11-25 ANCHORAGE ZONE DESIGN

General

The anchorage zone of a post-tensioned concrete box girder member is that area in front of the prestress blockout where stress concentrations occur. The design engineer is responsible for the design of both the local zone and the general zone. AASHTO LRFD 5.10.9 covers the requirements for these regions. In Figure 1, the limits of the anchorage zone are defined for the purposes of this memo. The equations presented herein are the result of empirically enveloping three dimensional model results and can be applied to bridges with P_{jack} per girder up to 6000 kips.

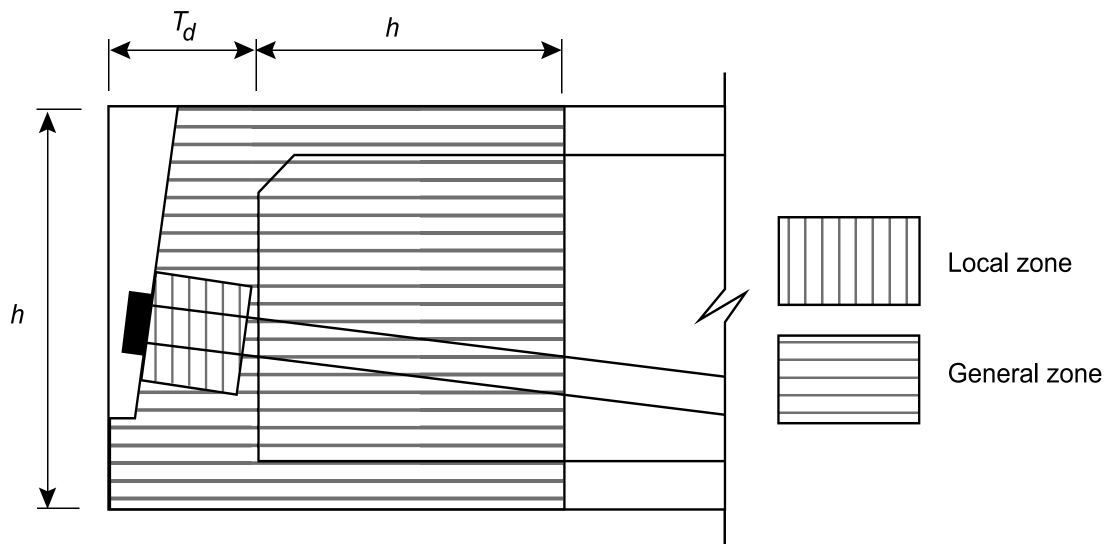


Figure 1 - Anchorage Zone limits

Background

General zone design can be accomplished with 3D finite element modeling. Such models show that most of the post-tensioning stresses within this region that are of concern to designers are the vertical tensile stresses and the longitudinal compressive stresses in the girder webs. Tensile stresses in the top and bottom slabs are relatively small and can be resisted with typical section transverse reinforcement. Because it is impractical to develop 3D models for every bridge, this memo provides a conservative approach to the design of the general zone.

Local Zone Design

The size of the local zone and the reinforcement design depend on the anchorage system used by the post-tensioning Contractor. The Contractor submits the prestress shop drawings with local zone details to the Design Engineer for review. It is the responsibity of the Design Engineer to ensure that the local zone details submitted are in agreement with the details of the preapproved system.

General Zone Design

End Diaphragm Thickness

3D models show that the vertical tensile stresses in the girder webs are reduced with a thicker diaphragm. Therefore, the minimum recommended diaphragm thickness is as follows:

$$T_d \geq 0.3 \times h \qquad (1)$$

In Equation (1) T_d and h are in feet.
For shallow structures, the absolute minimum diaphragm thickness is 2′-6″ at abutments and 2′-0″ at hinges. Refer to MTD 11-28 for additional diaphragm thickness requirements. The thickest of these diaphragm requirements shall be used.

Girder Stem Reinforcement

Minimum vertical reinforcement in the girder webs shall be designed as follows:

$$A_{s1} = \frac{1.33P * \left(h - \frac{P}{1200}\right)}{300 * h^2} \text{ Place within the first } {}^{h}/_{2} \qquad (2)$$

$$A_{s2} = \frac{0.67 * P\left(h - \frac{P}{1200}\right)}{300 * h^2} \text{ Place within the last } {}^{h}/_{2} \qquad (3)$$

Where:

A_{s1}, A_{s2} = Minimum vertical reinforcement to be extended a distance h in front of the diaphragm. Concentrate $^2/_3$ of this reinforcement in the first $h/2$ (A_{s1}) and $^1/_3$ in the latter half (A_{s2}). (in.^{2} per ft)

h = Cross section depth (ft)

P = P_{jack} per girder (kips) (consider the allowable final force variation between girders)

The designer should first establish the stirrup schedule for the girders considering all other loads. The stirrup schedule should then be checked using the equations above. The requirement for stirrups in the webs within the general zone due to prestressing forces should not be considered additive to other loads.

