TIDC Transportation Infrastructure Durability Center AT THE UNIVERSITY OF MAINE

Semi-Annual Progress Report

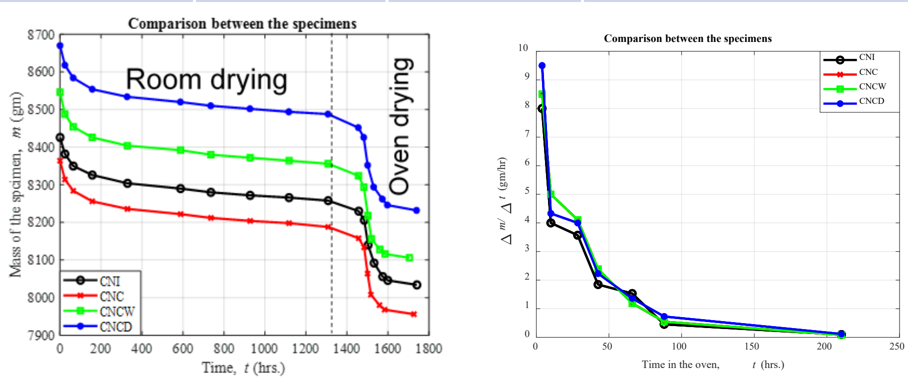
Project Number and Title: 1.4 Electromagnetic Detection and Identification of Concrete Cracking in Highway Bridges
Research Area: Thrust 1: Transportation infrastructure monitoring and assessment for enhanced life
PI: Tzuyang Yu (UMass Lowell)
Co-PI(s): N/A
Reporting Period: 04/01/2019~09/30/2019
Date: 09/30/2019

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. During the reporting period, we have been working on Tasks 1, 2, 3, 4, and 5 of the proposed research; **Task 1:** Preparation of laboratory concrete specimens with single and multiple cracking mechanisms (6 months). **Task 2:** Laboratory radar imaging of concrete specimens (6 months), **Task 3:** Preliminary field radar imaging of concrete bridges, **Task 4:** Development of EM database, and **Task 5:** Data analysis and image interpretation. In this semi-annual report, we will report our progress on analyzing and modeling our radar images (reported in our last semi-annual report on 03/29/2019) of concrete specimens CNI, CNC, CNCW, and CNCD. In past six months, we have accomplished 100% of Task 1, 70% of Task 2, 50% of Task 3, 35% of Task 4, and 30% of Task 5 by developing synthetic aperture radar (SAR) image-based data analysis and image interpretation procedures for concrete panels with and without a surface crack (Table 1). In order to model the background signal in all SAR images, we monitored the moisture variation in each concrete specimen for approximately three months (73 days) in two conditions; room-drying and oven-drying. Figure 1 (a) shows the three-month moisture level variation of all four concrete specimens. In Figure 1 (a), from the 0th hr to the 1450th hr shows the room-drying moisture measurement, while from the 1450th hr to the end shows the oven-drying moisture measurement. We found that the rate of moisture loss is positively affected by the surface area of concrete panels (shown in Figure 1 (b)). The ranking of rate of moisture loss for all concrete panels is: CNCD (surface=2,3115 cm^2) > CNCW (surface area=2,292 cm^2) > CNC (surface area=2,290 cm^2) > CNI (surface area=2,280 cm^2).

Table 1. Intact and damaged concrete panels

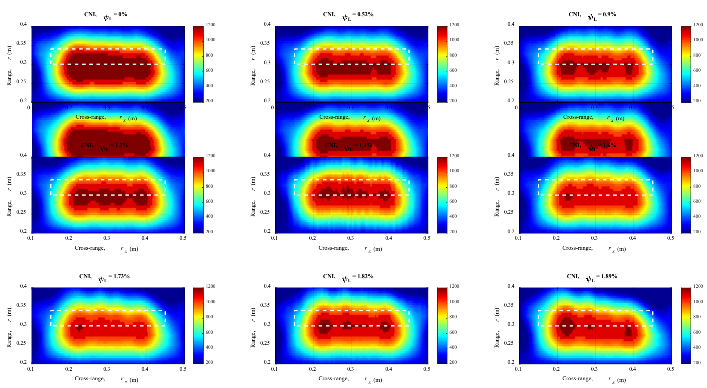
Specimen	Crack Dimensions			Note
	Length (cm)	Width (cm)	Depth (cm)	
CNI	0	0	0	Intact
CNC	10	0.5	0.5	With 10cmX0.5cmX0.5cm crack
CNCW	10	2	0.5	With 10cmX0.5cmX2cm crack
CNCD	10	0.5	1.5	With 10cmX1.5cmX0.5cm crack



