Semi-Annual Progress Report

TIDC Transportation Infrastructure Durability Center AT THE UNIVERSITY OF MAINE

Project Number and Title: C3.2018: Condition Assessment of Corroded Prestressed Concrete Bridge Girders
Research Area: Thrust 1: Transportation infrastructure monitoring and assessment for enhanced life
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Co-PI(s): Susan Faraji (UMass Lowell), ChangHoon Lee (WNEU), Moochul Shin (WNEU)
Reporting Period: 04/01/2019 ~ 09/30/2019
Date: 09/30/2019

Overview:

In the reporting period, the UML-WNEU team has been working on **Task 1: (Component- and System-Level) Field Inspection/Measurements of proposed research** and **Task 2: (Meso-to-Macro Level) Development of Macro-Scale Mechanical Damage Model due to corrosion**. The UML team has conducted field measurements of a local prestressed concrete (PC) bridge (Lincoln St. Bridge, Lowell, MA) using 3D ground penetrating radar (GPR).

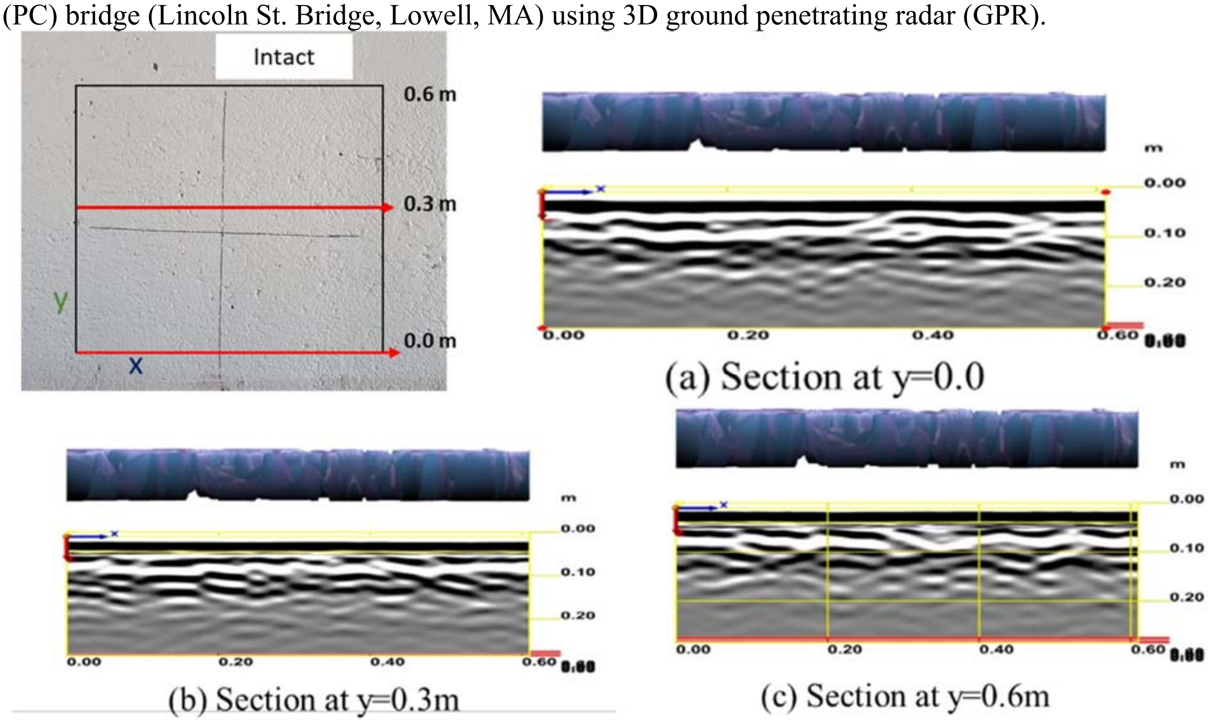

Figure 1: 3D GPR measurement of Lincoln St. Bridge, Lowell, MA

During the period, WNEU research team has been developing and validating the macro-scale mechanical property damage model due to corrosion (Task 2). Task 2 is progressed by developing a kinetics-based model as calibrated by the pull-out experiment results. The macroscopic damage model includes two sub-modules: (a) bond-slip (or pull-out force vs. slip) response, and (b) degradation of response parameters such as stiffness, bond strength, softening rate with respect to corrosion levels. While multiple models for the bond-slip response have been investigated, the model proposed by Wu and Zhao (2013) is considered as a base model due to the capability of obtaining the analytic form of the various characteristic points (the response parameters shown in Figure 2 (a)). Then, the degradation of such characteristic points due to corrosion are modelled on the basis of the kinetics approach as shown in Figure X(b). Even if the first-order kinetics is widely chosen to model any decay mechanism of the various system, the kinetic order fixed by 1 limits the representation of complex mechanical system decay induced by chemical reaction. Thus, the general-order (decay) kinetics' form follows Eq. (1):

