FRAMEWORK FOR IDENTIFYING SHEAR CRACKING IN BRIDGE COLUMNS USING LIDAR

Quarterly Progress Report
For the period ending July, 2025

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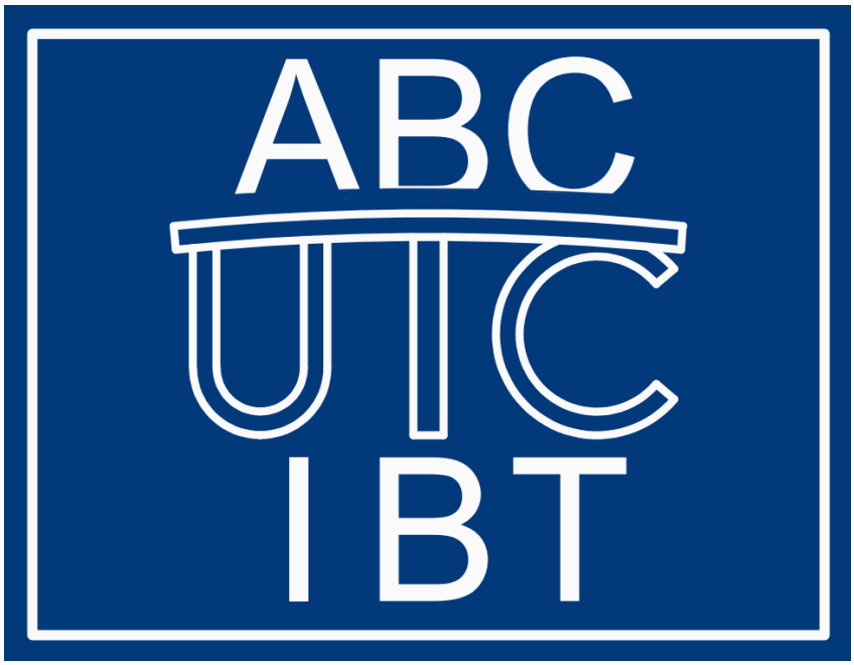

Submitted to:
IBT/ABC-UTC
Florida International University
Miami, FL

1. Background and Introduction

The researchers will be testing bridge columns near the critical intersection of shear and flexural failure as part of a WSDOT funded study that aims to help the prioritization of bridges for seismic retrofit. That testing, along with the terrestrial lidar equipment housed at the UW's RAPID Facility, offers an opportunity to explore the use of lidar to map cracks and subsequently use the crack information to correlate with failure modes and remaining capacity of reinforced concrete bridge components. There are several algorithms in the literature and available through open repositories such as GitHub that use lidar-derived point clouds to identify, map and measure cracks. Such algorithms will not need to be developed as part of this project, but instead the existing ones will be utilized to identify and characterize the cracks in the test columns. This project will focus on developing the link between the cracking (pattern and magnitude), the likely failure mode (shear or flexural), and the remaining capacity. Such information may be generalized to help inspectors understand what types of cracks are most problematic and might lead to deteriorated structural capacity. That information is relevant to inspection of both existing and new construction.

2. Problem Statement

Recently, lidar technology has evolved such that laser scanners can complete full-dome 360-degree scans collecting millions of points in less than one minute with sub-millimeter accuracy. Lidar has become a critical technology used for gathering data on the performance of infrastructure in natural hazards as described in Berman et al. (2020) and demonstrated in Aghababaei et al. (2021) and Calvi et al. (2024).

Leveraging these advances, several studies have explored the collection of lidar data to detect and measure cracks in reinforced concrete elements. Yan et al. (2021) and Alamdari and Ebrahimkhanlou (2024) are two examples where UAV and robotic inspection techniques are deployed to collect condition data with lidar. Both of those studies focused more on data collection and less on post-processing of the collected data. As noted below, other studies have focused on detecting and measuring cracks from the resulting 3D point clouds that lidar scans produce, such as Guan et al. (2015), Zhong et al. (2020), and del Rio-Barral et al. (2022) who did so for pavements and Jiang et al. (2018) and Cho et al. (2018) who did so for reinforced concrete structural elements. Additionally, several studies have focused on identifying the stress state of reinforced concrete elements using the geometry, distribution, and amplitude of cracking. A nice summary of the methods, which include empirically derived tools, theoretical models, fractal analysis and concrete mechanics, is provided in Zanorac et al. (2019). Of particular interest here are methods that estimate the likely failure mode and most importantly the potential for brittle failure.

