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Memo

Date: 11/3/2023

To: Bridge Design Engineers

From: Arielle Ehrlich 2023.11.03 08:11:11 -05'00'
State Bridge Design Engineer

RE: Memo to Designers #2023-01: Debonded Strands in Prestressed Concrete Beams

Introduction

This memo provides guidance on the use of debonded strands in prestressed concrete beams.

Debonded strands are used to reduce release stresses at the beam ends while maintaining flexural capacity at the midspan. This is accomplished by intentionally debonding the strands at the beam ends by mechanical means so that concrete does not bond to the strand, typically through the use of a sheathing applied to the debonded region. Debonding is only used on straight strands and is an alternative to the draped strands historically used by MnDOT.

MnDOT has historically required the use of fully bonded straight or draped strands only, not allowing debonded strands due to concerns with potential water and chloride intrusion at the beam ends. However, satisfactory in-service performance for beams with debonded strands located in states with similar climates has led to decreased concerns about corrosion related to debonded strands. Additionally, straight strands pose less of a safety hazard to fabricators than draped strands, and the use of debonded strands allows for safer fabrication without sacrificing efficiency.

Effective immediately, use debonded straight strands in prestressed concrete beams provided that both beam ends are encased in concrete to mitigate concerns regarding water intrusion. This typically limits the use of debonded strands to single span structures with integral or semi-integral abutments.

Design Requirements

General

Except as identified in this memo, design prestressed beams with debonded strands using the requirements for prestressed beams specified in the MnDOT *LRFD Bridge Design Manual* (BDM) and the current edition of the AASHTO *LRFD Bridge Design Specifications* (AASHTO). All AASHTO references will be for the 9th Edition, 2020, as it is the current edition as of publication of this memo.

AASHTO mentions both debonded and unbonded strands throughout Section 5. It is important to note that debonded and unbonded strands are different. AASHTO Article 5.2 defines a debonded strand as a "pretensioned prestressing strand that is bonded for a portion of its length and intentionally debonded elsewhere through the use of mechanical or chemical means." Unbonded strands are defined as strands "that are effectively bonded at only their anchorages and intermediate bonded sections." This memo addresses debonded strands only.

Do not combine debonded strands and draped strands within the same beam.

Resistance Factors

For beams that include debonded strands, use resistance factors for prestressed concrete sections per AASHTO Article 5.5.4.2 (i.e. $\phi = 1.00$ for tension-controlled flexure and $\phi = 0.90$ for shear and torsion). Note that the sixth bullet in AASHTO Article 5.5.4.2 specifies a lower resistance factor for shear and torsion for sections with debonded strands, but it applies only to post-tensioned segmental construction.

Shear

When determining the effective shear depth, d_v, neglect all debonded strands over their debonded length. As a result, the effective shear depth will vary over the length of the beam and must be accounted for appropriately in calculations.

It should also be noted that the vertical portion of prestressing force, V_p, will be zero since there are no draped strands.

Strand Placement

AASHTO Article 5.9.4.3.3 provides several restrictions for debonded strands at the ends of beams, including limits on the number of debonded strands per row, distribution of debonded strands, and locations where debonded strands cannot be placed. Follow the guidance of AASHTO Article 5.9.4.3.3 except as defined below.

For all I-beams with debonded strands, use fully bonded strands for the outermost strands in the bottom flange and for all strands located within the projection of the web width. For all rectangular beams with debonded strands, uniformly distribute the debonded strands across the width of the section and provide fully bonded strands for the outermost strands. Additionally, bond all base strands for I-beams and rectangular beams, as shown on the standard beam sheets and BDM Figure 5.4.3.1, for their entire length.

