DEVELOPMENT OF RAPID IN-SITU TESTING FOR CONCRETE DECK DURABILITY

Quarterly Progress Report
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Submitted to:
ABC-UTC
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1. Background and Introduction

Research has shown that the transport properties such as permeability, diffusivity, and absorption/sorption of concrete are indicators of the serviceability and durability of concrete structures as most degradation processes are dependent on the movement of fluid within the pore structure [1–8]. The currently accepted methods for assessing concrete resistance to penetration of chloride ions are the Rapid Chloride Permeability (RCP), Bulk Resistivity (BR) and the Surface Resistivity (SR) tests. The RCP test is time-consuming, laborious, has rather high variability, and is user sensitive, making it problematic for inclusion in a performance-based specification. Potential alternatives to the RCP test are the Surface Resistivity (SR) and the Bulk Resistivity (BR) Tests, methods which is dramatically easier, faster, and have less variability than the RCP test. However, the SR and BR tests have their own challenges. The moisture content, curing conditions, and temperature have can affect the results of the tests. In addition, accelerated moist-curing may not provide the same results as standard moist-curing. The proposed research aims at taking a concept that was recently developed at FIU and completing the procedure for marketing a novel approach for quickly (20 minutes) assessing the durability of existing concrete bridge decks.

2. Problem Statement

Assessing durability on-site is a challenging task. An interesting quality check test for the durability of concrete has been developed at FIU which could be modified for "in-situ" assessment of the durability concrete elements (column, beam, abutments, bridge deck, etc.) in less than 20 minutes. This which would allow for a quick quality control assessment of the concrete components used in Accelerated Bridge Construction (ABC). Following is a very brief description of this novel method. The method quickly assesses the durability of hardened concrete material against liquid ingress, at very high pressure. This proposal aims at relating this behavior to standard durability tests, such as Freeze/Thaw, Rapid Chloride Permeability, Bulk Resistivity and Surface Resistivity tests that are expensive and take a very long time. The entire test lasts 20 minutes, as described below. In the developed method, liquid at high pressure is applied to the surface of hardened concrete and time vs. pressure response is obtained. As an example, if water is used as a liquid, one foot of water, placed on a concrete surface would result in 0.433 psi pressure on concrete surface. Therefore, applying 200 psi pressure to concrete surface would be equivalent to having that concrete under 461.9 ft. of water.

3. Objectives and Research Approach

This project is aiming at establishing a relationship that might exist between routine Freeze/Thaw, Rapid Chloride Permeability (RCP), Bulk Resistivity (BR), and Surface Resistivity (SR) tests and the novel method developed. If such a relation exists, the durability assessment of concrete bridge elements can be achieved in less than 20 minutes.

4. Activities Completed

Concrete Conditioning

Concrete cylinders (4-inch and 2-inch) specimens were cast from four conventional concrete mix designs that included a 0.5 and 0.6 water-to-cement ratio and use of #57 and #89 limestone coarse aggregate. The concretes were tested for air content of the fresh concrete. After 56 days of curing within its plastic cylinder molds, the concrete specimens were conditioned in a 20%, 75%, and 97% humidity chambers or soaked in a saturated Ca $(OH)_2$ solution. The 20% RH was controlled by use of a silica gel desiccant. The 75% RH and 97% RH was controlled with the use of saturated salts solutions in an aerated sealed chamber. The concrete have been conditioned for 1 month and are being monitored until near terminal moisture conditions develop. The mass change, bulk electrical resistivity, electrochemical impedance spectroscopy (to measure concrete resistance and capacitance), and longitudinal resonant frequency have been monitored. Figure 1 and 2 show the results of mass change and bulk electrical resistance during the concrete conditioning. As expected, greater electrical resistance developed for specimens maintained at dryer conditions.

