Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

Evaluating Prestressed Concrete Beams with Cracks using Machine Learning – Phase II
UB-23-RP-01

Quarterly Progress Report
For the performance period ending *March 31, 2025*

Submitted by:
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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

Bridge owners face difficult decisions on whether a bridge should be posted, repaired or replaced when prestressed concrete members have shear cracks due to overloading. The decisions are currently made based on engineering judgment, costly load-testing or time consuming modeling. Guidance is needed to interpret cracks to avoid overly conservative load ratings and to keep bridges operational, without compromising safety and economy. Year 1 of this project developed a tool through machine learning (ML) that relates cracking to load history of bridge members. This web-based tool can be used by bridge owners, asset managers and inspectors to guide repair decisions. Year 2 of this project will generate the test data required to validate the data-driven tool and to improve its predictions by adding higher-quality data to the existing limited datasets. Integrating higher-quality data into the existing datasets will improve the reliability of the tool's predictions for real-world applications.

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

Task 1. Stiffness History Prediction: In this task, existing data in the literature on load history and stiffness history will be collected, filtered and used to train a Gaussian Process Regression (GPR) algorithm. This newly developed algorithm will be integrated with the algorithm for crack width vs load history.

Task 2. Pre-test Prediction: Algorithms for crack width vs load history and load history vs stiffness history will be used to predict the load history and stiffness corresponding to a set of crack widths for the beams that will be tested in Task 3.

Task 3. High Quality Data Generation: Prestressed concrete beams will be designed, fabricated, and tested to collect the data needed to refine and validate the evaluation tools.

Task 4. Refine Predictions: The data collected in Task 3 will be used to re-train and refine the predictions of shear strength, load history and stiffness history of the ML algorithms. The improvement in predictions due to higher quality data will be documented.

Task 5. Post-test Prediction: The web-based evaluation tool will be updated. Shear strength, load history and stiffness history of the tested prestressed beams will be predicted to demonstrate the use of the tool, build confidence in the tool, and set expectations for error.

Project Progress:

3. Progress for each research task

Task 1. Stiffness History Prediction [40% completed to date]: Data on load-displacement relationship of prestressed beams was collected from the published literature. The literature scan identified 47 beams tested under shear with load-displacement relationship as well as crack widths documented. The data was reviewed for accuracy and fit for the project. After filtering the beams that failed prematurely (e.g., bond failure) before reaching shear failure and beams where displacement data was collected at locations other than midspan, there were 37 beams. For these beams, the load-displacement curves were first digitalized and smoothened to eliminate jaggedness caused by pauses in testing. The post-peak (negative stiffness) parts of the load-displacement curves were omitted as the beams at this stage would fail rendering any evaluation inconsequential. Tangent stiffness values were then sampled from the load-displacement curves at ten equal load intervals from zero to the measured shear strength. This led to 218 data points on shear history vs stiffness history for beams with measured crack widths. A GPR algorithm is being trained using this data.

Task 2. Pre-test Prediction [0% completed to date]: This task requires the design of the test beams to be finalized.

Task 3. High Quality Data Generation [20% completed to date]: Two beams are being designed so that the expected failure mode is shear and that the capabilities of our Structural Engineering and Earthquake Simulation Laboratory regarding loading and space are not exceeded. The variable between the two beams is being identified. Compressive strength, ratio of shear to moment, draping vs debonding, longitudinal and shear reinforcement ratios are among the parameters considered to be selected as the variable. The designs have been shared with precast concrete manufacturers to obtain feedback and to obtain quotes for fabricating the beams. Only one quote was received to date and this quote was beyond the project budget.

Task 4. Refined Predictions [10% completed to date]: Test data from Task 3 is needed to complete this task. However, the existing algorithm on crack width vs load history is being refined by further filtering the data for crack width measurements that may not be accurate (e.g., indirect measurements of crack widths through average strains, premature failures, etc.).

Task 5. Post-test Prediction [0% completed]: This task requires test data to be collected in Task 3.

4. Percent of research project completed

This project is 20% completed.

5. Expected progress for next quarter

In the next quarter Task 1, 3 and 4 will be continued. Task 1 will be continued by finalizing the algorithm that can link shear history to stiffness. This algorithm will be integrated with the one that links crack widths to shear history. Progress in Task 3 will be the finalization of beam designs and quotes, loading plan and test setup, and scheduling of production and scheduling of testing.

6. Educational outreach and workforce development

A presentation was given to 33 high-school students in two groups from Western New York as part of the Science Exploration Day in Buffalo, NY as shown in Fig 1. The event took place on March 19, 2025. The presentation included demonstration of the web-based tool, as well as a laboratory tool that showcased the equipment used to test bridges.

