Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

Automated Construction of Concrete Bridge Components With Shape Memory Bars
Project No.: UI-25-RP-01

Quarterly Progress Report
For the performance period ending March 31st, 2026

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Collaborators / Partners:
LX Construction

Submitted to:
TRANS-IPIC UTC
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Urbana, IL

TRANS-IPIC Quarterly Progress Report:

Project Description:

1. Research Plan - Statement of Problem

This project aims to address the challenge of incorporating prestressing in the automated construction of bridge components without using hydraulic jacking or concrete forms. The approach will utilize existing large 3D concrete printers currently employed in the construction of 3D-Printed Concrete (3DPC) buildings, ensuring that the transportation industry can easily adopt the methods demonstrated. As prestressed concrete elements are commonly used in bridges, this project will introduce an innovative technique for internally prestressing large 3DPC components with complex shapes using rebars made from a novel class of metallic material known as shape memory alloy (SMA). This new reinforcement can be activated (prestressed) through heating. The research will explore induction heating as a potential industrial method for prestressing the SMA bars without the need for direct contact. Overall, this research aims to provide the transportation industry with an efficient and practical method for prestressing structural 3DPC components used in transportation infrastructure.

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

Task 1. Design of Specimens Using Finite Element Method:

A finite element model (FEM) of bridge girders will be employed to design optimized geometries through an iterative process. The quantity and placement of the SMAs will be varied to determine the optimal use of the material.

Task 2. 3D Printing and Testing of Beam Specimens:

Beam specimens will be manufactured with LX Construction. During the printing process, the SMA and steel reinforcement will be integrated between the layers, eliminating the need for rebar ties or concrete rebar chairs.

Task 3. 3D Printing and Testing of Large-Scale Truss Beam:

This task will focus on 3D printing a relatively large concrete truss with embedded SMA bars. The design of the truss will build upon the results of the previous tasks.

Task 4. 3D Printing and Testing of Topology Optimized Beam:

The specimen for this task will feature a more complex geometry with curved contours compared to the truss beam printed in task 3. The design will be created using topology optimization techniques.

Task 5. Induction Heating for SMA Activation:

Induction heating will be employed to heat the 3DPC specimens in this project. This task will focus on optimizing the design of the coil and the power and frequency of the induction system required to activate SMA bars inside the concrete efficiently.

Project Progress:

3. Progress for each research task

Task 1. Design of Specimens Using Finite Element Method [100% completed]

This quarter's progress focused on the design of the beams and trusses. This involved developing the overall geometry, selecting the reinforcement, and then adjusting the final designs for fabrication using a concrete printer. The designs were developed iteratively using the finite element (FE) software ABAQUS. A model was first developed without reinforcement and loaded to identify areas of maximum tension. Then the model is revised to contain steel and SMA reinforcement to address the tensile regions. Thus, the reinforcement quantity is optimized by only adding it where it is needed most.

The Howe truss was developed by building on the design of the completed TRANS-IPIC project titled “Innovative Precast Concrete Truss Using Adaptive Shape Memory Prestressing System”. The design needed modifications to work with the limitations of the concrete printer. A 4-inch nozzle was selected so that the vertical and diagonal members of the truss can be printed using singular lines and cut down on printing time. Backfilling was also introduced as part of the process. Only a portion of the truss will be printed, and irregularly shaped areas will be filled in with concrete, with the printed portion serving as formwork. This approach allowed greater flexibility in the member widths. The layer height was also important because of the planned usage of the induction heater. The strength of the induction heater decreases with distance, so a 1-inch cover was selected. This revised geometry was modeled in ABAQUS and evaluated for tensile stress and crack damage. The bottom chord is the first to crack, so steel and SMA bars were added to strengthen and prestress the bottom. When analyzed for vertical stresses, the unreinforced truss had high tensile stresses in the verticals. An asymmetric reinforcement design was chosen to allow two different reinforcement approaches to be studied in the same specimen. One vertical member is reinforced with steel rebars, while the other is reinforced with SMA bars. The tensile damage in the revised truss is shown in **Figure 1**. The steel and SMA bars in the bottom chord delayed crack formation. The cracks instead develop first at the vertical member without SMA, which is shown in red on the left side of the figure. The final reinforcement plan is shown in **Figure 2**.

