Quarterly Progress and Performance Indicators Report:
Project Number and Title: 1.4 Electromagnetic Detection and Identification of Concrete Cracking in Highway Bridges
Research Area: Thrust 1: Transportation infrastructure monitoring and assessment for enhanced life
PI: Tzuyang Yu (UMass Lowell)
Co-PI(s): N/A
Reporting Period: 10/01/2021~12/31/2021
Submission Date: 03/29/2022

Overview:

The research problem we are trying to solve is the structural assessment of aging concrete bridges (reinforced and prestressed) in New England, targeting at concrete cracking and degradation. The overall research objective is to develop a remote radar sensor for the characterization of corroded reinforced concrete structures. In the reporting period of this project, we continue our field test activities by inspecting intact and corroded concrete bridge piers of an I-495 bridge in Chelmsford, MA (Task 3.2) and another composite bridge in Somerville, MA. This activity also contributes to Task 4.

Meeting the Overarching Goals of the Project:

- We have collected GPR B-scan images of intact and corroded concrete bridge piers from I-495 bridge in Chelmsford, MA to study the detectability (signal-to-noise ratio) of corroded reinforced concrete.
- For field GPR B-scan images of **corroded** concrete bridge piers, we will study the pattern in GPR images and correlate it with the level of steel rebar corrosion.
- For field GPR B-scan images of **intact** concrete bridge piers, we will study the impact of background variation on corrosion detectability on concrete structures.

Accomplishments:

- We have expanded the electromagnetic (EM) database by adding GPR B-scan images of intact and corroded concrete bridge piers.

Task, Milestone, and Budget Progress:

Table 1: Task Progress

Task Number: Title	Start Date	End Date	% Complete
Task 1: Design and manufacturing of laboratory reinforced concrete specimens at various corrosion levels	10/01/20	09/30/21	100%
Task 2: Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR/GPR image of concrete	10/01/21	09/31/22	80%
Task 3.1: Development of a compact, self-powered, light-weight SAR imaging sensor	10/01/21	05/31/22	95%
Task 3.2: Field inspection of corroded RC structures (Preliminary)	06/01/21	09/30/22	80%
Task 4: Development of EM database and correlation between SAR and GPR images	08/01/21	03/31/23	60%
Task 5: Data analysis and image interpretation	10/01/20	09/30/23	60%

Table 2: Milestone Progress			
Milestone #: Description	**Corresponding Deliverable**	**Start Date**	**End Date**
Milestone 1: Design of laboratory reinforced concrete (RC) specimens at various corrosion levels	Experimentation design matrix; manufactured RC specimens (10%); Quarterly report on 12/31/20	10/01/20	12/31/20
Milestone 2: Manufacturing of laboratory RC specimens at various corrosion levels / Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Development of a compact, self-powered, light-weight SAR imaging sensor	Manufactured RC specimens (20%); SAR images of RC specimens (5%); design of a compact SAR imaging sensor (10%); Quarterly report on 03/31/21	11/01/20	03/31/21
Milestone 3: Manufacturing of laboratory RC specimens at various corrosion levels / Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	Manufactured RC specimens (80%); SAR images of RC specimens (30%); Development of a compact SAR imaging sensor (100%); Preliminary SAR imaging of RC specimens in the field (5%); Quarterly report on 06/30/21	12/01/20	06/30/21
Milestone 4: Manufacturing of laboratory RC specimens at various corrosion levels / Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	Manufactured RC specimens (100%); SAR images of RC specimens (40%); Preliminary SAR imaging of RC specimens in the field (10%); Quarterly report on 09/30/21	12/01/20	09/30/21
Milestone 5: Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	SAR images of RC specimens (50%); Preliminary SAR imaging of RC specimens in the field (25%); Quarterly report on 12/31/21	12/01/20	12/31/21
Milestone 6: Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	SAR images of RC specimens (80%); Preliminary SAR imaging of RC specimens in the field (50%); Quarterly report on 03/31/22	12/01/20	03/31/22
Milestone 7: Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	SAR images of RC specimens (100%); Preliminary SAR imaging of RC specimens in the field (100%); Quarterly report on 09/30/22	12/01/20	09/30/22
Milestone 8: Field inspection of corroded RC structures	SAR imaging of RC specimens in the field (15%); Quarterly report on 12/31/22	10/01/22	12/31/22
Milestone 9: Field inspection of corroded RC structures	SAR imaging of RC specimens in the field (100%); Quarterly and Final reports on 09/30/23	10/01/22	09/30/23

Table 3: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date (include the date)**
$330,495 (federal)	$220,315 (federal)	$66.7 (federal)

Is your Research Project Applied or Advanced?