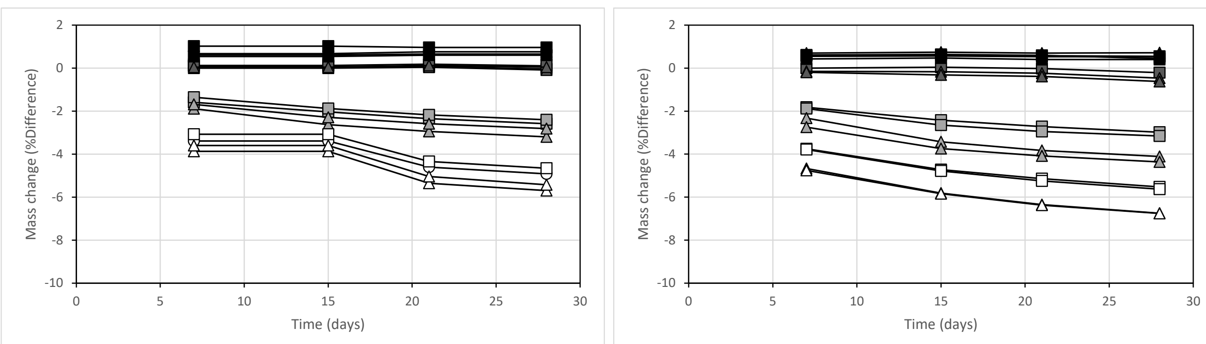


Figure 1. Mass Change during Concrete Moisture Conditioning.
Left: 0.5 w/c. Right: 0.6 w.c.
White: 20%RH, Light Grey: 75% RH, Dark Grey: 97% RH, Black: Soaked

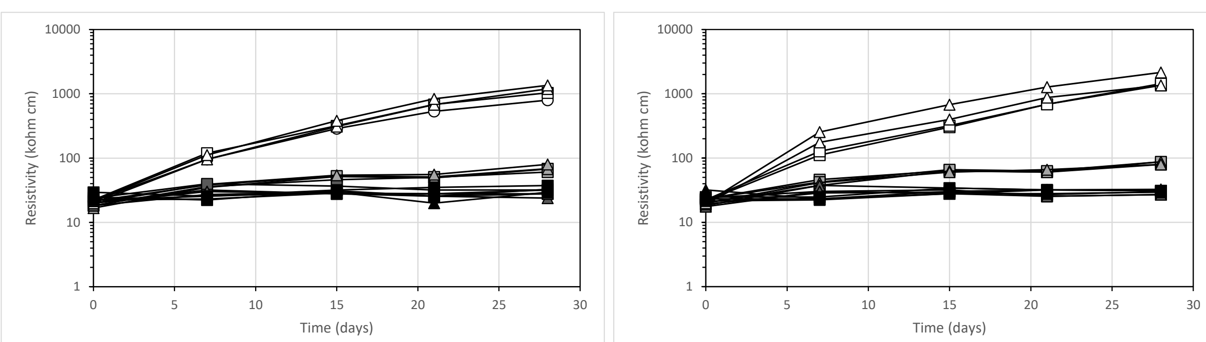
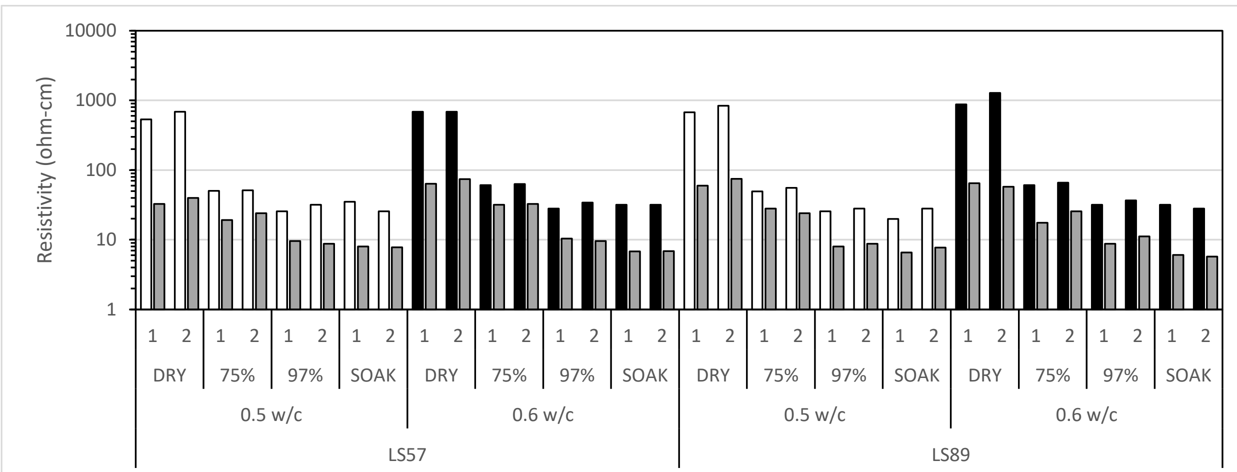
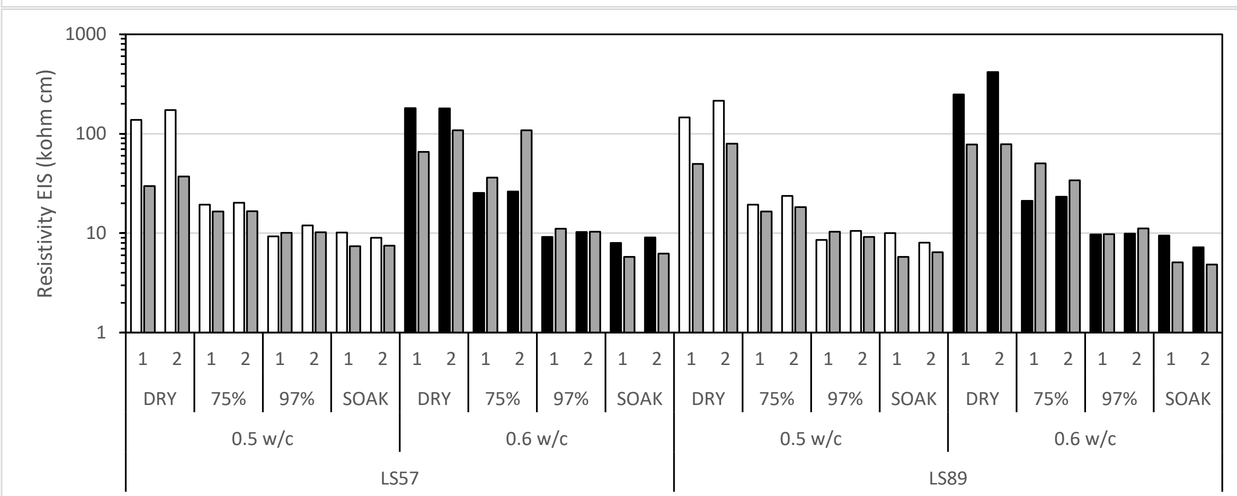


