5.26 ANCHORAGE ZONE FOR CAST-IN-PLACE PRESTRESSED BOX GIRDER BRIDGES

5.26.1 GENERAL

This BDM addresses the anchorage zone design of a post-tensioned concrete box girder bridge. The anchorage zone is the area in front of the prestress blockout where stress concentrations occur from post-tensioning. The design engineer is responsible for the design of the general zone and oversight of the local zone design by the Contractor via the authorized materials list. AASHTO-CA BDS Article 5.9.5.6 addresses the requirements for these regions. In Figure 5.26.1.1, the limits of the anchorage zone are defined for the purposes of this memo. The equations presented herein, based on strut and tie methods, are the result of experimental and analytical research on California bridges (Sanders and Maree, 2018).

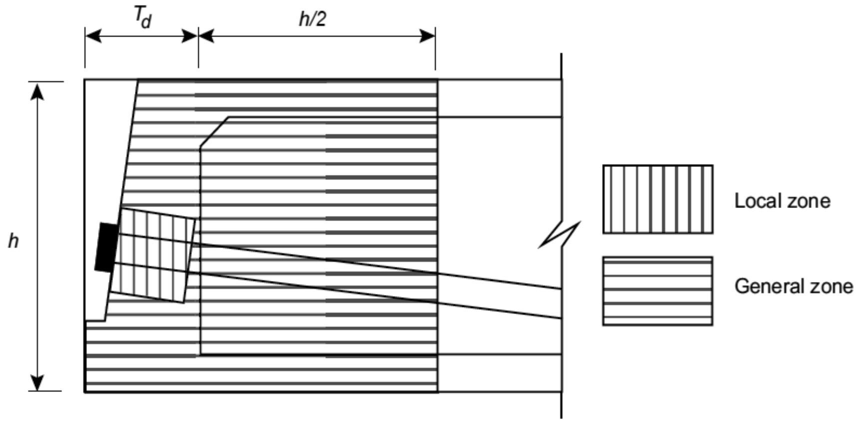

Figure 5.26.1.1 Anchorage Zone Geometry

To design the general zone comprehensively, a three-dimensional (3D) analysis would need to be performed. Historically, strut and tie analysis has been used. Research shows that most of the post-tensioning bursting forces within this region that are of concern to designers are the vertical tensile and longitudinal compressive stresses in the girder webs. Additionally, designers shall account for tensile stresses in the vertical and horizontal directions on the inside face of the diaphragm. Transverse tensile stresses in the deck and soffit slabs are relatively small and can be resisted with typical section transverse reinforcement. Rather than developing a strut and tie model for every bridge, this memo provides an efficient approach to the design of the general zone.

5.26.2 NOTATIONS

A_{ducts} = cross sectional area of all ducts within a girder (in^2)

A_{duct} = cross sectional area of 4.78-in diameter duct within a girder (in^2)

$(A_s)_{min}$ = minimum vertical reinforcement in a girder web located within a distance of h/2 from the inside face of the end diaphragm (in^2)

b = prestressing anchorage plate width or diameter (in.); unless otherwise known, assume 13.5 in.

b_{de} = effective diaphragm thickness measured perpendicular to centerline of bearing (in.)

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

f_y = bar reinforcing steel minimum yield strength (ksi)

h = cross section depth (in.)

P_J = jacking force per girder considering the allowable final force variation between girders (kips)

P_n = nominal axial resistance (kips)

P_u = factored axial load (kips)

S = center to center spacing of girders (in.)

T_d = end diaphragm thickness measured perpendicular to centerline of bearing (in.)

t_d = thickness of deck slab (in.)

t_s = thickness of soffit slab (in.)

t_w = thickness of girder web at the inside face of end diaphragm (in.)

y = variable to account for the spread of compressive forces at face of diaphragm (in.)

$\phi =$ resistance factor = 0.8

5.26.3 LOCAL ZONE

The size and reinforcement of the local zone 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 responsibility of the design engineer to ensure that the local zone details submitted agree with the details of the preapproved system.

5.26.4 GENERAL ZONE DESIGN

5.26.4.1 Minimum Diaphragm Thickness

3D models show that using a thicker diaphragm reduces the vertical tensile stresses in the girder webs. Therefore, the minimum recommended diaphragm thickness for abutments and hinges is as follows:

$$T_d \geq 0.4 * h \tag{5.26.4.1.1}$$

For shallow structures, the absolute minimum diaphragm thickness is 2’-6” at abutments and 2’-0” at hinges. Note that at hinges, prestress blockouts are usually not required due to the hinge closure pour. Refer to BDM 5.22 for additional diaphragm thickness recommendations. The largest diaphragm thicknesses of these recommendations should be used.

