Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

Innovative Precast Concrete Truss Using Adaptive Shape Memory Prestressing System
Project No.: UI-23-RP-02

Quarterly Progress Report
For the performance period ending *September 30th, 2024*

Submitted by:
PI: Bassem Andrawes, andrawes@illinois.edu
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign

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

   The ever-growing demand for making our transportation infrastructure more sustainable requires serious efforts to reduce carbon emissions associated with the concrete and steel used in transportation infrastructure. One way to achieve sustainability is by optimizing the materials used in transportation infrastructure. This research helps address this issue by studying the application of an innovative Adaptive Prestressing System (APS) in a geometrically optimized (truss) PC system. The new APS includes a shape memory alloy fuse that applies localized prestressing in any direction without mechanical tensioning or special hardware, ideal for prestressing short diagonal or vertical members of a PC truss. The research includes experimental testing and numerical simulation of geometrically complex PC truss structures with APS placed in tension members that are difficult to prestress using conventional methods. The performance of the new APS-reinforced PC truss is compared with traditional PC bridge girders to prove the feasibility of the new concept.

2. Research Plan - Summary of Project Activities (Tasks)

   This project aims to investigate the new technology of using APS to construct lightweight, sustainable, and durable (crack-free) PC truss systems for bridges. During this phase of the project (12 months), this research will attempt to address the following questions: 1) What is the optimum design (diameter and length) for the APS in PC truss that would help eliminate the cracking of concrete under realistic design loads. 2) What is the most efficient and practical method for installing and activating the APS's SMA fuse internally in PC truss members. The research plan for this project includes two primary tasks:

   Task 1: Design of Specimens using Finite Element Method:

   The first step of the research is to evaluate the behavior of the specimens through detailed finite element (FE) analysis using the software ABAQUS. This step aims to define the size and location of the APS strands and the level of the target prestressing force. A realistic prestress force that satisfies all AASHTO limit states will be adopted. Both concrete and strands (steel and SMA) will be modeled in 3D. The final decision on the design of the specimens will be made based on the results of the 3D FE analyses. Close attention will be given to the degree of cracking and/or stress concentration associated with various detailing configurations. The specimen's behavior with conventional (non-prestressed) steel reinforcement will be used as a baseline.

   Task 2: Fabrication, Instrumentation, and Testing of Specimens:

   Three specimens (one used as a control specimen with conventional steel and two specimens with SMA) will be fabricated. Before casting, prestressing strands in the bottom chord will be tensioned, and the APS will be placed in the vertical tension members. The SMA fuse used to activate the system will be in the form of pre-deformed no. 2 bars. The APS will be enclosed in a thermally/electrically insulating polymeric sleeve. To provide anchorage for the APS, the two HSS ends of the APS will be bent to form 90-degree hooks. After casting the concrete, the SMA fuse will be stressed using an electrical current. Next, the HSS strands in the bottom chord will be detensioned and the specimens will be tested under two concentrated loads. Digital Image Correlation (DIC), and conventional instrumentation will be used to evaluate the behavior of the tested trusses.

Project Progress:

3. Progress for each research task

Task 1 progress (90% completed):

*Additional bridge girder models were designed and analyzed in ABAQUS to iteratively determine the most optimal design. A reference girder without voids (**Fig. 1**) was created using the AASHTO type II cross-section.*

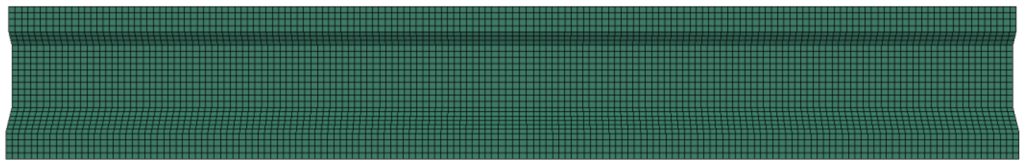


Figure 1. *Reference girder*

*A second girder with voids (**Fig. 2**) was created to study the performance of a trussed web design. Twelve triangular voids were added at the center of the girder. The voids were arranged to replicate a Howe truss behavior, and the corners of the voids were rounded to minimize localized stress concentrations. The web height was increased to improve the stiffness, while still requiring less concrete than the reference girder.*

