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Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

Shape Memory Alloy Transverse Reinforcement for Precast Bridge Girders End Regions - Phase II
Project No.: UI-23-RP-01

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

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Collaborators / Partners:
- None

Submitted to:
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TRANS-IPIC Quarterly Progress Report:

<u>Project Description:</u>

1. Research Plan - Statement of Problem

Despite the success of the concrete prestressing technology in the longitudinal direction, it has not been implemented in the transverse direction (i.e., prestressed stirrups, spirals, etc.) due to many practical challenges. The reason is simple; no practical method exists for prestressing internal shear reinforcement such as hoops, stirrups, or spirals because these reinforcements are fully embedded in the concrete; hence gripping the reinforcement ends for prestressing is not feasible. This research will investigate a new method for applying prestressing in the transverse direction using a class of metallic materials known as shape memory alloys (SMAs). The use of prestressed transverse reinforcement in precast/prestressed members could significantly impact how PC members are designed. For example, it will potentially impact the shear strength and provide better crack control, help with reducing significantly bursting and splitting stresses at end regions, reduce the size of members, and improve steel bond strength with concrete, which will, in turn, minimize transfer/development lengths, enable early release of strands, eliminate steel congestion, especially at end regions, enhance the constructability of joint connections with lap splices, etc. This research aligns with the mission of TRANS-IPIC to improve the durability of PC infrastructure and extend its service life. It aligns with the USDOT's strategic goal of performing transformative research that will advance the transportation infrastructure by introducing a novel reinforcement type that can innovatively mitigate PC infrastructure damage.

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

The research plan for this project includes three primary tasks:

<u>Task (1):</u> Design of Specimens using Finite Element Method:

This task will focus on evaluating the behavior of the specimens through a detailed finite element (FE) analysis. The end region behavior of the specimens at the web by a single prestressing strand will be investigated using the amount of transverse steel specified by AASHTO. The effect of SMA reinforcement compared to the conventional (non-prestressed) reinforcement will also be investigated, focusing on the end region. The case that produces the highest damage mitigation will be employed for the experimental stage of the project.

<u>Task (2):</u> Fabrication, Instrumentation, and Testing of Specimens:

Several small-scale specimens and two full-scale beam girder specimens will be fabricated and used in this project. The specimens will provide the research team with the opportunity to examine different end regions with different design, detailing, and SMA heating (activation) methods. At least one of the end region designs will be used as a control specimen using conventional steel stirrups, while the other specimens will be fabricated with SMA stirrups with different configurations and heating methods.

<u>Task (3):</u> SMA Activation Methods:

After casting the concrete and before releasing the longitudinal strands, the SMA spiral will be stressed by heating (activated). Next, the strands will be detensioned, and monitoring the bursting stresses/cracks will begin. Part of this research is to investigate two different methods for activating the SMA reinforcement inside large-scale concrete elements: (1) electrical resistivity, and (2) electromagnetic Induction. The PI recently purchased a portable induction heating system that will be used for this project as part of the in-kind cost share provided by the University of Illinois.