5.26.4.2 Minimum Girder Web Thickness

Girder webs shall be designed to resist the longitudinal compressive forces. The girder thickness at the inside face of diaphragm, tw, should be designed such that:

$$\emptyset P_n \geq P_u \tag{5.26.4.2.1}$$

$$P_u = 1.2P_J \tag{5.26.4.2.2}$$

$$\emptyset P_n = 0.8 * 0.8[0.85 * f'_{ci}\left(t_w * h - A_{ducts} + (4y - t_w)(t_d + t_s)\right)] \tag{5.26.4.2.3}$$

$$A_{ducts} = Number\ of\ ducts *\ A_{duct} \tag{5.26.4.2.4}$$

$$A_{duct} = \frac{\pi * 4.78^2}{4} \tag{5.26.4.2.5}$$

The duct outside diameter is 4.78 in.

$$Number\ of\ ducts = \frac{P_J}{1188\ kips} \tag{5.26.4.2.6}$$

This assumes a 27-strand tendon per duct at 44 kips per strand.

Use a fractional number of ducts to account for the use of smaller ducts.

$$y = \left(\frac{s}{4} - \frac{b}{4}\right) * \left(\frac{b_{de}}{b_{de} + \frac{S}{2}}\right)^{0.65} \tag{5.26.4.2.7}$$

$$b_{de} = T_d - 8" \qquad (5.26.4.2.8)$$

When evaluating the anchorage zone at intermediate hinge diaphragms, there is generally no prestress blockout. At these locations, $b_{de} = T_d$.

$$(t_w)_{min} \geq \frac{\frac{1.2P_J}{0.544f'_{ci}} + A_{ducts} - 4y(t_d + t_s)}{(h - t_d - t_s)} \qquad (5.26.4.2.9)$$

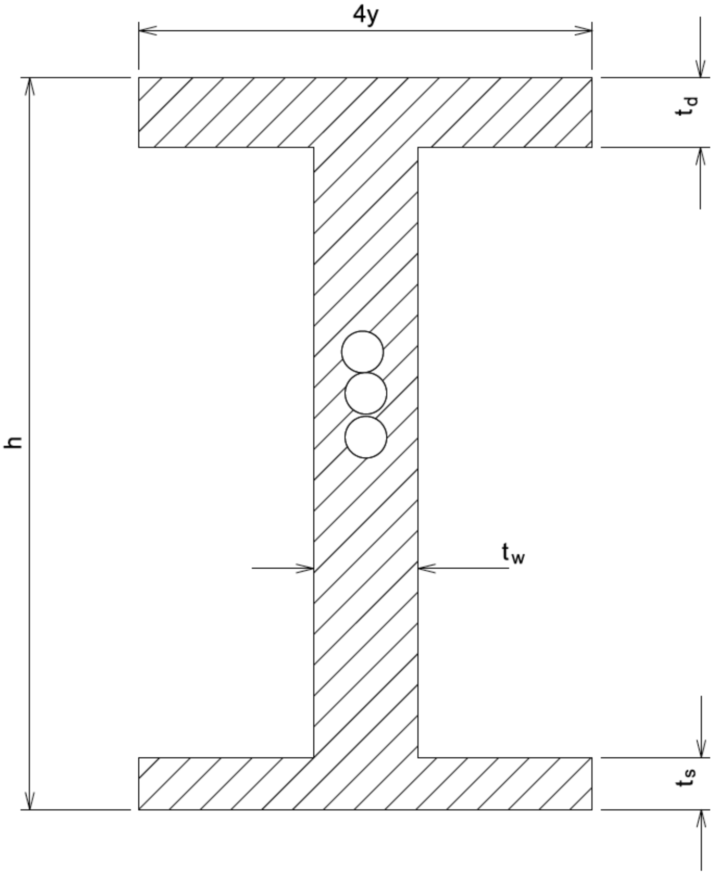

Figure 5.26.4.2.1 Compression Area

The hatched area in Figure 5.26.4.2.1 shows the effective area resisting the compressive forces at the interface between the end diaphragm and the girder web.

Since the ducts are ungrouted at the time of post-tensioning, Equation 5.26.4.2.9 subtracts the duct area from the area of the girder.

