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Modeling of FRP Strengthening Techniques in Concrete Infrastructure

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American Concrete Institute
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Editor:
Riadh Al-Mahaidi

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Preface

Modeling of FRP Strengthening Techniques in Concrete Infrastructure

Fibre reinforced polymers (FRP) have become an effective solution to retrofit and reinforce existing and new concrete and masonry structures. This has taken the form of externally bonded reinforcement in existing structures and internally installed reinforcement to replace steel bars in new structures; the latter particularly suited to structures exposed to corrosive environments. Over the last two decades, the use of FRP materials in civil infrastructure has become increasingly dominant worldwide due to the unique properties they possess such as high strength to weight ratio and excellent corrosion resistance. In Australia, the use of externally bonded FRP reinforcement has found wide application in recent years. A good example of this is the retrofitting of the concrete approach viaducts of the West Gate Bridge in Melbourne. When completed by the end of 2010, it will be the largest FRP retrofitting project in the world.

This special publication of the ACI contains eight papers on the Modeling of FRP Strengthening Techniques in Concrete Infrastructure. They were presented at a special session of the ACI Fall Convention, October 2011 in Cincinnati, Ohio. They cover a wide range of innovative contributions from researchers in the United States, Australia, Canada and United Arab Emirates.

The first paper in this issue is by Chen and El-Hacha and presents a finite element investigation into ultra-high performance concrete beams under flexural loading. Next in the series is a paper by Oudah and El-Hacha which deals with numerical simulations of RC beams strengthened with prestressed near-surface mounted CFRP subjected to quasi-static loading. The structural response of RC girders strengthened with FRP composites in shear is investigated by You et al in the third paper using numerical simulations. The next paper by Moslehy et al focusses on the development of new constitutive relations for FRP-strengthened RC elements subjected to pure shear for implementation into finite element models. The fifth paper written by Hawileh et al uses a finite element model to analyze the cyclic response of RC beams strengthened in shear with both externally bonded and near-surface mounted FRP. The response of RC beams strengthened with externally bonded FRP under elevated temperatures is investigated numerically in the sixth paper by Naser et al. This is followed by the seventh paper by Ahmed et al which investigates a numerical procedure to generate interaction diagrams for circular columns wrapped with FRP. The last paper by Kalfat and Al-Mahaidi covers numerical simulations of bi-directional fiber patch anchors used to enhance the strength of FRP-to-concrete joints.

As the editor of this special issue, I would like to thank all the authors who contributed to this special issue I would like to take this opportunity to thank the authors for all their efforts in preparing these papers and to thank the reviewers for their valuable contribution to ensure that a high standard is maintained.

Riadh Al-Mahaidi
Editor

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INVESTIGATION OF HYBRID FRP-UHPC BEAMS UNDER FLEXURE WITH FINITE ELEMENT METHOD

Donna Chen and Raafat El-Hacha

Synopsis: This paper explores the investigation using finite element methods of experimentally tested hybrid FRP-UHPC (Ultra-High Performance Concrete) beams under flexural loading. A combination of mesh sensitivity and cohesive element parameter studies were performed through validation with experimental data. Good correlation was found between experimental findings and the finite element method, though higher stiffness was found in the latter case. It was found that an overall mesh size of 12.5 mm (0.50 in) was suitable for use in the model in order to allow for proper convergence. For the parameters at the GFRP-UHPC interface, it was found that a bond-slip ratio of 5 along with a bond strength of 5 MPa (0.725 ksi) were the best fit to experimental data and should be used in future studies. Additional investigation into the incorporation of considerations to allow for more damage accumulation in the finite element model was recommended.

Keywords: Bond, hybrid, fiber reinforced polymer, ultra-high performance concrete, bond, cohesive element, mesh sensitivity

ACI Member, **Raafat El-Hacha**, is an Associate Professor in the Department of Civil Engineering at the University of Calgary, Canada. He is a member of ACI Committee 440 “Fiber Reinforced Polymer Reinforcement” and chair of Sub-Committee 440-I “FRP Prestressed Concrete”. He is an associate member of ACI 437 “Strength Evaluation of Concrete Structures”. His research interests include strengthening concrete/steel structures and reinforcing/prestressing concrete structures with FRPs, and use of high strength materials in new construction.