Figure 2. Bulk Resistivity during Concrete Moisture Conditioning.
Left: 0.5 w/c. Right: 0.6 w.c.
White: 20%RH, Light Grey: 75% RH, Dark Grey: 97% RH, Black: Soaked

Figure 3 and 4 show the results of electrical testing by 2-pt resistance measurements and electrochemical impedance spectroscopy. As expected, the electrical resistivity significantly drops in presence of high humidity and when the concrete is saturated compared to the dry conditions. Similarly, the concrete capacitance increases with the moist exposure environments due to the saturation of the concrete pores where the high dielectric characteristic of the water is detected. The longitudinal resonant frequency showed greater values for the concrete made with the larger limestone coarse aggregate and with the lower 0.5 w/c ration mix.
Figure 5 shows good correlation between the concrete capacitance to bulk resistivity which accounts for the extent of internal moisture presence in the concrete specimens. Also, the resolved concrete Young's modulus from the longitudinal resonant frequency showed good correlation to the concrete capacitance. The results show that the internal environments in the concrete pore structure and the bulk solid is affected by the moisture content developed by the various exposure conditions.





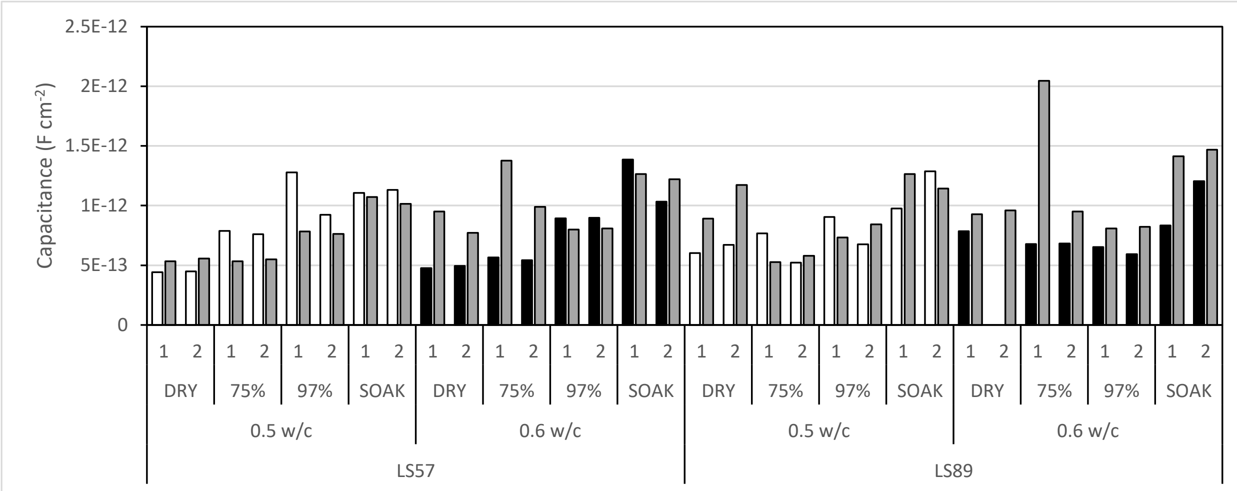


Figure 3. Comparison of Electrical Characteristics after ~23 Days of Conditioning

