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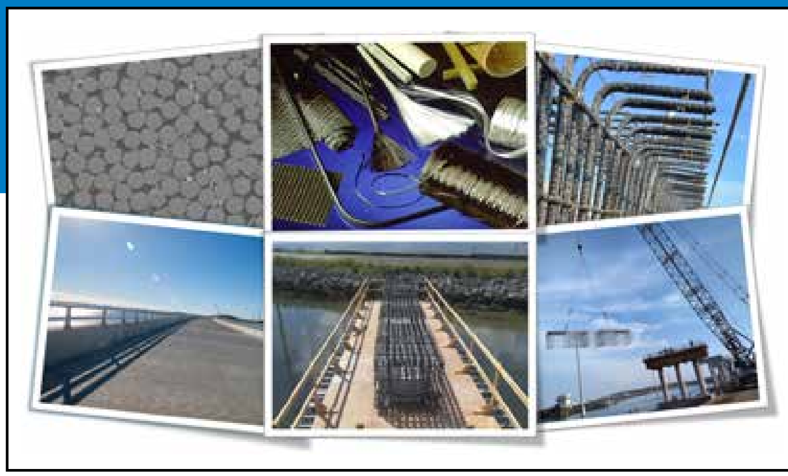

Proceedings of the 16th International Symposium on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures (FRPCS-16)

SP-360

Editors:
Ayman M. Okeil,
Pedram Sadeghian,
John J. Myers, and
Maria D. Lopez

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An ACI Center of Excellence for Nonmetallic Building Materials

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Proceedings of the 16th International Symposium on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures (FRPRCS-16)

The 16th International Symposium on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures (FRPRCS-16) was organized by ACI Committee 440 (Fiber-Reinforced Polymer Reinforcement) and held on March 23 and 24, 2024, at the ACI Spring 2024 Convention in New Orleans, LA. FRPRCS-16 gathers researchers, practitioners, owners, and manufacturers from the United States and abroad, involved in the use of FRPs as reinforcement for concrete and masonry structures, both for new construction and for strengthening and rehabilitation of existing structures.

FRPRCS is the longest running conference series on the application of FRP in civil construction, commencing in Vancouver, BC, in 1993. FRPRCS has been one of the two official conference series of the International Institute for FRP in Construction (IIFC) since 2018 (the other is the CICE series). These conference series rotate between Europe, Asia, and the Americas, with alternating years between CICE and FRPRCS. The ACI convention has previously cosponsored the FRPRCS symposium in Anaheim (2017), Tampa (2011), Kansas City (2005), and Baltimore (1999).

This Special Publication contains a total of 52 peer-reviewed technical manuscripts from 20 different countries from around the world. Papers are organized in the following topics: (1) FRP Bond and Anchorage in Concrete Structures; (2) Strengthening of Concrete Structures using FRP Systems; (3) FRP Materials, Properties, Tests and Standards; (4) Emerging FRP Systems and Successful Project Applications; (5) FRP-Reinforced Concrete Structures; (6) Advances in FRP Applications in Masonry Structures; (7) Seismic Resistance of FRP-Reinforced/Strengthened Concrete Structures; (8) Behavior of Prestressed Concrete Structures; (9) FRP Use in column Applications; (10) Effect of Extreme Events on FRP-Reinforced/Strengthened Structures; (11) Durability of FRP Systems; and (12) Advanced Analysis of FRP Reinforced Concrete Structures.

The breadth and depth of the knowledge presented in these papers is clear evidence of the maturity of the field of composite materials in civil infrastructure. The ACI Committee 440 is witness to this evolution, with its first published ACI CODE-440.11, "Building Code Requirements for Structural Concrete with Glass Fiber Reinforced Polymer (CFRP) Bars," published in 2022. A second code document on fiber reinforced polymer for repair and rehabilitation of concrete is under development.

The publication of the sixteenth volume in the symposium series could not have occurred without the support and dedication of many individuals. The editors would like to recognize the authors who diligently submitted their original papers; the reviewers, many of them members of ACI Committee 440, who provided critical review and direction to improve these papers; ACI editorial staff who guided the publication process; and the support of the American Concrete Institute (ACI) and the International Institute for FRP in Construction (IIFC) during the many months of preparation for the Symposium.

