**Determining Slipping Stress of Prestressing Strands in Confined Sections.**

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**Discussion by José R. Martí-Vargas**

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Based on the experimental results reported by Shahawy and Issa[4], the discussed paper studies the appropriateness of a modified equation presented by the authors[5] for the development length of prestressing strands which accounts for the effect of confinement stress in confined sections. The authors should be congratulated for producing a detailed paper which is acknowleged by the discusser. Some findings are interesting for the discusser, who would like to address the following comments for the authors' consideration.

1. Table 1 presents details of the test program carried out by Shahawy and Issa[4]. Data concerning transfer length are included. However, the discusser has not found these data in the paper authored by Shahawy and Issa[4]. Besides, in the comments by Buckner[26] on Shahawy and Issa[4], a remark detailing transfer lengths ranging from 25 to 30 in. (635 to 762 mm) is included, but there is no transfer length for each pile. How did the authors obtain these transfer lengths? Do the authors know how the transfer lengths were measured? Are there also strand end slip measurements at prestress transfer? On the other hand, what was the concrete age established for the development

length tests? It is noticed that transfer length can change with time[27,28] and also that prestress losses occur[29]; do the authors have some information on these aspects?

2. The nominal flexural strength of the prestressing strand ($f_{ps}$) is renamed by the authors as slipping stress ($f_{ss}$), which is introduced into Eq. (1b) in addition to the term $f_{ps}$ from Eq. (1a). In the discusser's opinion, readers may be confused as it seems that there is only one term –$f_{ps}$ renamed as $f_{ss}$– when it should be made clear that there are two different prestressing strand stresses: stress in the prestressing strand at nominal strength of the member ($f_{ps}$), achieved by bond along the development length; stress in the prestressing strand ($f_{ss}$), achieved by bond along an embedment length, which is lesser than the development length. Besides, the authors have stated that in the ACI 318-11[3] equation for development length of prestressing strands (Eq. (1a)), the development length is equal to the embedment depth of the pile. However, according to the development length definition[30-32], this is true only if $f_{ss} = f_{ps}$ –which implies that there is no strand end slip at loading–. Evidently, $f_{ps}$ will be reached in the case of embedment length longer than the development length, and $f_{ss}$ ($< f_{ps}$) will be reached in the case of embedment length shorter than the development length because of the strand slippage.

3. Experimental studies considering development length (without strand slippage) and also bond behavior after strand slippage, by defining a new development length with strand slippage, have been carried out[32,33] by means of the ECADA test method[34,35].

4. It is worth remarking that the equation (Eq. (2b) proposed by Shahawy and Issa[4] , which derives from Eq. (2a)), well matches the experimental data, as presented in Table 2. The authors have stated that Eq. (2b) uses the slipping stress of the strand as an input. The discusser believes that Eqs. (1b) and (4b) also use the slipping stress of the strand as an input; is this right?

5. Eq. (2a) is a modification of the ACI 318-11[3] equation (Eq. (1a)), as proposed by Shahawy and Issa[4] to incorporate an average bond stress term ($u_{ave}$) into the second part of the equation. However, it seems that Shahawy and Issa[4] have used an unrealistic strand area/perimeter ratio, as follows: strand cross-sectional area $A_{ps} = \pi * d_b^2/4$, and strand perimeter $\Sigma o = \pi * d_b$, which results

in $d_b/4$. For this reason, there is a constant of 4 in the denominator in the second part of Eq. (2a). Therefore, the $u_{ave}$ values are also unrealistic: when the actual strand area/perimeter ratio is used (strand cross-sectional area $A_{ps} = 0.725 * \pi * d_b^2/4$, and strand perimeter $\Sigma o = 4/3 * \pi * d_b$), the corresponding constant in the denominator is 7.36 (see Eq. (6)) and $u_{fb}$ is 140 psi (0.96 MPa), whereas according to Shahawy and Issa,[4] $u_{ave}$ is a nonreal value of 250 psi (1.72 MPa).

6. Besides, as $u_{ave}$ is used only in the second part of Eq. (2a), and Eq. (3) considers the available embedment length (available flexural bond length –embedment length minus transfer length– according to the footnote of Table 1), it seems that *T* should include the effective prestressing strand force.