Top Flange Strands

Ideally, use of debonding at the beam ends and accounting for bonded mild reinforcement will keep stresses near the beam ends below the AASHTO Article 5.9.2.3.1b tension limit at release:

$$0.24\lambda\sqrt{f'_{ci}}$$

However, in some cases where the amount of debonded strands has reached the AASHTO limit, additional strands may be required in the top flange to satisfy the tension stress limit at release. Fully bonded straight strands located in the top flange raise the center of gravity of the pretensioning force and therefore reduce the effectiveness of the prestressing at midspan. Debonding these top flange strands over the middle portion of the span may be necessary to keep beam stresses at midspan below the AASHTO Article 5.9.2.3.2b tension limit after losses:

$$0.19\lambda\sqrt{f'_{ci}} \leq 0.6 \text{ ksi}$$

In addition to controlling release stresses, top flange strands may also be necessary for handling and transportation stability concerns in long span beams per AASHTO Article 5.5.4.3. Strands located in the top flange that require debonding over the middle portion of the span shall be treated as temporary strands per AASHTO Article 5.9.4.5. They will require access pockets in the beam for cutting of the strands before deck placement. The designer must investigate if permanent diaphragms (when applicable) can safely accommodate any sweep or vertical deflection created during the temporary strand cutting process, or if temporary bracing is required until after all temporary strands are cut.

Place all temporary strands in one row, 3 inches from the top of beam. Limit the number of temporary strands to four or as directed by MnDOT fabricators. Horizontally locate temporary strands symmetrically about the beam centerline as shown in Figure 1. Permanent top flange strands (not debonded) may be placed in the two web strand columns at 2 inch spacing increments starting 3 inches from the top of beam.

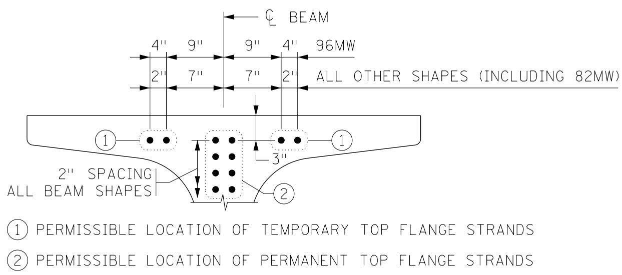


Figure 1

Prestressing Development

Per AASHTO Article 5.9.4.3.1, the stress in prestressing steel is assumed to increase linearly from zero to the effective stress after losses over the strand's transfer length. From the end of the transfer length to the end of development length the stress is assumed to increase linearly from the effective stress after losses to the stress at nominal resistance. This is the case for both bonded and debonded strands. As a result, the main difference between the design of a beam with debonded strands and a beam with draped strands is the amount of bookkeeping required.

With no debonding, all strands are fully transferred at the same point in the beam. This is also true for the development length. For beams with debonded strands, these points vary over the length of the beam. Due to the debonding, there will be several different locations at which various strands will become fully transferred or developed, increasing the locations needing to be checked. Note that AASHTO Article 5.9.4.3.3 requires a value of κ=2.0 when determining the development length of a debonded strand.

Camber

When determining estimated camber use the following equations from *Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures – Design Examples*, Publication No. FHWA-NHI-15-058, April 2007 Revised August 2015. The equations are found in Design Step 5.6.7:

$$\Delta_{ps_{total}} = \sum_{i=1}^{n} \Delta_{ps_i}$$

$$\Delta_{ps_i} = \frac{P_{t_i} \cdot e_{s_i} \cdot L^2}{8 \cdot E_{ci} \cdot I}$$ (straight bonded strands and temporary top strands)

$$\Delta_{ps_i} = \frac{P_{t_i} \cdot e_{s_i} \cdot \left[L^2 - \left(L_t + 2 \cdot L_{x_i}\right)^2\right]}{8 \cdot E_{ci} \cdot I}$$ (strands debonded at girder ends)

where:

$\Delta_{ps_{total}}$ = upward camber of beam immediately after release, due to prestress alone (in)

Δ_{ps_i} = upward camber contribution immediately after release, due to individual strand group (in)