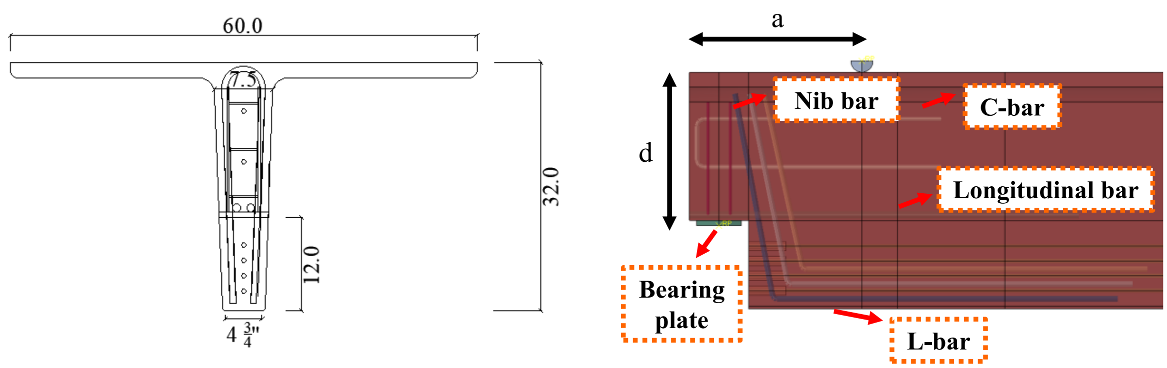
<u>Project Progress:</u>

3. Progress for each research task

***Task 1 progress (75% completed)*:**

This quarter's work focused on using the finite element (FE) method to design T-shaped dapped-end beams that compose different shapes of reinforcements (i.e., L-shape, C-shape, and straight). The goal was to numerically investigate the damage mechanism of the structure when each reinforcement is replaced with

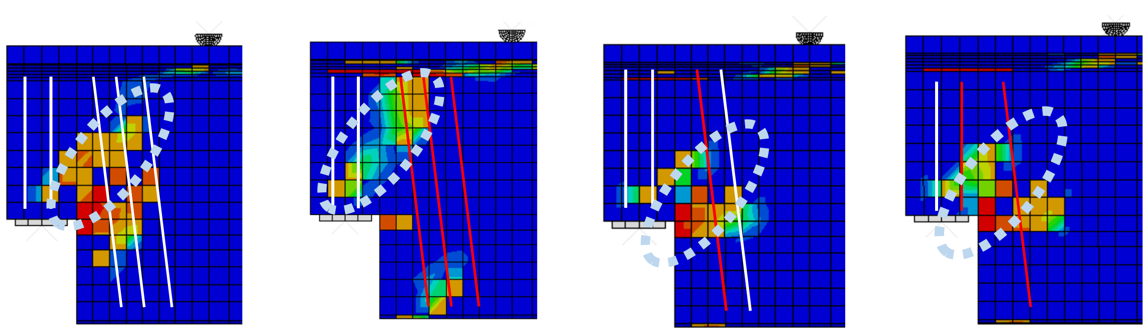
SMA bars. The loading location varied by shear span-to-depth ratio (*a*/*d*) from 0.5 to 2.0, with 1.0 being the typical ratio for considering shear failure of dapped-end beams, and 2.0 being applicable to general structures. **Fig. 1** shows the drawings of the numerical model and the reinforcement plan for each model. In the reference steel model, the reinforcement contained six steel L-bars, one steel C-bar, two steel Nib bars, two steel longitudinal bars, and four prestressing strands. To estimate the effect of SMA bars, models were designed by replacing existing steel transverse reinforcements (L-bar and Nib bar). When L bars were replaced, six steel bars were modified to SMA bars, which have six, four, and two SMA bars. In the case of Nib bar replacement, two steel bars were replaced, with each having one or two SMA bars, respectively. A hybrid model with one nib SMA bar and one L SMA bar was also designed as a comparison model.



