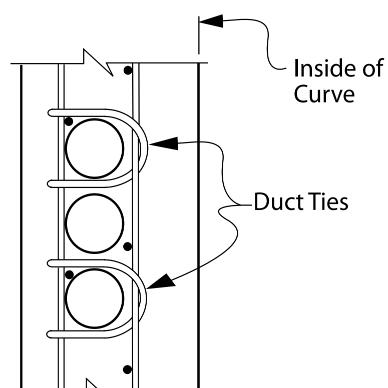


Figure 1

Procedure

Step 1

Determine if "Detail A" is required based upon Figure 3. "Detail A" is required when lateral force *($F_{u\text{-}in}$)* versus clear height (h_c) is plotted on Figure 3 and exceeds the curves shown for the girder's given radius. In general, the need for "Detail A" should be checked for exterior sloped girders and vertical interior girders separately.

The following variables will need to be identified or calculated:

h_c = clear height of girder (ft)

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

$$F_{u\text{-}in} = \frac{p_u \cos\theta}{R}$$

P_u = girder tendon force (P_{jack}) factored by the load factor $\gamma = 1.2$

R = horizontal radius of the centerline of the girder under consideration

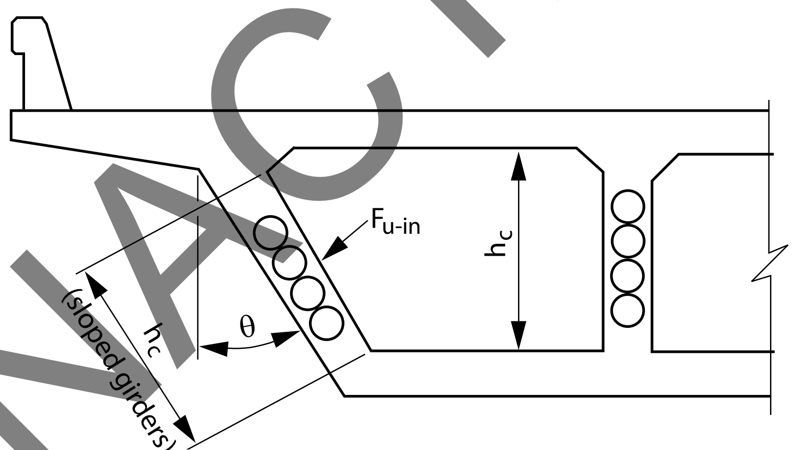


Figure 2

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 considered when calculating P_u. Consideration of the final force variation between girders shall be taken into account. In general, the final force variation between girders is allowed to be within the ratio of 10:9.

