Using Fully Bonded Top Strands in Pretensioned Concrete Bridge Girders

by Dr. Bruce W. Russell, Oklahoma State University

Fully bonded top strands provide significant benefits for precast, prestressed concrete bridge girders. By using fully bonded top strands, several serviceability issues are improved relevant to the engineer's ability to control stresses in the end regions and eliminate or mitigate unwanted cracking:

- Harped (or deflected) strand patterns can be eliminated for most designs.
- The need for debonded strands is eliminated in many designs, and, where debonding is required, the required length and number of debonded strands are significantly reduced.
- Girder camber is reduced in both the short term and long term.
- Cracks that occur in end regions at detensioning can either be eliminated or reduced in both number and size.

Many engineers, however, do not take advantage of this reasonable approach because of concerns that fully bonded top strands add tension to the bottom fiber. There are also concerns that top strands may reduce the flexural strength of the cross section. This article asserts that increases to bottom-fiber tensile stresses are small, easily overcome, and usually inconsequential; moreover, the flexural strength of the cross section is largely unaffected. It is the opinion of the author that the positive benefits of using fully bonded top strands far outweigh any adverse effects on service load stresses.

Background

My interest in this topic grew out of my research (while at the University of Texas at Austin) with Dr. Ned H. Burns to determine rational design guidelines for debonding strands. The overarching principle that we followed in our recommendations,[1-4] which was also presented in an earlier paper by Horn and Preston,[5] is that debonding strands should be minimized in number and length because the pretensioned concrete beam or girder is inherently stronger with bonded strands than with unbonded strands. While the topic of fully bonded top strands was not part of our original conclusions, a paper published in 1994 indicated that fully bonded top strands improve the efficiency of the prestressing strand pattern, and that one of those efficiencies was the elimination or minimization of the need for debonding.[6]

In 1997 and 1998, Dolese Bros. Co. of Oklahoma City, Okla., hired me to redesign strand patterns—from harped to straight—for two sets of bridges. The first, the Interstate 35 (I-35) Bridge over Rollercoaster and Pine Roads in Logan County, Okla., is featured in the example in this article. In this design example, the middle span, with 103.43-ft center-to-center bearings, was constructed from American Association of State Highway and Transportation Officials (AASHTO) Type IV girders spaced at 8.2 ft.

This I-35 bridge is the first bridge in Oklahoma designed to use straight strand patterns in lieu of harped strands. Also, and as part of the redesign, this bridge became the first in Oklahoma designed using the new (first edition) *AASHTO LRFD Bridge Design Specifications*[7] in place of AASHTO's *Standard Specifications for Highway Bridges.*[8]

There have been changes to the AASHTO LRFD specifications since that first edition—most notably the fact that the relatively new code provisions for prestress losses reduce the required number of prestressing strands. Another change is that the allowable compressive stress for temporary stresses is now $0.65f'_{ci}$ instead of $0.60f'_{ci}$.

Design

Figure 1 illustrates the strand pattern

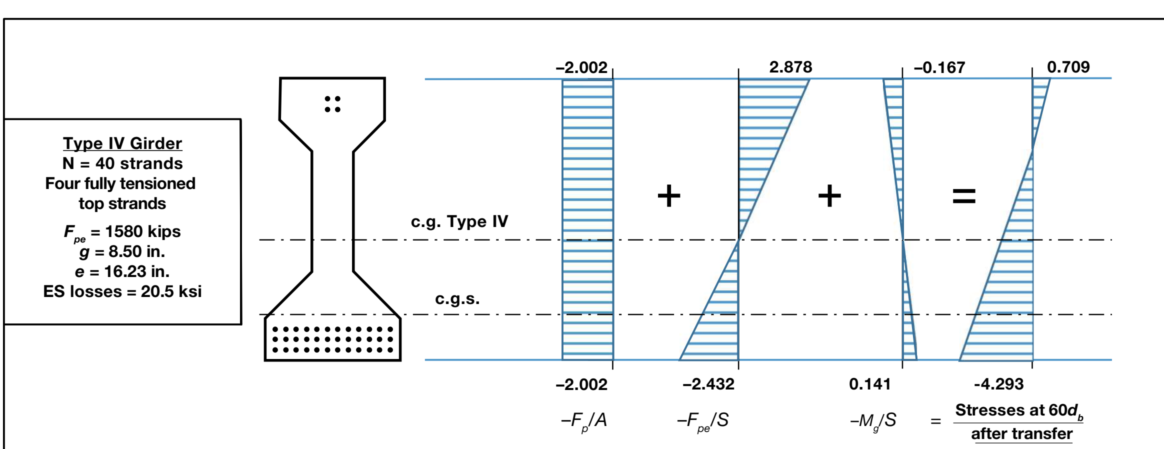

Figure 1. Calculated stresses at transfer at $60d_b$ from end of AASHTO Type IV bridge girder with straight strand pattern and four fully bonded top strands but with no debonded strands. Note: Compressive stresses are negative, stresses shown are in ksi, and figure is not to scale. All Figures: Dr. Bruce Russell.