(a) Section view (b) Reinforcement plan

Fig. 1 Dapped-end beam design and reinforcement

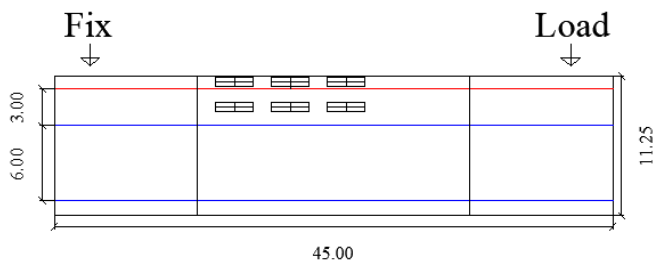
Fig. 2 shows the damage pattern in representative models. The loading plate is located at the *a*/*d* ratio of 1.0. Red lines and white lines represent the SMA bar and the steel bar, respectively. In the SMA-1 model, all steel L bars were replaced with SMA bars. Consequently, the diagonal cracking occurred in the steel model shifted to form at the nib area with the cracking load increasing to 135 kips from 80 kips (68.8% increase). In the SMA-2 model, one SMA L bar and one steel L bar were designed for the reinforcement. The cracking still propagated at the re-entrant corner in the diagonal direction, whereas the cracking load increased to 105 kips (31.3% increase). The reinforcement ratio was reduced by 20% in the SMA-2 model compared to the steel model, resulting in higher crack resistance. In the SMA-3 model, one SMA nib bar and one SMA L bar were used, resulting in a 41% decrease in the reinforcement ratio. Still, the cracking load was 98 kips (22.5% increase), resulting in cracking in the re-entrant corner in the diagonal direction. Overall, transverse SMA reinforcement at the dapped-end beam proven its effectiveness.



(a) Steel (b) SMA-1 (c) SMA-2 (d) SMA-3

Fig. 2 Finite element analysis results (damage pattern)

Task 2 progress (70% completed):
This quarter's work focused on testing and evaluating experimentally the end region with SMA bars. This task aimed to investigate the healing effect of the SMA bar in the girder scale specimen at the end region by cracking the specimen and activating the SMA. The reinforcement plan and manufactured specimen mold are shown in **Fig. 3**. The Red line represents the SMA bar, and the blue lines are the steel bars. First, the specimen was loaded at one end using the manual actuator without activating the SMA. The loading resulted in a cracking load of 1.8 kips, corresponding to a crack width of 0.025 in. The specimen was then healed by heating and cooling the SMA using an induction coil heating system.

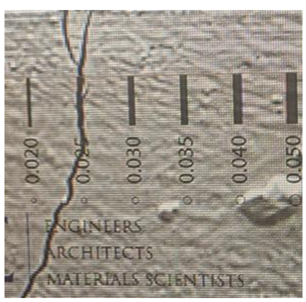


(a) Front view of the specimen


(b) Specimen mold

Fig. 3 Design and manufacture of the specimen

Fig. 4 shows the before and after of the specimen's crack by healing it with SMA activation. By SMA activation, the average compressive strain achieved at the first layer of concrete strain gauges was 78.7$\mu\varepsilon$. Consequently, the crack width decreased to 0.005 in., representing a 75% reduction in crack width. Although the crack was not fully closed, a single layer of SMA has proven its effectiveness in healing the structure.