Donna Chen is a Ph.D. student in the Department of Civil Engineering at the University of Calgary. She received her M.Sc. degree at the University of Calgary, Calgary, Alberta in 2011 and her B.Sc. degree at Queen’s University, Kingston, Ontario in 2007. Her research focuses on the performance of hybrid structural members using high performance materials, such as FRPs and ultra-high performance concrete, in bridge applications.

INTRODUCTION

The extension of research on Fiber Reinforced Polymers (FRPs) from the aerospace industry to civil engineering applications began approximately thirty years ago and since then, many findings and developments have been made. There are mainly three core streams for the use of FRP materials in structural applications, either for new construction, strengthening or rehabilitating structures. More specifically, FRP materials have been predominantly studied for the purpose of column confinement or to serve as internal or external reinforcements in flexural members or whole structural shapes. In this particular research program, FRP materials in the form of pultruded shapes as well as uni-directional sheets were used.

The use of FRP structural shapes as a primary load carrying structural element has both advantages and disadvantages. Due to its high strength-to-weight ratio, the resulting structural member has significant reductions in self-weight as well as overall dimensions. Nevertheless, structural shapes, which are typically made from Glass FRP (GFRP) have relatively low stiffness compared with conventional materials such as reinforced concrete and structural steel. This shifts the type of design methodology used from strength-oriented approaches to those that focus on serviceability requirements. In order to modify and enhance the stiffness of FRP structural members, several designs have been proposed by various researchers that utilize a combination of different materials in conjunction with the main GFRP structural shape.

Deskovic et al. [1, 2] investigated the design of a hybrid FRP-concrete beam that incorporated a thin-walled GFRP box section, a layer of concrete overtop and a thin sheet of Carbon FRP (CFRP) bonded on the tension side. The main design objectives were to increase the stiffness of the overall section, through the addition of both the concrete and CFRP, as well as to introduce an element of pseudo-ductility, where the failure strain of the CFRP material was chosen to be less than that for the GFRP material, therefore providing an advanced warning sign prior to failure of the overall section. Experimental testing under flexural loading for both static and fatigue loading conditions did exhibit fracture of the CFRP sheet prior to concrete crushing at ultimate failure. Stiffness was significantly increased in the hybrid beam, as compared with the GFRP box section alone. Under fatigue loading, it was found that performance was influenced by the load level applied, where sustained or alternating loads would result in a reduced effective stiffness over time.

Kitane et al. [3] studied the performance of a hybrid FRP-concrete bridge structure composed of three adjacent trapezoidal GFRP thin-wall shapes, bonded together as well as wrapped using FRP laminates. A thin layer of concrete was also cast directly below the top flange of the cross-section. Flexural testing under a combination of static and fatigue loading conditions showed that the addition of concrete did increase the stiffness of the hybrid structural member, while at the same time decreasing the amount of GFRP required in the cross-section. At ultimate failure, complete collapse did not occur and the following symptoms were noted: concrete crushing, compressive failure of the GFRP compressive flange, web buckling as well as delamination in the GFRP.

Cheng and Karbhari [4] examined the performance of steel-free hybrid bridge deck systems, which consisted of a FRP composite deck panel with alternating layers of uni-directional carbon and E-glass fibres. A combination of epoxy bonded carbon fibre rectangular stiffeners along with sand-epoxy paste shear ribs were also incorporated into the design to ensure composite action between the FRP deck panel and the cast-in-place concrete layer above. Flexural load testing of five deck specimens showed that the use of closely spaced stiffeners increased the load carrying capacity of the structural system whereas the presence of rib spacing did not have a significant impact on the performance of the composite deck panel.

Honickman and Fam [5] studied various configuration of hybrid girders that consisted of a trapezoidal pultruded