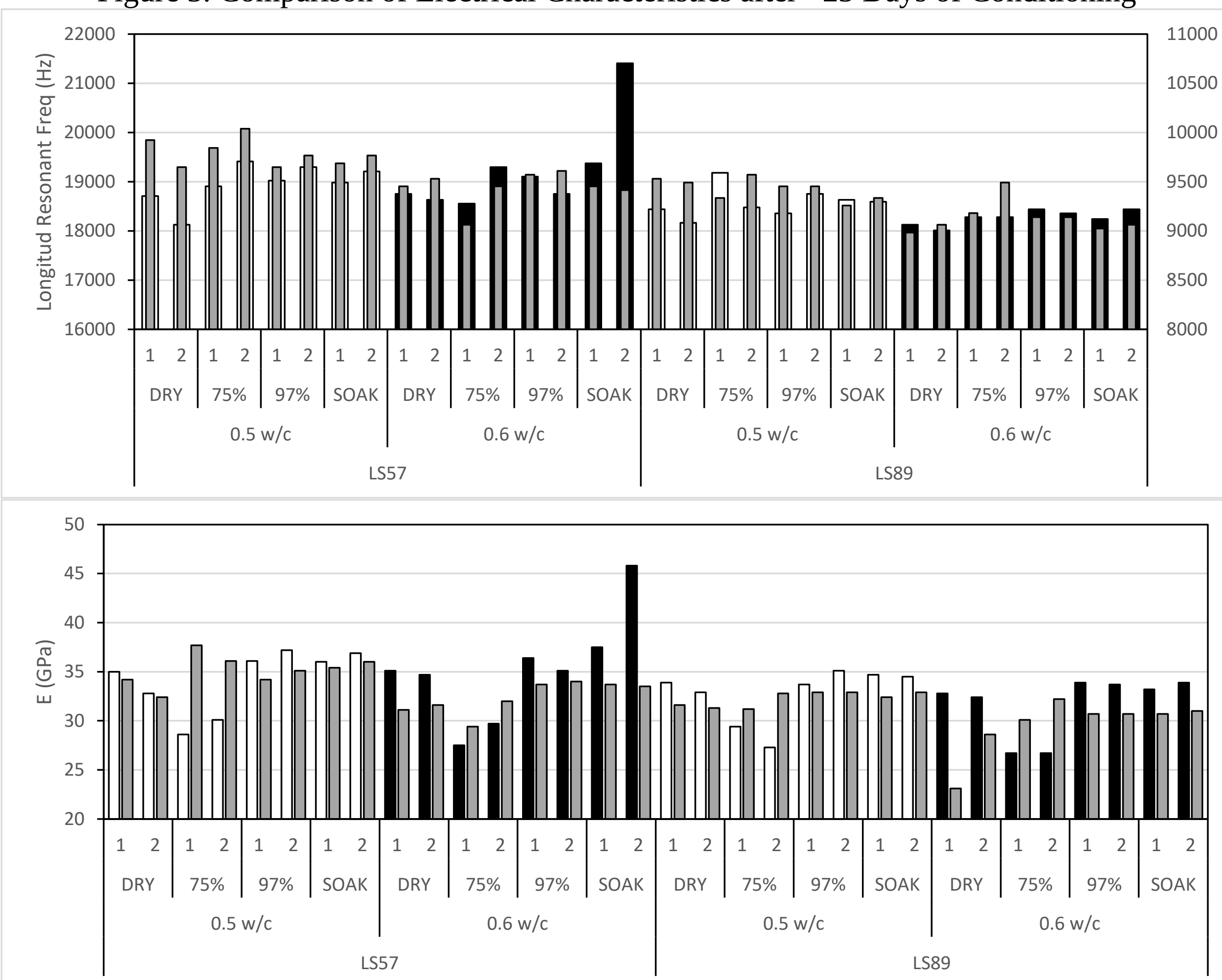


Figure 4. Longitudinal Resonant Frequency and Estimated Young's Modulus after ~23 days of Conditioning

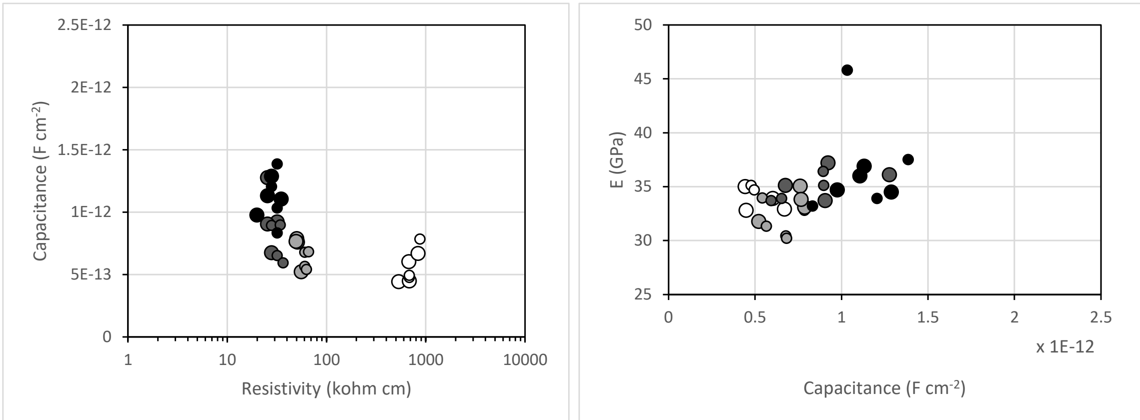


Figure 5. Comparison of Electrical and Acoustic Characteristics.
White: 20%RH, Light Grey: 75% RH, Dark Grey: 97% RH, Black: Soaked

Freeze Thaw Testing

Freeze thaw testing conforming to ASTM C666 was conducted on triplicate test specimens from the four mixes. Only 30 freezing/thawing cycles were completed. Figure 6 shown pictures of the