Appendix I

AASHTO Bridge Committee Agenda Item

2016 AASHTO BRIDGE COMMITTEE AGENDA ITEM:

SUBJECT: LRFD Bridge Design Specifications, Section 5, Debonded Strands

TECHNICAL COMMITTEE: T-10 Concrete

☒ **REVISION** ☐ **ADDITION** ☐ **NEW DOCUMENT**

☒ **DESIGN SPEC** ☐ **CONSTRUCTION SPEC** ☐ **MOVABLE SPEC**
☐ **MANUAL FOR BRIDGE EVALUATION** ☐ **SEISMIC GUIDE SPEC** ☐ **MANUAL BRIDGE ELEMENT INSP**
☐ **OTHER**

DATE PREPARED:
DATE REVISED:

AGENDA ITEM:

Item #1

Add the following notations to Article 5.3:

b_b = width of bearing (in.)
c_b = distance from the bearing reaction forces to the center line of section (in.)
h_b = depth of bottom bulb (in.)
N_w = total number of bonded strands aligned with web
n_f = number of bonded strands in one side of outer portion of web
x_p = horizontal distance from girder centerline to centroid of n_f strands in outer portion of bulb (in.)
y_p = vertical distance from girder soffit to centroid of n_f strands in outer portion of the bulb (in.)

Item #2

Revise the first paragraph of Commentary C5.7.2.8 as follows:

For flexural members, the distance between the resultants of the tensile and compressive forces due to flexure can be determined as:

$$d_v = \frac{M_n}{A_s f_y + A_{ps} f_{ps}} \qquad \text{(C5.7.2.8-1)}$$

For girders with debonded strand, d_v is calculated by neglecting the area of any debonded strand over the lengths where the strand is completely debonded. Once the strand is bonded, the area of the bonded strand is used in the calculation only when the strand has been bonded a distance of at least κl_d, where κ is equal to 2. The value of κ is equal to 1.6 for fully bonded strands in members with a depth greater than 24 in. For areas where previously debonded strand has been

bonded for distances less than κl_d, the value of d_v is calculated by accounting for the lack of development of the strand, according to 5.9.4.3.2. As an alternative, d_v can be conservatively taken as the lesser of d_v calculated by assuming all previously debonded strands are fully effective and d_v calculated by ignoring all previously debonded strands. The term d_v need not be taken less than the greater of $0.9d_e$ or $0.72h$ in areas with debonded strands.

Item #3

Replace Article 5.9.4.3.3 with the following:

5.9.4.3.3—Debonded Strands

Harped strands may not be debonded. Straight pretensioned strands may be debonded at the ends of beams subject to the following requirements:

- The total number of debonded strands shall not exceed 60 percent of the total number of strands unless test results or successful past practices indicate that a larger percentage of strands may be debonded.
- The number of debonded strands in any horizontal row within the bottom flange height, other than the bottom row, shall not exceed 80 percent of the number of strands in that row.
- The number of debonded strands in the bottom horizontal row shall not exceed 50 percent of the number of strands in that row.
- No more than 40 percent of the total number of debonded strands, or four strands, whichever is greater, shall have their debonding terminated at any section.
- Termination sections for debonding shall be at least $60d_b$ apart longitudinally.
- For single-web flanged sections (I-beams and bulb tees):
    - The outer-most strands in all rows located within the full-width section of the flange shall remain bonded.
    - Strands further from the section vertical centerline shall be debonded prior to those nearer the centerline.
    - Full flange width bearing shall be provided at supports.
- For multi-web sections having bottom flanges (voided slabs, box beams, and U-beams):
    - For girders supported at their corners, the strands located within a width equal to twice the extension of all the webs shall remain bonded.
    - Bearings placed below webs shall engage a width equal to twice the extension of all webs at supports.
    - For girders supported across their width, debonded strands shall be uniformly distributed across the flange width between webs.
    - For girders supported at their corners, strands shall be debonded from the

centerline outwards.

