

**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 *June 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.*

**Project Progress:**

1. Progress for each research task

*Task 1 progress [100% completed]: A database that consists of 897 shear test results for prestressed concrete beams was compiled, building up on existing databases in the literature. This database was filtered based on factors such as support conditions, type of prestressing, and shear reinforcement amount. Deep beams, beams with external prestressing and segmental beams were excluded considering differences in the shear behavior of these beams and prestressed beams that are more common in bridge construction. The ranges of features of the beams in the database were documented to understand the types of beams for which the ML predictions will be applicable.*

*A second database with 79 beams, which is a sub of the larger database, is compiled. This second database has information on beam material and geometric properties, as well as crack widths (391 data points) and corresponding shear load history. Statistical features of this smaller database are evaluated.*

*Task 2 progress [100% completion]: The literature was reviewed for ML algorithms suitable for the objectives of this project. Ordinary linear regression (OLR), support vector regression (SVR) and Gaussian process regression (GPR) algorithms were selected to be investigated as they can be applied to smaller datasets such as the ones available for prestressed concrete beams. Computational efficiency and prediction error in these algorithms have been quantified. It was determined that the three algorithms are computationally efficient, but their accuracy varies. GPR is determined to provide the most accurate estimates, comparable to or better than the ones provided by design codes.*

*Task 3 progress [80% 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 is being investigated. The automatic relevance determination (ARD) of covariance function of the GPR algorithm is being used to determine the influential parameters. The 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 ARDs of the rest of the features was small due to the limited number of data points. Therefore, future work will include all features in predictions.*

*Task 4 progress [80% 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.*

*Task 5 progress [50% 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 is also being developed for free access to the tool without a license.*

1. Percent of research project completed

*At the end of this quarter, 75% of the project is completed.*

1. Expected progress for next quarter

*In the next quarter, Tasks 3 to 5 will be completed. Task 6 will involve writing of the final project report and will also be completed in the next quarter.*

1. Educational outreach and workforce development

*A presentation was delivered to the advisory board of the Institute of Bridge Engineering on April 30, 2024 virtually. There were 19 attendees at the meeting, which included engineers from transportation agencies, engineers from the industry, as well as faculty at University at Buffalo.*

*A peer exchange is being planned to take place at the University at Buffalo, in Buffalo NY on August 7, 2024. Participants will include engineers from departments of transportation, industry, consultants and material producers. A presentation on the findings of this project is planned to be delivered at this event.*

*An undergraduate student has been recruited and started working on the project.*

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:

*None*

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

*Okumus, P., Elhami Khorasani, N., Hassan Lasheen, M. (2024) “Evaluating Prestressed Concrete Beams with Cracks using Machine Learning.” Presentation to the External Advisory Board of Institute of Bridge Engineering, University at Buffalo, the State University of New York, virtual, April 30.*

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*