freeze thaw and resonant frequency testing. Results of testing of its resonant longitudinal resonant frequency and calculated Young's modulus are shown in Table 1. All concretes exhibited degradation by the decrease in its longitudinal resonant frequency due to the accelerated freezing and thawing, and all specimens except for the 0.5w/c concrete with #57 limestone coarse aggregate showed significant concrete cracking (Figure 7).

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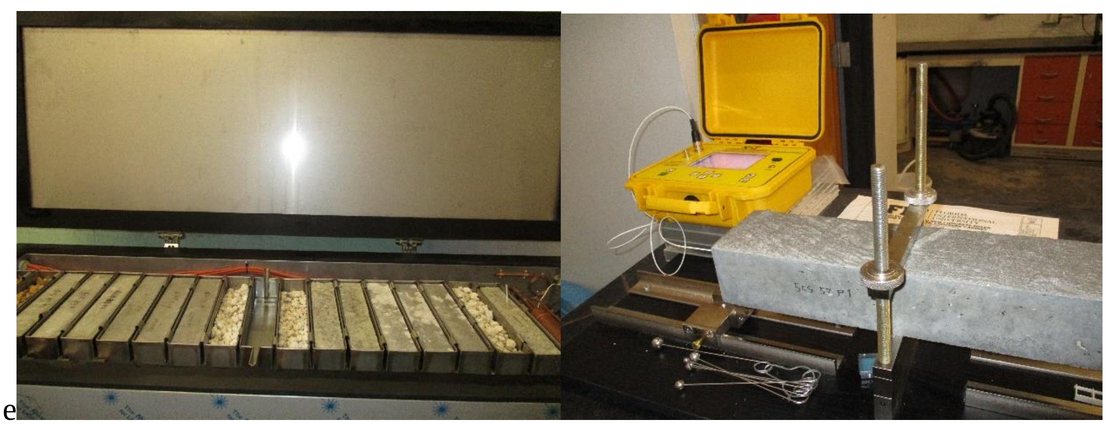