It is recommended to include a 6” fillet between the girder and the inside face of the end diaphragm. This will allow for a more gradual transition of the compressive force into the girder.

5.26.4.3 Vertical Stirrups in the Girder Web

Minimum vertical stirrup reinforcement in the girder web should be designed as follows:

$$(A_s)_{min} \geq \frac{0.1P_J}{f_y} \tag{5.26.4.3.1}$$

This reinforcement should be located within a distance of h/2 from the inside face of the diaphragm. This reinforcement is not in addition to vertical reinforcement required to resist other load combinations.

5.26.4.4 End Diaphragm Reinforcement

The reinforcement on the inside face of the end diaphragm should be designed to resist tension tie forces caused by the spread of the prestressing force into the typical section within this disturbed region.

Minimum horizontal and vertical reinforcement should be equivalent to #5 @ 6 (assuming f_y = 60 ksi).

This level of reinforcement applies to end diaphragms with openings not larger than the Standard Plan (B7-10) maximum opening size for future utility openings. If a more refined analysis is necessary to determine required reinforcement at this location for a specific condition, including cases with larger openings in the diaphragm, refer to anchorage zone research recommendations (Sanders and Maree, 2018).

Refer to Standard Plan B8-5 for additional end diaphragm reinforcement details. Figure 5.26.4.4.1 shows typical minimum reinforcement details for the inside face of the end diaphragm.

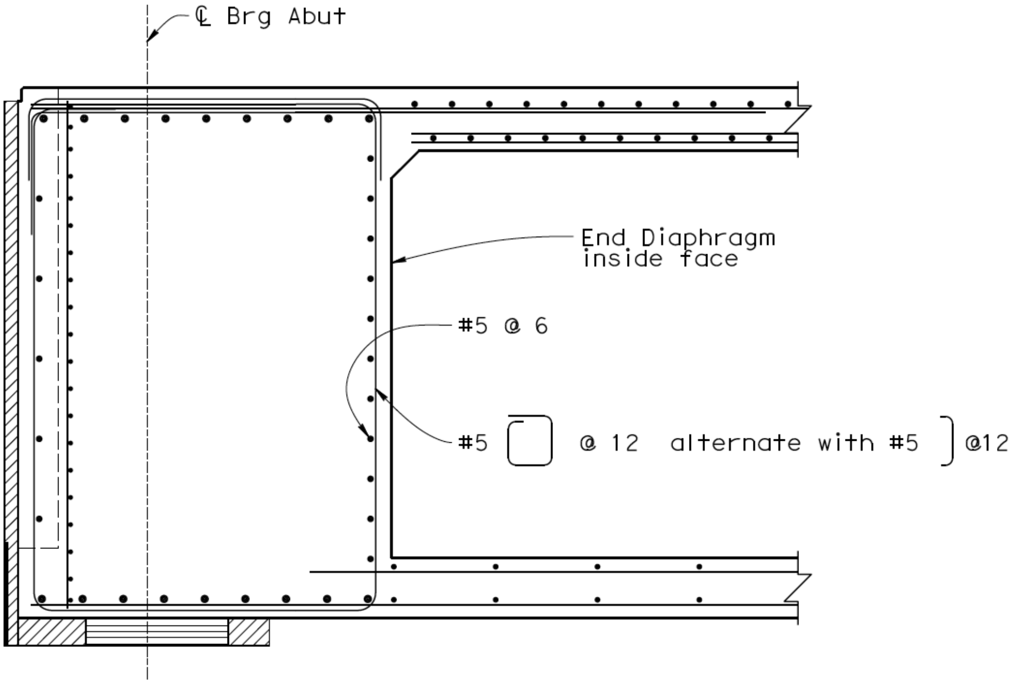

Figure 5.26.4.4.1 End Diaphragm Example Reinforcement

5.26.5 REFERENCES

1. AASHTO. (2017). *AASHTO LRFD Bridge Design Specifications*, 8th Edition, American Association of State Highway and Transportation Officials, Washington DC.
2. Caltrans. (2019). *California Amendments to AASHTO LRFD Bridge Design Specifications*, 8th Edition, California Department of Transportation, Sacramento, CA.
3. Sanders, D. and Maree, A. (2018). "*Performance and Design of Anchorage Zones for Post-Tensioned Box Girder Bridges*". Center for Civil Engineering Earthquake Research, Report number 18-01.