Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

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

Quarterly Progress Report
For the performance period ending *[September 30th, 2024]*

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Collaborators / Partners:
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- GTI General Technologies, Inc.

Submitted to:
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TRANS-IPIC Quarterly Progress Report:

Project Description:

1. Research Plan - Statement of Problem

Despite the success of using concrete prestressing technology in the longitudinal direction, it has not been implemented in the transverse direction due to many practical challenges. The reason is that 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 technology for applying prestressing in the transverse direction using a class of smart metallic materials known as shape memory alloys (SMAs). Excessively deformed bars and wires made of SMAs can remember their original shape when subjected to a temperature of approximately 200ºC. This project will use this novel material to solve the longstanding problem of splitting and bursting cracking at the end regions of precast concrete (PC) bridge girders. Applying prestressing in the transverse direction (i.e., vertically) within that local region will help mitigate concrete cracking during prestressing and reduce steel congestion in this region.

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

The research plan for this project includes two 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 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:
Three specimens (one used as a control specimen with conventional steel and two specimens with SMA) will be fabricated and tested. Before casting, prestressing strands will be tensioned, and SMA transverse reinforcement will be placed at the specimen's ends. Next, the strands will be detensioned, and the progression of bursting stresses/cracks will be monitored. The thermo-mechanical properties of SMA by electric activation method will be tested in a self-made test setup.

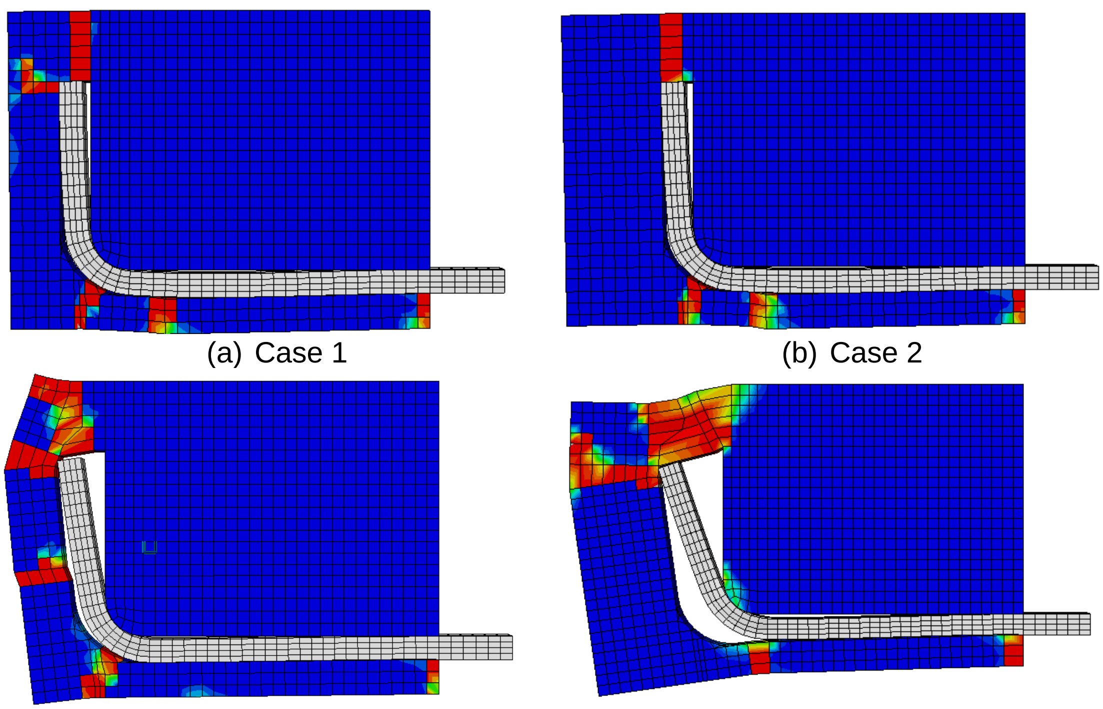
Project Progress:

3. Progress for each research task

Task 1 progress (100% completed): The work in this task during this quarter focused on using the finite element (FE) method to analyze the hook opening effect of shape memory alloy (SMA) stirrups placed in the concrete. The goal was to imitate the opening displacement of bent SMA hooks during activation (heating) and investigate the damage to the nearby concrete.

