

## DISCUSSION

### Experimental investigation of the web-shear strength of deep hollow-core units

In “Experimental Investigation of the Web-Shear Strength of Deep Hollow-Core Units” on pages 83 to 104 in the Fall 2011 issue of *PCI Journal*, Keith Palmer and Arturo Schultz have made important contributions to the understanding of the factors that affect the strength and behavior of deep hollow-core slabs.

In particular, they have broken new ground by comparing the effect of two different production processes on compaction and density of otherwise similar products and the significant effects on strand bond and consequent shear strengths. The detail contained in the article provides the opportunity for further research and testing to extend Palmer and Schultz’s findings and perhaps result in modifications to supplier A’s production process that might increase the shear strength of its product so that it is comparable to the strengths achieved by supplier B’s production process.

However, I do have concerns regarding the unusually low initial strand slips at the ends of the test specimens as reported in the article, with respect to both processes. Drawing upon more than 30 years of experience with measuring end slips in saw-cut hollow-core slabs and in experimental testing of structural beam specimens and hollow-core slabs, I am concerned that the experimental specimens tested and reported in the article do not appear to represent typical hollow-core slabs produced and accepted for structural use in the hollow-core products industry.

For 0.5 in. (13 mm), 270 ksi (1860 MPa) strand stressed to  $0.7f_{pu}$  (where  $f_{pu}$  is the specified tensile strength of prestressing steel), the acceptance criterion for initial end slip in saw-cut hollow-core slabs is typically set at a  $3/32$  in. (0.09375 in. [2.381 mm]) maximum. One firm that I interviewed accepts up to  $4/32$  in. (0.1250 in. [3.175 mm]). Table 3 on page 91 of the paper shows that the average measured end slips are B16 equals 0.03298 in. (0.8377 mm), B20 equals 0.04403 in. (1.118 mm), and A16 equals 0.07869 in. (1.999 mm).

Using the accepted relationship between measured end slips and transfer length noted on page 90, the comparison of end slips and transfer lengths  $L_t$  is as follows:

$$2\delta \frac{E_{ps}}{f_{pi}} \quad \text{Eq. (1)}$$

where

$\delta$  = end slip

$E_{ps}$  = modulus of elasticity of prestressing steel = 28,000 ksi (190,000 MPa)

$f_{pi}$  = initial stress in prestressing steel = 189 ksi (1300 MPa)

**Table 1** shows values for 0.5 in. (13 mm), 270 ksi (1860 MPa) strand stressed to  $0.7f_{pu}$ .

This suggests that the experimental results would only apply to hollow-core slabs that have abnormally short end slips or that hollow-core plants would need to reduce their acceptance criterion to require end slips of  $1/32$  in. (0.03125 in. [0.7938 mm]) or  $2/32$  in. (0.0625 in. [1.59 mm]) maximum to utilize the test data.

It is recommended that this research be extended to conduct tests on a limited number of 16 in. deep (410 mm) hollow-core slabs, produced by both supplier A and

**Table 1. Strand end slip and transfer length for 0.5 in., 270 ksi strand stressed to  $0.7f_{pu}$** 

Specimen	Strand end slip $\delta$ , in.	Transfer length $L_{tr}$ , in.
B 16	0.03298 average	9.8
B 20	0.04403 average	13.0
A 16	0.0780 average	23.1
Typical acceptance criteria	0.09375 maximum	27.8
Acceptance criteria, one plant	0.1250 maximum	37.0

Note:  $f_{pu}$  = specified tensile strength of prestressing steel. 1 in. = 25.4 mm; 1 ksi = 6.895 MPa.

supplier B, that have initial end slips at the typical maximum acceptance criteria. It would also be of interest to include a limited number of 16 in. deep slabs produced by a process that differs from both supplier A's and supplier B's, such as the hollow-core section developed by the ECHO Engineering, which uses slip-formed, vibrated concrete in its production process.

**Donald R. Logan, PE**

President, Logan Structural Research Foundation  
Colorado Springs, Colo.