$$\frac{dP(\xi)}{d\xi} = -kP^q \qquad (1)$$

where $P(\xi)$ is the property value at the corrosion level ξ, k is an apparent rate constant, and q is an order of the kinetics. Note that ξ is computed by the integration of corrosion-time response. For the accelerated corrosion test, the value of ξ can be obtained from the supplied current with time. The model will be adjusted incorporated with "Life365" software that has been widely used for estimating chloride penetration according to different structural geometries, concrete mixtures, and reinforcement arrangement. The resulting information will be used as a measure to evaluate the degree of corrosion in a given structure.

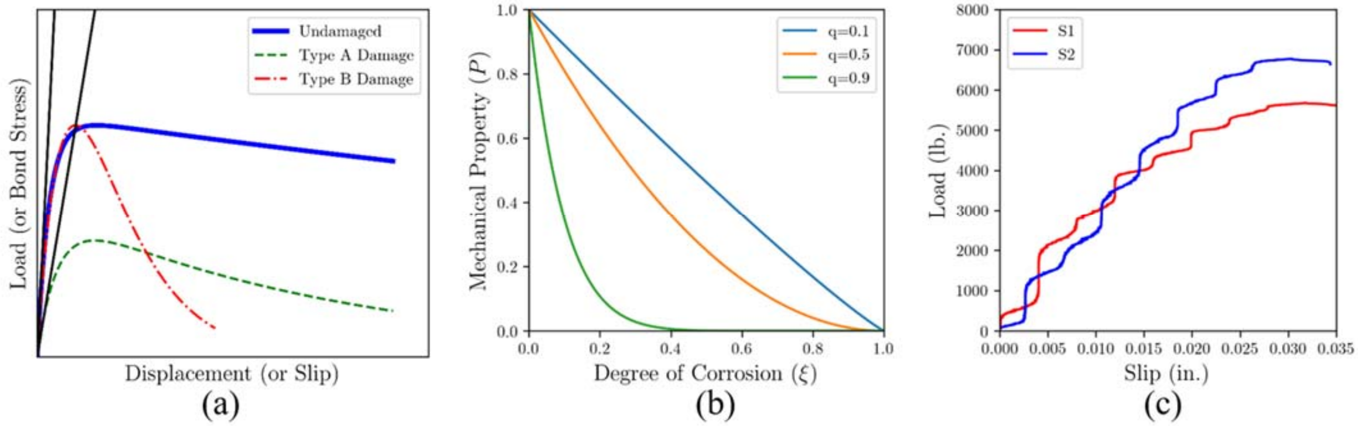

Figure 2. (a) Transformation of bond-slip response due to corrosion, (b) Damage model with different kinetic orders, and (c) pull-out load – slip response experimentally obtained for the un-corroded specimen

For measuring bond-slip response, WNEU built and calibrated the pull-out test apparatus as shown in Figure 3 (a). Two un-corroded specimens (a No.3 rebar embedded in a 3" by 6" cylinder) were prepared by the utility of the concrete which compressive strength was 4000 psi at 28 days. Two un-corroded specimens were tested as shown in Figure 2 (c) and Figure 3 (b), planning to perform the test of the specimens subjected to multiple levels of corrosion. From the test, both specimens are failed due to sudden splitting cracks, thus the post-peak response could not be obtained. In addition, it is worthwhile to note that "S1" in Figure X (c) is used to calibrate the testing apparatus, and several loading-unloading cycles within 1000 lb. has been applied. Nevertheless, the (tangential) stiffness of S1 and S2 is similarly about 400 kips/in, while the peak force (or bond strength) decreases by approximately 16% due to the pre-damaged process.

