

**Transportation Infrastructure Precast Innovation Center**

**(TRANS-IPIC)**

**University Transportation Center (UTC)**

*Evaluating Prestressed Concrete Beams with Cracks using Machine Learning*

*UB-23-RP-01*

Quarterly Progress Report

For the performance period ending *September 30, 2024*

**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 related cracks due to overloading. The decisions are currently made based on engineering judgment, costly load-testing or time consuming and complex modeling. Guidance is needed to interpret cracks and their impact on shear capacity to avoid overly conservative load ratings and to keep bridges operational, without compromising safety and economy. This project is developing a reliable and efficient tool through machine learning (ML) to relate cracking to load history of bridge members.*

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

*The project is composed of the following tasks:*

*Task 1. Compile and filter test data: Existing data in the literature on the shear behavior of prestressed concrete beams will be compiled and curated to create a comprehensive dataset. Existing databases will be reviewed to obtain crack and design information. Any gaps in data will be documented to plan for additional tests as needed.*

*Task 2. Investigate ML algorithms: ML will be used to train a supervised learning model. The model will determine relationships between structural design parameters, crack information and shear capacity from historical data presented in a training dataset. Linear and non-linear ML models will be explored.*

*Task 3. Predict load history and capacity: Using a suitable ML algorithm, shear capacity and loading that corresponds to given crack widths will be predicted. Input will be geometric properties, material properties, reinforcement details and crack widths under increasing loading for prestressed concrete beams for which test data is available. The models will be fine-tuned using a cross-validation analysis.*

*Task 4. Verify predictions: The predictions of ML will be tested on four beams that will be selected from the existing databases but are not part of the ML training. Shear load history and capacity of the beams predicted with ML will be compared to the ones obtained from testing. The beams will also be modeled using finite element analysis.*

*Task 5. Develop software for implementation: To facilitate the use of the evaluation method, a software tool with a simple user interface will be developed.*

 *Task 6: Write a final report: A report that documents project goals, methods and results will be prepared.*

**Project Progress:**

1. Progress for each research task

*Tasks 1 and 2 were completed in the previous quarters.*

*Task 3 progress [90% completion]: Shear capacity is predicted for the beams in the database using OLR, SVR and GPR algorithms. Features that have a significant influence on the predictions are determined and compared to the features considered by design codes. A combination of features that lead to the least error when compared to test data is determined. When effective prestress, strand area, location of strands in the cross-section, longitudinal reinforcement, shear reinforcement, section dimensions, concrete strength, and shear span were used as predictive features, the OLR, SVR and GRP had less than 40%, 20%, and 15% mean average percentage error in predicting the shear strength of the beams, respectively. The error was evaluated using cross-validation. The error in GPR is less than the ones of ACI 318 and AASHTO LRFD Design Specifications.*

*The GPR algorithm has been used to predict shear histories given crack widths and beam properties. Prediction error stemming from the limited number of crack width points was investigated. The automatic relevance determination (ARD) of covariance function of the GPR algorithm is being used to determine the influential parameters. An additional measure, called the Shapley Additive Explanations (SHAP), that can determine the contribution of features to the prediction is also being investigated. The ARD results show while the amount of prestress is the most influential parameter in determining shear history corresponding to a crack width, the difference in the ARD coefficients of the rest of the features was small due to the limited number of data points. Ongoing work includes finalizing a GPR algorithm with all features included.*

*Task 4 progress [90% completion]*: *Four beams (with features well and poorly represented by the training dataset, and with more and less than the minimum shear reinforcement areas required by design codes) were selected for the verification process. Shear capacity was predicted for these four beams using GPR. The results show between 8% and 21% error in predictions. The same exercise resulted in an error between 4% and 32% when predicting shear histories corresponding to crack widths.* These predictions were made for the crack widths measured during testing. To understand whether the ML algorithm can predict the response that corresponds to smaller crack widths, typical under service loading, the predictions are being extended to a larger range of crack widths. The beams are modeled using the finite element method. The load-displacement response from the finite element models is being studied to understand beam stiffness, average stirrups strains, and prestress levels at different crack widths.

*Task 5 progress [60% completion]: A software tool that facilitates the use of the ML algorithm in shear capacity predictions is being developed. A web-based tool that runs Matlab for ML has been developed. Considering Matlab is a licensed software, a second tool that utilizes an open source programming software (Python) is also being developed for free access to the tool without a license. The tool has become online and incorporated into a website. The tool is being expanded and improved with the latest research findings.*

*Task 6 progress [0% completion]:*

1. Percent of research project completed

*At the end of this quarter, 85% of the project is completed.*

1. Expected progress for next quarter

*All tasks are expected to be completed, as the project end date is within the next quarter.*

1. Educational outreach and workforce development

*The project results were presented at the Northeastern Peer Exchange for Resilient and Sustainable Bridges, that took place in Buffalo, NY on August 7, 2024. The event was attended by engineers from departments of transportation, industry, consultants and material producers, as well as academics and students.*

*An outreach event with Women in Science and Technology was scheduled on August 27, demonstrations were prepared to introduce female freshmen level students to bridge engineering. Although, no students chose to attend this event, the prepared demonstrations will be used in future outreach activities.*

1. Technology Transfer

*The project has not resulted in any patents, guidelines or specifications yet. At the conclusion of the project, a software tool is being developed to facilitate technology transfer.*

**Research Contribution:**

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

*A conference paper was submitted to be presented at the TRB Annual Meeting, in January 2025: Hassan Lasheen, M., Okumus, P., Elhami-Khorasani, N. “Evaluation of structural cracking in reinforced and prestressed concrete bridges: A review and a machine learning-based framework.” Accepted for presentation.*

*A journal paper is under preparation: Hassan Lasheen, M., Okumus, P., Elhami-Khorasani, N., Chandola, V. “Predicting shear strength of prestressed concrete beams using machine learning.” In preparation - to be submitted within the next quarter.*

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

*Hassan Lasheen, M., Okumus, P., Elhami Khorasani, N. (2024). “Machine Learning for Evaluating In-Service Concrete Bridges.”, Northeastern Peer Exchange Resilient and Sustainable Bridges, August 7, Buffalo, NY.*

1. 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*

**References:**

 *None*