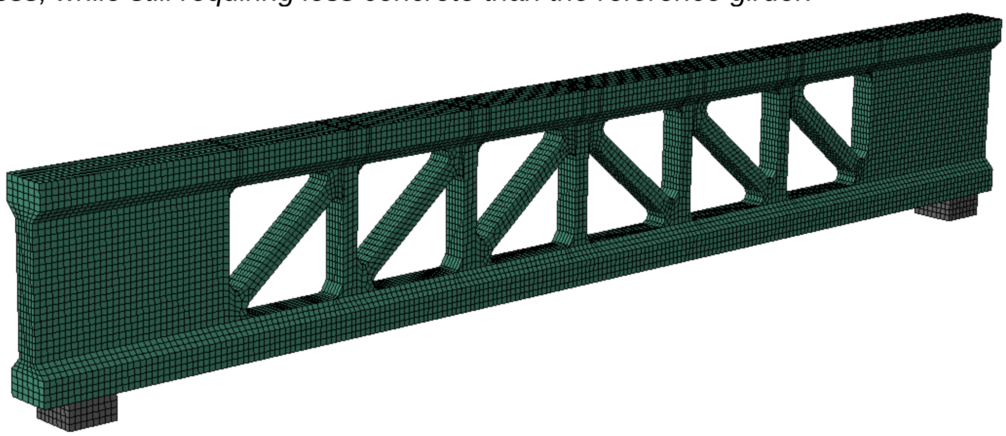


Figure 2. *Trussed web girder*

Task 2 progress (80% completed):

*A concrete beam was cast (**Fig. 3**) with two 2 mm diameter SMA wires inside near the bottom of the beam. These wires were prestrained to 6% and the ends were bent into 90-degree hooks. Sheet metal was folded around the hooks as reinforcement. A notch was added to the center of the beam to ensure the crack develops near the sensors.*

Figure 3. *Beam with SMA*

*The beam was subjected to a three-point flexure test until a 0.3 mm crack developed (**Fig. 4**). The beam was then unloaded and connected to a power supply. An electrical current was passed through both SMA wires, triggering the shape memory effect. The crack closed completely after the SMA was activated (**Fig. 5**).*

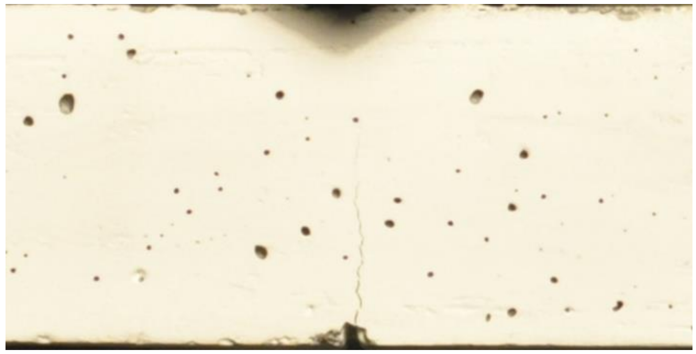


Figure 4. *Crack after loading and before SMA activation*

Figure 5. *Crack after SMA activation*

*The beam was tested again immediately after. It was unloaded when the crack width increased to 0.5 mm (**Fig. 6**). A second activation closed the crack once more (**Fig. 7**).*

Figure 6. *Crack after second loading and before SMA activation*

Figure 7. *Crack after second SMA activation*

*For a separate experiment, a concrete element representing a tensile trus member was cast. The member included four pre-strained 6 mm diameter SMA bars. The bars were sequentially heated with electricity to trigger the shape memory effect and prestress the concrete member (**Fig. 8**).*

