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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 *[March 31st, 2025]*

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Collaborators / Partners:
- None

Submitted to:
TRANS-IPIC UTC
University of Illinois Urbana-Champaign
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:

<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:

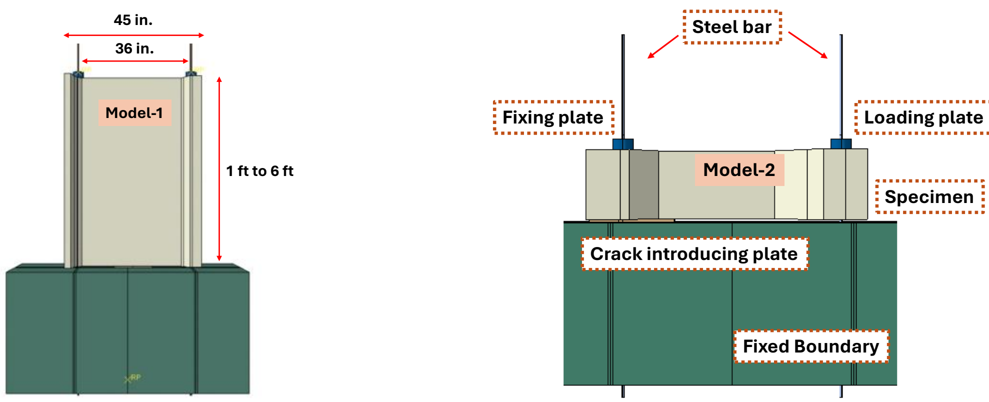
After casting the concrete and before releasing the longitudinal strands, the SMA spiral will be stressed by heating (activated). Next, the strands will be detensioned, and monitoring the bursting stresses/cracks will begin. Part of this research is to investigate two different methods for activating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

3. Project Progress:

***Task 1 progress (25% completed)*:**

This quarter's work focused on using the finite element (FE) method to design the end region of the girder that can imitate the splitting crack without introducing prestressing strands in the concrete girder. The goal was to simplify the experimental procedure and replace a large prestressing force with vertical actuator-loading. In addition, the effect of SMA transverse reinforcement compared to steel reinforcement was evaluated during the loading phase.

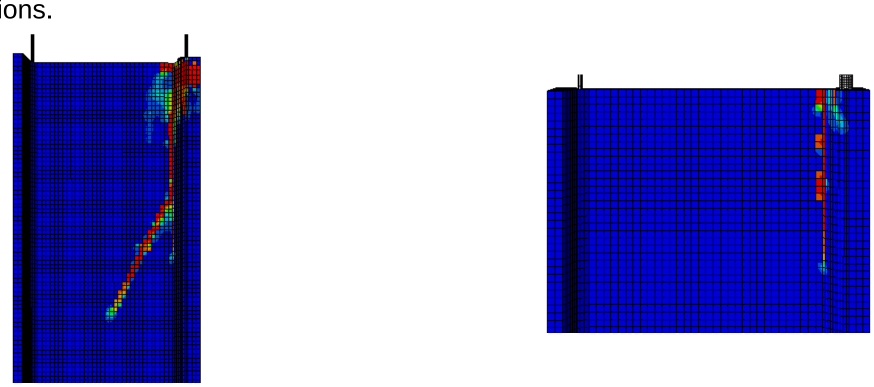
In the lab conditions, limitations in the site condition and achievable prestressing force exist to conduct experimental studies on large girder prestress transfer. Thus, using the FE analysis, the specimens were designed to mimic the behavior of prestressed concrete without introducing prestressing strands and by cutting girders into shorter lengths. For example, as shown in **Fig. 1**, the numerical girder models were rotated 90 degrees to apply vertical loading at the flange (where prestressing strands are typically placed), and damage progression was monitored to see if the girder model resembled the prestress transfer damage pattern at the end region. By rotation, it was expected that the loading process would be more convenient and the magnitude of forces applied to the girder could be larger. Two model types were designed, as shown in **Fig. 1**. For the Model-1 type, the end face was directly attached to the fixed boundary to add rigidity that a typical prestressed girder end section with long length would experience during prestress transfer. For the Model-2 type, a steel plate was added at the fixing flange to introduce cracking at the web region. This steel plate introduces the cantilever behavior for the girder, which eases crack propagation. The section of the girder was designed based on the AASHTO Type III girder.