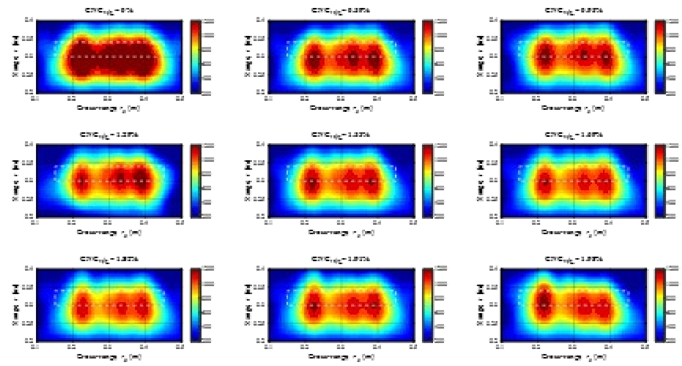
(a) Moisture measurement (b) Rate of moisture loss

Figure 1. Time-dependent of moisture level variation in four concrete specimens (approximately three months)

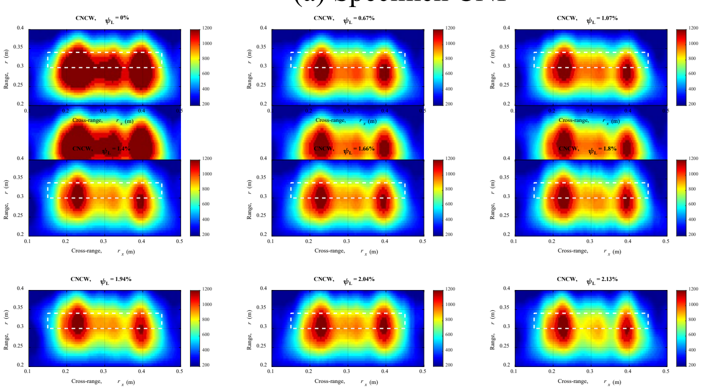
After room-drying, we oven-dried all concrete panels in order to obtain absolute content (oven-dried weight) of concrete panels. The radar image database (Task 2) for room-dried concrete specimens are shown in Figure 2. The correlation of absolute moisture content in concrete and the corresponding SAR image is the key to remove background noise is the SAR images of cracked concrete specimens and structures and to decipher the meaning of SAR amplitude and distribution.