Girder Stem Thickness

The webs shall be designed to resist the longitudinal compressive forces. The girder thickness at the face of diaphragm, t_w, shall be designed so that:

$$(t_w)_{REQUIRED} \geq \frac{P*1000}{\left[\left(\frac{P}{1200}-1\right)*18+3\left(T_d-12\right)\right]*0.7\phi f'_{ci}}$$

Where:

t_w = web thickness (in)
T_d = End diaphragm thickness (in)
ϕ = resistance factor for compression = 0.7
f'_{ci} = specified concrete strength of the webs at the time of stressing (psi)

Top and Bottom Slab Design

3D finite element analysis results indicate that the tensile and comprehensive stresses in the top and bottom slabs are relatively small and therefore resisted by typical section transverse reinforcement. Standard slab thickness and reinforcement design as indicated by MTD 10-20 will satisfy General Zone requirements.

Example

Given:

Single span bridge (160 ft) with sloped exterior girders
h = 7′-3″
P_{jack} per girder = 2710 kips
Stirrup design in general zone due to other loads: #5 @ 9″
T_d = 39″
f'_{ci} = 3500 psi
t_w = 12″
skew = 0 degrees

1) Minimum diaphragm thickness:
   a) MTD 11-28 requires 3′-3″ for sloped exterior girder, no skew, $P_j > 2400$ kips/girder

   b) $0.3*h = 0.3*7.25 = 2.175$ ft

   MTD 11-28 controls, use $T_d = 39''$

2) Vertical stirrup design for general zone bursting stresses, in.²/ft

   a) #5 @ 9″ as designed = 0.31*2*12/9 = 0.83 in.²/ft

   b) From Eq. (2) in the first $^h/_2$:

$$A_s = \frac{1.33*2710*\left(7.25-\frac{2710}{1200}\right)}{300*7.25^2} = 1.14 \text{ in.}^2/\text{ft}$$

   c) From Eq. (3) in the last $^h/_2$:

$$A_s = \frac{0.67*2710*\left(7.25-\frac{2710}{1200}\right)}{300*7.25^2} = 0.57 \text{ in.}^2/\text{ft}$$

   d) Modify the stirrup schedule as follows:

   Stirrups within the first $h/2$:

   Use #5 @ 6″, $A_s = 1.24$ in.²/ft ≥ 1.14 in.²/ft

   Stirrups within the second $h/2$:

   Use #5 @ 9″, $A_s = 0.83$ in.²/ft > 0.57 in.²/ft, as originally designed

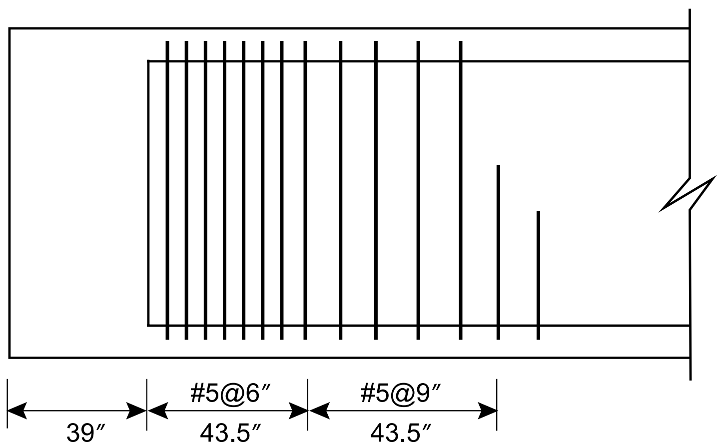
3) Check web thickness for compression

$$(t_w)_{REQUIRED} = \frac{2710*1000}{\left[\left(\frac{2710}{1200}-1\right)*18+3(39-12)\right]*0.7*0.7*3500} = 15.25''$$

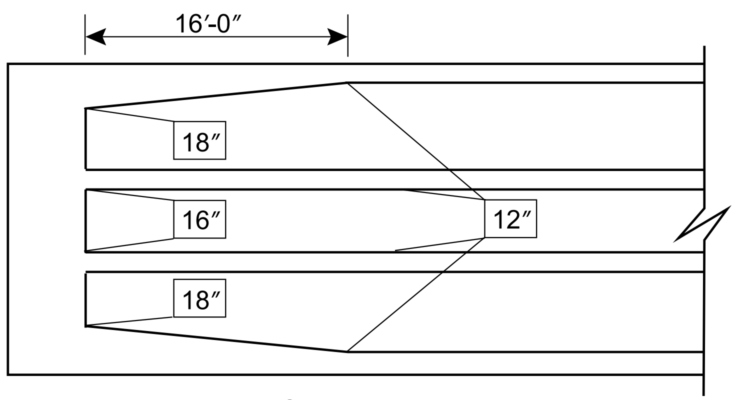
$$(t_w)_{PROVIDED} = 12'' < 15.25''$$

Increase the web thickness for interior girders to 16″ at the anchorages and flare to 12″ over 16 feet. Exterior girders are typically flared to 18″ near the anchorages to make room for the prestressing trumpets and spiral reinforcement. Therefore, the exterior girders are adequate as designed for compression.

4) Example details:



Longitudinal Section



Girder Layout

References

"Nonlinear Finite Element Analysis of Prestressed Anchorage Zones," Task Order No. 2, Contract No. 59A0603, Project No. CALT00590202, David Evans and Associates (2011)

Original signed by Barton J. Newton

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