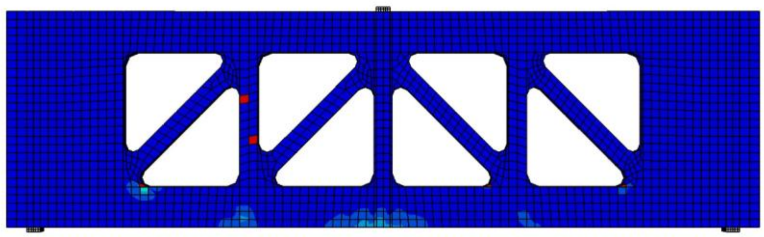

Figure 1. Tensile damage in asymmetrically reinforced Howe truss

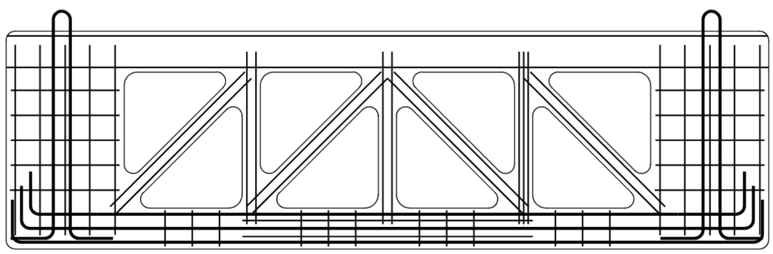

Figure 2. Howe truss reinforcement plan

The design of the beams was more straightforward. The width was dictated by the previously selected nozzle size, with a width of 4 inches. The height was also set to be compatible with the height of the Howe truss. The length of the beams was sized so that the beams would fail in flexure and not shear under 3-point loading. One beam was reinforced with two steel rebars. The other beam was reinforced with one steel rebar and two SMA bars. An FE model of the beam with two steel rebars was created first (**Figure 3**). Cracks formed in the middle region of the beam under 3-point bending. Based on this result, the second beam was reinforced with SMAs with lengths that extended just beyond where cracks are expected. This used the SMA in a more optimal manner through targeted prestressing. The final reinforcement design is shown in **Figure 4.**

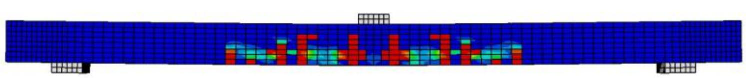

Figure 3. Tensile damage of the beam reinforced with two #2 steel rebars

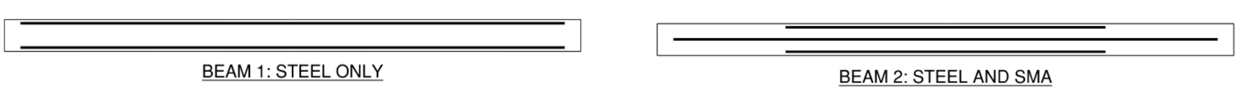

Figure 4. Reinforcement plans for the beams

The topology-optimized truss required a different approach to develop its geometry. The topology-optimization software TOSCA was used to generate the initial design. The beam was modelled as a simply-supported 2D plane with a uniform load across the top. The software used a volume fraction constraint while minimizing strain energy to produce voids in the center region of the beam. This geometry was then manually adjusted to be printable using a 4” nozzle. Backfilling was used to address the irregular shapes at the joints. This geometry was then analyzed using ABAQUS as an unreinforced truss. The cracks first formed in the bottom chord, so steel was added there. The diagonals that pointed outwards were also under tensile stresses. An asymmetric design was used to reinforce the two tensile members. One side was reinforced with steel rebar, while the other was reinforced with SMA bars. This reinforced model was loaded under three-point bending, and the crack damage is shown in **Figure 5**. The diagonal member with steel (left side) cracked before the side with SMA. The cracks in the bottom chord were delayed. The final reinforcement plan is shown in **Figure 6**.