☒ **Applied** (*The systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.)*

☐ **Advanced** *(An intermediate research effort between basic research and applied research. This study bridges basic (study to understand fundamental aspects of phenomena without specific applications in mind) and applied research and includes transformative change rather than incremental advances. The investigation into the use of basic research results to an area of application without a specific problem to resolve.)*

Education and Workforce Development:

1. Did you provide any workforce development or training opportunities to transportation professionals (already in the field)? If so, what was the training? When was it offered? How many people attended?
   The research team provided an in-field training for the GPR technology for one professional engineer (PE) from AECOM on 10/25/22 in Sommerfeld, MA. The PE learned how we use GPR for debonding inspection on concrete bridges.

2. Did you hold meetings with any transportation industry organizations or DOTs? If so, what was the meeting's purpose? When was it offered? How many people attended?
   The research team discussed our GPR and SAR imaging result with GSSI on the phone and in Zoom meeting during 10/15/21~11/20/21, with one engineer from GSSI.

3. Did you host/participant in any K-12 education outreach activities? If so, what was the activity? What was the target age/grade level of the participants? How many students/teachers attended? When was the activity held?
   N/A

Technology Transfer:

Table 4: Presentations at Conferences, Workshops, Seminars, and Other Events

Type	Title	Citation	Event & Intended Audience	Location	Date(s)

Table 5: Submitted/Accepted Publications, Technical Reports, Theses, Dissertations, Papers, and Reports

Type	Title	Citation	Date	Status
Peer-reviewed journal	Remote characterization of chloride content in concrete specimens using synthetic aperture radar images	Construction and Building Materials, Volume 302, 124317, doi: 10.1016/j.conbuildmat.2021.124317	4 October, 2021	Published
Peer-reviewed journal	Electromagnetic detection of concrete cracking by using synthetic aperture radar and ground penetrating radar	NDT&E International	December 20, 2021	Under review

Answer the following questions (N/A if there is nothing to report):

1. Did you deploy any technology during the reporting period through pilot or demonstration studies as a result of this work? If so, what was the technology? When was it deployed?
   Yes, we applied an EM sensor (ground penetrating radar or GPR) on intact and corroded concrete bridge piers in the field on October 25, 2021.

2. Was any technology adopted by industry or transportation agencies as a result of this work? If so, what was the technology? When was is adopted? Who adopted the technology?
   Not yet. We need to collect more data in order to confirm our findings and to address the variation in concrete structures in our development.

3. Did findings from this research project result in changing industry or transportation agency practices, decision making, or policies? If so, what was the change? When was the change implemented? Who adopted the change?
   Not yet. But we are moving toward the goal by conducting this applied research and by collaborating with industry partners like GSSI on this project.

4. Were any licenses granted to industry as a result of findings from this work? If so, when? To whom was the license granted?
   N/A

5. Were any patent applications submitted as a result of findings from this research? If so, please provide a copy of the patent application with your report.
   N/A

6. Did industry organizations or DOTs provide cost-share (cash or in-kind) to your research during the reporting period? Who was the organization? Please provide an in-kind support invoice from the organization with your report (this is kept confidential and used for record keeping purposes only).
   Yes. AECOM contributed to Project 1.4 by sending an inspection engineer with a vehicle. An in-kind support letter is attached to this progress report.

