Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

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

Quarterly Progress Report
For the performance period ending *September 30th, 2025*

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Collaborators / Partners:
- None

Submitted to:
TRANS-IPIC UTC
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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)**

   The research plan for this project includes three primary tasks:

   Task 1: Design of Specimens using Finite Element Method:

   The first step of the research is to evaluate the behavior of different options from the bridge truss girders with a wide range of span/depth ratios, and how these options compare to traditional bridge I-beams in capacity and overall weight. This process will involve using detailed FE models built and analyzed using the software ABAQUS. This step aims to define the number and distribution of prestressing strands, the level of prestressing force, and the amount and detailing of the SMA/APS reinforcement placed at the truss vertical members. Conventional designs of commonly used I-beams, such as the AASHTO I-beams and the Bulb Tees will be analyzed for comparison. The experience gained in Year 1 by the research team in building and analyzing models will be applied to this task. The design that produces the highest span/depth ratio will be the least amount of material will be used for the experimental stage of the project.

   Task 2: Fabrication and Instrumentation of Specimens:

   The truss specimen tested in this project will be fabricated in collaboration with an industry partner using the FE analysis in task 1. To create the voids of the truss, the team will introduce temporary modifications to the form by inserting 3D-printed components in the form. After casting the concrete, the SMA will be ready for activation as will be explained in task 3.

   Task 3: SMA Activation and Specimen Testing:

   Part of this research is to investigate practical methods for activating the SMA reinforcement inside the truss. Two heating methods will be investigated: (1) electrical resistivity, and (2) electromagnetic Induction. The PI recently purchased a portable induction heating system that will be used as part of this research. After the SMA activation, the truss specimen will be tested under point loads, and the load-deflection response will be recorded and compared with the nominal behavior of a traditional I-beam with a similar span/depth ratio.

3. **Project Progress:**

   Task 1: Design of Specimens using Finite Element Method [90% completed]

   The previously created finite element method model of the precast truss was modified to reflect the measured 28-day compressive strength of the concrete as opposed to the initial assumption. The results under self-weight during lifting were analyzed, and a potential area of damage is circled in red in **Figure 1**. This indicates that localized tensile cracks may occur. This will be taken into account during the relocation of the test specimen for activation of the SMA during heating.

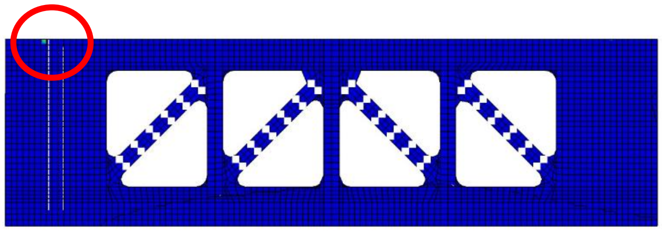


Figure 1. Section cut of the specimen showing area with tensile concrete damage

Task 2: Fabrication and Instrumentation of Specimens [75% completed]

The formwork for the precast truss was completed during this quarter. This involved adding the final wall panel, adding metal brackets around the corners, sealing the edges with caulk, screwing diagonal wood supports, and coating the insides with a release agent and form oil. The concrete was ordered from a nearby plant and delivered in a cement truck. Due to the height of the formwork, the concrete could not be poured directly from the truck. Instead, it was poured into a hopper, which was then lifted over the formwork (**Figure 2**). The concrete was poured starting from the middle of the truss. This approach pushed the concrete out to the ends, which avoids trapping air bubbles around where the foam cutouts are located. Flashlights were used to visually monitor the flow of concrete and to estimate the relative fill heights along the length of the truss. When the formwork was filled approximately halfway, the wood walls began to flex under the pressure of the concrete. Clamps were brought in to stabilize the tops of the formwork and prevent any further movements. The flexing introduced some imperfections in the specimen that will be discussed later. Once the clamps were added, the pouring resumed. When the foam cutouts were mostly surrounded by concrete, the hopper was moved from the center to other points along the truss, as the risk of trapping bubbles at this stage is low. The formwork was filled to the top, and vibration rods were inserted into the areas where the verticals of the truss were located to remove any potentially trapped air bubbles. The outside of the formwork was also vibrated to remove any bubbles in other areas of the truss that could not be reached directly by the vibration rods. A tarp was then placed over the top of the truss to help with its curing.

a)  b) 