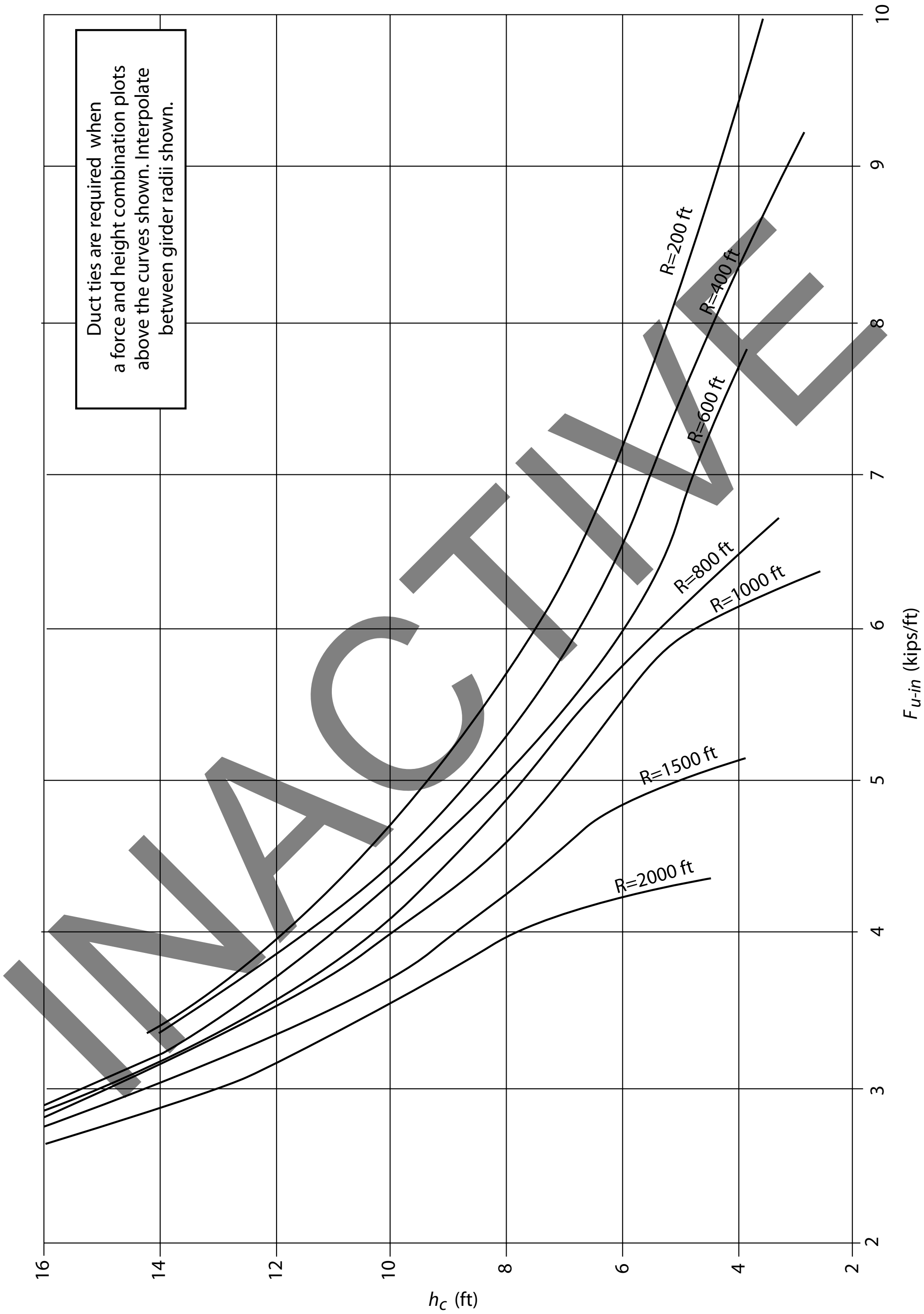
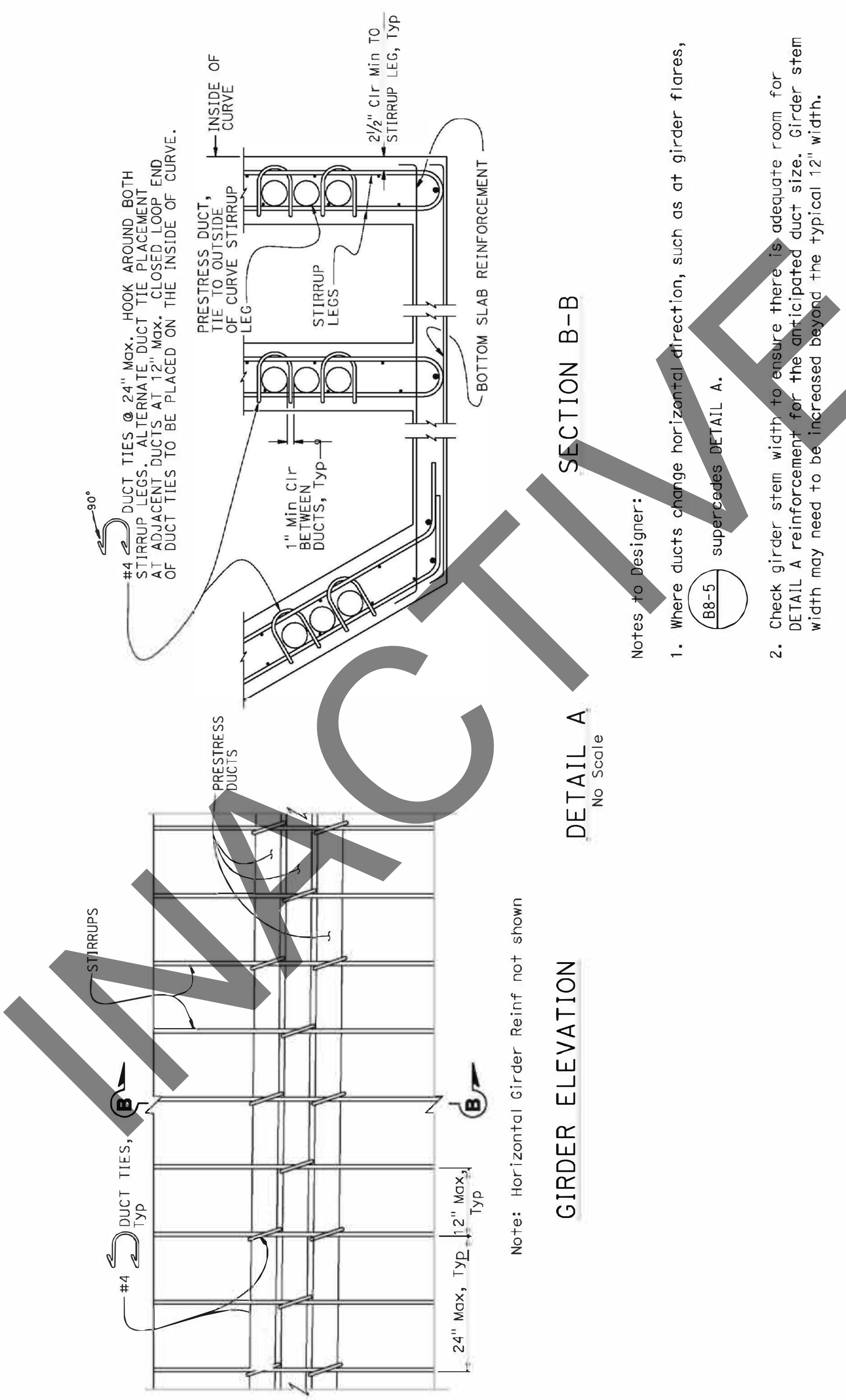

Duct ties are required when
a force and height combination plots
above the curves shown. Interpolate
between girder radii shown.
R=200 ft
R=400 ft
R=600 ft
R=800 ft
R=1000 ft
R=1500 ft
R=2000 ft
h_c (ft)
F_{u-in} (kips/ft)
16
14
12
10
8
6
4
2
2
3
4
5
6
7
8
9
10

Figure 3



Notes to Designer:

1. Where ducts change horizontal direction, such as at girder flares, B8-5 supercedes DETAIL A.
2. Check girder stem width to ensure there is adequate room for DETAIL A reinforcement for the anticipated duct size. Girder stem width may need to be increased beyond the typical 12" width.

Figure 4

Step 2

Determine the required stirrup spacing due to lateral tendon flexural effects utilizing Figures 5 through 10. This stirrup requirement is in addition to what is needed for other loads. Interpolation is necessary for bridges with radii that fall in between those shown below. Spacing for other stirrup sizes can be accomplished by using an equivalent area of steel.

Stirrup spacing requirements are determined using a combination of three different force effects. A strut and tie model is used to capture the interaction of the duct ties with the inside of curve stirrup leg. Local beam flexural effects are 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 are added assuming the girder acts as a beam spanning between the top and bottom slabs.

