Characterization of Mechanical Properties of Composite Materials for Infrastructure Projects

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Key Area

Transportation Infrastructure – State of Good Repair

OBJECTIVES

The goal of this project is to conduct a comparative study between two methods for estimating the design strength of composite materials. Composite materials have been used in the aerospace, automotive and boating industries for decades. Applications of composite materials in infrastructure projects are relatively new. Several agencies such as the American Concrete Institute (ACI) published guidelines to assist designers in using composite materials. The American Society for Testing and Materials (ASTM) published standards addressing several aspects of composite materials for several applications including for the structural design of the infrastructure projects. There is a major difference between the methods for estimating the strength of composite materials from both organizations. This study will review both methods using experimental data of typical test coupons.

ABSTRACT

Composite materials offer engineers many advantages that are especially appealing for infrastructure projects. Light weight, durability in harsh environments, and high tensile strengths are just a few examples of why the use of composite materials in infrastructure projects has increased in recent years. Fiber Reinforced Polymers (FRP) is the most commonly used form of composites, in which fibers are embedded in a resin material to form the final product. FRP is used in new projects in the form of all composite components (e.g. bridge decks) or as internal reinforcement (e.g. reinforcing bars) in concrete projects. They are also extensively used for strengthening ailing existing structures in the form of externally bonded sheets, laminates, or strips.

Despite their success in infrastructure applications, composite materials are still considered relatively new compared to traditional materials such as concrete and steel. As a result, the state-of-the-art is still in the stage of code development. Several methods for characterization of composite materials properties have been published from research efforts all over the world. In this project, it is proposed that methods for estimating the mechanical properties of composite materials; one of the most important aspects in design, be investigated. The goal is to provide designers with values based on high levels of confidence that will positively reflect on the development of any design provisions.

TASK DESCRIPTIONS

Task 1: ***Review of Material Characterization Methods***

A thorough literature review of current material characterization methods will be conducted. Te main focus of the review will be on composite materials. However, characterization methods in design codes for other materials such as concrete, steel, and timber will also be reviewed.

Task 2: ***Acquisition of Experimental Data***

The objective of this task is to collect experimental data of mechanical properties obtained from testing coupons of composite materials. The PI accumulated a database of reasonable size over the years. This database will be complemented by testing new coupons of different materials. The database will be limited to tensile and flexural strength since these are the two major utilizations of composite materials in infrastructure projects. Testing will be conducted using MTS material testing machines in the Materials Lab at LSU.

Task 3: ***Characterization of Mechanical Properties and Impact of Design Reliability***

Different methods for characterization of material properties will be applied to the database developed in Task 2. The objective of this task is to assess the statistical quantification of the material properties in different methods. For example, ACI method uses a direct statistical [mean – 3 times standard deviation] that does not account for the confidence in the mean and standard deviation values based on the number of coupons used in obtaining these values. The ASTM is more involved and accounts for confidence.

The reliability of structures design using both ACI and ASTM methods will be assessed using representative examples of simple components. The First Order Reliability Method (FORM) will be used for this task considering uncertainties on the load (highway bridge loads) and resistance sides of design equations including those associated with composite materials as characterized in this Task.

Task 4: ***Dissemination of results***

The findings of this project will have a long-term fundamental research value and will impact state and federal highway agencies. Findings will be shared with LA-DOTD bridge design section who is involved in a few projects involving FRP for strengthening of deteriorated structures. On a larger scale, the knowledge generated from this research project will be disseminated and transferred to the research community and composite materials industry as follows: (1) Submit one paper for presentation and publication at the Transportation Research Board Annual Meeting. A final report detailing the details of the project will also be prepared to archive the research effort.

POTENTIAL BENEFITS OF THE PROJECT

The proposed research is expected to benefit the transportation industry by providing information about the characterization methods for composite materials. This fundamental piece of information is essential for designing structures with consistent reliability levels. Overly conservative (uneconomical) designs, or more importantly uncoservative (unsafe) designs may result from using mechanical properties that do not properly account for the statistical characteristics of composite materials.

The education components of this project will focus on a number of activities aimed at highlighting the importance of statistical methods in structural engineering. The PI plans to include the research findings in a course that he teaches at the graduate level on Structural Reliability.

RELATIONSHIP TO RECENTLY COMPLETED, ONGOING OR PROPOSED RESEARCH PROJECTS

The PI has been involved in several projects related to the use of FRP materials in infrastructure projects over the last decade. In 2007, he received seed money from the Louisiana Transportation Research Center (LTRC) through the TIRE program to explore the use of pultruded FRP sections for strengthening of thin-walled steel structures. The project results were very promising, and a grant from the National Science Foundation (NSF) was awarded based on the results of this pilot project. As one of the few experts in this field who have applied structural reliability concepts to composite material design in infrastructure projects, he was assigned the task of calibrating ACI design guidelines through Committee 440 efforts. This effort was based on the existing material

characterization method. Therefore, the proposed study will investigate the effect of other characterization methods on the reliability of the calibrated guidelines.

CONTRIBUTING TO THE FIELD OF TRANSPORTATION RESILIENCE

This project is in line with the Gulf Coast Research Center for Evacuation and Transportation Resiliency's mission as it addresses the need to economically, effciently and safely develop a transportation system (photocatalytic concrete pavement) that can respond to increased pollution resulting from increased traffic demands. The success of this project will allow the pavement transpotation insdustry to lead the sustainble movement.

Facilities

An experimental program will be conducted in the Materials Lab at LSU. The Lab is equipped with an array of testing machines that cover a wide range of testing capacities. For the proposed project, testing of FRP flexural coupons will be conducted using the MTS Insight electromechanical system.