Figure 2. (a) Outside and (b) inside of the formwork during casting

After two weeks, the truss was demolded. A crane was hooked to the lift points to provide stability and safety during this process. The process took multiple days as the formwork tightly clung to the concrete despite the application of a release agent and form oil. The movement of the wood walls at the time of pouring had allowed some concrete to leak into the void regions, as shown in (**Figure 3a**). These extra pieces were chipped off using a hammer. The voids in the right diagonal were also formed when the wood walls flexed. These were later patched up using a non-shrink grout. Another difficulty was that the pink foam cutouts were tightly encased by the concrete and could not slide out. As a result, pieces of the foam were carefully carved out until the formwork loosened enough to be pulled off. The final result needed additional sanding and cleaning and is shown in **Figure 3b**.

a)
b)


Figure 3. (a) Truss immediately after demolding and (b) after cleaning

Once the concrete had cured, the preparation for the footings began. Grooves were cut into the surfaces of the truss that would be touching the footings to improve the bonding. Formwork was then built around the truss, and concrete was poured inside (**Figure 4a and b**). A total of four footings were completed, which are critical in allowing the truss to be detached from the crane and to stand freely during the activation of the SMA.

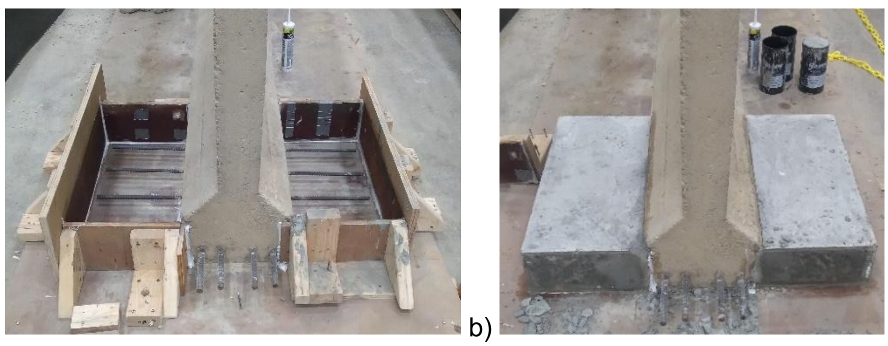
a) b)


Figure 4. (a) Footing formwork and (b) cured result

Task 3: SMA Activation and Specimen Testing [40% completed]:
The manufacturing and testing of practice UHPC heating specimens were completed this quarter. These specimens were created using the same mix and dimensions but with steel rebar instead of SMA and were needed to experimentally determine the response of the UHPC mix to heating via electrical resistivity and induction heating. The UHPC responded well to electricity and reached 189 °C without showing any visible signs of damage. On the other hand, the UHPC responded very differently to induction heating. Most notably, the surface temperature heated up along with the steel rebar, and a crack was visible on the surface when the steel reached 197 °C. Based on these results, it was decided to only use the induction machine for a single specimen during the prestressing stage of the experiment. This would reduce the risk of damaging the specimens prior to loading and losing valuable data.

The experiment had four distinct stages: prestressing, loading, healing, and re-loading. The prestressing stage involved heating three specimens with electricity and one with induction. To activate the SMA with electrical resistivity, the specimen was placed on concrete rollers, and the exposed ends of an SMA bar were connected to a power supply (**Figure 5a**). Once switched on, the internal thermocouple was monitored. The power supply was shut off once the SMA bar temperature exceeded 200 °C, which is the minimum temperature needed to trigger the shape memory effect in this type of SMA. The temperature and strains were continuously monitored until the bar cooled back down to the starting temperature. For the induction heating, the specimen was placed on the rollers, and a face was aligned with a custom-made coil (**Figure 5b**). The induction machine was turned on and the internal thermocouple was monitored. This procedure is similar to activation by electricity. However, the magnetic waves generate noise in the thermocouple readings, so the induction machine needed to be periodically turned off so the correct temperature could be read. Thus, the heating was not continuous as it was with electricity. Once the SMA bar exceeded 200 °C, the temperature and strains were continuously monitored until the bar cooled back down to its starting temperature. When comparing the results of the two heating methods, the UHPC responded more dramatically to induction and exhibited explosive spalling behavior during heating. However, all four specimens showed compressive strains after cooling, indicating that activation of SMA was successful across different mixes and heating approaches. This also validated the use of copper crimps as anchorage for induction heating.