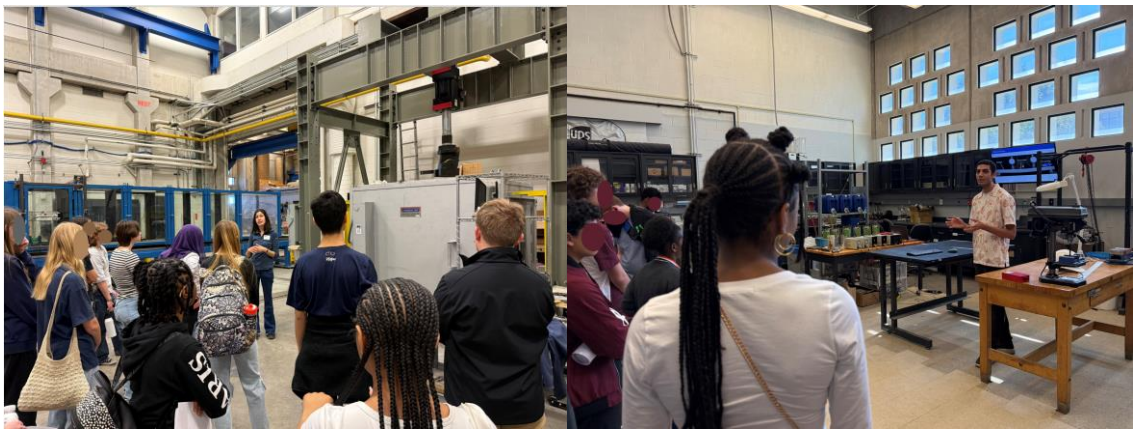

Fig. 1 (a) labotaroty tour, (b) demonstration of the machine learning tool

7. Technology Transfer

   A presentation was given to the PCI Northeast Executive Director, Ms. Sarah Patrie, and a local precast concrete manufacturer to introduce them to the project and to receive feedback from practicing engineers' and manufacturers' points of views. This meeting took place on January 28, 2025 in Buffalo, NY.

Research Contribution:

8. Papers that include TRANS-IPIC UTC in the acknowledgments section:

   Hassan Lasheen, M., Okumus, P., Elhami-Khorasani, N. (2025). "Evaluation of Structural Cracking in Reinforced and Prestressed Concrete Bridges: A Review and a Machine Learning-Based Framework." Transportation Research Board (TRB) Annual Meeting, January 5-9, Washington, DC.

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

   Hassan Lasheen, M., Okumus, P., Elhami-Khorasani, N. (2025). "Evaluation of Structural Cracking in Reinforced and Prestressed Concrete Bridges: A Review and a Machine Learning-Based Framework." Transportation Research Board (TRB) Annual Meeting, January 5-9, Washington, DC.

   Hassan Lasheen, M., Okumus, P., Elhami-Khorasani, N. (2025). "Evaluating Prestressed Concrete Beams with Shear Cracks Using Machine Learning." Poster Presentation, Transportation Research Board (TRB) Annual Meeting, January 5-9, Washington, DC.

   Hassan Lasheen, M., Okumus, P., Elhami-Khorasani, N. (2025). "Evaluating Prestressed Concrete Beams with Shear Cracks Using Machine Learning." Graduate Student Poster Competition, Department of Civil, Structural and Environmental Engineering, University at Buffalo, January 31, Buffalo, NY.

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.

    None.

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. = 9

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. = 16

D. Number of peer-reviewed conference papers published by faculty.
   - No. = 6

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
   - Research Tool #1 = A web-based prestressed concrete girder evaluation tool was developed in year 1. This tool is being expanded in year 2. The tool can be found at https://hassan-lasheen.onrender.com

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 = 1
   - Advisory committees (No. participated in & No. led)
     - No. participated in = 0
     - No. lead = 0
   - Conference Organizing Committees (No. participated in & No. led)
     - No. participated in = 0
     - No. lead = 0
   - Editorial board of journals (No. participated in & No. led)
     - No. participated in = 0
     - No. lead = 0
   - TRB committees (No. participated in & No. led)
     - No. participated in = 2
     - No. lead = 1

H. Number of relevant awards received during the grant year
   - No. awards received = 0

I. Number of transportation related classes developed or modified as a result of TRANS-IPIC funding.
   - No. Undergraduate = 0
   - No. Graduate = 2

J. Number of internships and full-time positions secured in the industry and government during the grant year.
   - No. of internships = 0
   - No. of full-time positions = 1

References:

None.