P_{t_i} = prestress force immediately after release of individual strand group (kips)

e_{s_i} = eccentricity of prestress force with respect to the beam centroid at midspan of individual strand group (in)

L = end to end length of beam (in)

L_t = transfer length of strand (in)

L_{x_i} = length of debonding from end of beam of individual strand group (in)

E_{ci} = modulus of elasticity of concrete at prestress transfer (ksi)

I = beam moment of inertia (in^4)

Note that P_{t_i}, e_{s_i}, and L_{x_i} in the above equations are based only on the strands in question (i.e. only straight fully bonded strands, temporary top strands, or individual debonded strand groups). The total camber due to prestressing is then the summation of each individual camber from the above equations. For beams with debonded strands, follow current BDM guidance regarding use of camber multipliers and when a refined camber analysis is required.

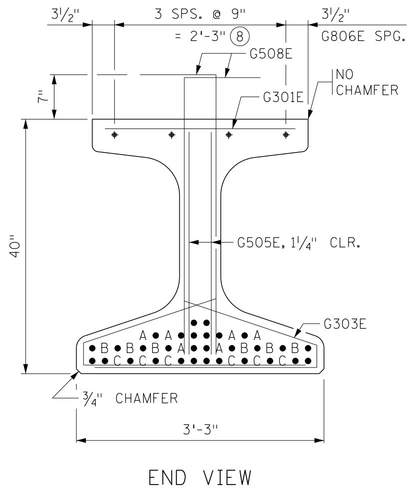
Include a construction stage in beam camber design for beams with temporary top flange strands debonded at midspan. For beams using camber multipliers, the added stage should remove the effect of temporary top flange strands after the camber multipliers are applied to all strands as described above. The effect of temporary top flange strands can be removed by using the camber equation for "temporary top strands" above and substituting updated values for time dependent variables P and E. This estimates the strand cutting process at a later date assuming the bonded region for top flange temporary strands is kept minimal. For beams that require a refined camber analysis, similarly add a construction stage for the removal of temporary strands debonded at midspan, incorporating time dependent properties of the concrete and prestressed losses.

Plan Development

Until there are standard beam sheets for debonding, modify the standard beam sheet for the correct size beam as follows:

- Remove all references to draped strands from the sheet.
- Modify the end view by labeling debonded strands with letters. The set of strands with the shortest debonded length should be labeled "A". Continue through the alphabet as needed. See Figure 2 below for an example.

- Include an “End Debonding” table near the “End View”. The table should include the debonding symbol, number of strands, and length of debonding from end of beam. See Figure 2 for an example.



END DEBONDING		
SYMBOL	NO.	LENGTH
A	6	14'-0"
B	6	18'-0"
C	6	22'-0"
TOTAL	18	

DEBONDING LENGTHS FOR A, B, AND C ARE MEASURED FROM EACH END OF BEAM.

Figure 2

- Modify the “Y Distances” table to show the total number of strands per row and the row’s corresponding center of gravity. See Figure 3 for an example.

Y DISTANCES		
	NO.	Y (INCHES)
ROW 1 (BOTTOM)	18	2
ROW 2	18	4
ROW 3	10	6
ROW 4	2	8
(5) TOTAL STRANDS	48	

Y = DISTANCE TO CENTER OF GRAVITY OF STRANDS FROM BOTTOM OF BEAM. ALL STRANDS SPACED 2" CENTER TO CENTER, HORIZONTALLY AND VERTICALLY, EXCEPT AS NOTED.

Figure 3

- For the special case where strands in the top flange require debonding over the middle portion of the span, include details for access pockets in the beams and notes/special provisions regarding cutting of the strands before deck placement. Space access pockets at 2 foot increments longitudinally, starting 2 feet from the bonded zone. Place access pockets symmetrically about the beam centerline at the low end of beam. See Figure 4 for an example.

