



DISCUSSION

New generation of precast concrete double tees reinforced by carbon-fiber-reinforced polymer grid

The following comments relate to “New Generation of Precast Concrete Double Tees Reinforced by Carbon-Fiber-Reinforced Polymer Grid”¹ by D. Lunn, G. Lucier, S. Rizkilla, N. Cleland, and H. Gleich, which appeared in the July–August 2015 issue of *PCI Journal*.

I have considerable difficulty calling the flanges of these members reinforced because they failed at initial cracking. ACI 318-14² and other codes have for many years had minimum reinforcement ratios, and one of the purposes of the minimum reinforcement ratio is to ensure that the failure moment is larger than, or at least equal to, the cracking moment. There is an exception when there is significant excess reinforcement, but its use in a statically determinate member, such as a cantilever flange, does not seem wise. In addition, ACI 318-14 has required that the failure moment be at least 1.2 times the cracking moment for some classes of prestressed members.

A way of looking at the problem, without computing moments, is to compare the tension capacity of the concrete with that of the carbon-fiber-reinforced polymer (CFRP) strands. The reported capacity of a single strand was about 1215 lb (5404 N). Using the reported average compressive strength and other factors, one obtains an average modulus of rupture of 795 psi (5480 kPa). For a 3.5 in. (89 mm) deep flange, the tensile force at cracking is $795 \times 1.75/2 = 696$ lb/in. (122 N/mm). The smallest strand spacing is 2.7 in. (69 mm), and the accompanying concrete tension force is $696 \times 2.7 = 1878$ lb (8353 N), about 1.5 times the strand strength. The strand has no chance of replacing the concrete tension force that is lost at cracking. The brittle nature of the CFRP strands does help the cause. ACI 318-14² minimum reinforcement requirements are based on an assumption of a ductile material (steel), with an unspoken assumption of some strain hardening. The CFRP material does not rust but otherwise does not supply the properties of properly selected steel reinforcement in this case.

The appropriate ϕ -factor for this application seems to be that for plain concrete, 0.60, but an unreinforced cantilever flange does not fall within the permitted uses of plain concrete in ACI 318-14.²

The tests were conducted in a load-control mode with an unlimited capacity for the load to follow the deflection, but the final results would have been about the same in a displacement-controlled mode.

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Reference

1. Lunn, D., G. Lucier, S. Rizkilla, N. Cleland, and H. Gleich. 2015. “New Generation of Precast Concrete Double Tees Reinforced by Carbon-Fiber-Reinforced Polymer Grid.” *PCI Journal* 60 (4): 37–48.
2. ACI (American Concrete Institute) Committee 318. 2014. *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)*. Farmington Hills, MI: ACI.



Authors' response

The authors would like to thank the reader for carefully reviewing this paper¹ and for his interest in this topic. Currently, there is no widely adopted design code that addresses the use of fiber-reinforced polymer (FRP) as reinforcement in concrete structures. ACI Committee 440 has developed design guidelines for FRP bars as reinforcement in concrete structures (ACI 440.1R-06);² however, these guidelines do not specifically address concrete-fiber-reinforced polymer (CFRP) grid as reinforcement. The intention of this paper is to discuss the experimental results of the study and to propose design recommendations for implementation of CFRP grid as reinforcement into ACI 440 design guidelines and eventually into the building code.

The double-tee flange cantilever is a reinforced concrete member in the transverse direction, rather than a prestressed member, because the flange cantilever is not prestressed in the transverse direction. Therefore, the requirement of section 7.6.2.1 of ACI 318-14³ that the reinforcement should develop at least 1.2 times the cracking load does not apply. The requirement for the minimum area of flexural reinforcement should instead be analogous to the value for nonprestressed one-way slabs provided in Table 7.6.1.1 of ACI 318-14, which is the same as the requirement for temperature and shrinkage reinforcement. For the same-sized double-tee flanges as in this study, the required minimum area of steel is $0.0018 \times 12 \times 3.5 = 0.076 \text{ in.}^2/\text{ft}$ ($160 \text{ mm}^2/\text{m}$). Assuming Grade 60 steel reinforcement, this amounts to a force of $0.076 \times 60 = 4.54 \text{ kip/ft}$ (66.3 kN/m). For the CFRP grid in this study with a 2.7 in. (69 mm) grid spacing and a strand capacity of 1.21 kip (5.38 kN), this amounts to a force of $1.21 \times 12/2.7 = 5.38 \text{ kip/ft}$ (78.5 kN/m), which is higher than that provided by the steel. Therefore, although CFRP grid is not yet implemented in the building code, the grid used in the study with a 2.7 in. grid spacing and 3.5 in. (89 mm) flange thickness meets the analogous code requirement for needed reinforcement. The grid with 3.9 in. (99 mm) spacing and 3.5 in. flange thickness does not meet the analogous requirement and until a minimum CFRP grid reinforcement ratio is codified, the engineer should use caution as to the suitability of this spacing for thick flanges.

The development of a recommended strength-reduction factor for CFRP-grid-reinforced double-tee flanges was based primarily on the experimental results and through analogy to existing code requirements for other brittle failure modes, such as shear. For the case of concrete cracking, a strength-reduction factor of 0.75 was recommended along with an additional load factor of 1.33 applied to the factored loads. This results in an equivalent strength-reduction factor of $0.75/1.33 = 0.56$. As stated in the paper,¹ the authors' recommended strength-reduction factor of 0.75 for the case of CFRP grid rupture differs from the strength-reduction factor of 0.55 provided by ACI 440.1R-06² for sections controlled by FRP bar rupture. The conservative value recommended by ACI 440.1R-06 is intended to prevent global failure in the event of rupture of one of the FRP bars. However, CFRP grid reinforcement is believed to have a more uniform distribution of reinforcement at a tighter spacing than the equivalent FRP bar reinforcement, such that the premature failure of one strand is less likely to result in global failure.

ERRATA

Eq. (3) and (4) on page 68 in “Effects of Anchorage Hardware on the Cyclic Tensile Response of Unbonded Monostrands” by Petros Sideris, Amjad J. Aref, and Andre Filiatrault in the Summer 2014 issue of *PCI Journal* should be written as follows:

$$\text{Eq. (3) } u_{Wn} = u_{Br} \cos \theta$$

$$\text{Eq. (4) } u_T = u_{Wt} + u_{Br} \sin \theta$$


We regret the error.

COMMENTS?


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All discussion of papers in this issue must be received by May 1, 2016. Please address reader discussion to *PCI Journal* at journal@pci.org. 

Reference

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1. Lunn, D., G. Lucier, S. Rizkalla, N. Cleland, and H. Gleich. 2015. "New Generation of Precast Concrete Double Tees Reinforced by Carbon-Fiber-Reinforced Polymer Grid." *PCI Journal* 60 (4): 37–48.
 2. ACI (American Concrete Institute) Committee 440. 2006. *Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars (ACI 440.1R-06)*. Farmington Hills, MI: ACI.
 3. ACI Committee 318. 2014. *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)*. Farmington Hills, MI: ACI.

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