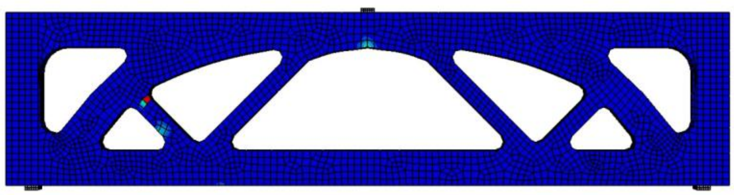

Figure 5. Tensile damage in asymmetrically reinforced topology-optimized truss

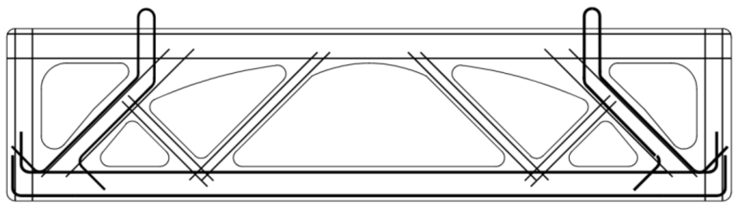

Figure 6. Topology-optimized truss reinforcement plan

The models were remade in Autodesk Fusion as lines. An important aspect to consider at this stage was the starting and stopping places for the lines. These areas will be inconsistent in quality and should be located away from critical regions. The geometries were converted so that end points were placed in the thickest regions of the specimens, where backfill will resolve the quality differences. The models were combined to form a single file for the printer. By printing all the specimens at the same time, the time between layers is increased which maximizes the time for laying rebar. An image of the printing simulation is shown in **Figure 7**.

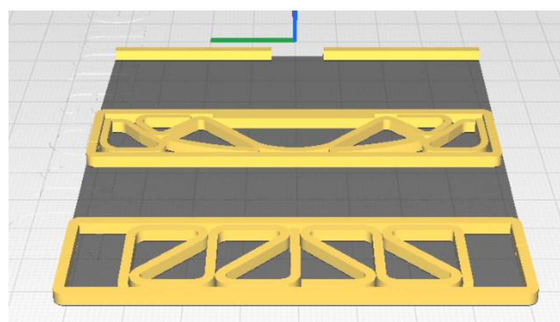

Figure 7. Visualization of printed specimens

Task 2. 3D Printing and Testing of Beam Specimens: [0% completed]
Nothing to report yet.

Task 3. 3D Printing and Testing of Large-Scale Truss Beam: [0% completed]
Nothing to report yet.

Task 4. 3D Printing and Testing of Topology Optimized Beam [0% completed]
Nothing to report yet.

Task 5. Induction Heating for SMA Activation: [0% completed]
Nothing to report yet.

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 next quarter will focus on the fabrication of specimens. This will involve cutting and bending the steel. Most of the elements will not require rebar ties but certain components, like the cages for the shear regions, will be tied to speed up the rebar laying process. This stage will also involve prestraining and bending the SMA bars and attaching thermocouples. Once prepared, the reinforcements will be transported to a warehouse where the 3D concrete printer is located. The test specimens will be printed and cured there before being transported to the University of Illinois at Urbana Champaign for testing.

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, A.; Andrawes, B. Prestressing and Self-Healing of Fiber-Reinforced and Ultra-High-Performance Concrete Using Shape Memory Alloys. Buildings 2026, 16, 1289. https://doi.org/10.3390/buildings16071289

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

Nothing to report yet.

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. = 0

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. = 1

D. Number of peer-reviewed conference papers published by faculty.
   - No. = 0

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:

[List all the references associated with this research project]