7. On the other hand[36,37], the actual strand cross-sectional area for today's prestressing strands of 0.5 in. (13 mm) in diameter is $A_{ps} = 0.779 * \pi * d_b^2/4$. Therefore, constant 7.36 in Eqs. (5, 6, 9a, and 9b) should be replaced with 6.85 to obtain more adjusted predictions.

8. It should be clarified that Eq. (4a) was proposed by Zia and Mostafa[8] for sudden release Another equation was also proposed by Zia and Mostafa[8] for the gradual release.

9. As stated by the authors, the transfer length in the absence of confinement is a function of the strand diameter, effective prestress and average transfer bond stress. This is in accordance with the ACI 318-11[3] transfer length model, whereas the European practice considers more variables[38]. In addition, other approaches have also stated the effect on the transfer length of variables such as concrete compressive strength[39], cement content[40], to result in a variety of proposed equations[41].

10. The confinement in the specimens tested by Shahawy and Issa[4] was provided by two sources: the spiral reinforcement placed at the end sections of piles, and the confined stress by a clamping force using post-tensioning thread bars. However, it should be pointed out that only the upper and lower faces were subjected to confinement via clamping force. Consequently, the discusser suggests the consideration of the Poisson's effect on the specimens in the reduction factor presented in Eq. (8a).

**REFERENCES**

26. Buckner, C.D.., “Effect of Pile Embedment on the Development Length of Prestressing Strands,” *PCI Journal*, V. 38, No. 5, Sept.-Oct. 1993, pp. 86-88.

27. Martí-Vargas, J.R.; Caro, L.; and Serna, P., “Experimental Technique for Measuring the Long-Term Transfer Length in Prestressed Concrete,” *Strain*, 2012, DOI: 10.1111/str.12019.

28. Caro, L.A.; Martí-Vargas, J.R.; and Serna, P., “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.

29. Caro, L.A.; Martí-Vargas, J.R.; and Serna, P., “Prestress Losses Evaluation in Prestressed Concrete Prismatic Specimens,” *Engineering Structures,* V. 48, 2013, pp. 704–715.

30. Buckner, C.D., “A Review of Strand Development Length for Pretensioned Concrete Members,” *PCI Journal*, V. 40, No. 2, March-April 1995, pp. 84-105.

31. Patzlaff, Q.; Morcous, G.; Hanna, K.; and Tadros, M.K., “Bottom Flange Confinement Reinforcement in Precast Prestressed Concrete Bridge Girders,” *ASCE Journal of Bridge Engineering*, Vol. 17, No. 4, July 2012, pp. 607-616.

32. Martí-Vargas, J.R.; Serna, P.; and Hale W.M., “Strand Bond Performance in Prestressed Concrete Accounting for Bond Slip,” *Engineering Structures*, 2013, DOI:10.1016/j.engstruct.2013.01.023.

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

34. Martí-Vargas, J.R.; Serna-Ros, P.; Fernández-Prada, M.A.; Miguel-Sosa, P.F.; and Arbeláez, C.A., “Test Method for Determination of the Transmission and Anchorage Lengths in Prestressed Reinforcement,” *Magazine of Concrete Research*, V. 58, No. 1, 2006, pp. 21-29.

35. Martí-Vargas, J.R.; Arbeláez, C.A.; Serna-Ros, P; and Castro-Bugallo, C., “Reliability of Transfer Length Estimation from Strand End Slip,” *ACI Structural Journal*, V. 104, No. 4, July-Aug. 2007, pp. 487-494.

36. Tabatabai, H., and Dickson, Th., “The history of the prestressing strand development length equation,” *PCI Journal*, V. 38, No. 5, Sept.-Oct. 1993, pp. 64-75.

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

38. Martí-Vargas, J.R., and Hale, W.M., “Predicting Strand Transfer Length in Pretensioned Concrete: Eurocode versus North American Practice,” *ASCE Journal of Bridge Engineering*, 2012, DOI:10.1061/(ASCE)BE.1943-5592.0000456.

39. Martí-Vargas, J.R.; Arbeláez, C.A.; Serna-Ros, P.; Fernández-Prada, M.A.; and Miguel-Sosa, P.F., “Transfer and Development Lengths of Concentrically Prestressed Concrete,” *PCI Journal,* V. 51, No. 5, Sept.-Oct. 2006, pp. 74-85.

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

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