Ayman M. Okeil, Pedram Sadeghian, John J. Myers, and Maria D. Lopez
Co-editors

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TOPIC: FRP Bond and Anchorage in Concrete Structures

TOPIC: Strengthening of Concrete Structures using FRP Systems

Proposed Design Method for EB-FRP Ties Debond Strain Encompassing Short/Long and Thin/Thick Ties

Junrui Zhang, Enrique del Rey Castillo, Ravi Kanitkar, Aniket D Borwankar, and Ramprasath R

Synopsis: A systematic literature review was conducted on pure tension strengthening of concrete structures using fiber-reinforced polymer (FRP), specifically for larger FRP tie applications. This work yielded a dataset of 1,627 direct tension tests, and highlighted the limitation of existing studies on studying thick and long FRP ties, which are typical in real construction scenarios. To overcome this shortcoming, 51 single lap shear tests were conducted on thicker and longer FRP ties, with the dimensions being 0.5 to 6 mm [0.02 to 0.24 in.] thickness, and 300 to 1,524 mm [12 to 60 in.] long. The critical parameters under consideration were concrete compressive strength, FRP thickness, and bond length. The findings demonstrate that thicker and therefore stiffer FRP ties have higher debond force capacity, while longer ties exhibit greater post-elastic deformation capacity but do not affect the debond force capacity. Concrete had a limited effect on either debond force or deformation capacity. A strength model is proposed for FRP systems under axial pure tension, which aligns well with both the published and tested results. This paper focuses on the development of design guidelines and codes to predict the debond strain for EB-FRP systems incorporating thicker and longer FRP ties, aiming to enhance the applicability of FRP to real-world construction scenarios.

Keywords: Externally bonded reinforcement (EBR), Fiber reinforced polymer (FRP), Reinforced concrete (RC), Interfacial bond behavior, Cohesive debonding, Single-lap shear test.

ACI student member **Junrui Zhang** is currently enrolled at the University of Auckland as a PhD candidate working on 'Seismic strengthening of floor diaphragms with carbon fiber composite materials (CFRP) ties'. Before that, Junrui completed his M.Phil. project in Structural Engineering at Lanzhou University with distinction. In the same period, he participated in an exchange program at the Swanson School of Engineering at the University of Pittsburgh.

ACI member **Enrique del Rey Castillo** is currently working at the University of Auckland as a Senior Lecturer, where he teaches and investigates concrete materials, design, and structures. His research interests include seismic behaviour and strengthening of existing concrete structures, mostly with FRP, and sustainability of concrete.

ACI member **Ravi Kanitkar** is currently working at KL Structures

ACI member **Aniket D Borwankar** is currently working at Simpson Strong-Tie

ACI student member **Ramprasath R** has recently completed the undergraduate studies in Civil Engineering at NIT Trichy and will be joining Virginia tech for fall 2023 to pursue master's in structural engineering. Research interest focuses on seismic strengthening of concrete structures.

INTRODUCTION

Application of externally bonded fiber-reinforced polymer (EB-FRP) is a widely used technique for retrofitting and strengthening existing structures. This technique involves bonding Fiber-Reinforced Polymer (FRP) materials such as glass, carbon, or aramid with an epoxy matrix to the external surface of the concrete structure. EB-FRP can provide improved resistance to flexural [1, 2], shear [3], and tension forces [4, 5], making it suitable for reinforcing various components such as beams [6], columns [7], walls [8], and floor diaphragms [9, 10]. Fig. 1 illustrates a regular FRP-strengthened concrete block under single-lap shear tests. The force transfer mechanism between the FRP and the concrete is the bond stresses provided by the epoxy resin, with the failure typically being related to the fracture of a shallow layer of concrete when subjected to tension and/or shear forces. In other words, neither the resin nor the fibers typically fail. Thus, the failure strain of the EB-FRP system is often much lower than the fracture strain of the FRP, due to the low tensile capacity of concrete. Current published studies predominantly focused on thin (< 0.5 mm [0.02 in.]) and short (< 300 mm [12 in.]) FRP ties (aka sheets), which are often not representative of real in-situ construction scenarios where thick and long FRP ties are typically used. This shortcoming is reflected in commonly used design guidelines. For example, Section 12.4 of the ACI 440.2R-17 design guidelines [11] establishes that the FRP pure axial tension strengthening is calculated using the shear provisions, which typically have short lengths, while the effective bond length is calculated using the flexural provisions. Thus, more research on thick and long ties is necessary to the debond force and deformation behavior can be characterized and the design guidelines updated.