The Effects of Strand Debonding

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To control stresses in the end regions of pretensioned concrete girders, strands are either harped or debonded. Some state departments of transportation (DOTs) have policies to discourage debonding because they prefer to harp strands in the end regions. Other DOTs prefer debonding over harping strands, citing concerns related to potential safety hazards associated with deflecting highly tensioned strands, as well as overall practicality. In fact, both methods have been successfully used since pretensioned concrete beams have gained widespread use in the United States. New debonding rules may change the way designers approach controlling stresses in end regions, and the design implications of the forthcoming changes are explored in this article.

As I mentioned in the LRFD article in the Fall 2019 issue of *ASPIRE*®, American Association of State Highway and Transportation Officials (AASHTO) Committee T-10 members have worked hard to improve the debonding rules based on the knowledge accumulated over decades of experience. The 25% maximum debonding limit in the *AASHTO LRFD Bridge Design Specifications,* 8th edition,[1] will give way to a series of rules in the 9th edition (scheduled to be published in 2020) stipulating that a maximum of 45% of the strands can be debonded in any single row. In this way, the theoretical upper bound on debonding can be perceived to be 45%. Additional rules limit debonding of strands underneath the webs, require that symmetry is maintained about the vertical axis that passes through the center of gravity of the cross section, and require alternating bonded and debonded strands in a row or in a column in the strand group. In addition, all strands within the horizontal limits of the web when the bottom flange-to-web width ratio b_f/b_w is greater than 4 are to be bonded. When all the rules explained in my previous article are applied to common pretensioned concrete girder sections, the actual upper limit on debonding ends up being less than 45%. Meeting all the new rules of debonding implies that roughly one-third of the strands can be debonded in the end regions of pretensioned concrete girders.

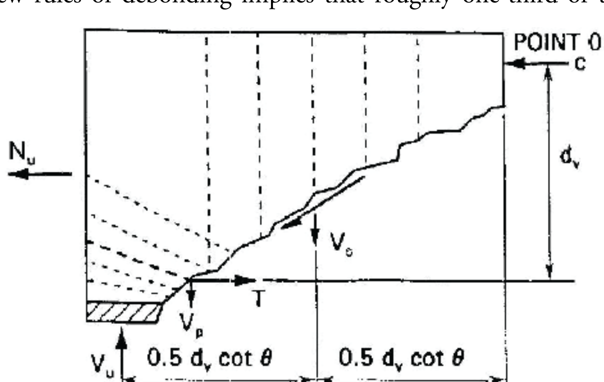


Figure 1. Anchorage of a longitudinal tie. AASHTO LRFD specifications C5.7.3.5-1.[1]

One important note is that debonding in the end regions must be implemented carefully. Strands (i.e., the longitudinal ties for flexural resistance) need to have adequate capacity and be properly anchored at the supports of girders (**Fig. 1**).[1]

Article 5.7.3.5 of the AASHTO LRFD specifications provides equations that shall be met to ensure an adequate tie force is provided considering available strand anchorage. The associated equations are as follows.

At each section, strength of the longitudinal tie (left side of the inequality in Eq. [5.7.3.5-1]) shall be greater than the demand on the tie (right side of Eq. [5.7.3.5-1]).

$$A_{ps}f_{ps}+A_sf_y \ge \frac{|M_u|}{d_v\phi_f}+0.5\frac{N_u}{\phi_c}\left(\left|\frac{V_u}{\phi_v}-V_p\right|-0.5V_s\right)\cot\theta \quad (5.7.3.5\text{-}1)$$

