DEVELOPMENT OF RAPID IN-SITU TESTING FOR CONCRETE DECK DURABILITY

Quarterly Progress Report
For the period ending June 30, 2023

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Submitted to:
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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

Water Pressure Drop Testing

Water pressure drop testing was conducted on concrete specimens with the following conditions:

- Concrete mix design followed simple mix proportions such as 1:1.5:3 (M20)
- Specimen water content of either 0.5 or 0.6.
- Internal moisture content of:
  - Dry
  - 75% Relative humidity
  - 95% Relative humidity
  - Soaked
- #57 or #89 sized limestone aggregate was used to make the specimens.

Figure 1 shows the water pressure testing system. It consists of a manual hydraulic test pump, pressure transducer, data acquisition system, and a test specimen holder.

Figure 1. Water pressure testing system

Figure 2 shows the combined results from all the tests. As can be seen from the figure, the greatest pressure drop occurred in the dry specimens. It is also observed that as the moisture content of the specimens increased, the pressure drop decreased with the wet specimens having the least pressure drop.

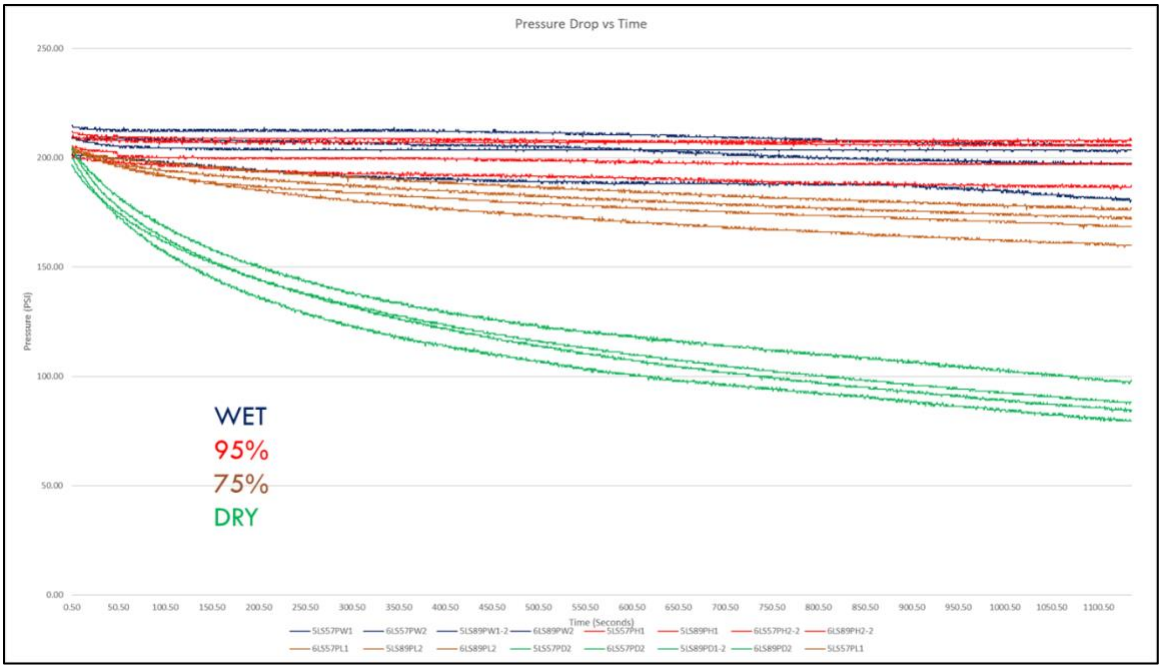


Figure 2. Combined pressure drop results

Figure 3 shows the results from the wet specimens, the results from the 57 aggregate specimens show that the pressure drop for the specimens with the 0.5 w/c ratios are almost identical to the results of the specimens with the 0.6 w/c ratios. However, for the specimens with the 89 aggregate, the pressure drop for the specimens with the 0.5 w/c ratios showed a slightly lower pressure drop than the results of the specimens with the 0.6 w/c ratios.