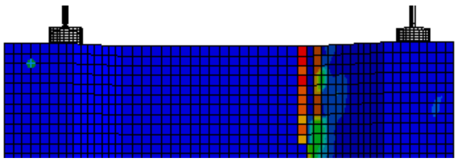
(a) Model-1 (b) Model-2

Fig. 1 Examples of the numerical model of a rotated girder

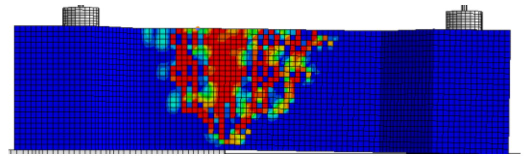
Fig. 2 shows the damage pattern by applying vertical loading to models with different dimensions and model types. In Model-1 cases, the end cracking was generated at the flange-web-connected areas due to a large compressive force acting on the flange. The sudden section-area change generated stress concentration that propagated cracks. Although the tensile strain was observed in the web area, it could not propagate cracks in the web region. In the Model-2 case, the height was fixed to 11.25 in., a quarter of the length of the girder (45 in. / 4 = 11.25 in.). This height was to narrow down the model size to the end region length. As shown in **Fig.2,** the cracking occurred at the web region where the steel plate was terminated due to the tensile bending acting on the web of the concrete. By analyzing two different models, it was possible to anticipate the cracking area using different dimensions and boundary conditions.



(a) Model-1, 10 ft height (b) Model-1, 3 ft height



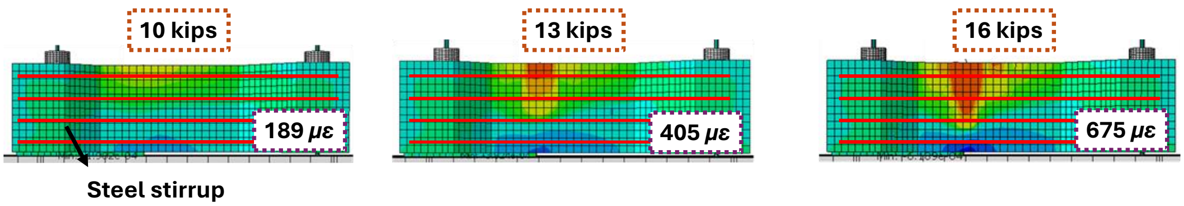
(c) Model-1, 1 ft height



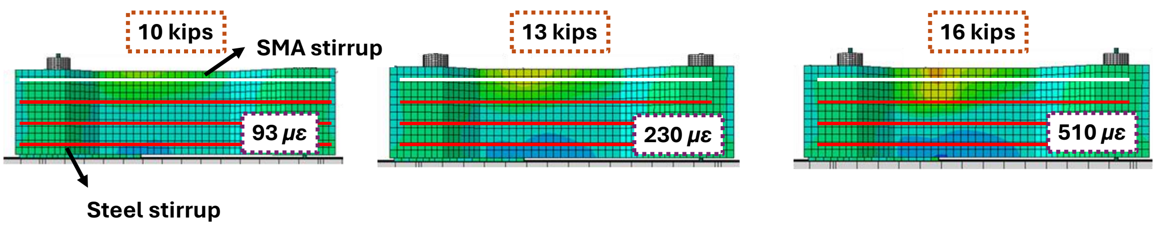
(d) Model-2, 11.25 in. height

Fig. 2 Damage progression by vertical loading

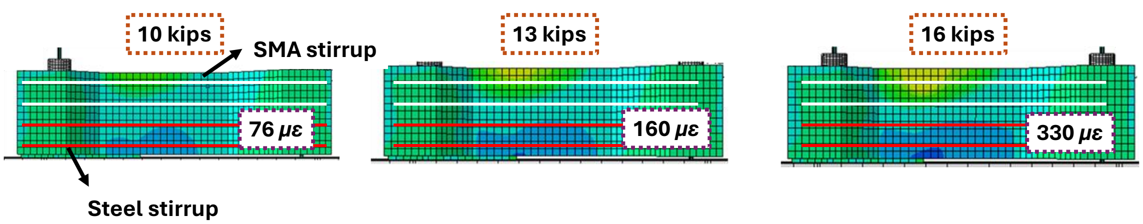
To maximize the effect of SMA reinforcement in the girder model, the Model-2 type was selected as a reference design. The steel stirrup was replaced by the SMA stirrup, as shown in **Fig. 3**. The tensile strain and cracking pattern were compared to evaluate the effectiveness of the SMA stirrup. As the vertical load increased from 10 kips to 16 kips, there was an indication that the steel model started to crack with a strain value of over 600 $\mu\varepsilon$. However, by introducing the SMA stirrup and its prestressing force, the strain value dropped by 51% and 40% in loading 10 kips, 44% and 60% in 13 kips, and 25% and 51% in 16 kips. By comparing the three models, it was proven that an SMA stirrup might delay crack propagation (or even prevent it during prestress transfer).