- Debonded strands shall be symmetrically distributed about the vertical centerline of the cross section of the member. Symmetrically debonded strands shall have their debonding terminated at the same longitudinal location.
- Where a portion or portions of a pretensioning strand are debonded and where tension exists in the precompressed tensile zone, the development length, measured from the end of the debonded zone, shall be determined using Eq. 5.9.4.3.2-1 with a value of $\kappa = 2.0$. The value of $\kappa = 1.6$ shall be used for fully bonded strands in members with a depth greater than 24 in.
- The length of debonding of any strand shall be such that all limit states are satisfied with consideration of the total developed resistance at any section being investigated.
- The sections with debonded strands shall satisfy the requirements of Article 5.9.2.3 for stress limits, Article 5.7 for shear strength, and Article 5.7.3.5 for longitudinal reinforcement.
    - Tensile force in prestressing reinforcement ($A_{ps}f_{ps}$) shall exceed the tensile force of nonprestressed reinforcement (A_sf_s) at all sections. Development of straight and bent-up strands as well as overhangs, if present, should be taken into account for determining the value of f_{ps}.
- For composite sections, the principal tensile stress in the web at the neutral axis of the composite section or at the web-top flange intersection where the neutral axis is located in the top flange shall not exceed $0.11\sqrt{f_c'}$ ksi under the loadings of Service I limit state of Article 3.4.1.
- For noncomposite sections, the principal tensile stress in the web at the neutral axis of the beam or at the web-top flange intersection where the neutral axis is located in the top flange shall not exceed $0.11\sqrt{f_c'}$ ksi under the loadings of Service I limit state of Article 3.4.1.
- The principal tensile stress may be calculated using the equations of Article 5.9.2.3.3 except within h to either side of the face of an internal and/or internal intermediate diaphragm. In areas within h of a concrete end diaphragm, a more exact analysis of the web stress shall be performed. In lieu of a more exact analysis, the stress calculated by Article 5.9.2.3.3 shall be limited to $0.08\sqrt{f_c'}$ ksi under Service I limit state of Article 3.4.1.

Item #4

Revise Commentary C5.9.4.3.3 as follows:

C5.9.4.3.3

Tests completed by the Florida Department of Transportation (Shahawy, Robinson, and Batchelor, 1993; Shahawy and Batchelor, 1991; and by Shahrooz et al. 2017) indicate that the anchored strength of the strands is one of the primary contributors to the shear resistance of

prestressed concrete beams in their end zones. Thus, it is critical that the provisions of Article 5.7.3.5 are met. The recommended limits of ~~25~~ 60 percent of debonded strands and 80 percent per row are ~~is~~ derived from ~~those~~ tests by Shahrooz et al. (2017). Shear capacity was found to be ~~in~~adequate with full-scale girders where ~~40~~ 60 percent of the strands were debonded provided the requirement for longitudinal reinforcement was satisfied.

Some states have had success with greater percentages of ~~partially~~ debonded strands. Successful past practice should always be considered, but the shear resistance in the region should be thoroughly investigated with due regard to the reduction in horizontal force available when considering the free body diagram in Figure C5.7.3.5-1 and to all other determinations of shear capacity by any of the provisions of this section.

Research conducted at various institutions has validated the following design details:

- Pretensioned strands that are ~~partially~~ debonded have a longer development length.
- For sections with a single web (I-beams and bulb tees), debond the strands furthest from the vertical centerline, other than those at the end of the row, prior to those nearest the centerline.
- For multi-web beams, supported at their corners, debond strands from the centerline outwards.
- For multi-web beams, supported across their widths, distribute debonded strands uniformly across the flange width between webs.
- For slab beams uniformly supported across their width, debond strands uniformly across the width.
- Where possible, alternate bonded and debonded strands in each row.