In what follows, our field test result on the I-495 bridge in Chelmsford, MA is provided. Twenty-one concrete bridge piers were inspected using the portable 1.6 GHz GSSI StructuralScan system, as shown in Fig. 1. All bridge piers were numbered in our inspection plan. In Fig. 2, pier S-10 (intact) and its 2D GPR B-scan are shown. In Fig. 3, two small cracks on pier N-06 at distances 57-in. and 61-in. and its GPR image are shown. In Figures 2 and 3, we can see reduced GPR amplitudes and the formation of a hyperbola located at the center of a surface crack (Fig. 3).

Fig. 1. a) I-495 Bridge in Chelmsford, MA b) Location of twenty-one concrete bridge piers

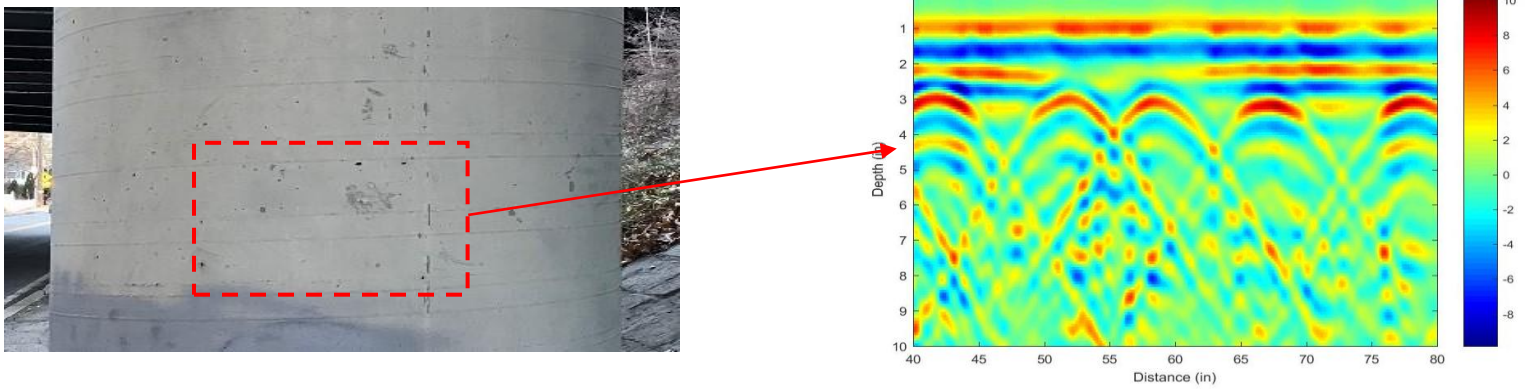

Fig. 2. a) Pier S-10 b) 2D GPR image of region (intact)