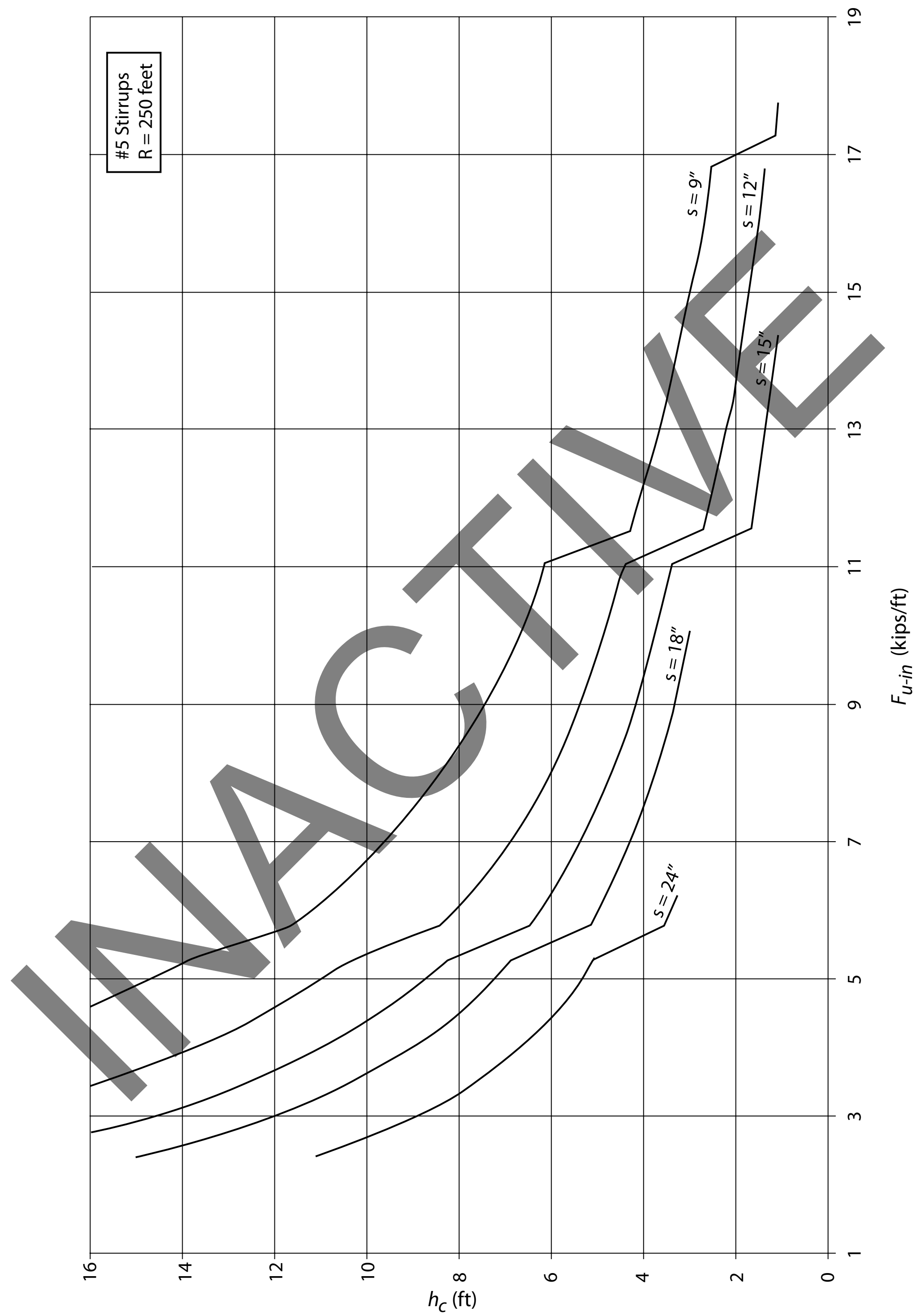

#5 Stirrups
R = 250 feet
s = 9"
s = 12"
s = 15"
s = 18"
s = 24"
$F_{u\text{-}in}$ (kips/ft)
h_c (ft)
16
14
12
10
8
6
4
2
0
1
3
5
7
9
11
13
15
17
19

Figure 5

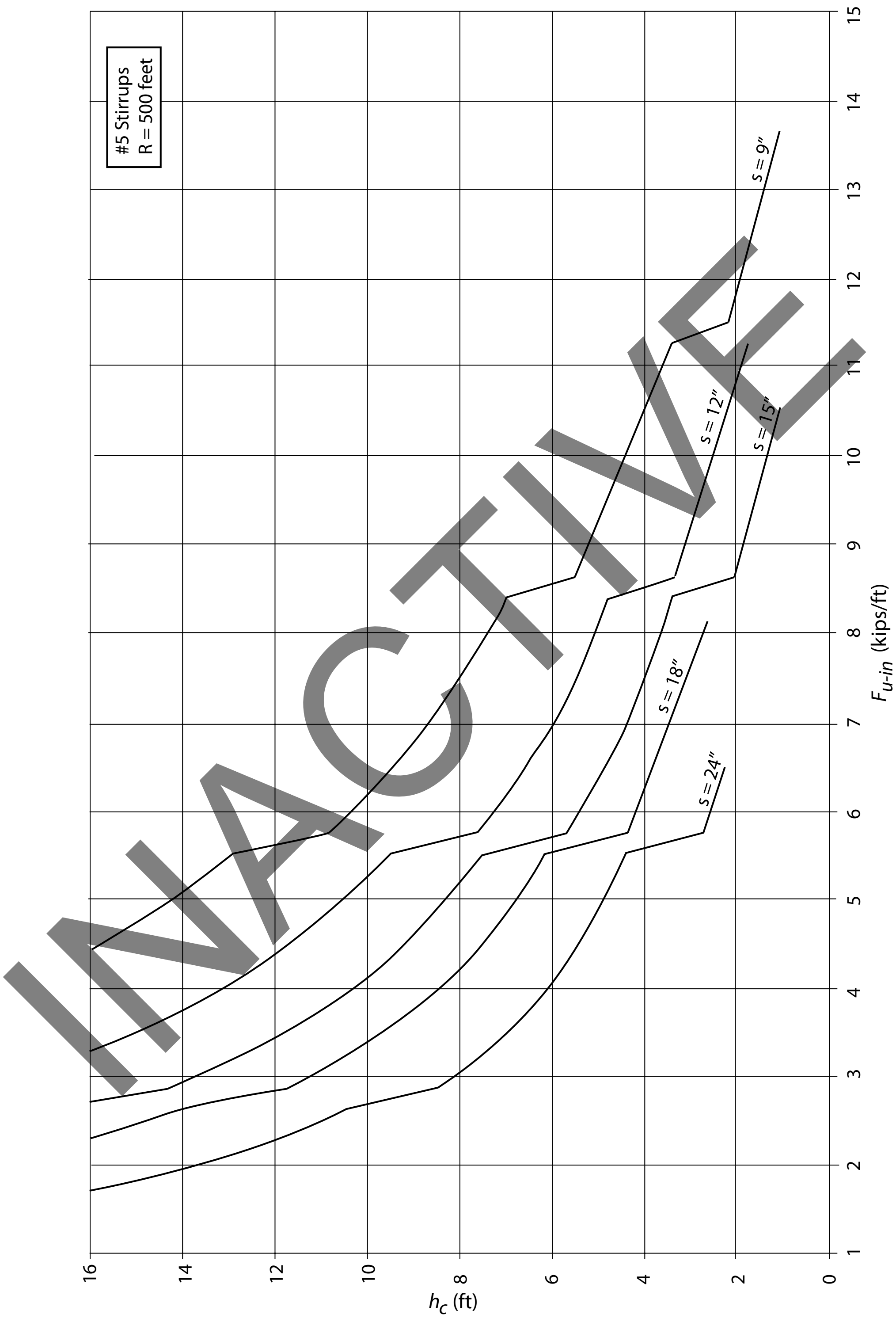

#5 Stirrups
R = 500 feet
s = 9″
s = 12″
s = 15″
s = 18″
s = 24″
$F_{u\text{-}in}$ (kips/ft)
h_c (ft)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
14
12
10
8
6
4
2
0

