Bond Performance in Self-Consolidating Concrete Pretensioned Bridge Girders.

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Discussion by José R. Martí-Vargas

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The discussed paper presents an interesting study on the potential application of high-early-strength self-consolidating concrete in precast, prestressed bridge girders. The authors should be congratulated for providing comprehensive information on the bond characteristics and prestress losses of prestressed concrete girders. The discusser would like to offer the following comments and questions, mainly about transfer and development length.

1. As stated by the authors, it seems that ACI 318 provisions for transfer length have differed over the years. The reader believes that: a) a transfer length of $50d_b$ is specified by ACI 318-02; b) the $50d_b$ transfer length requirement is not referred to in ACI 318-08; c) ACI 318-08 recommends a transfer length of $(f_{pe}/3)d_b$. However, the $50d_b$ transfer length requirement in the ACI 318-02 shear provisions (Section 11.4.3) is also referred to in ACI 318-05 (Section 11.4.4), in ACI 318-08 (Section 11.3.4) and in ACI 318-11 (Section 11.3.4) –ACI 318-11 was first printed in August 2011 and is not included as a reference in the paper–. On the other hand, current ACI 318 provisions on transfer length first appeared in ACI 318-63 and remain to date as $(f_{se}/3000)d_b$ (ACI 318-11, the first part of Eq. 12-4).

2. Eq. (1) is presented using l_{tf} (final transfer length according to the footnote of Table 1), whereas this equation is applicable immediately after transfer (Mitchell et al. 1993). However, Eq. (1) (which considers stress in prestressed reinforcement immediately after prestress transfer) was proposed by Barnes et al. (2003) as an upper bound for the long-term transfer length. Can the authors explain these inconsistencies?

3. The constant 10 in. in Eq. (2a) [254 mm in Eq. (2b)] should be replaced with 5 in. [127 mm] in accordance with Eq. (9) proposed by Lane (1998). Besides, some details of references about AASHTO LRFD BDS should be clarified: the text mentions the years 1996, 2004, 2006 and 2008, whereas the years included in the references section are 2005, 2006 and 2008.

4. Several strand bond equations (Martí-Vargas *et al.* (2007, 2012b)) can be used in the analysis for comparisons. An evaluation of these equations for SCC beams is available in Floyd *et al.* (2011).

5. Some references on bond of prestressing strands in SCC have been neglected; for example, Martí-Vargas *et al.* (2006) and Larson *et al.* (2007). In particular, Martí-Vargas *et al.* (2006) report findings on similar transfer lengths in SCC and CC, and greater development lengths in SCC when using cement contents of the order of those considered in the mixture proportions used by the authors. This tendency has been followed for only girders R2. More findings on the effects of cement content on transfer length are reported in Martí-Vargas *et al.* (2012a).

6. Both the initial and final transfer lengths are determined from the Type II embedded concrete strain gauges. The discusser's opinion is that there are few gauges and that there is a considerable distance between them (for example: the first gauge is located at 5 in. (127 mm) from the beam end, however a transfer length of 3.3 in. (84 mm) is reported; also several transfer length values are under 10 in. (254 mm) –the location of the second gauge from the beam end–). This fact has influenced the quality of the test results and adjustments..

7. The Type I strain gauges were attached to the side faces with 10 in. (254 mm) intervals. Only the locations at 10 in. (254 mm), 20 in. (508 mm), and 70 in. (1780 mm) coincided with the locations of the Type II gauges. The surface and embedded measurements were very similar. Did the authors

determine the transfer lengths from the Type I gauges? As the transfer of the prestress from the strands to the concrete requires a certain length, why is there no difference between the concrete strains from the side faces in relation to the concrete strains at the centroid of the tension strands?

8. Regarding Fig. 4: in cases (a) and (b), it seems that embedded gauges are placed at 18 in. (457 mm) instead of at 20 in. (508 mm); in case (a), the 10 in. (254 mm) gauge shows a high initial value, and a more logical expected transfer length value of around 15 in. (380 mm) should be obtained instead of 8 in. (203 mm) –consequently, the discusser believes that girder SCC-R also has shorter (instead of similar or shorter, as the authors state) initial and final transfer lengths if compared to girder CC-R–; in case (c) a tentative initial transfer length could be 20 in. (508 mm) instead of 28 in. (710 mm) –precisely, this girder is the only one showing underestimated values from some predictions–; in cases (c) and (d), it seems that the adjustments in the plateau zones should show measured values both above and below the best fit lines for the final transfer length. How did the authors make the adjustments?