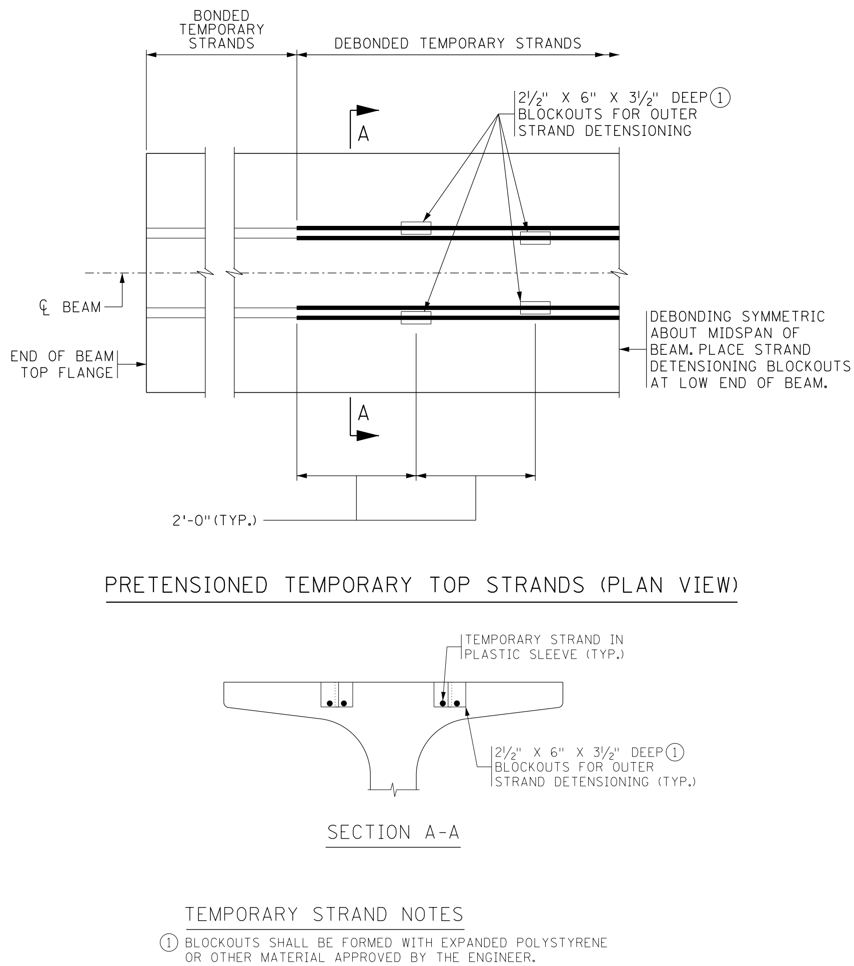


Figure 4

Bridge Special Provision Requirements

A standard special provision for beams that include debonded strands is available as part of the *2020 "SB" Bridge Special Provisions* which can be downloaded from the Bridge Office web site at:

http://www.dot.state.mn.us/bridge/construction.html

The special provision is denoted as SB2020-2405.7 and describes proper fabrication practices for prestressed girders containing debonded strands. Requirements for material properties are provided, as well as instructions for proper sealing of debonded regions to prevent moisture ingress. The sheathing must be sealed within the formwork prior to casting the girder concrete, as well as at the girder ends after the strands have been released. Oversized rigid sheathing is the required debonding material to ensure adequate space for strand dilation and prevent cement paste leakage into the sheathing. Double slit sheath debonding is only allowed in remedial cases to the allowable length listed in the special provisions. The strand release pattern used for girders containing debonded strands also differs from the typical strand release pattern specified for prestressed girders with draped strands. This alternative strand release pattern for girders containing debonded strands is described in SB2020-2405.4B.

For questions about this memo, please contact Karl Johnson (karl.johnson@state.mn.us or 651-366-4521) or Arielle Ehrlich (arielle.ehrlich@state.mn.us or 651-366-4506).