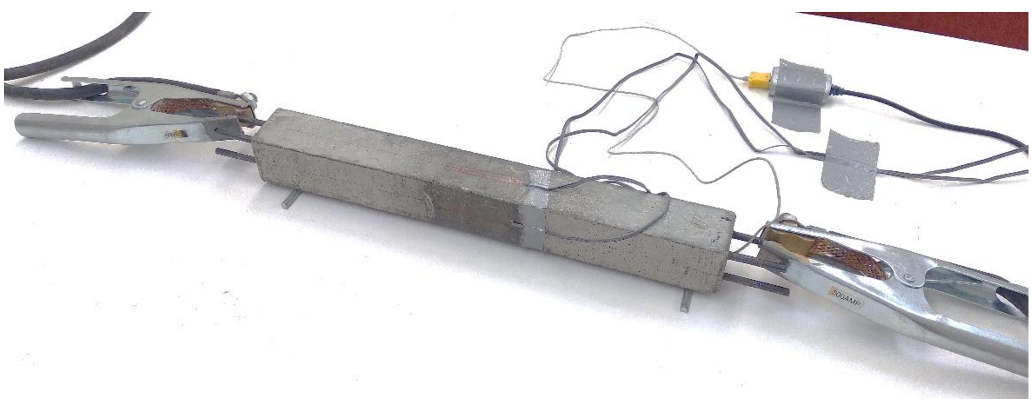


Figure 8. *Activation of concrete truss member*

*Aluminum plates were then attached to the beam using epoxy to create connection points to the test machine. Representing the actual load condition in a truss, the member was tested under pure tension and stopped when a 0.5 mm diameter crack developed at the center of the member (**Fig. 9**).*

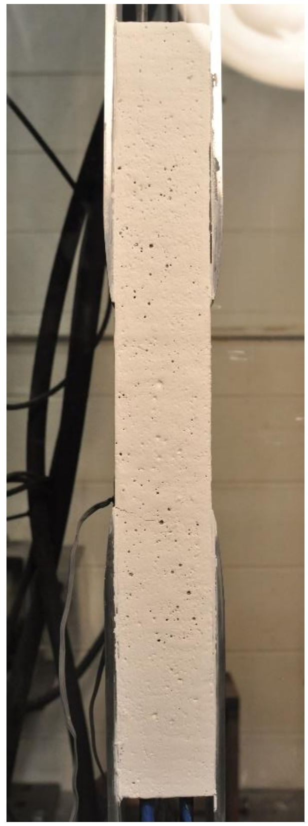


Figure 9. *Tensile testing*

*To examine the self-healing capability of embedded SMA bars, after unloading, the bars were heated again with electricity to activate the shape memory effect. This caused the cracks to close completely (**Fig. 10a and 10b**).*

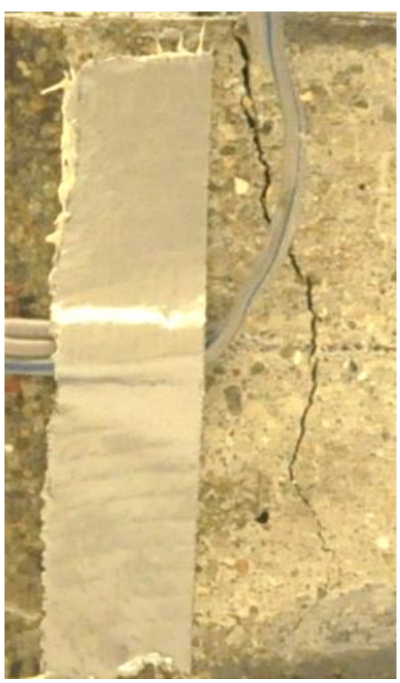
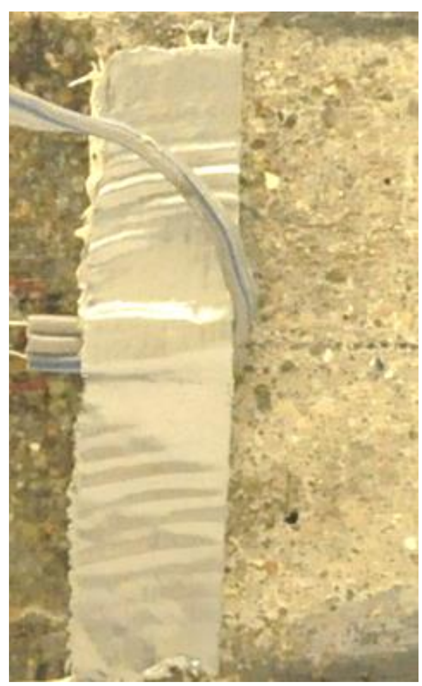
a)  *b)* 

