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: 7/1/2022~9/30/2022
Submission Date: 9/30/2022

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 designed and manufactured new concrete panel specimens (Task 1) with artificial cracks different from our previous design in order to further the development of an electromagnetic (EM) database (Task 4). We also have identified another highway bridge in Chelmsford, MA for radar inspection (Task 3.2).

Meeting the Overarching Goals of the Project:

- We have designed ten concrete panel specimens with different artificial cracks to improve the accuracy in our study on the scattering effect of concrete cracking.
- For field GPR inspection of cracked concrete bridge piers, we have identified a highway bridge in Chelmsford, MA for data collection.

Accomplishments:

- We have manufactured ten concrete panel specimens for improving our crack detection technique using GPR B-scan images.

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	95%
Task 3.1: Development of a compact, self-powered, light-weight SAR imaging sensor	10/01/21	05/31/22	100%
Task 3.2: Field inspection of corroded RC structures (Preliminary)	06/01/21	09/30/22	90%
Task 4: Development of EM database and correlation between SAR and GPR images	08/01/21	03/31/23	75%
Task 5: Data analysis and image interpretation	10/01/20	09/30/23	70%

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)	$280,917 (federal)	$85 (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?
   N/A

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?
   N/A

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	Electromagnetic detection of concrete cracking by using synthetic aperture radar and ground penetrating radar	NDT&E International	July 1, 2022	Under revision

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 cracked concrete bridge piers Chelmsford, MA on September 29th, 2022.

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.

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.

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).
   N/A

During the reporting period, we have been working on Task 1 (Preparation of laboratory concrete specimens with single and multiple cracking mechanisms) of the proposed research, by manufacturing 10 laboratory concrete specimens (30 by 30 by 5.0 cm^3). Styrofoam (extruded Polystyrene) was used to create artificial cracks of various sizes in the middle surface of the specimens. Figure 1 shows the specimens before demolding, in the storage tank, and at 7-days of age. These specimens are extension from our previous four concrete panel specimens of the same dimensions with three types of artificial cracks (CNI, CNC, CNCD, and CNCW). This set of laboratory concrete panel specimens share a similar mix design and dimension (Table 1). Moreover, the crack sizes are derivatives of the previous artificial cracks, with an emphasis on the effect of crack length in this experiment. Dimensions of the specimens are provided in Table 2. These fourteen specimens (four old and ten new) will provide us the data to better understand how a single crack on concrete specimens can be characterized and quantified by radar images. Ultimately, we can use radar images to quantify cracks on real concrete bridges and develop predictive models for crack detection.

Table 1. Material and mix design of the concrete specimens.

Material	**Water**	**Type I/II PC**	**Sand (ASTM C33)**	**Gravel (ASTM C33)**
Mix ratio	0.5	1.0	1.5	3.0
Weight (kg/m^3)	216	432	646	1080

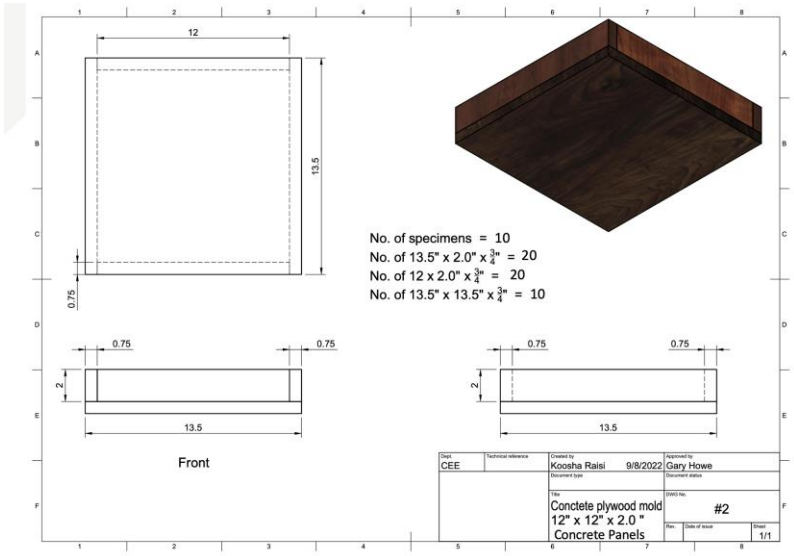

Figure 1. a) Schematics of concrete panel specimens. b) Manufactured concrete panel specimens. c) Specimens under curing.

Table 2. Specimen dimensions.

Specimen	Crack Group	Crack Dimensions (L x W x D cm^3)
CNL1	Length	5.0 x 0.5 x 0.5
CNL2		15.0 x 0.5 x 0.5
CNL3		20.0 x 0.5 x 0.5
CNW2	Width	10.0 x 0.25 x 0.5
CNW3		10.0 x 0.5 x 0.5
CNW4		10.0 x 1.0x 0.5
CND2	Depth	10.0 x 0.5 x 1.0
CND3		10.0 x 0.5 x 2.0
CND4		10.0 x 0.5 x 2.5
CNI	Intact (baseline)	-

Outputs:

- New concrete specimens have been created to advance our prediction accuracy in radar imaging.
- New GPR B-scan image datasets have been included to our EM database for the nondestructive inspection and structural health monitoring of a highway bridge (I-495) in Massachusetts.

Outcomes:

- N/A

Impacts:

- N/A

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	7/01/2022 ~ 9/30/2022	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**
Koosha Raisi	7/1/22	9/30/22	Prof. Yu		Ph.D.	Civil and Environmental Engineering	TIDC	Laboratory specimen design and manufacturing, data processing and analysis, field data collection
Nimun Nak Khun	7/1/22	8/30/22	Prof. Yu		M.S.	Civil and Environmental Engineering	TIDC	Laboratory specimen manufacturing and field data collection
Ritham Batchu	7/1/22	9/30/22	Prof. Yu		M.S.	Civil and Environmental Engineering		Laboratory specimen manufacturing

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?**
Nimun Nak Khun	Masters in Civil Engineering	8/30/2022	Yes, he is working for a construction firm in Boston.

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?
Yaneliz Garcia	Bachelor's in Civil Engineering	6/30/2023	She continues her study in our program.

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
City of Lowell	Lowell, MA				X	X

Table 11: Other Collaborators

Collaborator Name and Title	Contact Information	Organization and Department	Date(s) Involved	Contribution to Research
Gregory Krikoris		MassDOT	9/13/22	Technical champion
Mark Jen		Kiewit Corporation	7/3/22	Technical champion

Table 12: Course List

Course Code	Course Title	Level	University	Professor	Semester	# of Students

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