This previous research has greatly advanced the state of knowledge and practice, but in order to apply these technologies, a framework is needed to link lidar-derived point cloud data to interpretation methods for determining the potential for brittle failure. In particular, the quality of the data depends on the data collection equipment and methods and there is no guidance for doing collection such that the data is useful in the crack assessment tools. Further, there is no guidance on which of the many available methods for crack detection and quantification will be most useful for bridge structural elements. It is the goal of this research to develop a framework

that includes such details so that these technologies can be more useful to DOT's and other bridge owners for inspections of new and existing reinforced concrete bridge components.

3. Objectives and Research Approach

The research objective is to advance bridge evaluation by developing a framework to:

(i) capture cracking in bridge elements with lidar,
(ii) characterize the cracking geometry using automated algorithms, and
(iii) correlate the resulting cracking with remaining capacity and the potential for brittle shear failure of concrete bridge components.

The framework will include practical recommendations on how to achieve the best outcomes. This includes recommendations on the equipment requirements, scan resolution and other scan acquisition settings, algorithms for crack identification, methods for crack characterization, and methods for estimating remaining capacity and the potential for brittle failure.

The project will advance rapid identification of reinforced concrete bridge components that may be susceptible to brittle shear failure due to age; loading; and construction, fabrication or design errors. The research will develop a framework for bridge engineers that guides them through all the steps of using lidar to capture crack geometry, algorithms to automatically find and characterize those cracks in the lidar generated point cloud, and methods for determining if those cracks indicate the potential for brittle shear failure. The framework will include: (i) laser scanning details necessary to obtain data at sufficient resolution to identify and characterize cracking, (ii) recommended open source algorithms to find and characterize cracks in the lidar point cloud, and (iii) recommendations for identifying cracks and crack patterns that are likely to lead to a brittle shear failure for the component. To carry out this research, the project team has identified the following research tasks.

4. Description of Research Project Tasks

This project has not received funding yet and has not begun work on any of the tasks below.

Task 1 – Lidar Scanning of Reinforced Concrete Columns being Tested at the UW Structural Engineering Testing Laboratory.

Proposed Task Description: The PI's recently received a grant ($200,000) from WSDOT to help them understand when bridge columns are shear critical, such that bridges can be prioritized for seismic retrofit or replacement. The new feature of these tests is that the columns will be subjected to a variety of deformation histories to assess differences between flexure-shear behavior during long-duration and short-duration earthquakes.

This project involves testing several columns under combined axial force and shear/flexure. For each test, the PI's will utilize the laser scanners (terrestrial lidar) from the NSF supported NHERI RAPID Facility (https://rapid.designsafe-ci.org/) at the University of Washington to scan the specimen at several stages of loading. They will use the Facility's Leica RTC 360 scanners, which capture one million points per second and complete a full scan in less than one minute with a single point accuracy of less than 1 mm. The scans will be registered together using software available at the RAPID facility to create full 3D models of each specimen at the various loading stages. Importantly, the scanner collects high-definition photos at the same time as the

laser scans, which the software then uses to color the point cloud, but which also can be interrogated individually. The resulting 3D models are high resolution and high precision.

Description of Work Performed Up To This Period: No progress has been made on this task because the funding has not arrived at UW. However, progress was made on the WSDOT supported portion of the project. In particular, the design for the test column was initiated with the expectation that they will be completed in fall 2025.

Task 2 – Application of Crack Detection Algorithms.