9. Table 2 should be improved: both ends should be identified (live or dead end, End (I) or (II) according to Fig. 7, R1 or R2 according to Table 3; What is the correspondence between them?); the ratios are measured/predicted instead of predicted/measured; these ratios were obtained for only the measured final transfer length (but there is no indication of this); ACI 318-02 should be replaced with ACI 318-11 [50d_b]; ACI 318-08 should be replaced with ACI 318-11 [(f_{se}/3000)d_b]; in AASHTO (2008), there should be details of the use of 60d_b or [4$d_b f_{bpt}/f'_c$ - 21 (ksi, in.)] in accordance with Lane (1998); the concrete compressive strength (specified at 28 days, measured at 90 or 91 days, measured at 128 or 130 days) and strand stress (f_{pi} or f_{pe}) used in each prediction should be detailed.

10. Can the authors report the measured strand end slip at prestress transfer from the 10 LVDTs used?

11. It is worth remarking that transfer length can change over time. A transfer length model with a factor accounting for transfer length changes with time is presented in Caro *et al.* (2012). However,

changes in strand stress (influenced by concrete creep and shrinkage and strand relaxation) are not directly related to changes in transfer length, which seems a contradiction: based on some references, the authors state that "Creep, shrinkage and relaxation around the transfer region were reported to increase transfer length" –these phenomena cause prestress losses (strand stress diminishes)– and the authors also state that "High effective stresses f_{pe} result in a longer transfer length". Therefore, strand stress diminishes and transfer length increases with time. Can the authors explain this?

12. The discusser believes that the bond failure for girder SCC-R1 indicates that development length is greater than 70 in. (1780 mm) and that this information should be included in Table 3.

13. The Type II gauges were also used to measure prestress losses. The last gauge is located at 70 in. (1780 mm) from the beam end, and this location is not midspan. However, Fig. 7 shows concrete compressive strains at the midspan and at both ends of each girder. How did the authors measure these compressive strains at the midspan? Were the values at both ends obtained from the gauges within the transfer length?

14. In Fig. A, did the authors illustrate the compressive strains due only to the applied load? The ε'_c values are greater than ε_{c1} and ε_{c2} at the first point in case (c), and there is also an initial constant plateau for ε'_c with greater values than ε_{c1} and ε_{c2} in case (d). Can the authors explain this or provide some information on cracks within the transfer length?

15. Finally, the discusser suggests using the actual perimeter of strands ($\pi d_b 4/3$) instead of the nominal perimeter (πd_b) to obtain average bond stresses. This fact does not affect the bond ratio values obtained by the authors, and it reports more realistic bond stress values.

REFERENCES

ACI Committee 318, 1963, "Building Code Requirements for Reinforced Concrete (ACI 318-63)," American Concrete Institute, Detroit, MI.

ACI Committee 318, 2005, “Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary,” American Concrete Institute, Farmington Hills, MI.

ACI Committee 318, 2011, “Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary,” American Concrete Institute, Farmington Hills, MI, 509 pp.

Caro, L.A.; Martí-Vargas, J.R.; and Serna, P., 2012, “Time-dependent Evolution of Strand Transfer Length in Pretensioned Prestressed Concrete Members,” *Mechanics of Time-Dependent Materials*, 2012, DOI: 10.1007/s11043-012-9200-2.

Floyd, R.W.; Howland, M.B.; and Hale, W.M., 2011, “Evaluation of strand bond equations for prestressed members cast with self-consolidating concrete,” *Engineering Structures*, V. 33, pp. 2879-2887.

Larson, K.H.; Peterman, R.J.; and Esmaeily, A., 2007, “Bond Characteristics of Self-consolidating Concrete for Prestressed Bridge Girders,” *PCI Journal*, V. 52, Nº 4, pp. 44-57.

Martí-Vargas, J.R.; Serna-Ros, P.; Arbeláez, C.A.; and Rigueira-Victor, J.W., 2006, “Bond Behaviour of Self-Compacting Concrete in Transmission and Anchorage,” *Materiales de Construcción*, Vol. 56, No. 284, pp. 27-42.

Martí-Vargas, J.R.; Arbeláez, C.A.; Serna-Ros, P.; Navarro-Gregori, J.; and Pallarés-Rubio, L., 2007, “Analytical Model for Transfer Length Prediction of 13 mm Prestressing Strand,” *Structural Engineering and Mechanics*, V. 26, No. 2, pp. 211-229.

Martí-Vargas, J.R.; Serna, P.; Navarro-Gregori, J.; and Bonet, J.L., 2012a, “Effects of Concrete Composition on Transmission Length of Prestressing Strands,” *Construction and Buiding Materials*, V. 27, pp. 350-356.

Martí-Vargas, J.R.; Serna, P.; Navarro-Gregori, J.; and Pallarés, L., 2012b, “Bond of 13 mm Prestressing Steel Strands in Pretensioned Concrete Members,” *Engineering Structures*, V. 41, pp. 403-412.