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Field Applications of Non-Conventional Reinforcing and Strengthening Methods for Bridges and Structures

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Editors:
Yail J. Kim, Steven Nolan, and Antonio Nanni

American Concrete Institute
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PREFACE

Field Applications of Non-Conventional Reinforcing and Strengthening Methods for Bridges and Structures

A Sustainable built-environment requires a comprehensive process from material selection through to reliable management. Although traditional materials and methods still dominate the design and construction of our civil infrastructure, non-conventional reinforcing and strengthening methods for concrete bridges and structures can address the functional and economic challenges facing modern society. The use of advanced materials, such as fiber reinforced polymer (FRP) and ultra-high performance concrete (UHPC), alleviates the unfavorable aspects of every-day practices, offers many new opportunities, and promotes strategies that will be cost-effective, durable, and readily maintainable. Field demonstration is imperative to validate the innovative concepts and findings of laboratory research. Furthermore, documented case studies add value to the evaluation of emerging and maturing technologies, identify successful applications or aspects needing refinement, and ultimately inspire future endeavors. This Special Publication (SP) contains nine papers selected from three technical sessions held during the virtual ACI Fall Convention of October 2020. The first and second series of papers discuss retrofit and strengthening of super- and substructure members with a variety of techniques; and the remaining papers address new construction of bridges with internal FRP reinforcing and prestressing in beam, slabs, decks and retaining walls. All manuscripts were reviewed by at least two experts in accordance with the ACI publication policy. The Editors wish to thank all contributing authors and anonymous reviewers for their rigorous efforts. The Editors also gratefully acknowledge Ms. Barbara Coleman at ACI for her knowledgeable guidance.

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Application of UHPC 2.0™ for a Non-Conventional Reinforcing and Strengthening of a Reinforced Concrete Beam for Bridges and Structures

Peter W. Weber and Su Wang

Synopsis: Conventional reinforcing and strengthening methods and material for bridges and structures has several limitations including include the increased weight of structure, the limited service life of the repair, short periods between repairs, uncertain strength of the reinforcement, extended time of repair and typically a heavy carbon footprint based on the materials used. Application of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) solutions have shown the potential to replace traditional methods over the coming decade because the superior mechanical and durability properties reduce the required thickness of a repairing layer and extend the service life. Based on the overall cost of a given rehabilitation project, UHPFRC based solutions can already compete today but require certain specialized equipment and trained workforce creating real or perceived barriers. In this paper, a new type of nano-engineered UHPFRC based on carbon-nanofibers (CNFs) was introduced, named UHPC 2.0™. The test results show that UHPC 2.0™ possesses ultra-high mechanical properties, improved direct tension performance and durability. In addition, an analytical procedure is provided for case studies to show the performance and economic benefits of usage of UHPC 2.0™ compared to traditional UHPFRC.

Keywords: direct tension; durability; mechanical properties; nano-engineered binder; UHPFRC

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Su Wang is an application specialist at ceEntek Pte Ltd. He received his MS and Ph.D. from Nanyang Technological University. His research interests include structural lightweight concrete, application of nanomaterial in concrete and ultra-high performance concrete

INTRODUCTION

The ultra-high performance fiber reinforced concrete (UHPFRC) was developed in the mid-1990s and characterized by a high amount of binder (cement, pozzolana and reactive powders), low water-to-binder ratio (normally 0.2), high packing density of fine ingredients and high volume fractions of steel fibers (> 2% by volume) [1, 2]. These characteristics create a concrete with superior compressive strength (17~29 ksi, 120~200 MPa), tensile strength (1.0~2.2 ksi, 7~15 MPa), deformation (0~5‰) with unique strain-hardening behaviour, energy absorption capacity and durability [3]. The outstanding mechanical properties of UHPFRC resulted in a significant reduction in the volume and size of structures made from such type of concrete. Compared to conventional concrete, usage of UHPFRC not only reduces the overall construction costs but also provides a greener solution. Meanwhile, the high durability properties of UHPFRC address the problems of structures under severe exposure, resulting in less maintenance and long service life. Nowadays, there is a surge in applying UHPFRC to repairing of concrete elements (bridge decks, pavement, panel, etc.), element connection/joint grouting and manufacture of architectural facade panel, structural wind towers elements, tall buildings, and long-span bridges. Although the technology and development of UHPFRC have been well investigated and proved from micro- to macro-level, it is still difficult to promote UHPFRC widely due to the challenges of complicated production process and high cost. The complicated production process mainly results from too many categories of ingredients used (up to 15), which leads to difficult handling. Thus, the performance of produced UHPFRC is highly dependent on the quality of contractors and workers. Steel fibers content is another critical factor to control the cost of UHPFRC. Increasing the steel fiber content from 1.5 to 2.5% by volume could improve the tensile strength and strain capacity of UHPFRC from 1.2 to 2.0 ksi (8 to 14 MPa) and 1.7 to 2.4‰ (for straight steel fibers) [4]. Decreasing the volume of steel fibers without degrading the mechanical properties of UHPFRC is the key to reducing cost. Present UHPFRC needs high temperature and pressure curing treatment to increase performance. This process not only increases the cost of UHPFRC but also consumes high energy which is not environmentally friendly. In this study, a new type of nano-engineered UHPFRC based on carbon-nanofibers (CNFs) was introduced, named UHPC 2.0™. The mechanical properties, especially the direct tension performance, and durability of UHPC 2.0™ were determined experimentally according to the standard methods. In addition, an analytical procedure is provided for case studies to investigate the bending performance of UHPC 2.0™ in repairing reinforced concrete beam compared to traditional UHPFRC.

RESEARCH SIGNIFICANCE

The present research introduces a new type of nano-engineered UHPFRC based on carbon-nanofibers (CNFs), named UHPC 2.0™, for non-conventional reinforcing and strengthening of a reinforced concrete beam for bridges and structures. The modification and enhancement of microstructure by nanomaterials result in the outstanding mechanical properties, superior direct tensile performance and extraordinary durability properties of UHPC 2.0™. By employing UHPC 2.0™ on bridge repairing and strengthening, the sizes and weight of elements could be reduced resulting in equal or lower construction costs compared to conventional methods due to the excellent strength and toughness. The lifetime under severe exposure of repaired structures would be also extended because of the high durability of UHPC 2.0™. In general, UHPC 2.0™ provide a new solution with ideal engineering properties, easy handling, environment friendly and reduced cost for rehabilitation project of bridge structures.

MIX DESIGN

The mix design of UHPC 2.0™ was shown in Table 1. Graded quartz sands with a particle size of 100~600 µm (0.000039~0.024 in.) were used as fine aggregates. An optimal packing density of cement and quartz sands was achieved by considering the modified Andreasen and Andersen model [5]. A new type of CNF was produced by ceEntek based on catalytic vapor deposition method. The CNF has diameters of 10~100 nm (3.9×10^{-8}~3.9×10^{-6} in.) and fiber lengths of 10~20 µm (0.00039~0.00079 in.). SEM images of the CNFs are shown in Fig. 1. The dispersion