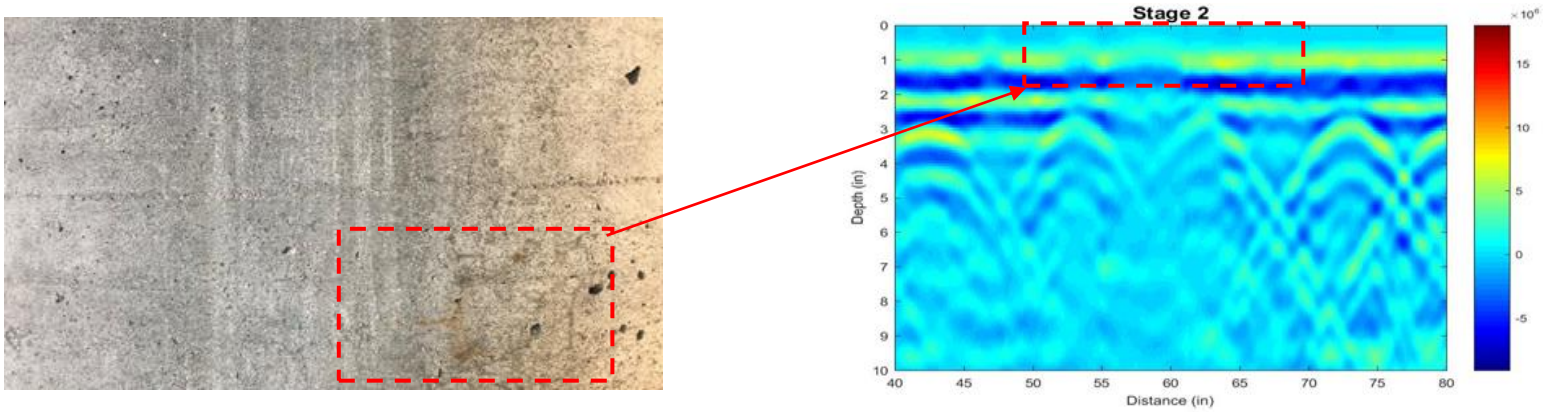

Fig. 2 a) Pier N-06 **b)** 2D GPR image of region (corroded)

Outputs:

- New GPR B-scan image datasets have been developed for the nondestructive inspection and structural health monitoring of a highway bridge in Massachusetts.
- New image processing algorithm (written in Matlab) is under development with the GPR B-scan images collected during this period of the project.

Outcomes:

- N/A

Impacts:

- Through the collaboration with our industry collaborator AECOM on October 25, 2021 at the Sommerfeld bridge, we have demonstrated the use of EM sensors and the principle of EM backscattering for subsurface sensing on concrete structures. This hands-on field test has increased the level of understanding on the use of EM sensors for inspection concrete structures at the end-user side, potentially promoting the use of EM sensors for practitioners on bridge inspection.

Participants and Collaborators:

Table 6: Active Principal Investigators, faculty, administrators, and Management Team Members				
Individual Name & Title	**Dates involved**	**Email Address**	**Department**	**Role in Research**
Tzuyang Yu	10/01/2021~ 12/31/2021	Tzuyang_Yu@UML.EDU	Civil and Environmental Engineering	Project principle investigator and Institutional Lead at UML; overseeing all projects and working on radar imaging and interpretation

Table 7: Student Participants during the reporting period								
Student Name	**Start Date**	**End Date**	**Advisor**	**Email Address**	**Level**	**Major**	**Funding Source**	**Role in research**
Aiyad Alshimaysawee	10/01/21	12/31/21	Prof. Yu		Ph.D.	Civil and Environmental Engineering	TIDC	Laboratory radar imaging and data processing
Sophe Ying	10/01/21	12/31/21	Prof. Yu		B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests
Yaneliz Garcis Ruiz	10/01/21	12/31/21	Prof. Yu		B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests
Tiana Robinson	10/01/21	12/31/21	Prof. Yu		B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests

Table 8: Students who Graduated During the Reporting Period			
Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**

Table 9: Industrial Internships

Student Name	Degree/Certificate Earned	Graduation/Certification Date	Did the student enter the transportation field or continue another degree at your university?

Table 10: Research Project Collaborators during the reporting period

Organization	Location	Contribution to the Project				
		Financial Support	In-Kind Support	Facilities	Collaborative Research	Personnel Exchanges
MassDOT	Boston, MA				X	X
City of Lowell	Lowell, MA				X	X
Geophysical Survey Systems, Inc. (GSSI)	Nashua, NH				X	X
AECOM	Boston, MA		$396		X	X

Table 11: Other Collaborators

Collaborator Name and Title	Contact Information	Organization and Department	Date(s) Involved	Contribution to Research
David Cist		GSSI	11/10/21	Technical champion
Mark Jen		Michael Baker Engineering, Inc.	12/16/21	Technical champion
Ting Chang, City Engineer		City of Lowell	11/30/21	Opinion exchange, end-user's input

Table 12: Course List

Course Code	Course Title	Level	University	Professor	Semester	# of Students
CIVE 5570	Structural Dynamics	Grad	UMass Lowell	Tzuyang Yu	Fall	18
ENGN 2050	Statics	Undergrad	UMass Lowell	Tzuyang Yu	Fall	41

Changes:

N/A

Planned Activities:

In the next reporting period, we plan to continue following research tasks with limited access to our laboratories.

- Task 3.2: Field inspection of corroded RC structures (Preliminary)
- Task 4: Development of EM database and correlation between SAR and GPR images
- Task 5: Data analysis and image interpretation