(a) Before healing


(b) After healing

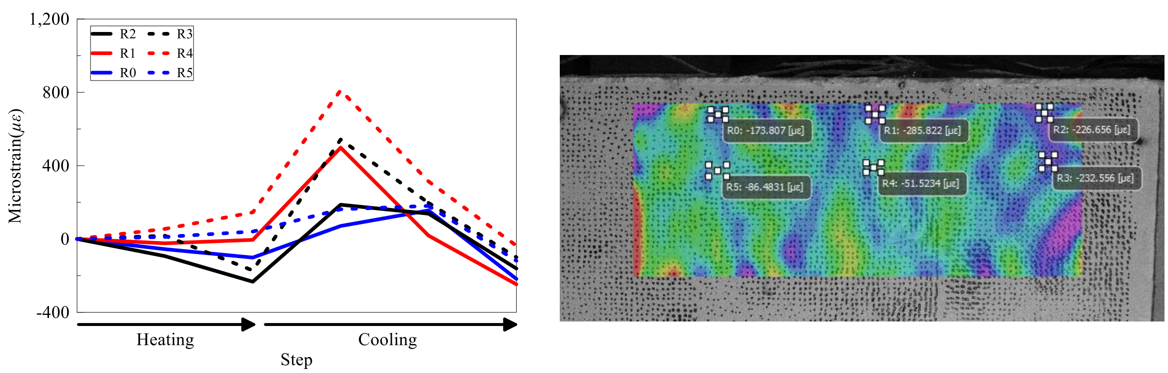
Fig. 4 Specimen's crack width

Task 3 progress (60% completed):
The work on this task focused on studying the SMA activation method when SMA is placed inside the end region of an I-shaped concrete component. Compared to the previous quarterly report, SMA was embedded into concrete without adding sleeves, but bending 90 degrees at the end tips with an anchorage length of 2 in. This specimen setup was designed to induce stress transfer from SMA to concrete in the global region, whereas the sleeves transfer stresses in localized areas. **Fig. 5(a)** shows the assembled steel frame inside the manufactured wood mold. At the surface of SMA bars, six thermocouples were attached every quarter length of the SMA in 1st and 2nd layers to track the temperature variation during heating and cooling. After casting concrete, speckle patterns were applied to the concrete surface (**Fig. 5(b)**) for digital image correlation (DIC) analysis. By using the DIC method, it was estimated that strain tracking is enabled during the heating and for a day of cooling. Photographs were taken at the steps of first face heating, second face heating, 1 hour of cooling, 3 hours of cooling, and 12 hours of cooling (concrete returned to room temperature at this stage) to run DIC analysis and measure strain variation along the concrete surface.

(a) Assembled reinforcement frame and mold (b) Speckle pattern on the concrete surface

Fig. 5 Manufacture of specimen and test preparation

Fig. 6 shows the strain variation at the concrete face near the SMA bar during heating and cooling phases. The strain variation was measured at six points, which are aligned with the locations of the opposite strain gauges. During the heating of SMA bar, the prestressing force by SMA activation applied a compressive force to the concrete, resulting in a maximum strain of -230 $\mu\varepsilon$ at the R2 location. After the termination of SMA heating, a tensile strain developed throughout the concrete due to the expansion of the concrete. However, as the specimen cooled to room temperature, a compressive strain rebuilt at the concrete surface, maintaining a value of -230$\mu\varepsilon$ to -250$\mu\varepsilon$. For the activation of SMA, bending the end tips was sufficient for transferring the recovery stress of SMA and holding it in position.



(a) Strain variation in each step (b) DIC result after cooling to room temperature

Fig. 6 DIC analysis results

4. **Percent of research project completed**
   Total project completed through the end of this quarter = 75%

5. **Expected progress for next quarter**
   Testing of the SMA specimen with various variables is expected to occur in the next quarter. This will involve load testing of prestressed concrete and comparing the effectiveness of different SMA anchorage methods.

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:**

   - Park, S. and Andrawes, B. Application of NiTiNb Shape Memory Alloys in the End Region of

Prestressed Girders, Advances in Structural Engineering. (Accepted)

- Andrawes, B., Sung, M., and Park, S. NiTiNb Shape Memory Bars for Concrete Prestressing Applications, ASCE Journal of Materials in Civil Engineering. (Accepted)

- Park, S. and Andrawes, B. Evaluating the Stress Transfer and Detailing of Shape Memory Alloy Transverse Reinforced at the End Region of Prestressed Concrete Beams, Journal of Intelligent Material Systems and Structures. (Under review)

9. **Presentations and Posters of TRANS-IPIC funded research:**
   - Park, S. and Andrawes, B. Shape Memory Alloy Reinforcement in the End Regions of Concrete Beams, TRANS-IPIC UTC Workshop, 2025.

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. = 5

B. Number of peer-reviewed publications submitted based on outcomes of UTC funded projects
   - No. = 1

C. Number of peer-reviewed journal articles published by faculty.
   - No. = 2

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 = 0
   - No. PhD dissertations = 0
   - No. citations of each of the above = 0

F. Number of research tools (lab equipment, models, software, test processes, etc.) developed as part of TRANS-IPIC sponsored research
   Nothing to report

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 = 1
   - Editorial board of journals (No. participated in & No. led)
     - No. participated in =
     - No. lead =
   - TRB committees (No. participated in & No. led)
     - No. participated in = 3
     - 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