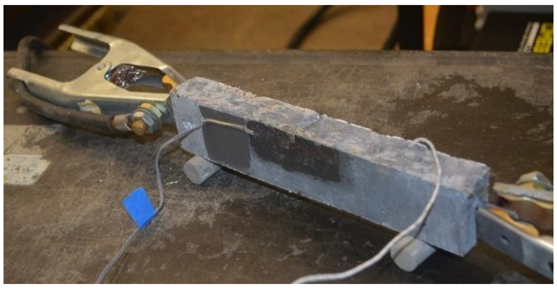
a)  b) 

Figure 5. Heating using (a) power supply and (b) induction coil

The second stage involved loading the specimens in a three-point flexural setup. The specimen was placed on two supports, which are connected to rubber bands that eliminate torsional forces. Two razor blades were epoxied to the bottom of the specimen so that a CMOD could be attached beneath the notch. This setup is shown in **Figure 6**. The specimens were loaded and the force, displacement, strain, and CMOD displacement were recorded. For the conventional concrete specimens, the loading was stopped after a certain CMOD displacement was reached. For the FRC and UHPC specimens, the crack formation was delayed due to the presence of steel fibers, and so the loading was stopped based on the capacity as opposed to the CMOD reading. The collected data will be used to determine the effectiveness of SMA reinforcement across different types of concrete mixes. The effect of prestressing will also be analyzed using these results.

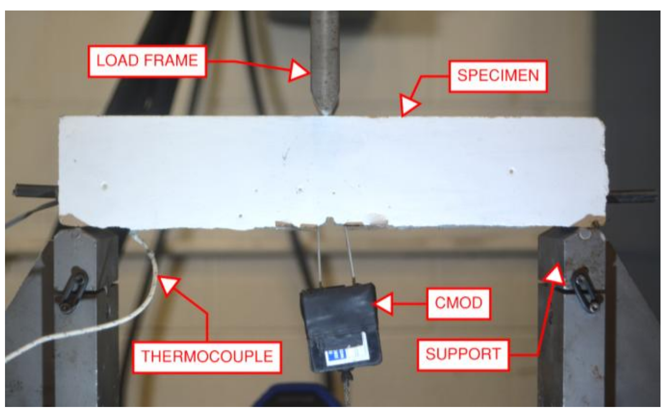


Figure 6. Test setup

The third stage involved activated the SMA in ten specimens: four which had previously been activated and six that had not. The setup for heating was identical to the setup used during the prestressing stage. Electricity was used for seven of these specimens, and the CMOD was used to document the crack closure. Three used induction heating, in which case the CMOD could not be attached as it would be damaged by the magnetic fields. Instead, the crack widths were measured before and after using a ruler. The activation of the SMA helped close cracks in all cases, with some specimens demonstrating full crack closure.

The final stage of the experiment was bringing all the specimens to failure. The same setup used to initially crack the specimens was re-used again for this stage. The strain gauges were damaged by the previous loading, so only the force, displacement, and CMOD displacement readings were documented. This step was necessary to quantify the results of the healing on the different types of concrete mixes. Since the primary failure mode was through development of a hinge, the failure criteria was determined as a percentage decrease of the peak capacity.

4. Percent of research project completed
   Total project completed through the end of this quarter = [75% completed to date]

5. Expected progress for next quarter
   The truss will be painted white to aid in the visual detection of cracks during testing. The vertical member containing SMA will also be painted with a black speckle pattern for analysis using a camera and a Digital Image Correlation (DIC) software. Strain gauges will also be installed along the vertical member containing SMA to measure the prestressing forces during the activation of the SMA bars. The activation will be carried out using an induction heating machine with a custom copper coil. The SMA's will be heated in segments, with the initial segments being monitored using the embedded thermocouples, and the remaining segments being heated based on time. Once all the SMA bars in the truss are activated, additional strain gauges will be instrumented. These will be distributed along critical points of the truss, such as the verticals and diagonals, to monitor the forces at these points. The truss will then be moved into a three point flexural test setup and loaded using a displacement-controlled actuator. During the loading, the strain gauges will be monitored using a data acquisition system (DAQ) and crack propagation will be documented with cameras and rulers. These values will be critical in demonstrating the effectiveness of SMA prestressing in a concrete truss configuration. Analysis of the UHPC specimens' data will be completed during the next quarter.

6. Educational outreach and workforce development
   TRANS-IPIC participated in the Grainger School of Engineering's City Designer and Builders Camp held on July 23rd. During the event, members of TRANS-IPIC presented key concepts regarding transportation infrastructure to 24 high school students. The session started with a mix of classroom presentations, hands-on activities, and demonstrations that allowed the students to understand different research materials, such as SMA, TEC bars, and 3D-printed concrete (**Figure 9a**). The session concluded with a tour of the Newmark crane bay, during which the high school students were showed the current experimental tests on precast slabs and girders being carried out by TRANS-IPIC researchers (**Figure 9b**).