Figure 6. Freeze Thaw and Resonant Frequency Testing

Figure 7. Cracking due to Accelerated Freeze/Thaw Cycling

Table 1. Freeze Thaw Longitudinal Resonant Frequency

	2/4/2023			2/25/2023			3/3/2023		
	Before Freeze Thaw						After 30 Cycles		
ID	Mass (kg)	Resonant Frequency (Hz)	E (Gpa)	Mass (kg)	Resonant Frequency (Hz)	E (Gpa)	Mass (kg)	Resonant Frequency (Hz)	E (Gpa)
5LS57P1	7.33	4883	36.8	7.35	5000	38.8	7.36	3984	24.6
		4883	36.8						
5LS57P2	7.31	4805	35.7	7.32	5000	38.2	7.33	4023	25.1
		4805	35.7						
5LS57P3	7.30	4883	36.8	7.32	4961	37.6	7.33	3867	22.9
		4883	36.8						
5LS89P1	7.11	4961	37	7.14	4883	35.5	7.20	1914	5.5
		4961	37						
5LS89P2	7.09	5000	37.6	7.11	1805	34.3	7.22	938	1.3
		5000	37.6						
5LS89P3	7.05	4961	37	7.07	4883	35.5			
		4961	37						
6LS57P1	7.23	4688	33.5	7.25	4805	35.3	7.35	1797	4.9
		4688	33.5						
6LS57P2	7.26	4609	32.4	7.29	4894	35.9	7.39	977	1.5
		4609	32.4						
6LS57P3	7.26	4609	32.4	7.28	4805	35.3	7.38	977	1.5
		4609	32.4						
6LS89P1	7.03	4805	34.2	7.04	4688	32.2	7.21	703	0.7
		4805	34.2						
6LS89P2	7.05	4844	34.7	7.07	4648	32.1	7.22	625	0.6
		4844	34.7						
6LS89P3	6.99	4805	34.2	7.01	4698	31.7	7.18	469	0.3
		4805	34.2						

5. Description of Research Project Tasks

Task 1 – Literature review
A comprehensive review of existing technologies used to determine the durability of existing concrete bridge decks will be conducted. The objective of this task is to develop a database identifying all existing technologies.

The literature review is ongoing.

Task 2 – Compare Freeze-Thaw test results to FIU method test results
Conduct Freeze-Thaw tests on concrete specimens as per ASTM C 666, “Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing” and AASHTO T 161, “Standard Method of Test for Resistance of Concrete to Rapid Freezing and Thawing”. Compare results to the FIU method.

See section 4 for updates on material and equipment preparation.

Task 3- Compare Rapid Chloride Permeability test results to FIU method test results.
Conduct Rapid Chloride Permeability tests on concrete specimens as per AASHTO T277, “Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete” and ASTM C1202, “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration”. Compare results to the FIU method.

See section 4 for updates on material and equipment preparation.

Task 4- Compare Electrical Resistivity tests to FIU method test results.
Conduct Surface Resistivity (SR) tests on concrete specimens as per AASHTO T358 Conduct Bulk Resistivity (BR) test on concrete specimens as per AASHTO TP 119. Compare results to the FIU method.

See section 4 for updates on material and equipment preparation.

Task 5- Final reporting.
Write final report summarizing experimental results and complete system design, ABC-UTC Guide, and a video presentation will be prepared that summarize the methods used and the findings reached during the project.

No activity for Task 5 was made in this phase of work.