Figure 6

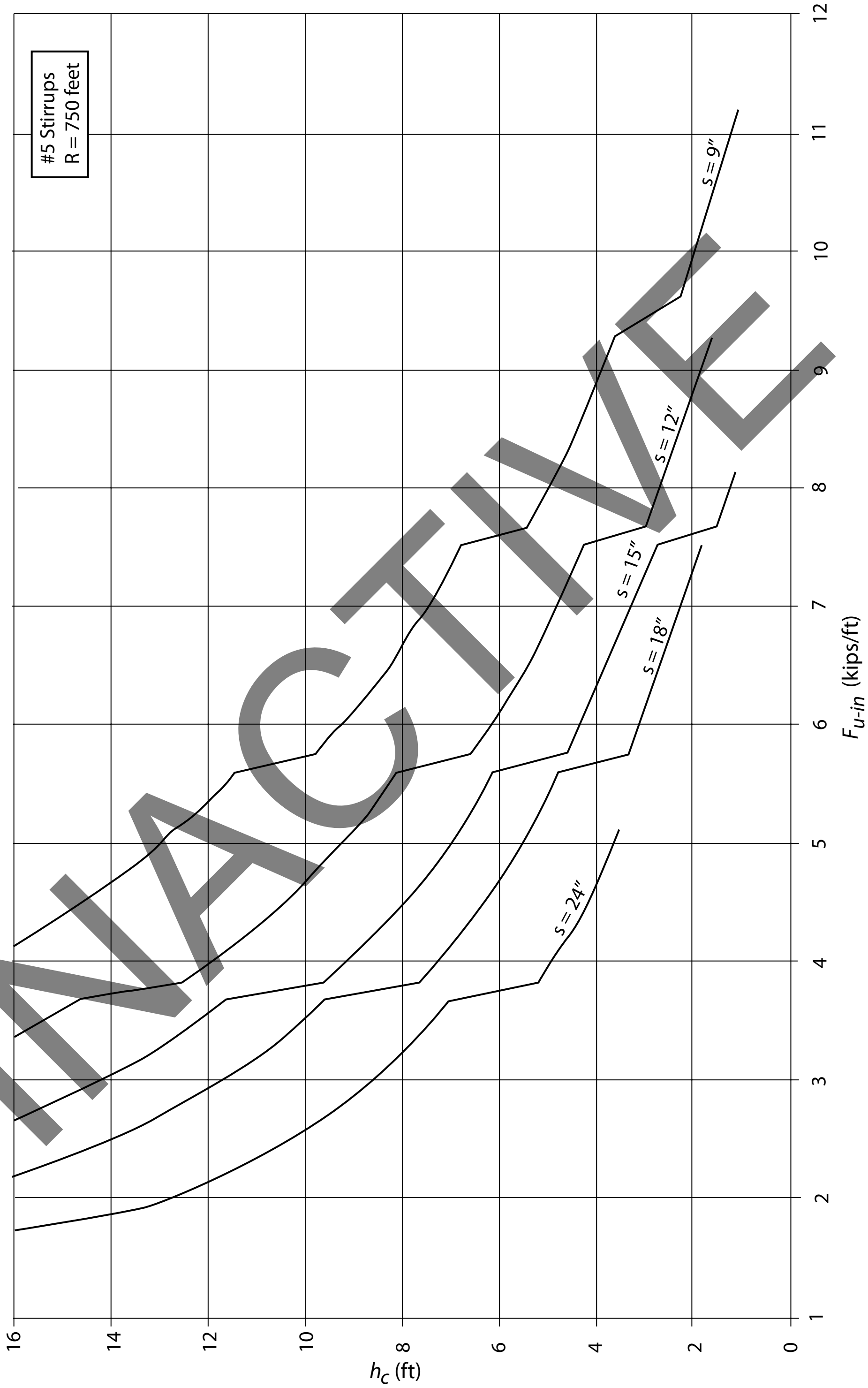


Figure 7

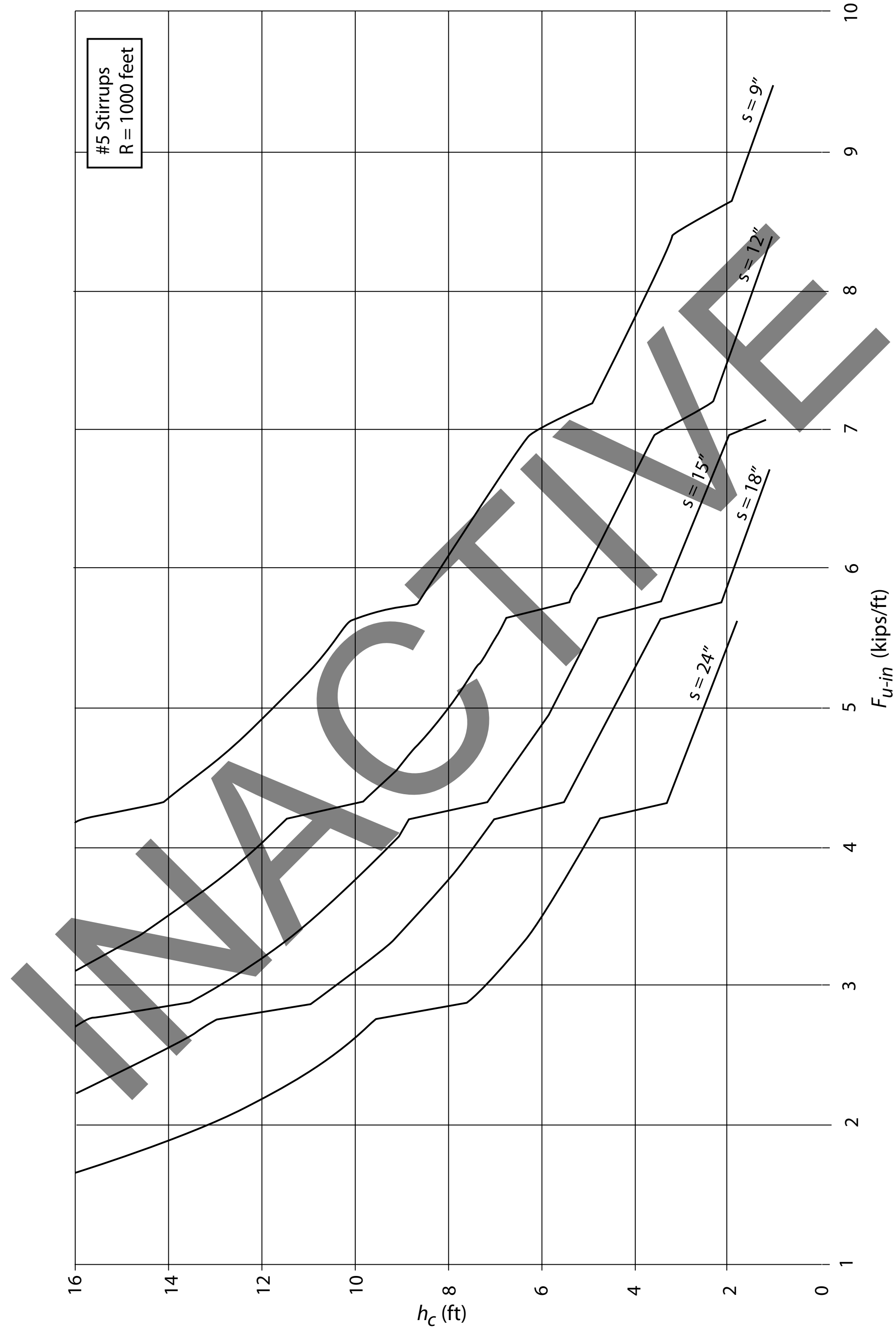

#5 Stirrups
R = 1000 feet
s = 9″
s = 12″
s = 15″
s = 18″
s = 24″
$F_{u\text{-}in}$ (kips/ft)
h_c (ft)
1
2
3
4
5
6
7
