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 *June 30th, 2025*

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Collaborators / Partners:
- None

Submitted to:
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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 [60% completed]

   The Finite Element Method (FEM) software, ABAQUS, was used to evaluate the reinforcement of the precast truss girder being constructed for testing. An ABAQUS model was built and iteratively modified to reach an optimal design. The procedure was as follows: First, a model of the concrete truss girder without any reinforcement was analyzed under three-point flexural loading. This confirmed that the girder would behave similarly to a truss, with the top chord and diagonal members in compression, and with the bottom chord and verticals in tension. Next, steel reinforcement was added to the model. For the web of the truss, #3 steel rebar was used. For the top and bottom chords, #5 steel rebar was used. The model was again loaded at its midspan, and the resulting damageT parameter is shown in **Figure**

1, where the red lines are areas with tensile damage. This result showed that the outer verticals will crack first and are the weakest members in this truss system. Therefore, to improve the performance of this girder under service loads, prestressing with SMA is needed in the verticals.

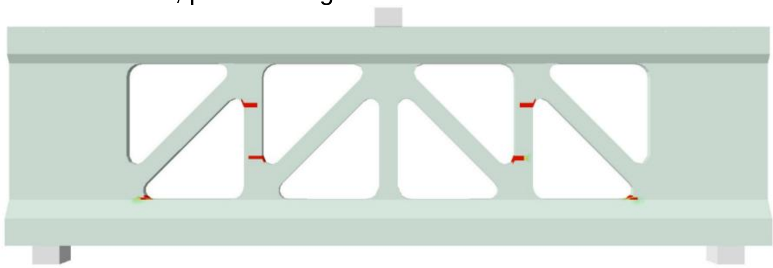

Figure 1. Tensile damage for the model with only steel reinforcement

The model was then modified to incorporate SMA bars made of NiTiNb. However, rather than changing both outer verticals to SMA, only one would use SMA. This asymmetric design will allow two different reinforcement designs to be compared simultaneously. This approach halves the numerical analysis computation time and reduces the number of test specimens needed. To have similar strength, one vertical would use eight 6 mm SMA bars while the other would use six #2 steel rebar (**Figure 2a**). The steel reinforcement in the rest of the girder remains unchanged. An additional step was introduced into the ABAQUS model to incorporate the activation of the SMA before loading. The damageT result under three-point loading is shown in **Figure 2b**. The difference in the capacities of the two outer verticals is reflected in the amount of damage present under flexural loading, with the side of the girder containing only steel showing signs of cracking first.

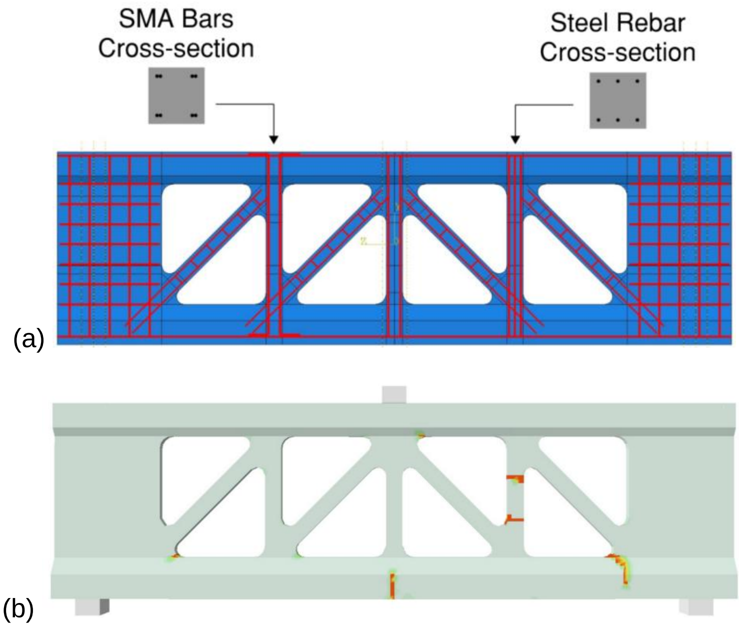

Figure 2. (a) Asymmetric reinforcement and (b) corresponding tensile damage

A copy of the ABAQUS model was used to determine the design of lifting points for relocation of the specimen for testing. Traditional cast-in-place anchors would not be strong enough, so custom-bent #5 rebars were required. These were modelled in ABAQUS and treated as support points while the specimen is loaded under gravity loads. The results showed that the two bent bars would be sufficient and would not damage the specimen. These lifting points are further discussed in Task 2.

Meanwhile, an ABAQUS model was developed using data from the prestressed tensile test specimen from Year 1 of this project. There were two stages of the experiment to study numerically: a prestressing stage in which the SMA bars were activated using electrical resistivity, and a loading stage in which the specimen was placed in tension. The strain gauge data from the prestressing stage indicated that the prestress was not uniform across the cross-section. By considering the strain data along with the temperature and time data from the thermocouple, it was concluded that the first bar was not fully activated. To validate this, the ABAQUS model was initially modelled with all the bars being fully activated in the order used during the experiment. Then, the model was analyzed again with a lower amount of prestress in the first bar to form the strain gradient. This amount was lowered until the strains at the specimen sides approached the strains measured by two strain gauges (**Figure 3**).

