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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 *[June 30th, 2025]*

Submitted by:
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Collaborators / Partners:
- None

Submitted to:
TRANS-IPIC UTC
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Urbana, IL

TRANS-IPIC Quarterly Progress Report:

Project Description:

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:

Task (1): 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.

Task (2): 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.

Task (3): SMA Activation Methods:

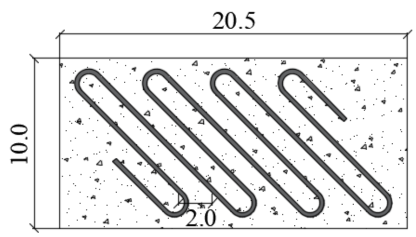
After casting the concrete and before releasing the longitudinal strands, the SMA spiral will be stressed by heating (activated). Next, the strands will be detensioned, and monitoring the bursting stresses/cracks will begin. Part of this research is to investigate two different methods for activating 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.

Project Progress:

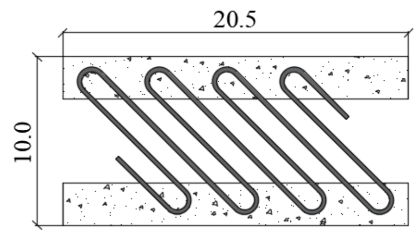
3. Progress for each research task

***Task 1 progress (50% completed)*:**

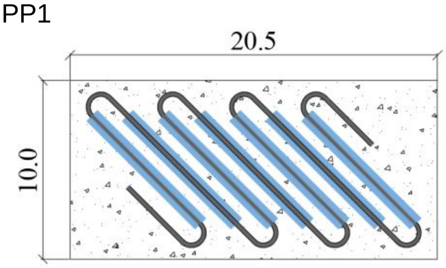
This quarter's work focused on using the finite element (FE) method to design the precast prestressing plate (PPP) that embeds SMA inside the concrete and introduces prestressing force to the attached structure. The goal was to numerically investigate the increase in the structure's capacity by attaching PPP to the girder. Additionally, the effectiveness of different PPP shapes was compared to evaluate the performance of each plate. **Fig. 1** shows three different shapes of PPP with SMA embedded inside the concrete plate. The geometry of the plate was designed 20.5 in. × 10.0 in. × 0.75 in., considering the girder on which the PPP will be attached in the experimental study. The PPP configurations differed in the volume of concrete used to compose the PPP. SMA-PPP1 was filled with concrete, whereas SMA-PPP2 had a void at the center, and SMA-PPP3 had an empty window zone along the SMA. The void at the center of SMA-PPP2 was to reduce the amount of concrete, which is unnecessary for SMA anchoring and transfer of prestressing force. The window zone in SMA-PPP3 was to enable direct heating for SMA activation.



(a) SMA-PPP1



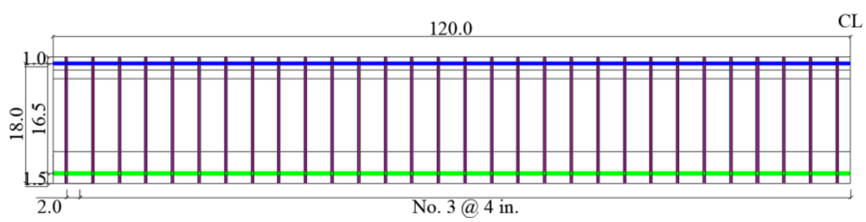
(b) SMA-PPP2



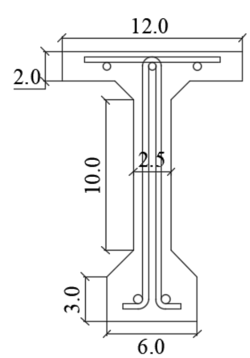
(c) SMA-PPP3

Fig. 1 Different shapes of PPP (unit: in.)

Following the design of SMA-PPP, a control specimen was used to assess the enhancement in shear performance. **Fig. 2** shows the schematic drawing of the T-beam that was used as a control specimen. The beam length was designed to be 20 ft, with a height of 18 in. and a web width of 2.5 in. For the reinforcement, three #4 longitudinal bars at the top flange, two 0.6" strands at the bottom flange, and double-legged #3 stirrups at a spacing of 4 in. were used in the beam. The prestressing value was defined as 189 ksi, considering both short-term and long-term prestress losses in the numerical model. The load plate was positioned at the shear span-to-effective depth ratios (*a*/*d*) of 1.0 and 1.5 to evaluate the shear capacity of the beam. For models with PPP, the plates were attached on both sides of the beam web, from the support to the load plate location, where the SMA was diagonally aligned along the beam to improve shear capacity.



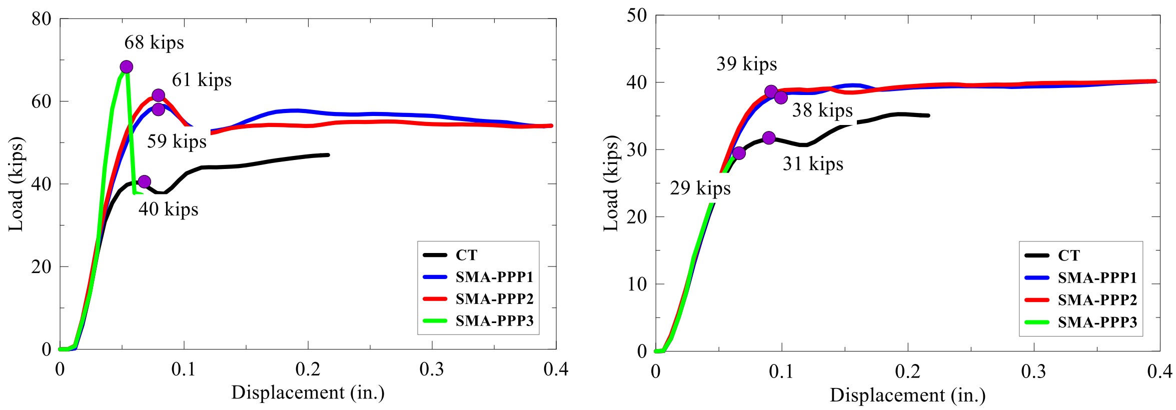
(a) Front view with reinforcement plan



(b) Section view

Fig. 2 T-beam (unit: in.)