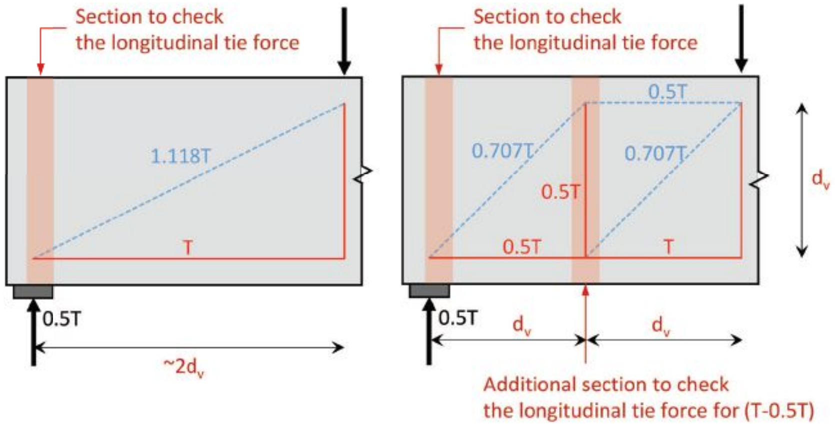
At the inside edge of a bearing, Eq. 5.7.3.5-1 can be simplified as:

$$A_sf_y+A_{ps}f_{ps} \ge \left(\frac{V_u}{\phi_v}-0.5V_s-V_p\right)\cot\theta \quad (5.7.3.5\text{-}2)$$

Setting moment and axial load equal to zero in Eq. (5.7.3.5-1) produces Eq. (5.7.3.5-2). Note that V_s appears on the right side of Eq. (5.7.3.5-1) as a negative quantity, which indicates that adding stirrups effectively reduces the demand on the longitudinal tie. However, the V_s used in the equation cannot be greater than V_u/ϕ_v. That is, adding stirrups can only reduce the demand on the longitudinal tie up to a point. When the upper limit on V_s is inserted in Eq. (5.7.3.5-2), the minimum value for the longitudinal tie force can be computed using the following equation:

$$A_{ps}f_{ps}+A_sf_y \ge \left(0.5\frac{V_u}{\phi_v}-V_p\right)\cot\theta$$

The effect of adding stirrups on the demand for the longitudinal tension tie is presented graphically in **Fig. 2**. The typical inclination of the compression field in a pretensioned girder is 25 to 30 degrees, as depicted in Fig. 2a, for an assumed truss geometry. In this case, the full tie force *T* has to be properly anchored at the support, which may be difficult. By providing the maximum allowed shear reinforcement, a two-panel truss mechanism is formed to transfer the load into the support, and the demand on the longitudinal tie force to be anchored at the support is reduced by approximately 50%. As previously discussed, using the quantity of stirrups corresponding to the maximum limit on V_s forces the inclination of the compression field to be 45 degrees, rendering the relevant provisions of the AASHTO LRFD



a. Tie Force to be Anchored at the Support = T b. Tie Force to be Anchored at the Support = 0.5T

Figure 2. Influence of maximum allowed shear reinforcement on longitudinal tie anchorage demand. Figure: Oguzhan Bayrak

specifications equivalent to the *fib* (International Federation for Structural Concrete) Model Code 2010 for reinforced concrete design.[2]

The requirement to check the force in the longitudinal tie has been in effect since the 1st edition of the AASHTO LRFD specifications (1994). The 25% limit placed on strand debonding in the current specifications made this longitudinal tie check a seldom-necessary backstop, even though it was a requirement of the specifications. As we move forward, the implementation of new debonding rules will, in some cases, result in a significantly larger percentage of the strands being debonded at the ends of simply supported pretensioned concrete girders. In these cases, we must be especially careful about meeting this requirement of the specifications.

Finally, if we take a high-level look at strand debonding, we must acknowledge that higher percentages of debonded strands reduce the level of precompression at the ends of pretensioned concrete girders. This reduction in precompression results in a reduction in concrete contribution to shear strength. For these reasons, debonding must be done judiciously. Overall, concrete bridges and pretensioned concrete elements offer excellent durability while maintaining cost-effectiveness for a great number of bridges across the United States and worldwide. By recognizing the structural benefits (e.g., reduced end-region cracking) and costs (e.g., reduced level of precompression in the end regions) when using debonded strands, we can maintain or improve the durability of our concrete bridges.

References

1. American Association of State Highway and Transportation Officials (AASHTO). 2017. *AASHTO LRFD Bridge Design Specifications*, 8th ed. Washington, DC: AASHTO.

2. *fib* (Federation Internationale du Beton/International Federation for Structural Concrete). 2013. *fib Model Code 2010 for Concrete Structures*. Lausanne, Switzerland: *fib*.