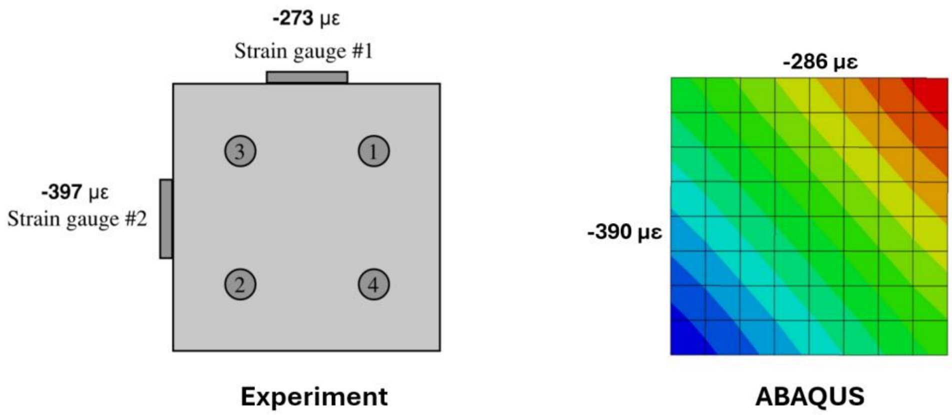

Figure 3. Specimen midpoint cross-section strain gradient comparison

To study the second stage of the experiment, the ABAQUS model support condition was changed from simply-supported to having four planes of support, mimicking the four aluminum plates that were epoxied to the test specimen. One pair of planes was moved away from the other pair to simulate the displacement-controlled tensile test. The resulting damageT (**Figure 4**) shows that a crack appears at the same location as the experiment. A difference between the ABAQUS and the experimental test is that two cracks appeared in ABAQUS while only one appeared in the experiment. This is due to ABAQUS treating concrete as a homogenous material, when in reality the concrete is not uniform and more prone to cracking at one end despite symmetrical loading conditions.

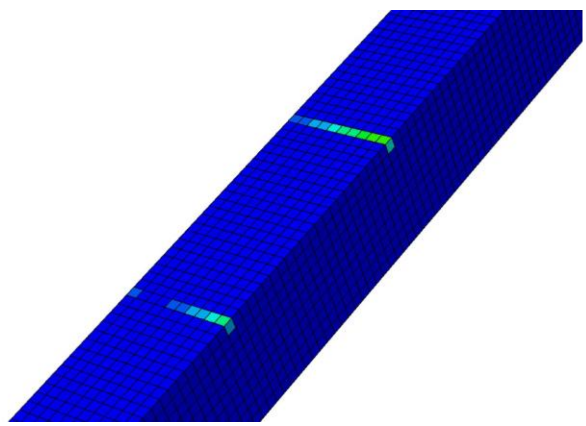

Figure 4. Crack propagation across ABAQUS specimen

Task 2: Fabrication and Instrumentation of Specimens [45% completed]

The results from the Task 1 ABAQUS truss models were used to modify the reinforcement for the experimental specimen (**Figure 5**). The SMA in the right-most vertical was replaced with six #2 rebar to match the asymmetric case. Additionally, bent #5 bars were added at each end of the girder to serve as lifting points. The ends of the bars were bent into 90-degree hooks with radii and lengths based on ACI standards. Half of the plastic rebar chairs supporting the bottom longitudinal bars were removed to reduce the number of areas of weakened concrete cover. The location of the remaining eight rebar chairs was chosen to avoid the locations of tensile damage seen in the ABAQUS model from Task 1. Furthermore, the seats were staggered to help spread out their influence on the concrete cover. Lastly, two thermocouples were attached to one of the SMA bars. Only two were needed because, by taking advantage of the symmetry, the other portions of the SMA can be activated based on timed duration alone.