PROJECT SCHEDULE

The proposed tasks will be performed over a 6-month period according to the schedule shown below. Success of this project will be measured through timely completion of two major milestones. The two milestones set for this project are as follows:

- Complement the database of test coupons with additional tests from different FRP products.
- Prepare and submit one paper to the Transportation Research Board that presents the results of this project.

Table 1. Project Schedule

	Jan	Feb	Mar	Apr	May	Jun
Task 1 – Literature Review						
Task 2 – Experimental Testing						
Task 3 – Material Characterization						
Task 4 – Dissemination of results						

EXPERTISE

Ayman M. Okeil has been involved in several research projects over the last decade. His work for the Center for Nuclear Power Plant Structures, Equipment, and Piping at North Carolina State University led to introducing new design concepts to the nuclear industry. The concepts were based on intensive nonlinear finite element simulations of steel structures under seismic loading. He initiated a research thrust in the field of NDT after joining LSU. Dr. Okeil also has a vast experience in the field of bridge engineering, which resulted in numerous journal publications in the area of flexural strengthening of concrete girders using composite materials and behavior of box girder bridges. His research in the field of structural repair using composite materials is groundbreaking and is considered the first to introduce LRFD calibration to this area of research. He developed and co-developed several computer codes for the analysis and design of different bridge systems. Code examples include BOXWARP, which calculates warping related parameters for composite box girder bridges, and MACS which is a program for the nonlinear analysis for continuous bridge girders that can handle composite construction for different types of girders including, reinforced concrete, prestressed concrete, and steel girders. Dr. Okeil is full member of several professional societies (ACI, ASCE, AISC. He is a voting member in several national committees (ACI 440, ASCE-ACI 343, and TRB AFF80). He also serves on the

Editorial Board of the ASCE J. of Composites for Construction. Dr. Okeil has a longstanding record in teaching. He has developed and taught several structural engineering design and analysis classes and labs at four universities. His teaching abilities were recognized when he received the ***"Outstanding Teaching Award"*** at NCSU, the ***"Outstanding Achievement Award"*** at LSU (twice), and the ***"Educator of the Year Award"*** from the Baton Rouge Branch of ASCE (twice). He also served as consultant and senior engineer to several consulting firms on various projects related to both buildings and bridges. Dr. Okeil is a registered professional engineer (P.E.) in the state of Florida.

Ayman M. Okeil, Ph.D., P.E.

1. Professional Preparation

2002: P.E., State of Florida (License #: 58719)

1995: Ph.D., Structural Engineering, North Carolina State University, Raleigh, NC 27695.

1990: M.S., Structural Engineering, Alexandria University, Alexandria 21544

1985: B.S., Civil Engineering, Alexandria University, Alexandria 21544

2. Appointments

Aug. '09 - Present : Associate Professor, Louisiana State University, Baton Rouge, LA.

Aug. '03 - Aug. '09 : Assistant Professor, Louisiana State University, Baton Rouge, LA.

Apr. '98 - Aug. '03 : Visiting Assistant Professor, University of Central Florida, Orlando, FL.

3. Related Research Awards

Exploring A Novel Buckling Mitigation Techniques for Thin-walled Steel Structures using Pultruded FRP Sections (**NSF – $179,978 – Sole PI)**.

Evaluation of Continuity Detail for Precast Prestressed Girders, (**LTRC [RFP] – $249,578 – PI**).

A Novel Technique for Stiffening Steel Structures, (**LTRC [TIRE] – $29,998 – PI**).

Mitigation of Cracking in Webs of Segmental Concrete Bridges: A Structural Reliability Approach, (**LSU [CoR] – $10,000 – PI**).

4. Selected Journal and Refereed Conference Publications

Okeil, A. M., Belarbi, A. and Kuchma, D. (2012) "Reliability Assessment of FRP-Strengthened Concrete Bridge Girders In Shear," (accepted for publication in the Journal of Composites for Construction, ASCE)

Alshibli, K. A., **Okeil, A. M.**, Alramahi, B., and Zhang, Z. (Nov. 2011) "Reliability Analysis of CPT Measurements for Calculating Undrained Shear Strength," Geotechnical Testing Journal, ASTM, Vol. 34, No. 6, pp. 712-729.

Okeil, A. M., Bingol, Y. and Ferdous, M.R. (2009) "Novel Technique for Inhibiting Buckling of Thin-Walled Steel Structures Using Pultruded Glass FRP Sections," *J. of Composites for Construction*, ASCE, Vol. 13, No. 6, pp. 547-557.

Okeil, A. M. and Andrepont, S. (2010) "FRP Configuration Effect on Reliability of Flexurally Strengthened Concrete Beams," *Journal of the Transportation Research Board*, No. 2172, TRB, National Research Council, pp. 201-207.

Okeil, A. M. and Cai, S.C. (2008) "Damage to Coastal Bridges due to Hurricane Katrina," *J. of Bridge Engineering*, ASCE, Vol. 13, No. 4, pp. 377-387.

Okeil, A. M. (2006), "Allowable Tensile Stress for Webs of Prestressed Segmental Concrete Bridges," *Structural Journal*, ACI, Vol. 103, No. 4, pp. 488-495.

Okeil, A. M., El-Tawil, S., and Shahawy, M. (July-August 2001) "Short-Term Tensile Strength of CFRP Laminates for Flexural Strengthening of Concrete Girders," Structural Journal, ACI, Vol. 98, No. 4, pp. 470-478.