(a) Steel model



(b) SMA 1 model

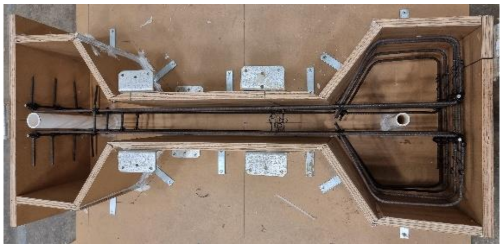


(c) SMA 2 model

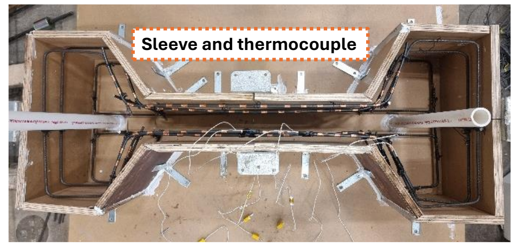
Fig. 3 FE analysis result by vertical loading in different models

***Task 2 progress (15% completed)*:**

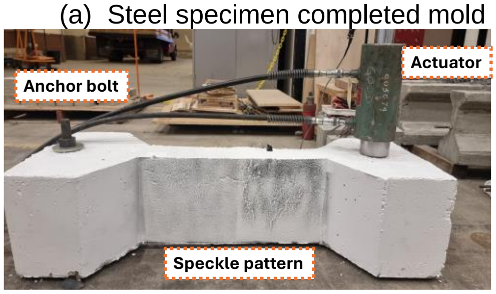
This quarter's work focused on fabricating and testing small-scale specimens. The specimens were manufactured based on the preliminary analysis performed in Task 1. **Fig.4** shows the procedure for making specimens. Specimen with steel stirrup and SMA stirrup were each fabricated to compare the effect of SMA prestressing force at the end region of girder. For the specimen with SMA stirrup, the third stirrup was eliminated to check if the prestressing force by SMA could mitigate end damage with less transverse reinforcements, which would benefit steel congestion. The specimen with steel stirrup was manufactured and tested, whereas the specimen with SMA stirrup is currently in the process of testing. In the specimens, six strain gauges were attached to the concrete surface where cracking was expected. The strain gauges were labeled C1-1, C1-2, C2-1, C2-2, C3-1, and C3-2, as shown in **Fig. 4(d)**. C1-1 and C1-2 were closer to the actuator, and C2-1 and C2-2 were at the place where the steel plate ended. For the specimen with SMA stirrup, sleeves were bonded to SMA for extra bonding with concrete, and six thermocouples were installed for temperature tracking. The speckle pattern was applied to the opposite side of the strain gauge attached surface for digital image correlation (DIC) analysis. **Fig. 4(c)** shows the test setting of the experiments. One end was fixed with an anchor bolt, and a manual actuator was mounted for vertical loading in the other end.