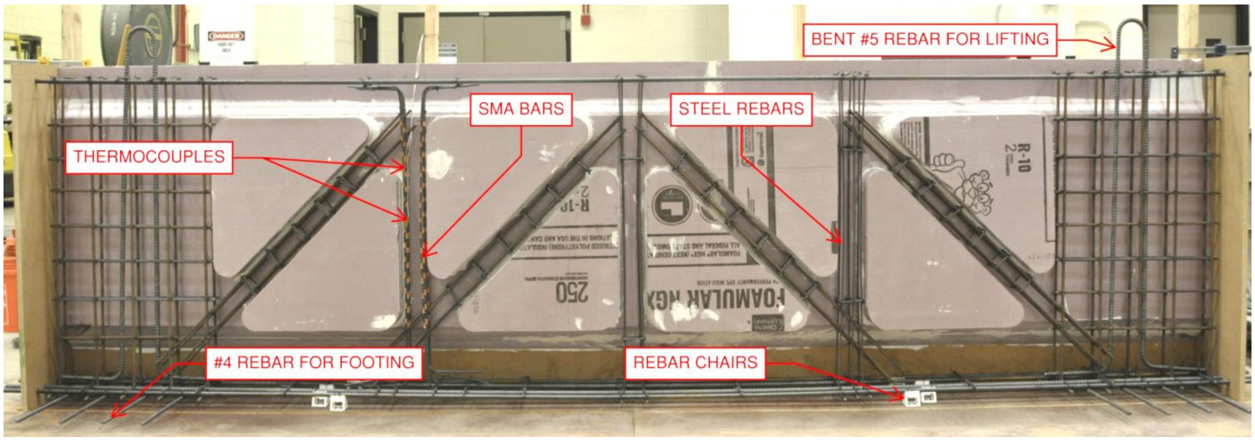

Figure 5. Changes to truss girder formwork and reinforcement

One final modification to the girder is the addition of four perpendicular #4 rebars at each end. The stability of the girder during testing was critical, considering how slender the girder is. Therefore, footings will be added to widen the base where the supports will be located during testing (**Figure 6**). The concrete for the footings will be poured after the main girder is cast and will use the exposed ends of the #4 for connection. In addition to a widened base, lateral bracing will be added to the top chord. These will reuse the lifting points for connection.

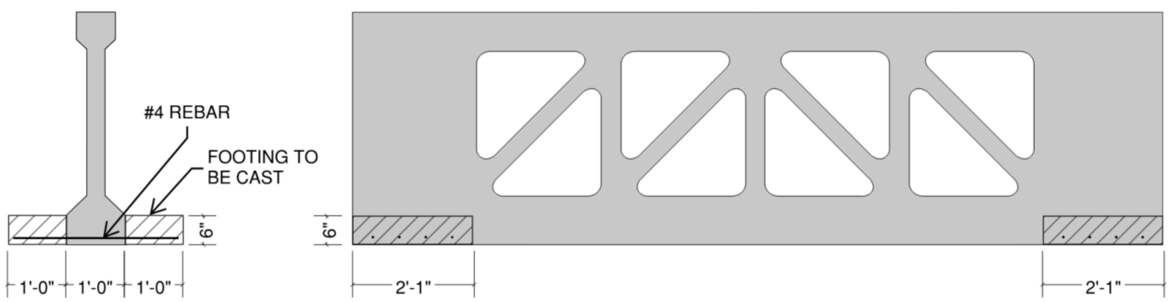

Figure 6. Footing dimensions

Task 3: SMA Activation and Specimen Testing [20% completed]:

The behavior of the UHPC used in the previous quarter is unknown for high temperatures. Existing literature indicates that UHPC could explosively spall at temperatures as low as 200 °C. Thus, the thermal conductivity of this UHPC when exposed to electricity and induction heating will be studied on practice specimens first. The practice specimens will be cast using the same mold as before (**Figure 7**), but with #2 steel rebar instead of SMA. Thermocouples will be attached to the rebar to monitor the internal reinforcement temperature, while another thermocouple will be on the outer surface to monitor the UHPC temperature. The specimen will be wrapped with fiberglass to contain the potential spalling. The reaction of the specimens to heating by electrical resistivity and induction will be studied and used to modify the test procedure for the thirteen specimens with SMA.

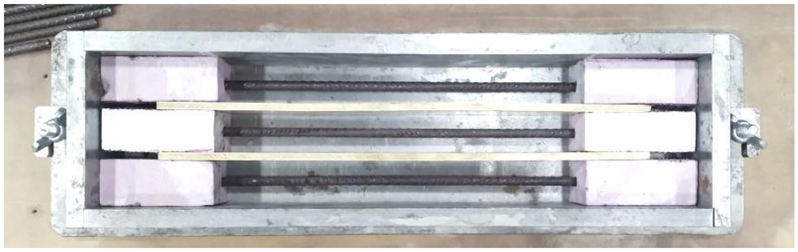

Figure 7. Formwork for practice specimens

4. Percent of research project completed
   Total project completed through the end of this quarter = [40% completed to date]

5. Expected progress for next quarter
   The concrete truss girder will be cast early in the next quarter, and the footings will be cast after the girder is demolded. Concrete strain gauges will be installed along the surface of the vertical members and the bottom chord. Once the concrete is cured, the SMA bars will be activated using induction heating. Each pair of SMA bars will be heated in three segments, and the timing and temperature will be monitored using the thermocouples embedded inside. Once the SMA is fully activated, the specimen will be tested in a three-point flexural setup. The difference in performance of the two outer vertical members will then be monitored using both the strain gauges and by visual inspection.

   The heating of the practice UHPC specimens will also be carried out. Both induction and electrical resistivity will be studied to determine if there is any spalling of the UHPC. Once these preliminary tests are conducted, the flexural test specimens containing SMA will then be activated. These will then be tested in three-point bending and monitored using strain gauges and a COD (crack opening displacement) gauge. Once cracked, the specimens will be activated again to study the healing capabilities of SMA on concrete.

6. Educational outreach and workforce development
   Nothing to report yet.

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 9th-11th.

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

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