

**Transportation Infrastructure Precast Innovation Center**

**(TRANS-IPIC)**

**University Transportation Center (UTC)**

*3D Printed Advanced Materials to Mitigate Prestressed Concrete Girder End Cracks*

*UB-23-RP-02*

Quarterly Progress Report

For the performance period ending March 31, 2024

**Submitted by:**

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**Collaborators / Partners:**

*None*

**Submitted to:**

TRANS-IPIC UTC

University of Illinois Urbana-Champaign

Urbana, IL

**TRANS-IPIC Quarterly Progress Report:**

**Project Description:**

1. Research Plan - Statement of Problem

*Precast-prestressed concrete bridge girders are susceptible to cracking at their ends [1]. Release of large prestress forces within a short distance causes high tensile strains in concrete at the girder ends. This combined with the brittleness and low tensile strain capacity of conventional concrete lead to end cracking. This is a major concern for bridge owners as these cracks, especially those near the bottom of the beam that do not close under live load, could facilitate rapid chloride penetration and lead to corrosion of the prestressing strands and deterioration of the girder’s load capacity.*

*The specific objectives of this one-year project are as follows:*

1. *To investigate the feasibility of using strain-hardening cementitious composites (SHCC) shells for mitigating end cracking in precast-prestressed concrete beams*
2. *To develop a 3D-printable SHCC and appropriate printing parameters for the above application*
3. *To understand the level of composite action between SHCC shells and conventional concrete.*
4. Research Plan - Summary of Project Activities (Tasks)

*The following research tasks will be performed to meet the objectives of this study:*

*Task 1: Numerical simulation of pretensioned beams with SHCC shells at the end zone: Building upon the investigators’ experience with simulations of precast-pretensioned concrete girder ends [1-4], numerical models of girders with SHCC shells will be developed. The properties of a base SHCC will be used as input in these models. The models will be used to gain insights into the tensile strain distributions at the end zone and to understand how various parameters, such as shell thickness, strand placement, beam cross-section, and material tensile ductility impact end cracking. The results will inform the SHCC material development and shell design.*

*Task 2.1: Determination of target material properties for a printable SHCC: Targets for material properties needed for enabling 3D printing, such as viscosity, yield stress, storage moduli and loss moduli, extrudability, buildability, and shape retention ability, will be determined hand-in-hand with Task 1 using an extrusion printer to achieve optimal printing of SHCC shells. Computational fluid dynamics modeling and rheological characterization will be conducted to study the printability of SHCC. Based on past research, mechanical property targets for printable SHCC will be tensile strain capacity of at least 1% and compressive strength of at least 55 MPa.*

*Task 2.2: Trial mix designs: A two-prong approach will be used to develop trial mix designs. First, using the base SHCC as the starting point, material ingredients will be altered based on investigators’ experience and understanding of the effects of ingredients on each of the material properties described in task 2.1. Second, mix designs will be generated using first principles, such as particle packing, porosity-strength relationships, and effects of aggregate/paste ratio on various material properties. Approximately 4-6 convergent mix designs from these two methods will be developed for further analysis.*

*Task 2.3: Fresh and hardened properties testing and shortlisting of mix designs: Trial batches of the mixtures developed in the previous task will be prepared. A variety of fresh and hardened property tests will be conducted to determine which mix designs meet the targets set in task 2.1. Sample SHCC shells will be printed with the best-performing 1-2 mixtures to evaluate/verify their printability.*

*Task 2.4: Mixture refinement: Some iterative changes to the ingredient proportions may be needed to fine-tune the mix. This task might involve repeating a few steps performed in previous tasks.*

*Task 3.1: Preparation of composite beam specimens with 3D-printed SHCC shells: SHCC shells will be 3D-printed and composite beam specimens will be prepared to understand constructability of a composite beam. These non-prestressed beams will be composed of a small-scale rectangular beam and a similar sized I-shaped beam. They will be reinforced using mild reinforcement.*

*Task 3.2: Testing of beams under mechanical loading: Reinforced beam specimens prepared in task 3.1, as well as control specimens, will be evaluated under 3-point bending. Control specimens will be composed of monolithically cast beams that are identical to the ones in task 3.1 but made without the SHCC shells, and beams that have mold-cast (not 3-D printed) SHCC shells. The goal of these tests is to understand the level of composite action that can be developed between the SHCC and conventional concrete layers, and to compare 3-D printed SHCC shells to mold-cast SHCC shells.*

**Project Progress:**

1. Progress for each research task

*Task 1 95%*

*Task 2.1 95%*

*Task 2.2 70%*

*Task 2.3 25%*

*Remaining tasks not yet started.*

1. Percent of research project completed.

*50%*

1. Expected progress for next quarter.

*In the next quarter, Tasks 1 and 2.1-2.3 will be completed. Mixture refinement (Task 2.4) will also be performed in the next quarter.*

1. Educational outreach and workforce development

*A key outcome of this research will be the method for developing a printable SHCC. The material development process and the applications of the material to bridges be included in a lecture of the PI’s graduate course on Advanced Concrete Materials taught every Spring semester at the University at Buffalo.*

*On March 20, 2024, we hosted local high school students in our structures laboratory as part of the Science Exploration Day. The visiting students were noticeably excited to learn about advanced concrete materials and construction methods (such as 3D-printing and precast concrete) and their role in improving the quality of our infrastructure while saving time and money and protecting the environment. The students also observed the raw ingredients of SHCC and some of the 3D-printed SHCC specimens. The goal of these laboratory visits (and Science Exploration Day) was to motivate high school students toward pursuing STEM fields in college.*

1. Technology Transfer

*None*

**Research Contribution:**

1. Number of papers

*None*

1. Number presentations (when, where)

*1 poster presentation at the Annual meeting of the Transportation Research Board (TRB) in Washington, D.C. from January 7-11, 2024. The authors and title are given below:*

*Authors: Singh, P., Gadde, V.S., Zhou, C., Okumus, P., and Ranade, R.*

*Title: 3D printed advanced materials to mitigate prestressed concrete girder end cracks*

**References:**

[1] P. Okumus, M.G. Oliva, Evaluation of crack control methods for end zone cracking in prestressed concrete bridge girders, PCI Journal 58(2) (2013) 91-105.

[2] P. Okumus, R.P. Kristam, M.D. Arancibia, Sources of Crack Growth in Pretensioned Concrete-Bridge Girder Anchorage Zones after Detensioning, J. Bridge Eng. 21(10) (2016) 04016072.

[3] P. Okumus, M.G. Oliva, S. Becker, Nonlinear finite element modeling of cracking at ends of pretensioned bridge girders, Engineering Structures 40 (2012) 267-275.

[4] P. Okumus, M.G. Oliva, Strand Debonding for Pretensioned Bridge Girders to Control End Cracks, ACI Structural Journal 111(1).