## Authors' response

We thank Don Logan for his interest in our paper and for his insightful comments on various issues presented in the paper. However, we disagree with Logan's suggestion that the hollow-core slabs tested as part of our experimental program are not representative of those used throughout the United States because they have "unusually low initial strand slips at the ends of the test specimens."

The end slips that were reported fall squarely within the range of values that are typical for each of the producers who provided hollow-core slabs for this research. The average end slips measured for the 16 in. deep (410 mm) units that were tested in shear were 0.078 in. ( $3/64$  in. [1.9 mm]) and 0.033 in. ( $1/32$  in. [0.84 mm]), respectively, for supplier A and supplier B. Both suppliers have long records of hollow-core slab production, and initial end slips seldom if ever exceed  $4/32$  in. (0.125 in. [3.18 mm]) for supplier A (with the majority falling below  $2/32$  in. [0.0625 in. (1.59 mm)]), and they are consistently below  $2/32$  in. for supplier B.

Due to length limitations, the paper did not include transfer-length tests<sup>1,2</sup> that were conducted using a hollow-core unit each from supplier A and supplier B. These tests revealed transfer lengths  $L_{tr}$  that greatly exceed those obtained using the well-known formula cited by Logan (Eq. [1]).

We noted in the paper that other researchers<sup>3</sup> have questioned the accuracy of Eq. (1), and we found that this formula would have to be changed to Eq. (2) to accurately describe the relationship for  $L_{tr}$  and  $\delta$  values that were measured in the transfer length tests.<sup>1,2</sup>

$$5\delta \left( \frac{E_{ps}}{f_{pi}} \right) \quad \text{Eq. (2)}$$

Of course, we recognize that it is not appropriate to propose such a dramatic departure from industry practice with just two transfer-length tests.

Our hypothesis is that the longer transfer lengths in the hollow-core units we tested are responsible for the low shear strength of deeper slabs. Economic and efficient production of hollow-core units requires use of one of the various dry-cast production

methods available, such as extrusion or slip forming. When these methods are used for deep hollow-core units ( $h > 12$  in. [300 mm]), the consolidation that takes place in the concrete below the prestressing strand is not as high as it is above the strands or in wet-cast products. This mechanism can affect not only the web shear strength of the units but also their flexural performance.

In closing, we join Logan in making an urgent call to hollow-core slab producers and PCI for supporting additional research on both the shear strength and the transfer length of hollow-core units.

**Keith D. Palmer, PE**

PhD candidate, Department of Civil Engineering, University of Washington  
Seattle, Wash.

**Arturo E. Schultz, PhD**

Professor, Department of Civil Engineering, University of Minnesota  
Minneapolis, Minn.

## References

1. Palmer, K. D. 2009. "The Web-Shear Tension Capacity of Deep, Precast, Prestressed Hollow Core Units." MS thesis, Department of Civil Engineering, University of Minnesota.
2. Palmer, K. D., and Arturo Schultz. 2010. "Web Shear Strength of Precast, Prestressed Concrete Hollow Core Slab Units." Final report, Department of Civil Engineering, University of Minnesota.
3. Martí-Vargas, J. R., C. A. Arbelaez, P. Serna-Ros, and C. Castro-Bugallo. 2007. "Reliability of Transfer Length Estimation from Strand End Slip." *ACI Structural Journal* 104 (4): 487–494. [■](#)

### COMMENTS?

The editors welcome discussion of the technical content of *PCI Journal* papers. Comments must be confined to the scope of the paper to which they respond and should make a reasonable and substantial contribution to the discussion of the topic. Discussion not meeting this requirement will be returned or referred to the authors for private reply.

Discussion should include the writer's name, title, company, city, and email address or phone number and may be sent to the respective authors for closure. All discussion becomes the property of the *PCI Journal* and may be edited for space and style. Discussion is generally limited to 1800 words with each table or illustration counting as 300 words. Follow the style of the original paper, and use references wherever possible without repeating available information.

The opinions expressed are those of the writers and do not necessarily reflect those of PCI or its committees or councils.

All discussion of articles in this issue must be received by November 1, 2012. Please address reader discussion to *PCI Journal* at [journal@pci.org](mailto:journal@pci.org).