8
9
10
16
14
12
10
8
6
4
2
0

Figure 8

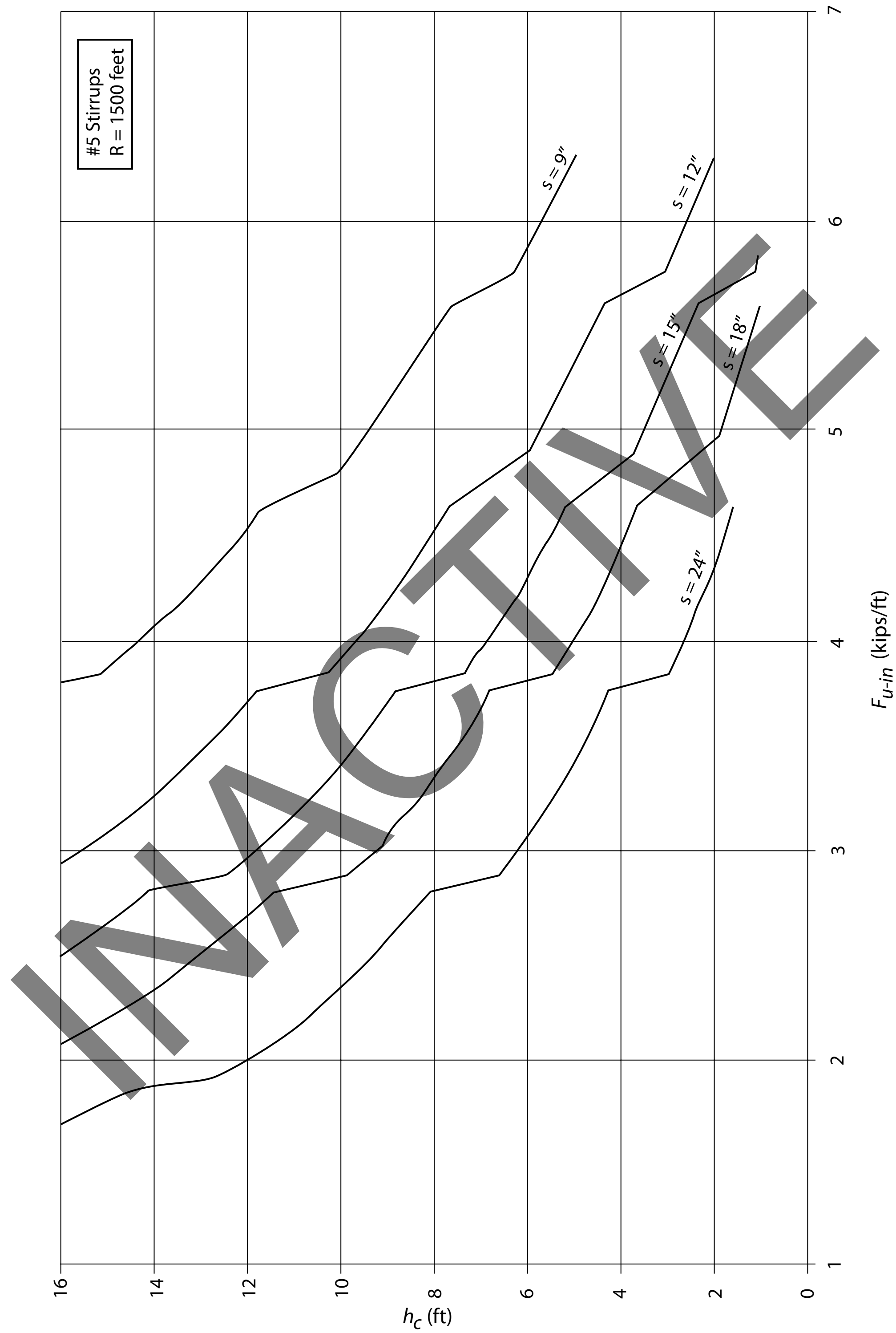

#5 Stirrups
R = 1500 feet
s = 9″
s = 12″
s = 15″
s = 18″
s = 24″
h_c (ft)
16
14
12
10
8
6
4
2
0
$F_{u\text{-}in}$ (kips/ft)
1
2
3
4
5
6
7