Full-width is understood to mean the full width of the bottom flange less a distance accounting for the chamfer – typically two in. on both sides. The detailing requirements are illustrated in Figures C5.9.4.3.3.1 and C5.9.4.3.3.2.

Research by Shahrooz (2017) shows that using a principal tensile stress of $0.11\sqrt{f_c'}$ ksi is a reasonable lower bound for predicting shear cracking in webs for girders with debonded strands. However, in sections with concrete end diaphragms, the Mohr's Circle approach of Article 5.9.2.3.3 does not correctly predict stresses in areas near the diaphragm as these are "disturbed" regions where the assumptions implicit in a Mohr's Circle analysis do not apply. Mohr's Circle underpredicts the actual web stresses in these areas. A finite element approach was needed to correctly assess the stresses in these areas. Since a finite element is impractical in a design situation, a reduced stress limit is a practical solution until more research can provide another approach.

Strand debonding in girder ends having a large skew is recommended (Shahrooz et al. 2017) in the portion of flange extending beyond the web although no test results addressing this condition are available.

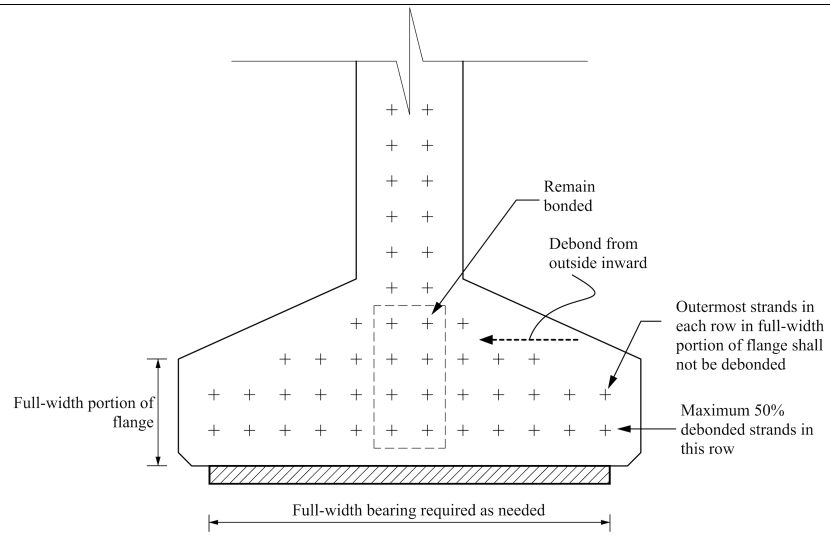
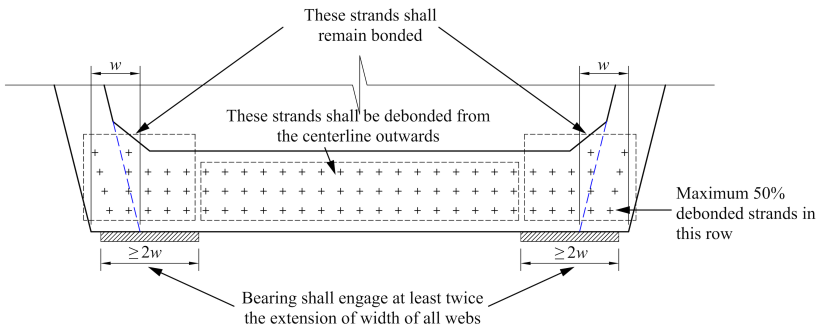
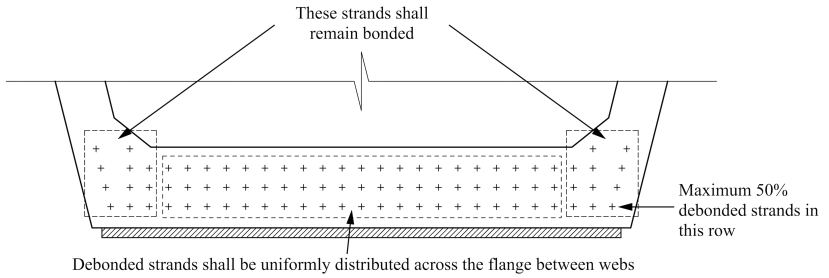