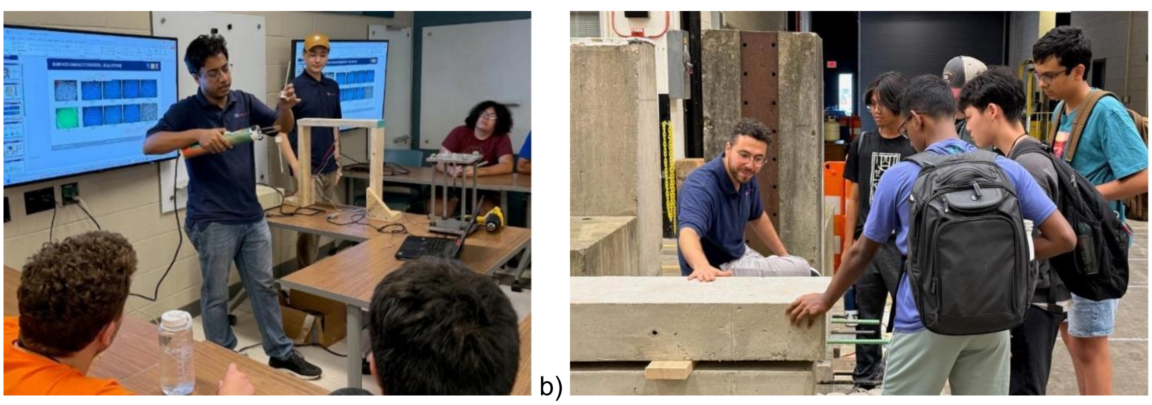

a) b)

Figure 9. (a) Classroom demonstration and (b) crane bay tour

7. Technology Transfer
   Nothing to report yet.

Research Contribution:

8. Papers that include TRANS-IPIC UTC in the acknowledgments section:
   Chen, Alexander, and Bassem Andrawes. "Crack Healing of Concrete Structures Using Hooked Shape Memory Bars." In Structures Congress 2025, pp. 348-361. 2025.

9. Presentations and Posters of TRANS-IPIC funded research:
   A presentation on the healing of tensile and flexural specimens using SMA activation was presented at the ASCE Structures Congress held in Phoenix, Arizona on April 9^{th}-11^{th}.

   A poster on the healing of tensile and flexural specimens using SMA activation was presented at the 2^{nd} annual TRANS-IPIC workshop held in Chicago, Illinois on April 22^{nd}-23^{rd}.

10. Please list any other events or activities that highlights the work of TRANS-IPIC occurring at your university (please include any pictures or figures you may have). Similarly, please list any references to TRANS-IPIC in the news or interviews from your research.
    Nothing to report yet.

Appendix 1: Research Activities, leadership, and awards (cumulative, since the start of the project)

A. Number of presentations at academic and industry conferences and workshops of UTC findings
    - No. = 2

B. Number of peer-reviewed publications submitted based on outcomes of UTC funded projects
    - No. = 0

C. Number of peer-reviewed journal articles published by faculty.
    - No. = 0

D. Number of peer-reviewed conference papers published by faculty.
    - No. = 1

E. Number of TRANS-IPIC sponsored thesis or dissertations at the MS and PhD levels.
    - No. MS thesis =
    - No. PhD dissertations =
    - No. citations of each of the above =

F. Number of research tools (lab equipment, models, software, test processes, etc.) developed as part of TRANS-IPIC sponsored research
    - Research Tool #1 (Name, description, and link to tool) = None

G. Number of transportation-related professional and service organization committees that TRANS-IPIC faculty researchers participate in or lead.
    - Professional societies
        - No. participated in = 7
        - No. lead =
    - Advisory committees (No. participated in & No. led)
        - No. participated in =
        - No. lead =
    - Conference Organizing Committees (No. participated in & No. led)
        - No. participated in = 1
        - No. lead =
    - Editorial board of journals (No. participated in & No. led)
        - No. participated in = 1
        - No. lead =
    - TRB committees (No. participated in & No. led)
        - No. participated in = 1
        - No. lead =

H. Number of relevant awards received during the grant year
    - No. awards received =

I. Number of transportation related classes developed or modified as a result of TRANS-IPIC funding.
    - No. Undergraduate =
    - No. Graduate = 2

J. Number of internships and full-time positions secured in the industry and government during the grant year.
    - No. of internships =
    - No. of full-time positions = 1

References:
None