Proposed Task Description: Algorithms from the literature and open repositories will be tested for efficacy in crack detection from the point clouds for the tested columns. A substantial amount of research has been dedicated to detecting cracks in pavement from point clouds obtained from mobile lidar mounted on vehicles, some examples include: Guan et al. (2015), Zhong et al. (2020), and del Rio-Barral et al. (2022). Such algorithms may be easily applied to concrete structures and many are open source. Additionally, Jiang et al. (2018) and Cho et al. (2018) are examples of applications of crack detection applied to concrete structural components. This task of the research will review the available detection methods and implement them to illustrate crack detection and characterization (i.e., determining their size, orientation, and density) for the tested columns.

Description of Work Performed Up To This Period: No progress has been made on this task because the funding has not arrived at UW.

Task 3- Assessing Remaining Capacity and Potential for Shear Failure.

Proposed Task Description: Crack size, orientation, and density are key factors in determining how close a concrete component may be to shear failure. Zanorac et al. (2019) provides a summary of methods available for estimating remaining capacity of concrete sections with cracking. These methods include empirically derived tools, theoretical models, fractal analysis and concrete mechanics. Studies such as Calvi et al. (2018), Veletzos et al. (2008) and Birrcher et al. (2009) have had success in using a combination of statistics and mechanics to estimate the likely failure mode of reinforced concrete panels, columns, and deep beams. Those methods will be compiled and used in Task 4 below to develop and test the complete evaluation framework on the column specimens tested in the UW Structural Research Laboratory.

Description of Work Performed Up To This Period: No progress has been made on this task because the funding has not arrived at UW.

Task 4- Development of the Evaluation Framework.

Proposed Task Description: Using the results of Tasks 1, 2, and 3 the complete evaluation framework will be developed. This includes recommendations for equipment specifications for scanning structural reinforced concrete elements, recommended algorithms for detecting and measuring cracks, and guidelines for determining the severity of the cracking with respect to the potential for brittle failure. The framework will be demonstrated and refined using the tested column specimens available via the WSDOT supported testing.

Description of Work Performed Up To This Period: No progress has been made on this task because the funding has not arrived at UW.

Task 5 - Dissemination.

Proposed Task Description: The research team will disseminate the lidar evaluation framework through journal papers and presentations at national conferences. The team will prepare a report on the framework development and its application to the tested bridge columns and applications for evaluating new and existing construction as is standard for IBT/ABC UTC projects.

Description of Work Performed Up To This Period: No progress has been made on this task because the funding has not arrived at UW.

5. Expected Results and Specific Deliverables

The proposed output for this project is a framework for using lidar to identify the potential for brittle failure in bridge components. The framework will include: (i) recommendations for lidar scanning procedures including necessary point cloud accuracy and resolution, (ii) recommended algorithms for identifying cracks in reinforced concrete bridge components using lidar derived point clouds, (iii) recommendations for identifying potentially brittle failure modes from cracking patterns and amplitudes in reinforced concrete bridge components, and (iv) example applications to bridge columns tested in the UW Structural Research Laboratory.

These recommendations will be summarized in the final report and disseminated via journal paper such that DoT's may learn about the recommended methods for using NBI available data to enhance their bridge inventory information for use in emergency response planning and bridge retrofit and replacement prioritization.

At this time, the research team sees no need to modify the expected results and specific deliverables.

6. Schedule

Progress of tasks in this project is shown in the table below. Note that the schedule for the project has been changed to run from January 2026 to December 2026 because the column tests are now scheduled for Spring 2026 and the funding for this project (increment in the UW subcontract) did not arrive at UW until spring 2026.

Task	% Completed
1. Lidar Scanning of Reinforced Concrete Columns being Tested at the UW Structural Engineering Testing Laboratory.	0%
2. Application of Crack Detection Algorithms	0%
3. Asses Remaining Capacity and Potential for Shear Failure.	0%
4. Development of the Evaluation Framework.	0%
5. Dissemination.	0%

	2026											
Task	J	F	M	A	M	J	J	A	S	O	N	D
1: *Lidar Scanning of RC Columns*												
2: *Application of Crack Detection*												
3: *Assessing Remaining Capacity*												
4: *Development of the Evaluation Framework*												
5: *Dissemination*												
Work Performed												
Work to be Performed (note that this is updated from the proposal)												

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