Figure C5.9.4.3.3.1. Details for single-web sections



(a) Supported at the corners



(b) Supported across full width

Figure C4.9.4.3.3.2. Details for multi-web sections without end diaphragms

Item #5

Revise Article 5.9.4.4.2 as follows:

For the distance of ~~1.5d~~ 1.5*h* from the end of the beams other than box beams, reinforcement shall be placed to confine the prestressing steel in the bottom flange. The reinforcement shall not be less than No. 3 deformed bars, with spacing not exceeding 6.0 in. and shaped to enclose the

strands.

For box beams, transverse reinforcement consisting of not less than No. 3 bars with a spacing not exceeding 6 in. shall be provided over a distance of 1.5*h* and anchored by extending the leg of the stirrup into the web of the girder.

Item #6

Add new Article 5.9.4.4.3 as follows:

5.9.4.4.3—Transverse Tension Tie Reinforcement

In lieu of the requirements of this article, steel sole plates shall be embedded at the girder ends. Articles 5.9.4.4.1 and 5.9.9.4.2 shall still be applicable when a steel sole plate is used.

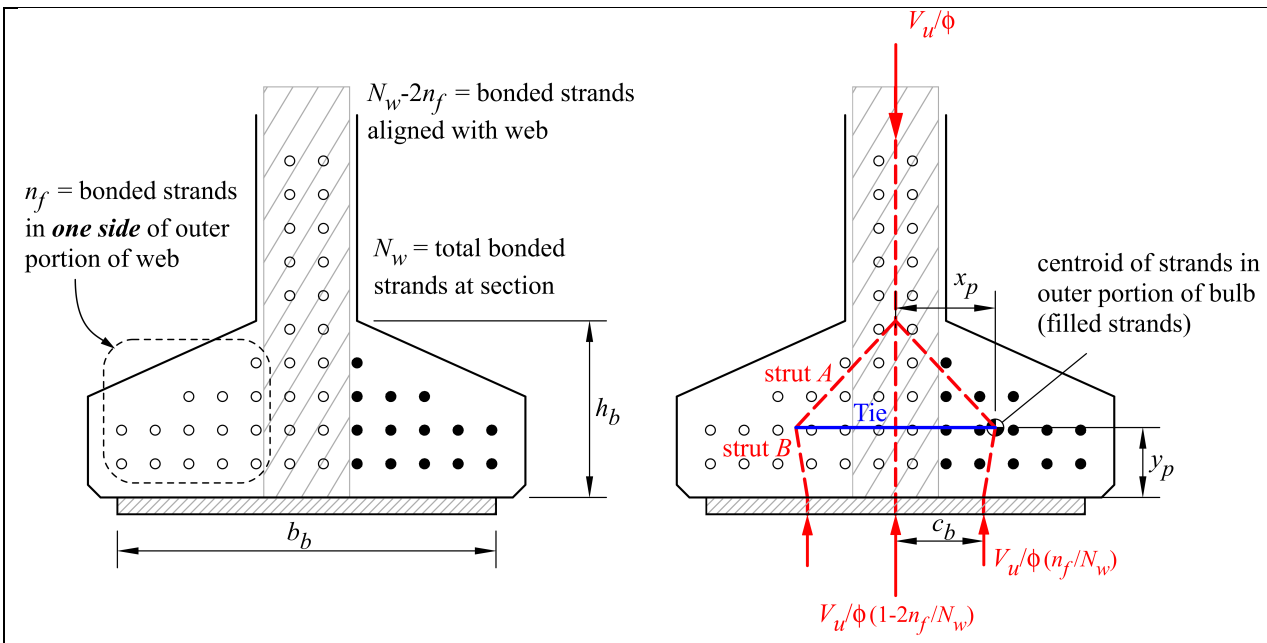
The tension tie reinforcement required by this article may also be used as the confinement reinforcement required by Article 5.9.4.4.2.