Fig. 3 shows the comparison of the shear capacity of each model with *a*/*d* of 1.0 and 1.5. SMA-PPP1 and SMA-PPP2 both showed 50% and 25% improvements in shear capacity compared to the control specimen (CT) at *a*/*d* ratios of 1.0 and 1.5, respectively. As the anchoring of the SMA to PPP was formed at the bent region, the prestressing force generated by SMA activation was equally transferred to the beam regardless of the existence of the center concrete. However, as shown in the SMA-PPP3 case, the window zone of the SMA-PPP concentrated stresses at the corners of the window zones, resulting in early rupture of the PPP during loading.

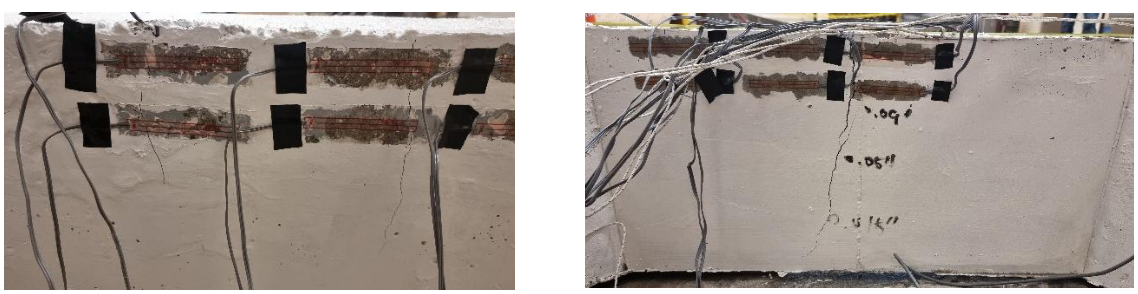


(a) a/d = 1.0 (b) a/d = 1.5

Fig. 3 Shear capacity of each model

Task 2 progress (40% completed):

This quarter's work focused on testing and evaluation of the experimental program. A reduced-scale specimen mentioned in the 5th quarterly report was experimentally tested with steel and SMA cases and theoretically validated. The prestressing force applied by SMA activation was 78.7 $\mu\varepsilon$ (446 psi) and 40.0 $\mu\varepsilon$ (227 psi), respectively. After SMA activation, the specimen was loaded from the bottom flange until the web area cracked, as shown in **Fig. 4**. The load values at the initial stage of cracking were 2.7 kips and 5.0 kips, respectively, in steel and SMA specimens. As shown in **Eq. 1**, the cracking loads of steel and SMA specimens were theoretically calculated using section analysis. By comparing the theoretical calculation results to the experimental results, the steel specimen showed an 8.3% difference, and the SMA specimen showed a 4% difference, adding credibility to the experimental results. By introducing SMA's prestressing force, although the third steel stirrup was eliminated, the cracking load increased by 85%, proving the effectiveness of the SMA stirrup.



(a) Steel specimen crack (b) SMA specimen crack

Fig. 4 Shear capacity of each model

$$M_{cr} = \frac{f_r I_g}{y} = \frac{0.783 * 474.6}{5.625} = 66.1(k - in.)$$

$$P_{cr} = \frac{M_{cr}}{22.6} = 2.9\,kips$$

Eq. 1(a) Steel specimen

$$M_{cr} = \frac{(\sigma_{SMA} + f_r)I_g}{y} = \frac{(0.65 + 0.783) * 474.6}{5.625} = 117.6\,(k - in.)$$

$$P_{cr} = \frac{M_{cr}}{22.6} = 5.2\,kips$$

Eq. 1(b) SMA specimen

***Task 3 progress (25% completed)*:**
The work on this task focused on studying the SMA activation method when SMA is placed inside the concrete. Within the clear cover of 0.5 in., the electromagnetic induction heating was selected as the activating method. First, with the given electromagnetic induction heating equipment, two types of induction coils were manufactured to transfer the magnetic flux. **Fig. 5(a)** shows the shape of each coil. To secure a sufficient magnetic field for the copper tube path, inductance was calculated before manufacturing the loop. Consequently, a circular-rectangle path with two circulations was created for heat generation. Then, the induction coil was connected to the magnetic field generator, positioned at the SMA location for heating. **Fig. 5(b)** shows the SMA activation test setup. After heating the SMA bars, they were cooled down for a day. The compressive strain (stress) measured at the first and second layers of strain gauges (0.5 in. and 1.5 in. from the top face) by SMA activation was 78.7 *με* (446 psi) and 40.0 *με* (227 psi), respectively. Induction heating was sufficient to activate the SMA fully within the concrete.

(a) Self-made induction coil (b) SMA activation test setup

Fig. 5 Shear capacity of each model

4. Percent of research project completed
Total project completed through the end of this quarter = 45%

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 using the induction heating procedure (Task 3). PPP testing and detailed FE work are also expected in the next quarter.

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. (Under Review)

- 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. (Submitted)

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

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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. = 2

C. Number of peer-reviewed journal articles published by faculty.
   - No. = 1

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