Figure 9

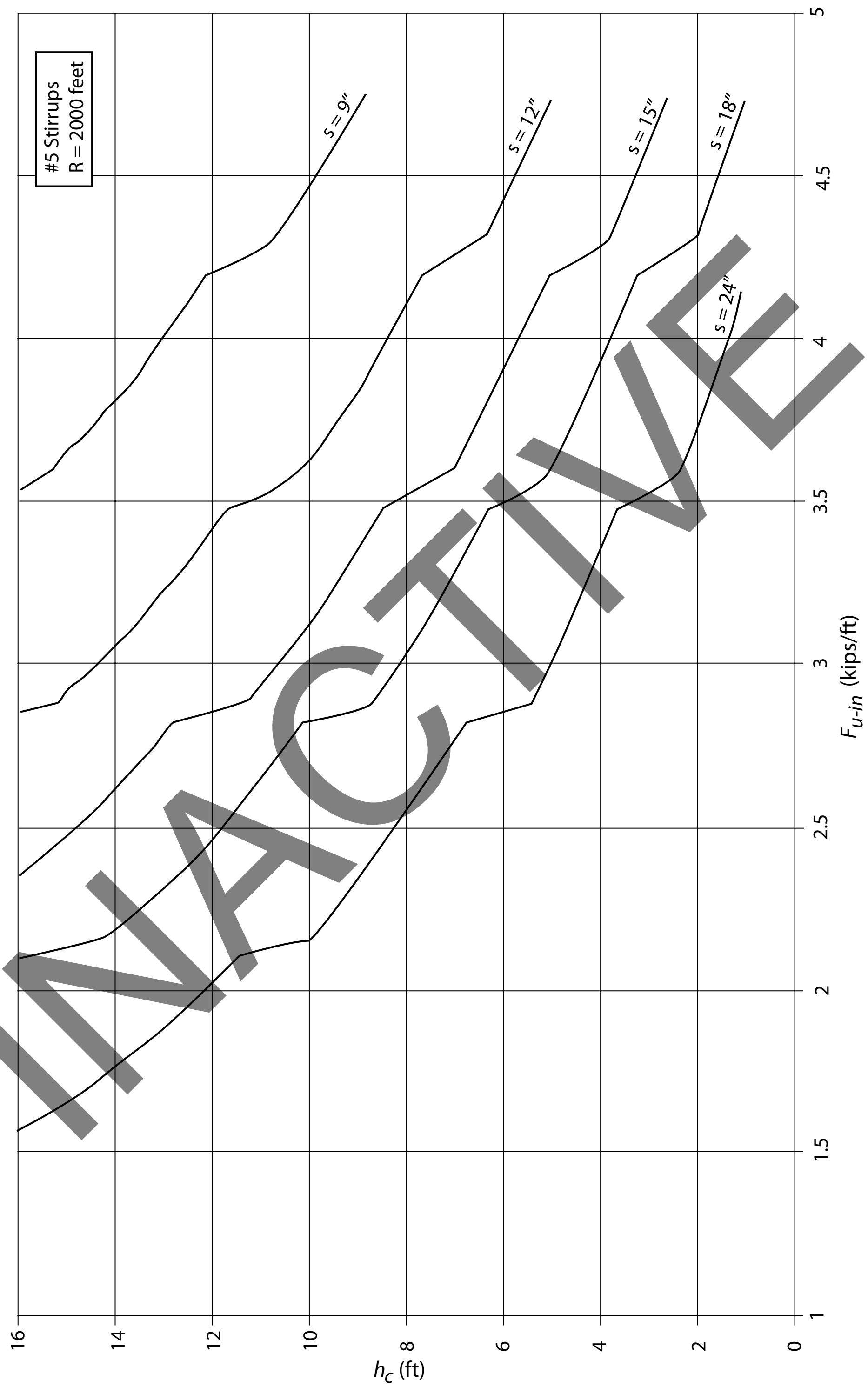

#5 Stirrups
R = 2000 feet
s = 9″
s = 12″
s = 15″
s = 18″
s = 24″
$F_{u\text{-}in}$ (kips/ft)
h_c (ft)
1
1.5
2
2.5
3
3.5
4
4.5
5
16
14
12
10
8
6
4
2
0

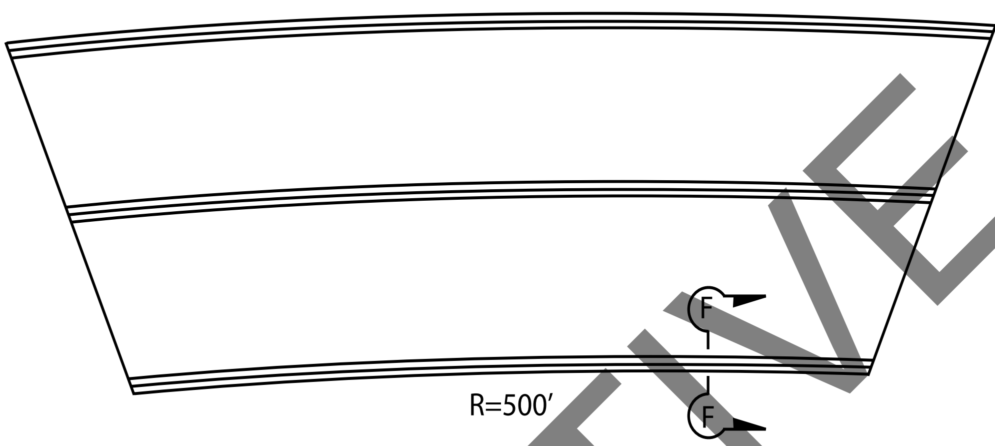
Figure 10

Assumptions used in Figures 3 through 10

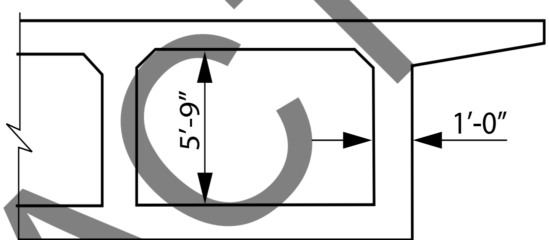
- There is 4” cover between the duct and the girder face on the inside of curve. There is only one vertical or sloped column of tendons.
- Exterior girders are assumed as they control regional flexural effects with the higher continuity factor of 0.7.
- There is a 1-inch vertical gap between tendons.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