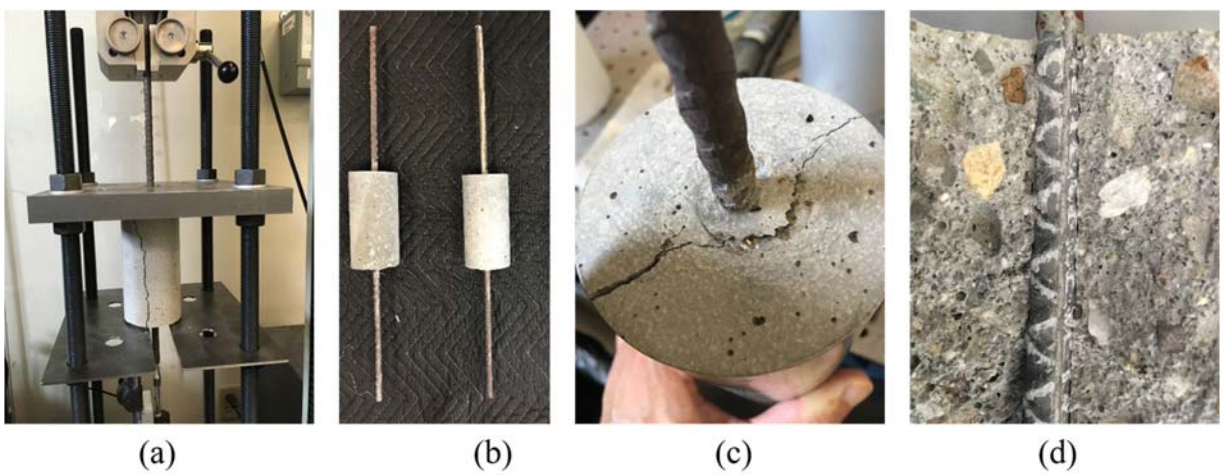

Figure 3. Pull-out test apparatus (a), three prepared un-corroded specimens(b), and the splitting failure mode of the specimens in the top view(c) and in the side view (d)

Participants and Collaborators:

During the reporting period, the following participants have worked on the project at **UML**.

- Dr. Tzuyang Yu, Associate Professor, Civil and Environmental Engineering – Project principle investigator and Institutional Lead at UML; overseeing all projects and working on nondestructive testing/evaluation and data interpretation with other RAs
- Dr. Susan Faraji, Professor, Civil and Environmental Engineering – Co-PI, bridge design and analysis
- Mr. Ahmed Alzeyadi, full-time graduate RA, doctoral candidate, Civil and Environmental Engineering – Design and manufacturing of laboratory specimens, field radar imaging of structures, data analysis and signal processing
- Mr. Harsh Gandhi, part-time graduate RA, Master's student, Civil and Environmental Engineering – Manufacturing of laboratory specimens, field radar imaging of structures, data analysis and signal processing

- Mr. Jade Man, part-time undergraduate RA, Freshman in Civil and Environmental Engineering – Manufacturing of laboratory specimens

During the reporting period, the following participants have worked on the project at **WNEU**.

- Dr. ChangHoon Lee, Assistant Professor, Civil Engineering – Co-PI, concrete materials, data analysis and modeling,
- Dr. Moochul Shin, Associate Professor, Civil Engineering – Co-PI, design of pull-out test on reinforced concrete specimens
- Mr. Cameron Cox, part-time undergraduate RA, Junior in Civil Engineering – Preparing concrete cylinders and pull-out test specimens.
- Mr. Nicholas Pantorno, part-time undergraduate RA, Junior in Civil Engineering – Preparing concrete cylinders and pull-out test specimens.
- Mr. Andrew Masullo, part-time undergraduate RA, Junior in Civil Engineering – Preparing concrete cylinders and pull-out test specimens.

Collaboration with MassDOT and the City of Lowell – We will continue collaborating with MassDOT (Mr. Alex Bardow, PE, Director of Bridges and Structures) and the City of Lowell (Ms. Christine Clancy, PE, City Engineer) on this project.

Changes:

At this stage of the project, we do not anticipate any problems or delays in our project. We also do not plan any changes to be made to our original research plan.

Planned Activities:

In the next reporting period, we plan to continue working on following tasks.

Task 1: (Component- and System-Level) Field Inspection/Measurements (UML: T. Yu and S. Faraji)

Task 2: (Meso-to-Macro Level) Development of Macro-Scale Mechanical Damage Model due to corrosion (WNEU: C. Lee and M. Shin)

Task 3. (System Level) Development of capacity reduction model for PC bridges due to corrosion (all members)

We also plan to attend the 2019 QNDE (Quantitative Non-Destructive Evaluation) Symposium in Portland, OR during July 14~18, 2019 to disseminate our research findings.