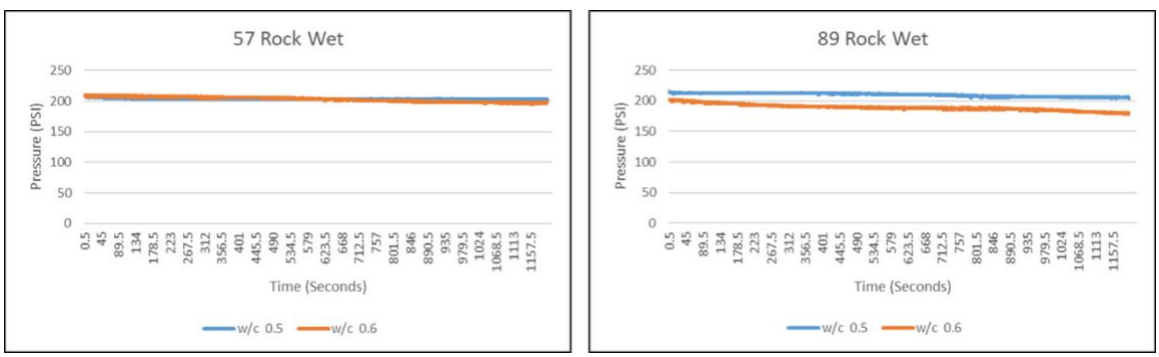


Figure 3. Wet specimen results

Figure 4 shows the results for the 90% RH specimens. Like the results from the wet specimens, the 57 aggregate results show the 0.5 w/c ratio pressure drop very similar to the 0.6 w/c ratio results. In addition, like the wet results, the pressure drop for the 89 aggregate show a slight difference between the two w/c ratios. However, unlike the wet results, the 0.6 w/c ratio specimens had a lower pressure drop than the 0.5 w/c ratio specimens.

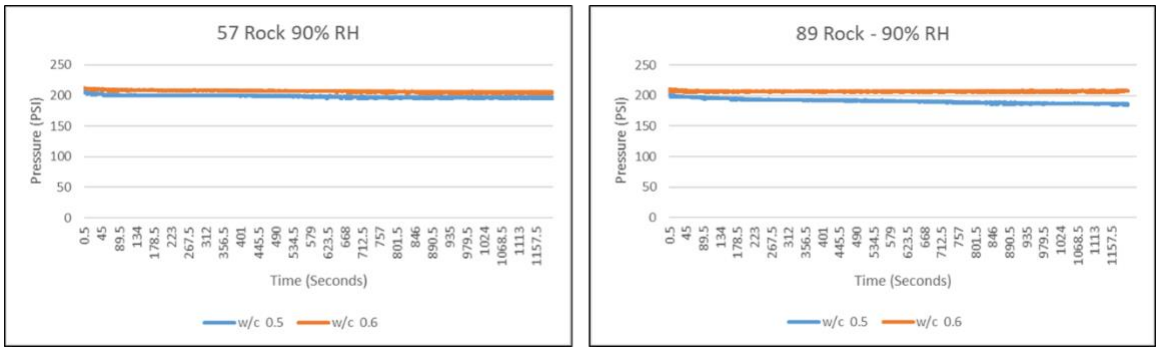


Figure 4. 90% relative humidity results

Figure 5 shows the results for the 75% RH specimens, unlike the results from the 90% RH, the 57 rock results show that 0.6 w/c ratio specimens had a greater pressure drop than the 0.5 w/c ratio specimens. However, the 89 rock results show that the pressure drop for both w/c ratios are almost identical. In addition, the pressure drop of all specimens have a greater pressure drop than both the wet and the 90% RH results.