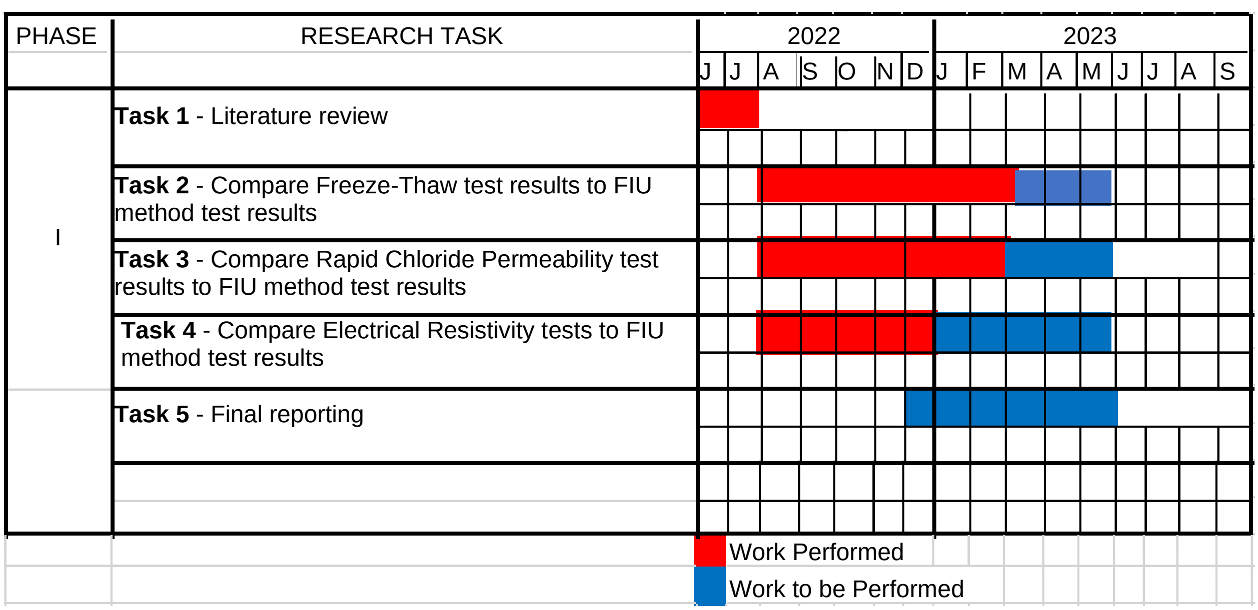
6. Expected Results and Specific Deliverables

The method, when completed, using the proposed project has the potential to make a paradigm shift in the way we assess the durability of existing concrete bridge decks and for that matter any concrete elements, such as columns, etc.

7. Schedule

Progress of tasks in this project is shown in the table below.

Item	% Completed
Literature review	90
Compare Freeze-Thaw test results to FIU method test results	45
Compare Rapid Chloride Permeability test results to FIU method test results	40
Compare Electrical Resistivity tests to FIU method test results	30
Final reporting	0



8. References

[1] Relating Water Permeability to Electrical Resistivity and Chloride Penetrability of Concrete Containing Different Supplementary Cementitious Materials, Cement And Concrete Composites, Volume 107, 2020, 103491, Issn 0958-9465, https://doi.org/10.1016/j.cemconcomp.2019.103491.

[2] Graybeal, B. (2014) "Design and Construction of Field-Cast UHPC Connections." FHWA Publication No: FHWA-HRT-14-084, USDOT FHWA, Washington, DC.

[3] Yuan, J. and Graybeal, B. (2014) "Bond Behavior of Reinforcing Steel in Ultra-High Performance Concrete." Report No. FHWA-HRT-14-90, USDOT FHWA, Washington, DC.

[4] Graybeal, B, and Baby, F. (2013) "Development of Direct Tension Test Method for Ultra-High-Performance Fiber-Reinforced Concrete." ACI Mat J, 110 (2): 177-186

[5] Haber, Z.B. and Graybeal, B.A. (2018) "Lap-Spliced Rebar Connections with UHPC Closures" J. Bridge Eng, 04018028

[6] Peruchini, T.J., Stanton, J., and Calvi, P. (2017) "Investigation of Ultra-High Performance Concrete for Longitudinal Joints in Deck Bulb Tee Bridge Girders" WA-RD 869.2, Washington State Department of Transportation, Olympia, WA.

[7] ACI (2009) Guide for the Use of Polymers in Concrete (ACI 548.1R-09), Committee 548, American Concrete Institute, Farmington Hills, MI, USA

[8] DePuy, G. W., and Dimmick, F. E., Sr., 2003, "Polymer Concrete Overlays for the Repair and Protection of Concrete," Polymers in Concrete: The First Thirty Years, SP-214, A. O. Kaeding and R. C. Prusinski, eds., American Concrete Institute, Farmington Hills, MI, pp. 139-149.