First, based on the experimental work conducted for activating the sole-SMA bar (refer to the 3rd Quarterly Progress Report), the opening displacement was decided, which was employed in designing the numerical model. The thermal elongation property was employed to induce the opening of the SMA bar in the numerical model. The SMA bar was segmented into 4 different layers in the bent region, and each layer was assigned with different thermal expansion coefficient values. The thermal expansion coefficients were decided based on the FE analysis results of SMA bar loading at the end tip.

As the numerical analysis matched well with experimental results, a 3-D model with concrete and SMA was developed to anticipate the vulnerable regions by activating the bent SMA. Figure 1 shows the FE analysis results with different conditions. All models were designed with a thickness of 0.25 in., which is the same as the SMA bar diameter. Case 1 and Case 2 are designed to be bent only, whereas Case 3 and Case 4 are pre-strained and bent. The clear cover of Case 1 and Case 3 was 0.5 in. (from SMA tip to concrete surface), whereas Case 2 and Case 4 had a clear cover of 1.0 in. By visually inspecting the analysis results, expected cracking zones were decided to be the surroundings of the bent region and the tip of the SMA, which will be used for deciding critical spots for future experimental research.



(a) Case 1 (b) Case 2

(c) Case 3 (d) Case 4

Figure 1. FE analysis results of SMA hooked bar in concrete

Task 2 progress (80% completed): This task during this quarter focused on fabricating end region specimens and releasing prestressing strands. Figure 2 shows the procedure for making specimens. Specimens with steel stirrup and SMA stirrup were each fabricated to compare the effect of SMA prestressing force on crack damage mitigation. Spacers were located at the top of the stirrups to maintain spacing and longitudinal bars were lifted by a wood-chair. Self-consolidated concrete was used for casting concrete since vibrating the concrete was not possible during casting. The mixture for self-consolidated concrete was designed by referring to ACI 237R-07. After demolding wood molds, concrete strain gages were attached at the end face of web regions in horizontal and vertical directions.

(a) Steel stirrup specimen

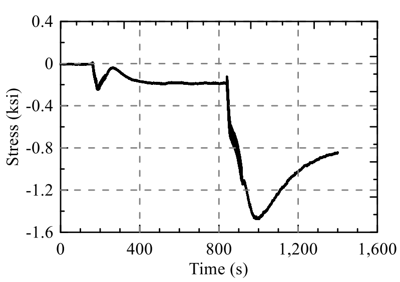
(b) SMA stirrup specimen

(c) Concrete casting

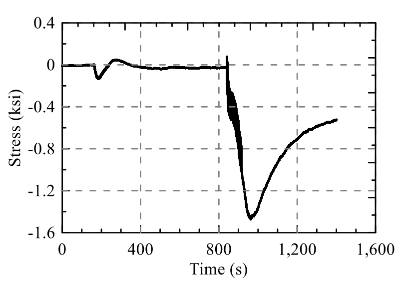
(d) Completed specimens

Figure 2. Specimen fabricating procedure

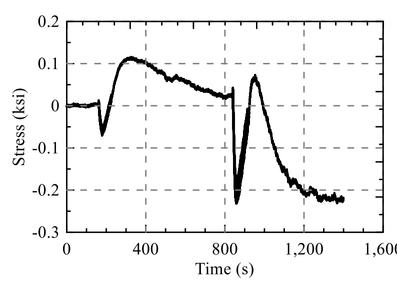
The experimental study was conducted first by activating the SMA bars. Figure 3 shows the compressive stress built into the surface of the concrete. Concrete strain gages were attached at the places where the prestressing strand was running through, and at the distance of 0.875, 1.75, and 2.625 in., from the end face (each is labeled as V1, V2, and V3, respectively). The vertical SMA stirrup was placed 1.75 in. from the end face. At the first activation, compressive stress with a maximum value of 0.3 ksi was applied in V1, which matches well with the theoretical calculations. After the second activation, the compressive stress of 0.9 ksi, 0.6 ksi, and 0.2 ksi was developed at strain gages V1, V2, and V3, respectively. The average value was 0.625 ksi, which theoretically should be 0.6 ksi. Throughout the experiment, it was proven that SMA prestressing force was sufficiently transferred to the concrete.