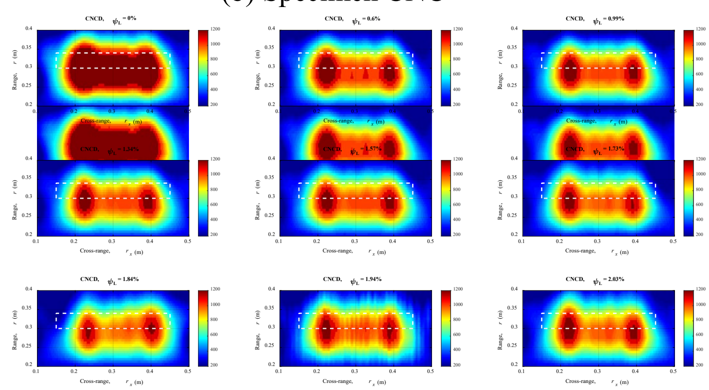
(a) Specimen CNI



(b) Specimen CNC



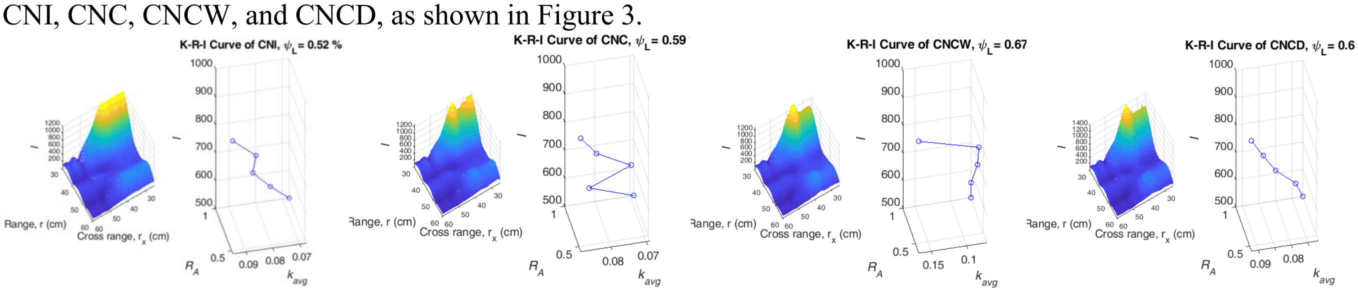
(c) Specimen CNCW



(d) Specimen CNCD

Figure 2. Room-dried SAR images of all four concrete specimens

In order to develop a data driven field inspection procedure for concrete cracking on concrete bridges (Task 1), With a 10cmX0.5cmX2cm crack, **inspection parameters** must be identified. In this project, we identified the following inspection parameters for bridge engineers to use in the field, including i) distribution of SAR amplitude (1 D and 2D) and ii) critical contour area (A_c) of SAR images. A quantitative measure (the K-R-I transform) was applied to all SAR images of specimens CNI, CNC, CNCW, and CNCD, as shown in Figure 3.