Example

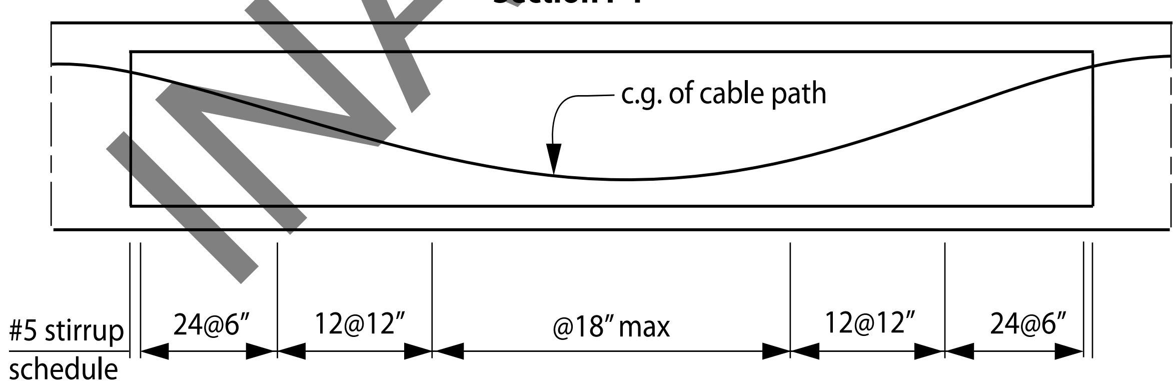
Consider the following example bridge:



Plan View



Section F-F



Longitudinal Section
(vertical loads only)

Key variables

P_{jack} = 2917 kips/girder
h_c = 5.75 feet
$F_{u\text{-}in}$ = 1.2 X 2917/500 = 7.0 kips/ft

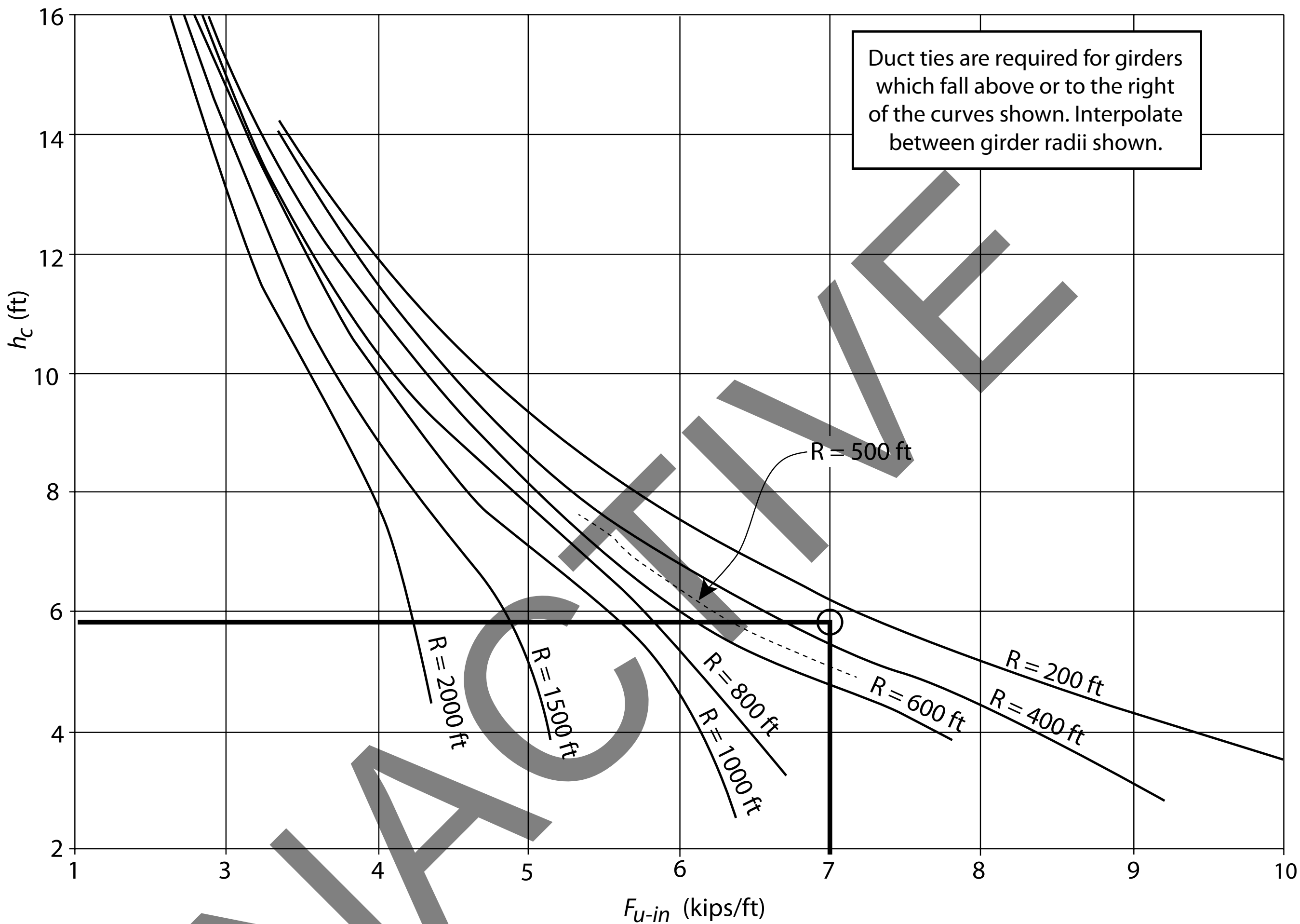


Figure 11

From Figure 3, plot the point (7, 5.75) (see Figure 11). Since this point plots above the curve for R=500 feet (see dashed line), “Detail A” is required.

Additionally, since duct ties are required, the vertical girder stirrup design must include the effects of lateral tendon forces. Figure 6 applies as R=500 feet.