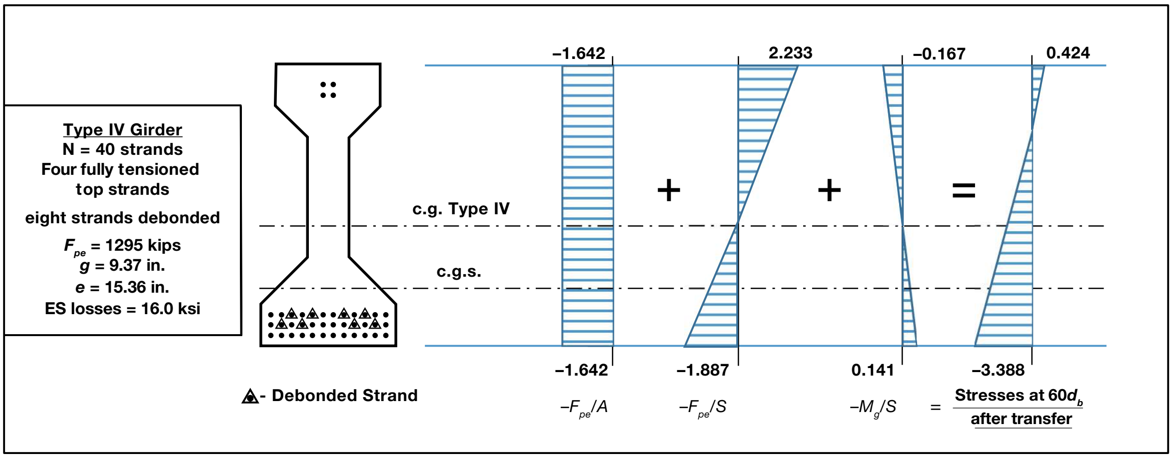

Figure 2. Calculated stresses at transfer for same girder and location as Fig. 1 but with eight of the bottom strands debonded.
Note: Compressive stresses are negative, stresses shown are in ksi, and figure is not to scale.

for the cross section that contains forty 0.6-in.-diameter, Grade 270 low-relaxation strands conforming to ASTM A416. Thirty-six strands are located in the bottom flange, and four fully bonded straight strands are located near the top of the cross section. The specified concrete strengths were 6.5 ksi at transfer and 8.7 ksi at 28 days. The strand pattern shown in Fig. 1 does not include debonded strands. The beam stresses shown in the figure are computed after transfer at $60d_b$ (36 in.) from the end of the beam, as if debonding were not applied. Please note that d_b is the diameter of the strand, compressive stresses are shown as negative stresses, and stress units are ksi.

Figure 2 shows the cross section, including the eight strands that were debonded, and illustrates the stresses after transfer at the location $60d_b$, but with eight of the bottom strands debonded. Significant differences from debonding eight bottom strands include the following:

- Reduces the prestress force BEFORE transfer P_{pi} by 25%.
- Reduces the effective prestressing force AFTER transfer F_{pe} by approximately 18%.
- Decreases the eccentricity of the center of gravity of the strands by 0.88 in. Engineers often do not anticipate this factor or appreciate its effects. The change in eccentricity is an important benefit derived directly by combining fully bonded top strands with debonding of bottom strands.
- Reduces the elastic shortening loss ES by 22%.
- Significantly reduces both the maximum tensile and compressive stresses at the extreme fibers.

Not fully discussed nor illustrated is the significant reduction in girder curvature brought about by the inclusion of top strands. This factor, perhaps more than any other, helps mitigate the incidence of web cracking in end regions of prestressed concrete beams upon detensioning.

Tensile Stress in Bottom Fiber at Service III Limit State

Figure 3 illustrates the concrete stresses at midspan for the non-composite girder and the composite girder (Type IV girder with cast-in-place slab) and includes the effect of pretress losses. Since the stresses are computed at midspan, debonding has no effect. The figure shows that the tensile stress at the bottom fiber is less than the allowable stress in the current AASHTO LRFD specifications. Stresses in beams with fully bonded top strands were also compared with stresses in beams with no top strands. **Table 1** shows the tabulation. For this design case, with AASHTO Type IV girders at 8.2 ft spacing and spanning 103 ft 5 in., the tabulation shows that the addition of four fully bonded top strands added 137 psi of tension to the bottom fiber at midspan. There will be some design cases where the addition of fully bonded top strands may require a designer to add another pair of strands to the bottom strand pattern. This option is an economical alternative that the engineer may wish to consider.