(a) Specimen CNI (b) Specimen CNC (c) Specimen CNCW (d) Specimen CNCD

Figure 3. K-R-I curves of SAR images of all four concrete specimens

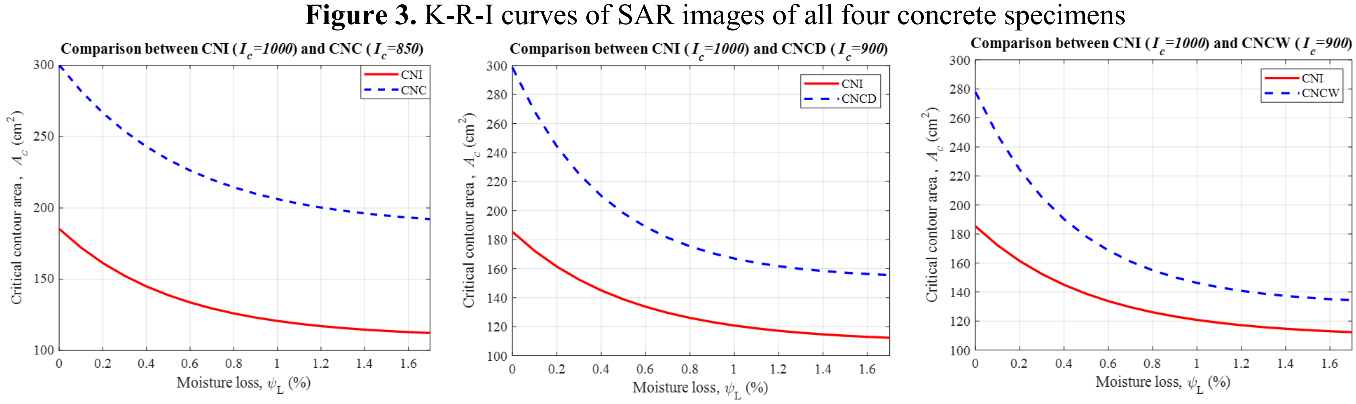


Figure 4. (a) Critical contour area with moisture content of room-drying

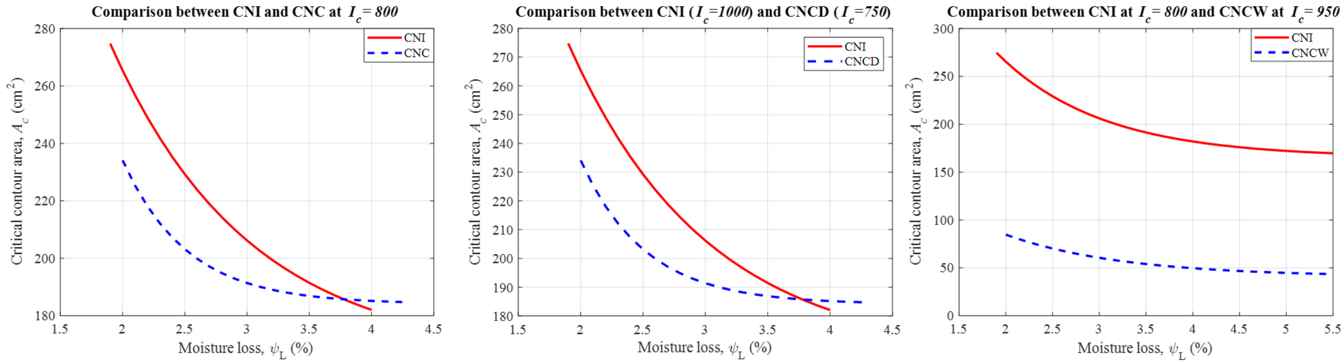


Figure 4. (b) Critical contour area with moisture content of oven-drying

Eq. (1) represents the relationship between coefficient b from critical contour area model and crack volume (V).

$$V(b) = 11.16\,b\ - 16.9 \qquad (1)$$

where V = crack volume (cm^3) and b = coefficient of critical contour area model of specimens. Coefficient of determination of Eq. (1) is 0.736.

$$\text{Crack depth } (d) = \frac{\text{Crack volume (V)}}{\text{Length(L)}*\text{Width (W)}}$$

$$d\,(b, L, W) = \frac{11.16\,b - 16.9}{L\,W} \qquad (2)$$

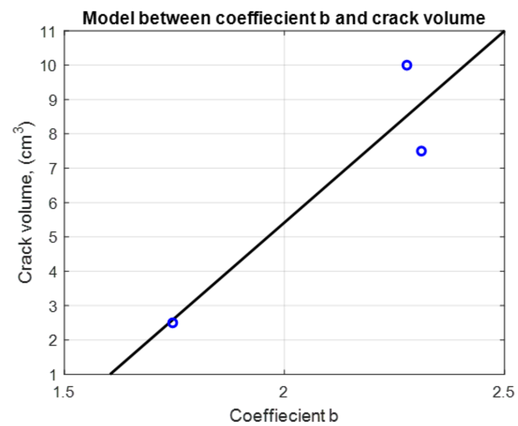
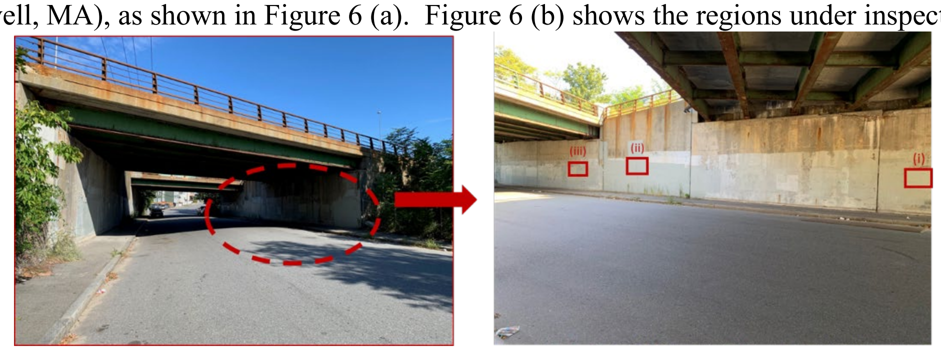


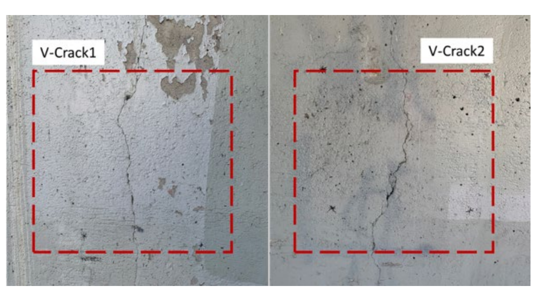
Figure 5. Crack volume of damaged concrete panels

Also, we collected radar imaging using a SAR imaging sensor and a GPR (ground penetrating radar) sensor in field (Lincoln Street Bridge in Lowell, MA), as shown in Figure 6 (a). Figure 6 (b) shows the regions under inspection.



Lincoln Street Bridge — Tyree scanned regions on bridge

Figure 6. (a) Lincoln Street Bridge, Lowell, MA



(i) Vertical crack 1 — (iii) Vertical crack 2

Figure 6. (b). Intact region and cracked regions in the field test

Figure 7 shows the SAR images of intact and cracked regions, we have collected from Lincoln Street Bridge, Lowell, MA. 3D GPR images are shown in Figure 8.

