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 *March 31st, 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 [25% completed]

The concept of a bridge girder with voids was studied using the finite element analysis software, ABAQUS. To start, a 120-foot-long AASHTO bulb-tee (BT-72) girder was modeled (**Figure 1**). It is prestressed by 24 0.6” diameter prestressing strands at the bottom. The span length and number of strands were chosen based on PCI recommendations so that it would represent a realistic precast girder with which we can compare our optimized designs. The girder was then simply supported and loaded with a concentrated force at midspan. The force and deflection were extracted to quantify its stiffness.

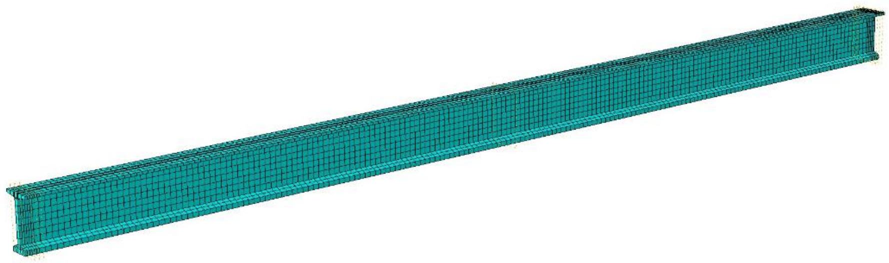

Figure 1. Reference girder

Other girder designs that require less concrete were then developed by introducing voids in the web of the BT-72. The span length and amount of prestressing were held constant to start. Triangular voids with rounded corners were arranged so that the web resembled a Howe truss. This changed the girder so that instead of behaving like a beam in flexure, it behaved more like a truss with tension and compression elements. The voids had identical sizes so as to not over-complicate the formwork needed to manufacture the shape. The design process involved iteratively alternating between increasing the voids and increasing the girder depth to balance the changes in stiffness. One design with similar initial stiffness to the reference girder is shown in **Figure 2**. This truss girder contains 14% less concrete than the reference girder (**Figure 3**). The reduction in weight correlates to reduced concrete consumption, which improves the sustainability of the design. This also improves the sustainability of the rest of the bridge because the substructure of the bridge will need to carry less load and can be also reduced in size.

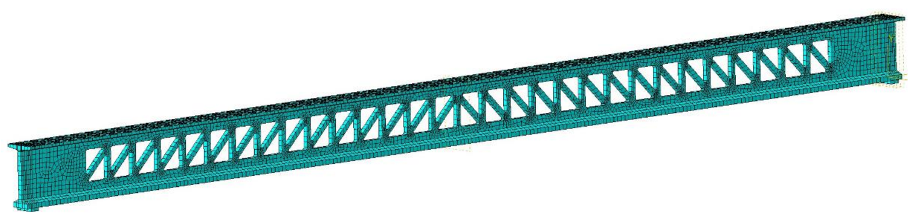

Figure 2. Truss web girder

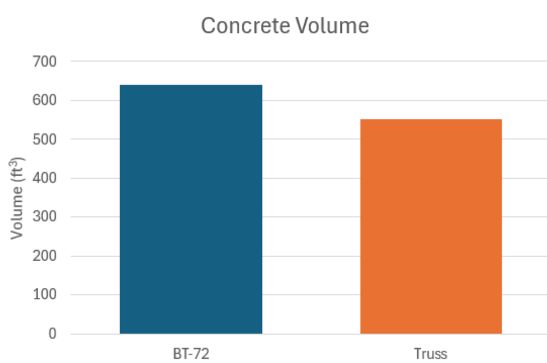

Figure 3. Concrete volume comparison

Task 2: Fabrication and Instrumentation of Specimens [20% completed]

The optimized truss web girder designed in ABAQUS during Year 1 was modified to use a span length of 14 feet. This made the design quicker to construct, while still containing multiple tensile members in the web where SMA can be incorporated. The construction of the formwork and reinforcement is complete (**Figure 4**). This included cutting foam elements using a hot wire and gluing them together to shape the voids and web in the formwork. The rebar chairs were 3D printed out of plastic and used to support the longitudinal reinforcement. The steel bars were cut, bent, and tied together. Rebar cages were built at the two ends where shear forces are anticipated. Hoops were added to the diagonals to provide confinement where compressive forces are anticipated. Lastly, 16 pre-strained 0.25” diameter SMA bars were bundled into pairs and placed where tension is anticipated (**Figure 5**). Copper connectors were crimped onto the SMA bars to improve bonding between the SMA and the concrete. The crimps were chosen because of their good performance in the prestressing experiment from Year 1. The ends of the SMA bars are bent into 90-degree hooks to provide further anchorage of the SMA to the concrete at the joints.

Figure 4. Precast trussed web girder formwork and steel

Figure 5. Close-up of SMA alloy with crimps

The same truss concept is being explored for production by a 3D concrete printer. This is a continuation of the 3D concrete printing done in Year 1 but on a larger scale. The benefits of 3D printing this type of complex geometry include the elimination of the formwork and rebar chairs. This truss will feature a similar geometry of eight triangular voids (**Figure 6**). It will also incorporate SMA reinforcement in the tensile regions to explore the concept of prestressing 3D printed concrete. The remaining portions will be reinforced with conventional steel bars. A topology-optimized design was also created. The shape was optimized using ABAQUS Tosca Structure Optimization Module with the aim of minimizing weight. The result was then adjusted to accommodate the 3D concrete printer capabilities.