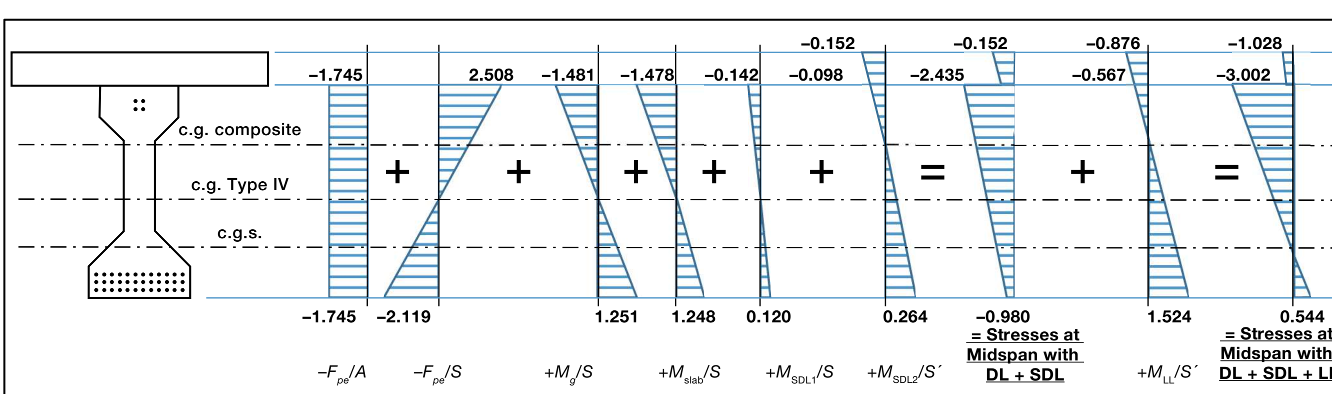

Figure 3. Stresses at midspan at service load for same girder as Fig. 1, with or without debonded strands.
Note: DL = dead load; LL = live load; SDL = superimposed dead load. Compressive stresses are negative, stresses shown are in ksi, and figure is not to scale.

Discussion and Conclusions

The intention of this article is to document the practice of using fully bonded top strands in the precast, prestressed concrete bridge industry. My hope is that engineers, owners, and precasters will read this article and consider implementation of these basic principles. I have asserted that the inclusion of fully bonded top strands can provide benefits that improve the serviceability of bridge beams. These improvements will be manifested in reduced concrete stresses in end regions, and by reducing cambers and decreasing the incidence of cracking near end regions that may occur during detensioning.

This article outlines the basic design principles for the design of straight strand patterns. Some engineers may find the assertions and conclusions challenging. As a response, I encourage readers to work out the controlling stresses, "play" with different strand patterns, and see whether they come to the same or similar conclusions. The design of the I-35 bridge over Rollercoaster and Pine Roads and its subsequent maintenance-free performance over the past 20 years illustrates that fully bonded top strands can be integrated into the design and construction of prestressed concrete bridge girders with favorable results.

Finally, I believe there is conclusive evidence from both theory and practice that suggests that bridge designers and bridge builders should consider the regular inclusion of fully bonded top strands along the whole length of a bridge girder. It is my opinion that this practice will help control stresses in end regions, work symbiotically with the practice of debonding strands, limit cambers, and improve the overall serviceability of precast, prestressed concrete bridges.

References

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Dr. Bruce W. Russell is the director of the Bert Cooper Engineering Laboratory and associate professor of Civil and Environmental Engineering at Oklahoma State University in Stillwater, Okla.

Table 1. Concrete stresses at midspan at service load comparing designs with straight strands. Case I: thirty-six bottom strands as in example girder; Case II: Case I plus four fully bonded top strands. The values show that the addition of the top strands adds 137 psi tension to the bottom fiber of the composite section.

Concrete Stresses at Midspan at Service Loads After All Prestress Losses (ksi) Both designs contain 36 fully tensioned bottom strands				
DL + SDL				
	Case I No Top Strands		**Case II Four Top Strands**	
	f_{top}	f_{bot}	f_{top}	f_{bot}
Prestress-Axial (F_{pe}/A) Prestress-Bending (F_{pe}/S)	–1.568 2.880	–1.568 –2.433	–1.745 2.508	–1.745 –2.119
Stresses due to Prestressing Only ([F_{pe}/A] + [F_{pe}/S]) (Difference: Case II - Case I)	**1.312**	**–4.001**	**0.763** (-0.549)	**–3.864** (+0.137)
Girder Self Weight (M_g/S) Slab Weight (M_{slab}/S) SDL on Non-Composite (M_{SDL1}/S) SDL on Composite (M_{SDL2}/S')	–1.481 –1.478 –0.142 –0.098	1.251 1.248 0.120 0.264	–1.481 –1.478 –0.142 –0.098	1.251 1.248 0.120 0.264
Total Stresses with DL + SDL	**–1.887**	**–1.118**	**–2.435**	**–0.980**
Add Effect of LL: DL + SDL + LL				
LL on Composite	–0.567	1.524	–0.567	1.524
Total Stresses @ Midspan @ DL + SDL + LL (Difference: Case II - Case I)	**–2.454**	**0.407**	**3.002** (+0.548)	**0.544** (+0.137)

Note: DL = dead load; LL = live load; and SDL = superimposed dead load. Compressive stresses are negative, and stresses shown are in ksi.