(a) V1



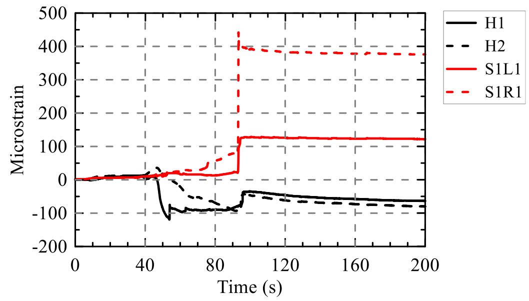
(b) V2



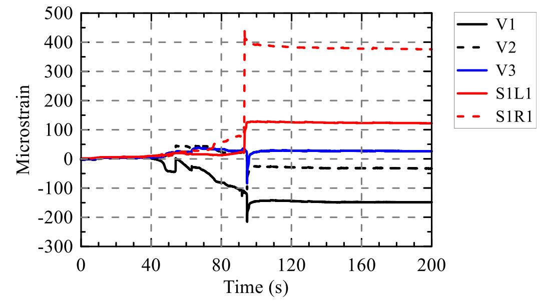
(c) V3

Figure 3. Compressive stress on concrete during activation

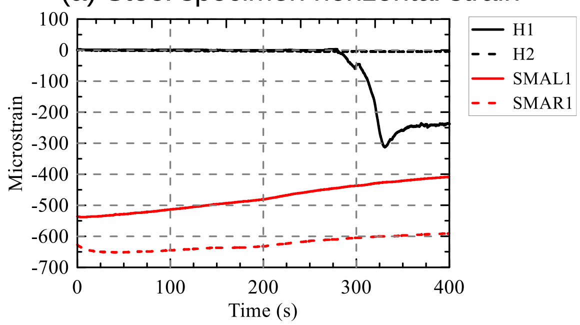
After activating SMA stirrups, prestress release testing was conducted on both steel and SMA specimens. “H1” and “H2” are concrete strain gages installed at 1.75 in. and 7.75 in. from the end face, parallel to the prestressing strand. “S1L1”, “S1R1”, “SMAL1”, and “SMAR1” are steel strain gages installed at the end stirrup next to the prestressing strand. After prestressing release, the compressive strain was well developed along the prestressing strands. In terms of vertical strain, SMA prestressing force reduced the amount of tensile strain development, which is expected to reduce cracking damage.



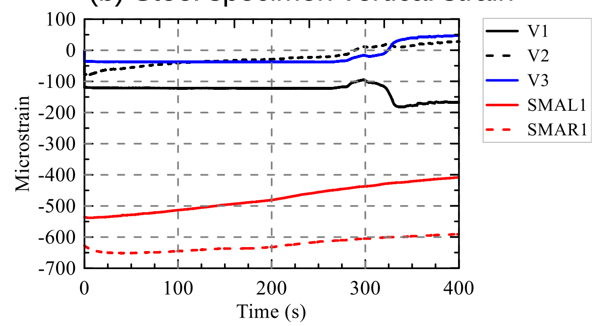
(a) Steel specimen horizontal strain



(b) Steel specimen vertical strain



(c) SMA specimen horizontal strain



(d) SMA specimen vertical strain

Figure 4. Strain variation during prestress release

4. Percent of research the project completed
Total project completed through the end of this quarter = 85%

5. Expected progress for next quarter
The next quarter will focus on 1) Optimizing the design of the experimental specimens using FE analysis, and 2) Writing the project’s final report for Year 1.

6. Educational outreach and workforce development
The research team participated in two summer events for educating high school students: **1) Summer Camp**: Approximately 20 high school students were invited to participate in a one-day event at the Newmark Lab at UIUC (see Fig. 5a). Students learned about how bridges are built and how SMAs can be used to improve the durability of transportation infrastructure. **2) TRIO Upward Bound Program:** Through this program, a group of six high school students from underrepresented groups were hosted for three weeks at the CEE department at UIUC. Students received hands-on experience in building small-scale specimens made of SMAs and how they could be used in bridges (see Fig. 5b).

a) Summer Camp b) TRIO Program

Figure 5. Educational summer activities that was carried out at CEE at Illinois

7. Technology Transfer
   Nothing to report yet

Research Contribution:

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. (Submitted)

Presentations and Posters of TRANS-IPIC funded research:
Park, S., and Andrawes, B. Transverse Prestressing of End Regions of Pretensioned Concrete Bridge Girders, 2025 Structures Congress, Apr. 2025. (Accepted)

8. 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

References:

ACI Committee 237 (2007) Self-Consolidating Concrete, American Concrete Institute, Farmington Hills, MI, USA.