

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 *[June 30th, 2024]*

## Submitted by:

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## Collaborators / Partners:

* County Materials Corporation
* GTI General Technologies, Inc.

## Submitted to:

TRANS-IPIC UTC

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# TRANS-IPIC Quarterly Progress Report:

## Project Description:

### 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 200⁰C. 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.

### 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:

### Progress for each research task

*Task 1 progress (90% completed)*: The work in this task during this quarter focused on using the finite element (FE) method to analyze several designs for bridge girders with and without shape memory alloy reinforcement placed at the end region. The goal was to examine numerically the feasibility of the new concept of applying transverse prestressing to mitigate the end region damages due to the transfer of prestressing force.

First, non-prestressed (conventional) reinforcement placed at the end region, the tensile damage index by prestress release was analyzed using FE program. The numerical girder model set for analysis was half-scale of the AASHTO Type I girder. The prestressing force applied to the girder per strand was assumed to be from 12.4 kips to 18.5 kips. The number and location of prestressing strands were determined based on the configuration of the girder as shown in Figure 1.

|  |  |  |
| --- | --- | --- |
|  |  |  |
| (a) Case 1 | (b) Case 2 | (c) Case 3 |
|  |  |
| (d) Case 4 |  | (e) Case 5 |
| Figure 1. Prestressing strand layouts |

Table 1 shows the FE analysis results of tensile damage index in each case of non- prestressed reinforcement and SMA reinforcement models at prestressing force of 17.4 kips. The tensile damage magnitude was represented in color from blue to green to red, which is 0%, 50%, and 100% damage, respectively. At the prestressing force of 17.4 kips, most of the cases with non-prestressed transverse reinforcements showed a certain level of splitting crack propagating near the end face. By employing SMA reinforcements, the end cracks in web regions were eliminated, whereas there was negligible effect in the inclined region at the bottom flange.

Table 1. Tensile damage index due to prestressing force of 17.4 kips in each model

|  |  |  |
| --- | --- | --- |
| Case | Non-prestressed reinforcement | SMA reinforcement |
| 1 |  |  |
| 2 |  |  |

|  |  |  |
| --- | --- | --- |
| 3 |  |  |
| 4 |  |  |
| 5 |  |  |

*Task 2 progress (40% completed)*: This task during this quarter focused on testing the process for pre-tensioning strands at the fixed steel frame. 0.5 in. diameter strands with ultimate strength of 270 ksi were used for testing. Different anchor chucks were used to develop stress in the prestressing strands to the design level (31.0 kips). A load cell and extensometer were installed to monitor the stress development of the strands and compare with the pump gauge pressure. The hook opening effect of SMA due to activation was also investigated by testing two specimens: one specimen was bent 90 degrees without pre-straining procedure, and the other was pre-strained 15% and then bent 90 degrees. Longitudinal displacement was measured, which will be utilized for building numerical model for next quarter.

Figure 2. shows the jacking and releasing process of the prestressing strand. Reusable strand chuck was used at the stressing end and anchor chuck was installed at the fixed end of the frame for anchorage. The experiment was conducted with forcing pump pressure to 2000 psi, 3500 psi, and 5200 psi, which corresponds to prestressing force of

11.9 kips, 20.8 kips, and 30.8 kips, respectively.

|  |
| --- |
|  |
| (a) Jacking |
| A person using a torch to blow a metal rod  Description automatically generated with medium confidence |
| (b) Releasing |
| Figure 2. Pre-tensioning process of a prestressing strand |

Figure 3. shows the load variation as by jacking prestressing strand. At each step, the measured forces were 11.5 kips, 21.2 kips, and 31.4 kips in both load cell and extensometer, which is near to the expected values. However, as the stretcher was detached, an immediate drop of force (31.4 kips to 6.7 kips) was observed. To recheck the drop of force, the prestressing strand was re-tensioned to 24.1 kips. After detaching the stretcher, the applied prestress force reduced to 8.1 kips. In the next quarter, the possibility of accumulation of prestressing force will be checked, and the maximum prestressing force that the test setup can reach will be investigated.

35

Load cell Extensometer

30

Prestressing force (kips)

25

20

15

10

5

0

0 100 200 300 400 500 600

Time (s)

Figure 3. Jacking force variation of prestressing strand

Figure 4. shows the induction heating applied on SMA for full activation. Heating area was concentrated at the bent regions to solely evaluate the opening occurred at the bent region. Two specimens were both heated beyond 200°C to fully activate the SMA. Specimen which was not pre-stained showed 0.20 in. displacement in longitudinal direction, whereas the other specimen experienced 0.65 in. displacement. It is evaluated that the pre- straining builds more compressive strain at the outer section of the SMA at bent regions, resulting in larger displacement.

|  |
| --- |
| A close-up of a machine  Description automatically generated |
| Figure 4. Induction heating test setup on 90 degrees bent SMA |

### Percent of research project completed

*Total project completed through the end of this quarter = 65%*

### Expected progress for next quarter

*The next quarter will focus on casting pre-tensioned precast concrete specimens. The SMA opening effect to concrete will also be investigated. Specimens with non-prestressed reinforcement are assumed to be constructed and tested.*

### Educational outreach and workforce development

*Nothing to report yet*

### Technology Transfer

*Nothing to report yet*

## Research Contribution:

1. Papers that include TRANS-IPIC UTC in the acknowledgments section: *Andrawes, B., Sung, M., and Park, S. Behavior of Hot-Rolled Annealed NiTiNb Bars under Full and Partial Heating for Concrete Prestressing Applications, Smart Materials and Structures. (Submitted)*

### Presentations and Posters of TRANS-IPIC funded research:

*Park, S., and Andrawes, B. PC Girders End Region Damage Mitigation Using Shape Memory Alloys, 2024 TRANS-IPIC UTC Workshop, Apr. 2024.*

### 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:

*N/A*