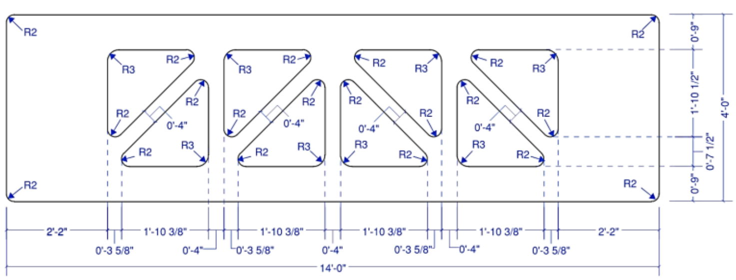

Figure 6. Truss geometry for 3D concrete printing

The self-healing of concrete that was studied in Year 1 will continue with these trusses. In addition to this, the effect of mix design and heating methods on crack healing will be studied. To this end, 13 test specimens were cast. The specimens are designed to fail in flexure. A notch is added to the midspan to ensure the crack propagates near the instrumentation. The crimped SMA inside will then be heated to help close the crack. The main variation between the different mix designs was the amount of steel fibers being included. This is of interest because the steel fibers will influence the heating speed of the SMA during healing. Four of the specimens were cast without steel fibers to represent a typical concrete mix design. Four specimens were cast with 1% steel fiber content to represent a fiber-reinforced concrete mix design. The other five specimens were cast with ultra-high performance concrete (UHPC), which have 2% steel fiber content.

Within each group, one specimen is unreinforced while the remaining contain one 0.25” diameter SMA bar each (**Figure 7**). The bars are equipped with a thermocouple inside to monitor the temperature during heating. On the concrete surface, near the notch, is a strain gauge to monitor the forces in the concrete during heating. The opposite face of the specimens was painted white to ease the visual inspection of cracks during testing (**Figure 8**). The other parameter being varied is the heating method. One specimen from each mix design will be heated using electrical resistivity. Another specimen from each mix design will be heated using induction heating. Both methods have been demonstrated to be effective in the past, but the rates of heating have not been directly compared before. The final parameter that will be studied is the effect of prestressing the specimen before healing. One specimen from each mix design will be heated only after loading, while the others will be heated both before and after loading.

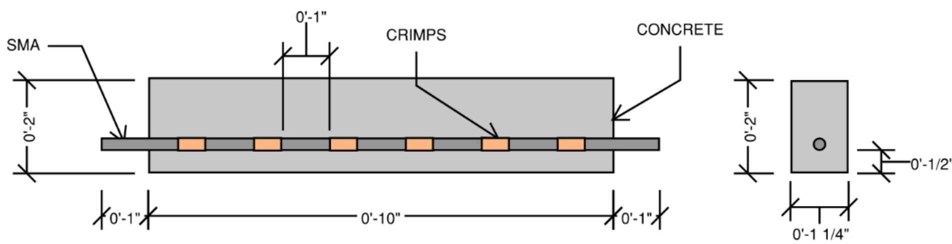

Figure 7. Flexural specimen geometry

Figure 8. Flexural specimens with instrumentation

Task 3: SMA Activation and Specimen Testing [15% completed]:
This quarter focused on preparing and testing the portable induction heating machine. The coil portion of the machine is interchangeable, so a custom copper coil was created for use on the aforementioned flexural specimens (**Figure 9**). The coil features two loops and was sized to match the surface area of the flexural specimens. This is a “pancake” type coil which produces a strong magnetic field near the face of the coil. Practice tests were conducted, and they showed that this coil can quickly heat up 0.25” diameter SMA bars to the target activation temperature through the concrete cover. This provides significant advantages over electrical heating because no portions of the SMA need to be exposed. It also allows the SMA to be heated in smaller increments, so that the same coil can be used on specimens of different shapes and sizes. In contrast, heating with electrical resistivity requires either exposure of the SMA or incorporation of lead wires which could negatively affect the structural integrity of the concrete. The amount of power needed also

scales up with the length of the SMA being heated, making heating of larger specimens by electrical resistivity more difficult than with induction.

Figure 9. Induction coil with practice test specimen

4. Percent of research project completed

Total project completed through the end of this quarter = [20% completed to date]

5. Expected progress for next quarter

The iterative design process for Task 1 will continue and the geometry of the truss web girder will be further optimized. SMA reinforcement will then be introduced into the verticals of the web to apply a prestressing force which will delay cracking and improve the serviceability of the girder.

For Task 2, the focus will be on instrumenting the precast truss and casting the concrete. Once the concrete is cured, the activation of the SMA reinforcement will be carried out using the portable induction heater prepared during Task 3. Thermocouples and strain gauges will be used to monitor the prestressing forces from activation of the SMA in the tensile regions. Then, the specimen will be loaded across the top to investigate its structural performance. The work on the 3D printed trusses will also continue. The reinforcement plan and instrumentation plan will be finalized. Once printed and fully cured, the trusses will be transported to the university for testing under flexural loads.

Work on the flexural specimens will also continue. The first step will be to prestress the specimens using the different heating methods described earlier. Then the specimens will be loaded until cracking occurs at midspan. During this stage, a crack opening displacement (COD) gauge will monitor the crack growth. Once unloaded, the specimens will be heated to heal the cracks.

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:

A conference paper on the work done with healing of specimens will be part of the 2025 ASCE Structures Congress.

9. Presentations and Posters of TRANS-IPIC funded research:

A presentation on the healing of specimens will be presented at the ASCE Structures Congress taking place in Phoenix, Arizona on April 9th-11th.

A poster on the healing of specimens will be presented at the 2nd annual TRANS-IPIC workshop taking place 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. = 1

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