The requirements of this article shall apply to all single-web flanged sections.

For beams other than box beams, reinforcement shall be placed to confine the prestressing steel in the bottom flange.

For single-web sections, the strut-and-tie model shown in Figure 5.9.4.4.3-1 shall be used to determine the required amount of confinement reinforcement.

The reinforcement determined in these requirements shall be uniformly distributed over the length of the bearing plus a distance equal to one quarter of the overall height of the girder (including the composite slab if provided) towards the midspan of the girder.



$$t = \left(n_f / N_w\right)\left[x_p / \left(h_b - y_p\right) + \left(x_p - c_b\right) / y_p\right]\left(V_u / \phi\right)$$

$$where\ c_b = \left(b_b / 2\right)\left(1 - n_f / N_w\right)$$

Figure 5.9.4.4.3-1 – Strut and Tie model for confinement

where:

b_b	=	width of bearing (in.)
c_b	=	distance from the bearing reaction forces to the center line of section (in.)
h_b	=	depth of bottom bulb (in.)
N_w	=	total number of bonded strands aligned with web
n_f	=	number of bonded strands in one side of outer portion of web
x_p	=	horizontal distance from girder centerline to centroid of n_f strands in outer portion of bulb (in.)
y_p	=	vertical distance from girder soffit to centroid of n_f strands in outer portion of the bulb (in.)

Item #7

Add new Commentary C5.9.4.4.3 as follows:

The development of tension oriented transversely across the bulb of single-web flanged sections is a potential failure mode requiring tie reinforcement through the bulb to control the resulting longitudinally oriented cracking at the Strength I limit state. The nature of the resulting failure, however, is related to excessive transverse deformation and cracking of the flange and is not likely to be catastrophic in nature since reinforcement satisfying Article 5.10.10.2 contribute to the tie capacity, and in many instances will be sufficient to fully resist the tie force.

In some instances, the above requirements may result in impractical confinement reinforcing

details. An embedded sole plate would likely be more practical in such cases. Full flange width bearing is not needed if a sole plate is provided.

Item #8

Add the following reference to Article 5.15:

Shahrooz, B. M., R. A. Miller, K. A. Harries, Q. Yu, and H. G. Russell. 2017. *Strand Debonding for Pretensioned Girders*, NCHRP Report XXX. Transportation Research Board, National Research Council, Washington, DC.

OTHER AFFECTED ARTICLES:

None

BACKGROUND:

Strand debonding is an alternative for reducing stresses in the end regions of pretensioned concrete beams. The *AASHTO LRFD Bridge Design Specifications* currently limit the amount of debonding to 25 percent of the total number of strands within a pretensioned girder. This limit was imposed in recognition of the potential detrimental effects that excessive debonding could have on shear performance.

NCHRP Project 12-91 titled "Strand Debonding for Pretensioned Girders" was initiated to develop recommended revisions to the current debonding provisions considering both service and strength limit states and various beam cross sections. The proposed revisions are the outcome of the research and provide a more uniform approach to strand debonding.

ANTICIPATED EFFECT ON BRIDGES:

The proposed revisions will allow designers to use a larger percentage of debonded strands to control concrete stresses at the ends of prestressed concrete beams, while providing more guidance about proper debonding patterns. The additional requirement for transverse tension ties will ensure that any splitting cracks in the bottom flanges at the ends of prestressed concrete beams are adequately controlled even when no strands are debonded.

REFERENCES:

Shahrooz, B. M., R. A. Miller, K. A. Harries, Q. Yu, and H. G. Russell. 2017. *Strand Debonding for Pretensioned Girders*, NCHRP Report XXX. Transportation Research Board, National Research Council, Washington, DC. To be published.

OTHER:

None