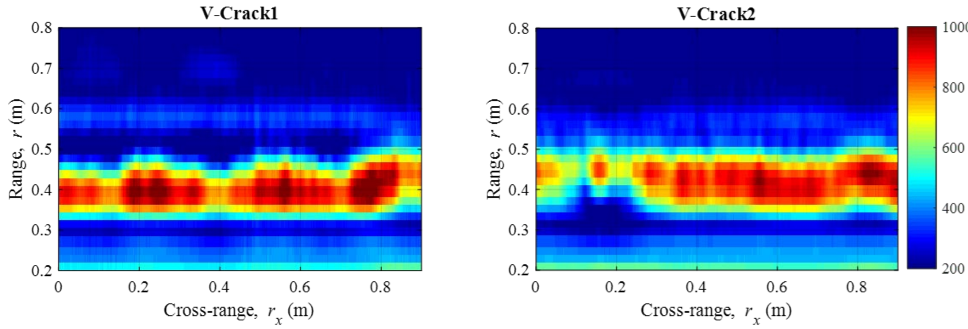


Figure 7. SAR images of the field test for regions (i) V-crack1 and (ii) V-crack2

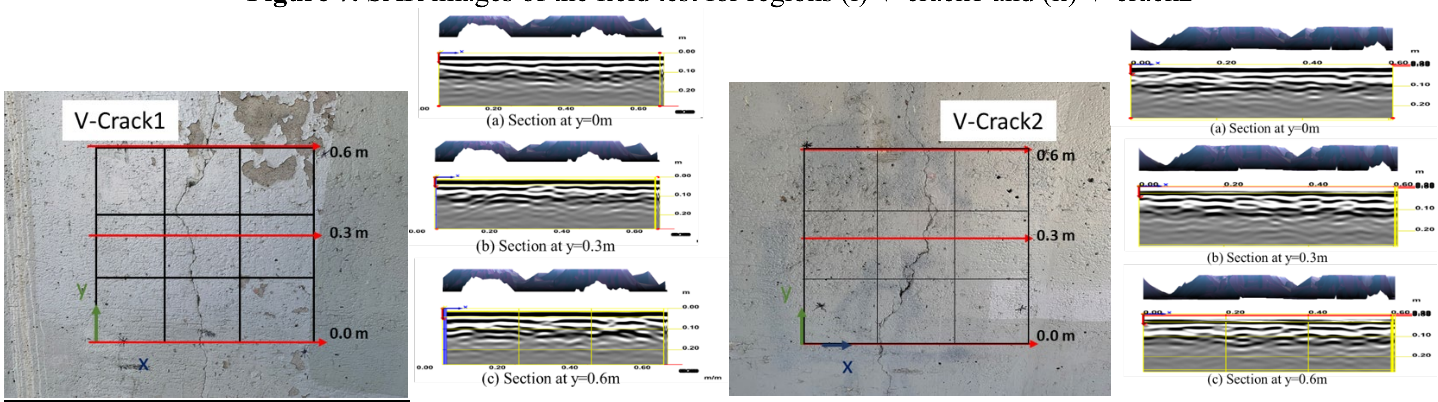


Figure 8. 3D GPR images of regions (i) V-crack1 and (ii) V-crack2

Participants and Collaborators:

During the reporting period, the following students have worked on the project.

- Dr. Tzuyang Yu, Associate Professor, Civil and Environmental Engineering – Project principle investigator and Institutional Lead at UML; overseeing all projects and working on radar imaging and interpretation
- 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
- Ms. Sanjana Vinayaka, part-time graduate RA, doctoral 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, Bachelor's student, Civil and Environmental Engineering – Manufacturing of laboratory specimens

<u>Collaboration with MassDOT and the City of Lowell</u> – 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.

Planned Activities:

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

Task 2: Laboratory radar imaging of concrete specimens – To be completed in the next four months.

Task 3: Preliminary field radar imaging of concrete bridges – Have started our first preliminary field inspection. Will continue working on this task.

Task 4: Development of EM database – Have started developing this EM (electromagnetic) database and will continue working on this task.

Task 5: Data analysis and image interpretation – Have started developing algorithms for analyzing and interpreting radar images for condition assessment. Will continue developing more algorithms.

We also plan to attend the 2020 SPIE Smart Structures/NDE Symposium in Anaheim, CA during April 26~30, 2020 to disseminate our research findings.