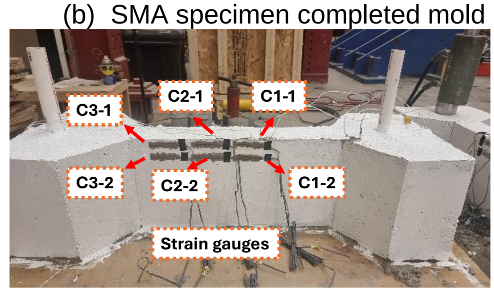
(a) Steel specimen completed mold



(b) SMA specimen completed mold



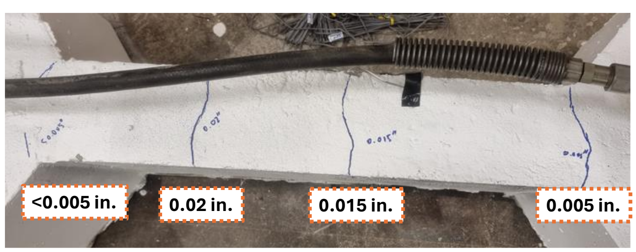
(c) Steel specimen test setting



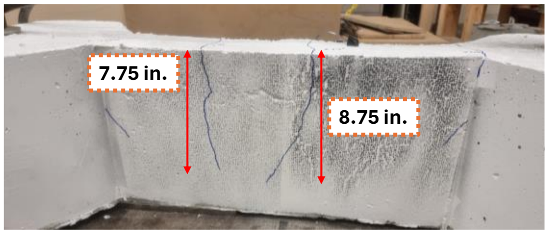
(d) SMA specimen test preparation

Fig. 4 Specimen fabrication procedure

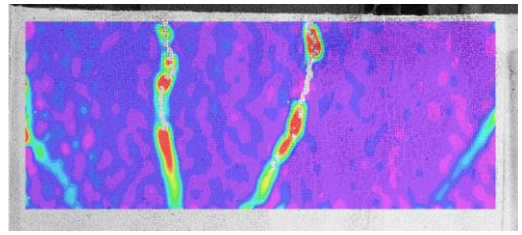
Fig. 5 shows the test results of the steel specimen after loading the specimen up to a displacement of 0.5 in. The concrete started to crack at the C1-1 and C1-2 locations at a load level of 2.7 kips. By loading 2.7 kips to 2.9 kips, the crack passed through the second stirrup (located at 4 in. from the end face), elongating to 8.75 in. at the end of the experiment with 9 kips of loading. Although the FEA showed the first cracking possibility in the C2-1 and C2-2 strain gauge locations, it was the second position for cracking at a load level of 3.6 kips. At 3.6 kips to 3.7 kips, it cracked right away through the second stirrup and terminated at the crack length of 7.75 in. The reason for C1 location cracking, compared to C2, is under research. DIC analysis was capable of visualizing the cracking pattern in each loading step. This experiment was the initiative for a simplified experimental setup. As shown by the test results, rotating the specimen and applying vertical loads introduced similar behavior as a prestress transfer, demonstrating the study concept.



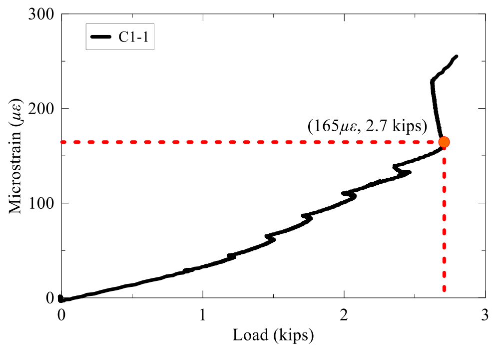
(a) Cracking at the top surface of the web



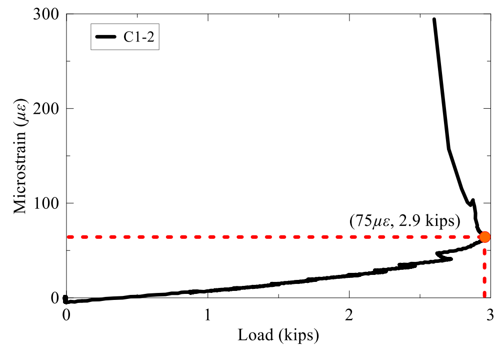
(b) Cracking at the side surface of the web



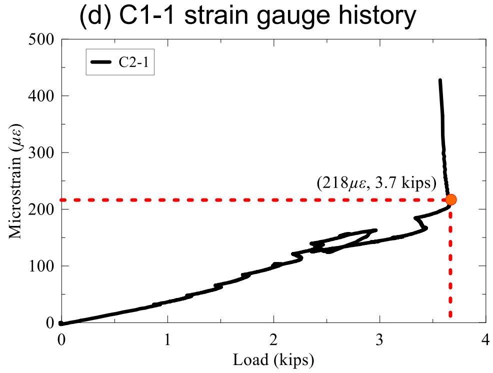
(c) DIC result of cracking at the side surface of the web



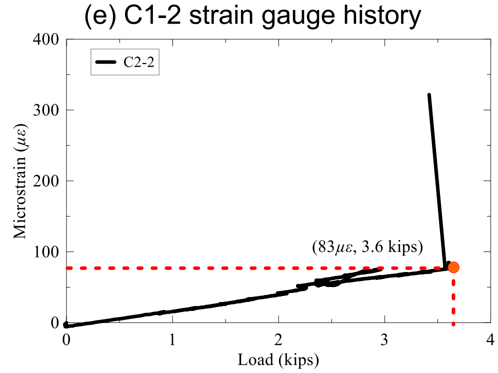
(d) C1-1 strain gauge history



(e) C1-2 strain gauge history



(f) C2-1 strain gauge history



(g) C2-2 strain gauge history

Fig. 5 Test results of steel specimen

***Task 3 progress (0% completed)*:**
No progress to date.

4. Percent of research project completed

Total project completed through the end of this quarter = 20%

5. Expected progress for next quarter

Testing of the SMA specimen is expected in the next quarter. This will involve using the induction heating procedure (Task 3). The experimental results will be verified using finite element analysis.

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)

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

- Park, S. and Andrawes, B. Transverse Prestressing of End Regions of Pretensioned Concrete Bridge Girders, Structures Congress 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. = 3

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. = 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