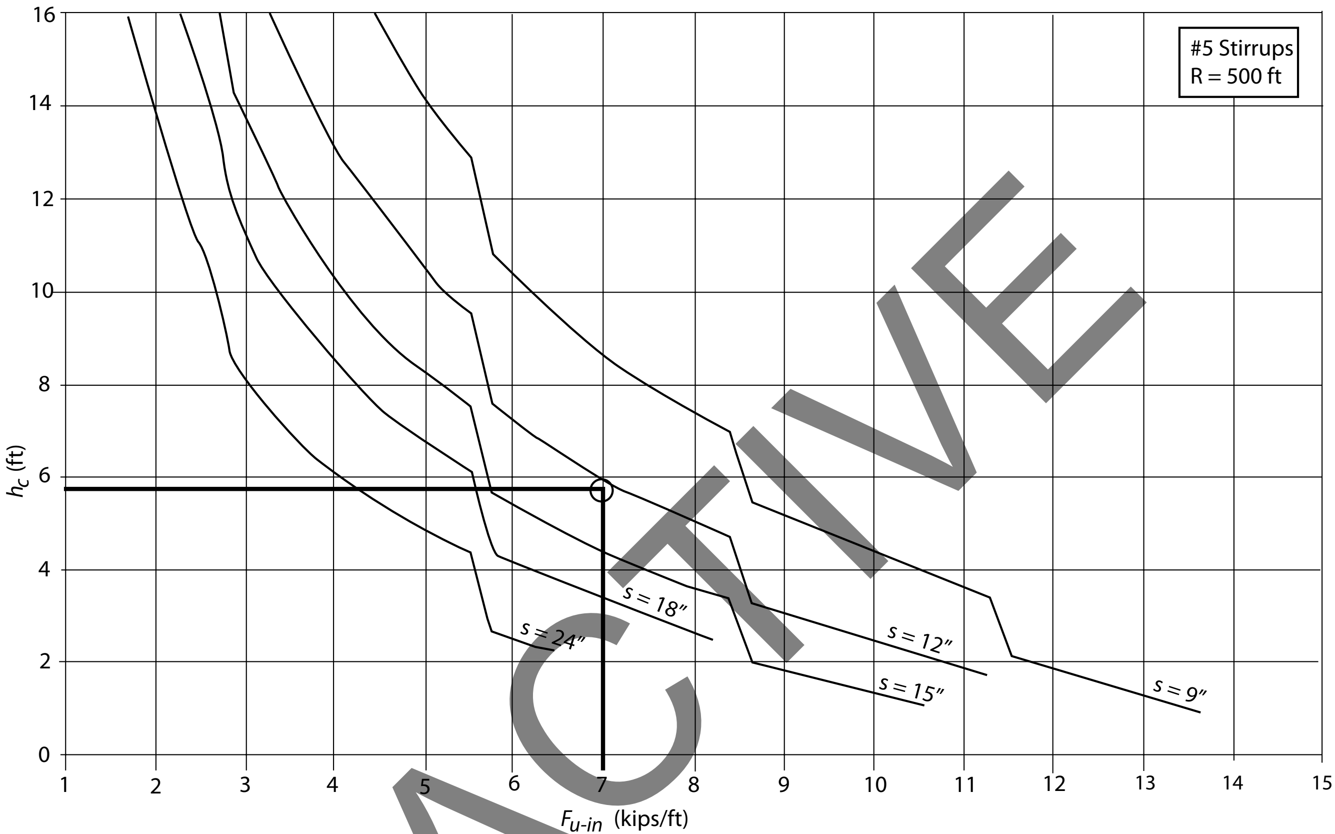


Figure 12

Using Figure 6, plot the point (7, 5.75) as before (see Figure 12). This point lies just below the curve for s =12 inches. Therefore, the stirrup schedule will need to be revised to add this stirrup requirement. #5 @ 12 = 0.31 in^2/feet.

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-Muller.

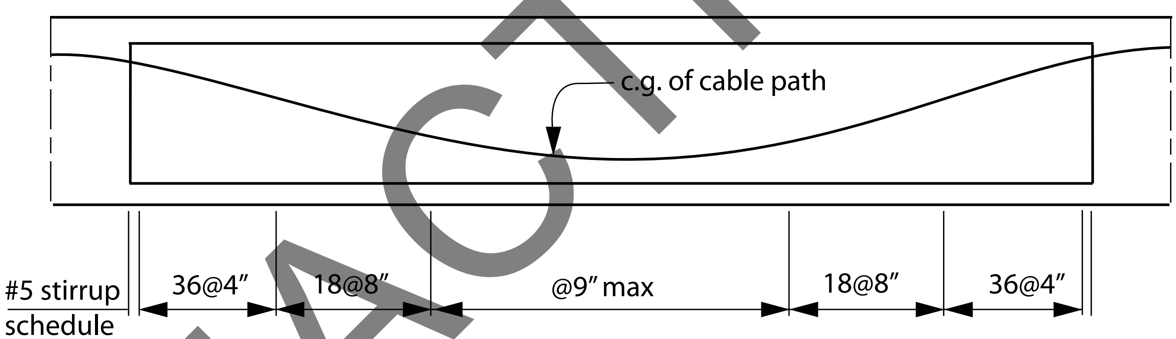
Using this combination method, a final stirrup design is shown in Table 1 (values are in^2/ft for one stirrup leg):

	(a)	(b)	(c)	(d)	(e)	Max c,d,e	
Region	$(As)_{OL}$	$(As)_{LB}$	(a)+$^1/_2$(b)	$^1/_2$(a)+(b)	0.7 (a+b)	Design As	Design Spacing
24@6″	0.62	0.31	0.775	0.62	0.65	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

Table 1

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



Longitudinal Section

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.

Constructability

To facilitate maintaining the correct concrete cover thickness over the stirrups, mid-height dobies, or other means to keep the rebar cage in place should be considered. Alert the structure representative to the importance of maintaining good cover concrete especially at mid-height of the stirrup legs.

When P_{jack}/girder results in a tall duct stack (more than 3 tendons), consideration should be given to providing well consolidated concrete around each duct. The girder design could utilize a thicker stem width, a concrete mix design could be considered which limits the aggregate size to ensure reliable concrete placement, or the lost forms inside the box could be removed to inspect the integrity of the stem and soffit pour.

References

NCHRP Report 620 "Development of Design Specifications and Commentary for Horizontally Curved Concrete Box-Girder Bridges" Nutt, Redfield and Valentine, David Evans and Assoc., Zocon Consulting Engineers (2008)

AASHTO LRFD Bridge Design Specifications, 4th Edition, with CA Amendments, Article 5.10.4.3

Original signed by Barton J. Newton

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