__Figure 10.__ Crack closure due to SMA activation

4. Percent of research the project completed
   Total project completed through the end of this quarter = 85%

5. Expected progress for next quarter
   The next quarter will focus on optimizing the ABAQUS girder model. The best truss design will be cast with SMA bars inside. The girder specimen will then be tested and compared to a reference girder to determine the performance and difference in concrete consumption. The final report of the project will be developed.

6. Educational outreach and workforce development
   We hosted high school students during the Grainger College of Engineering's "City Designers and Builders" summer camp. The program encourages high school students to pursue civil engineering degrees. Our session demonstrated the use of Shape Memory Alloys in civil engineering applications. The students were given a tour through the Newmark crane bay and allowed to inspect the various research projects. (__Fig. 11 and Fig. 12__).

__Figure 11.__ The formwork and equipment for prestressing bridge girders

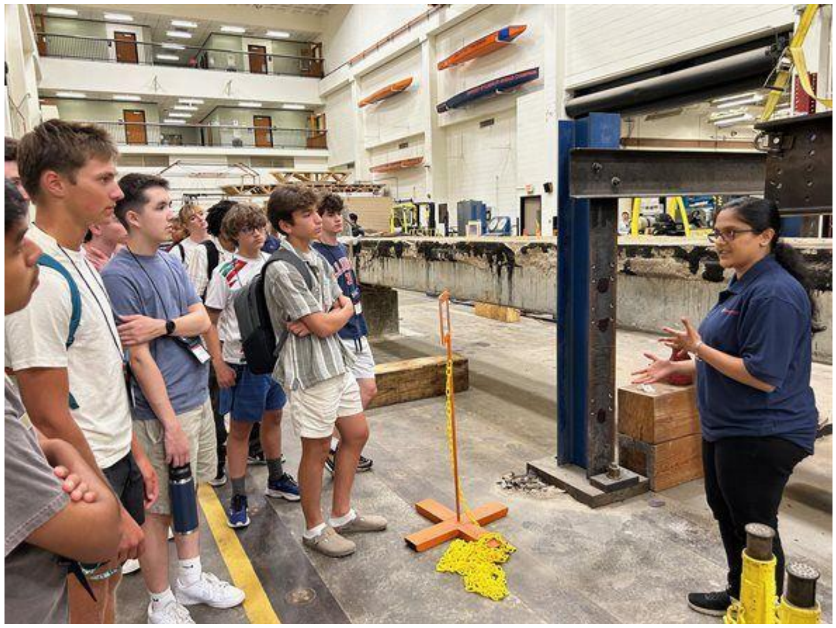


Figure 12. *A bridge girder ready for testing*

7. Technology Transfer
   None yet.

Research Contribution:

8. Papers that include TRANS-IPIC UTC in the acknowledgments section:
   - *Minsoo Sung and Andrawes B. "Innovative Precast Concrete Truss System Using Shape Memory Alloys for Infrastructure Applications" Intelligent Materials Systems and Structures journal (Accepted). (Federal Funds Acknowledgment: Yes)*
   - *A paper was accepted for publication and presentation at the 2025 ASCE Structures Congress.*

9. Presentations and Posters of TRANS-IPIC funded research:
   - *A poster was presented at the 2024 US DOT Future of Transportation Summit held in Washington, DC on August 13th-15th, 2024.*