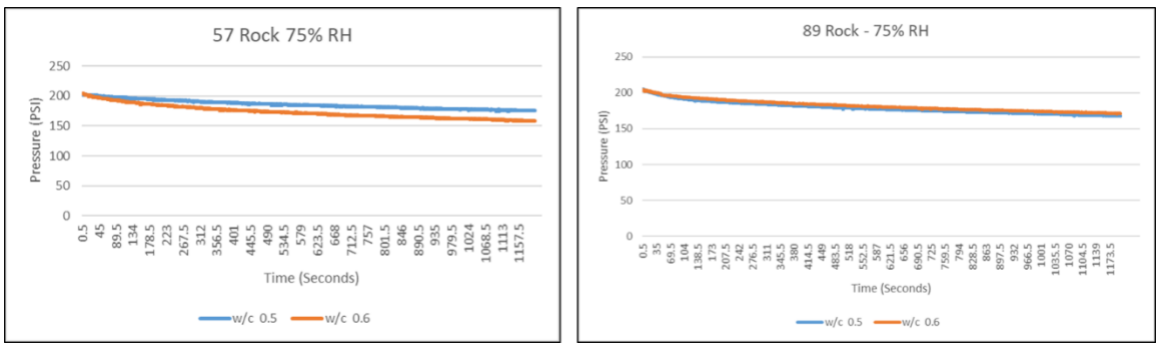


Figure 5. 75% relative humidity results

Figure 6 shows the results for the dry specimens. The dry specimens showed the greatest pressure drop of all the specimens. Unlike the 75% RH results, the 57 rock results show that the 0.5 w/c ratio specimens had a greater pressure drop than the 0.6 w/c ratio specimens. However, like the 75% RH, the 89 rock results show that the pressure drop for both w/c ratios is almost identical.

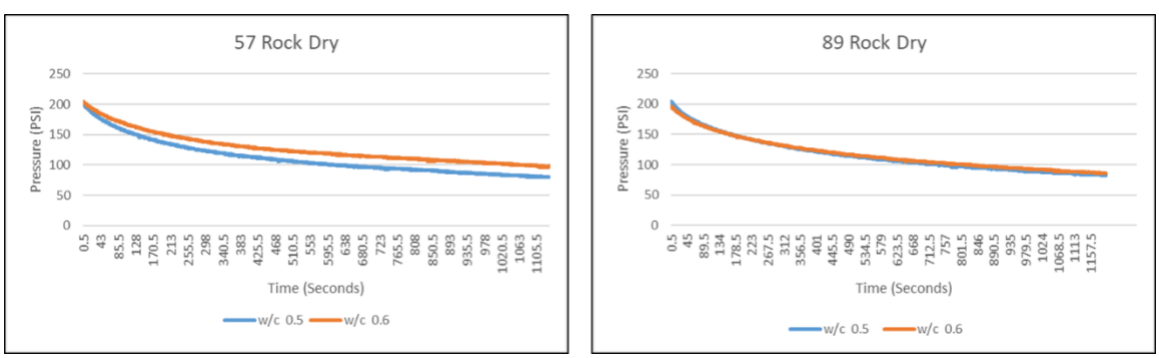


Figure 6. Dry results

The water pressure drop consistently showed an exponential decay in the pressure with time. This behavior was attributed to water penetration through the concrete pore spaces with time as shown in Figure 19. Following mass and energy balance,

$$S = -Q \qquad \text{Eq. 1}$$

$$p_B = \tfrac{1}{2} \rho V_A^2 \qquad \text{Eq. 2}$$

where S is the water storage within the water pressure vessel, Q is the discharge through the concrete, p_B is the water pressure in the vessel, ρ is the density of water, and V_A is the water velocity through an idealized pore; $p_B(t) = [\sqrt{p_o} - Kt/2]^2$ where p_o is the initial water pressure and K is a decay factor. However, this idealized expression did not provide good description of the actual measured pressure drop. An additional term, k relating to water transport through partly saturated pores with time was introduced. The differential equation expressing the change in pressure was introduced as

$$dp/dt = -K \exp(-kt) \times \sqrt{p} \qquad \text{Eq. 3}$$

and

$$p_B(t) = [\sqrt{p_o} - K + K \exp(-kt)]^2. \qquad \text{Eq. 4}$$

The function expresses the water pressure with time due to an initial pressure p_o, pore saturation factor k, and a pressure decay factor K. Factors k and K ideally would be characteristic to the concrete material and exposure conditions. Figure 20 shows an example of fitting test data to Eq. 4, and Figure 21 shows the good correlation between the apparent pressure drop measured after 20 minutes from the initial ~200 psi to K.

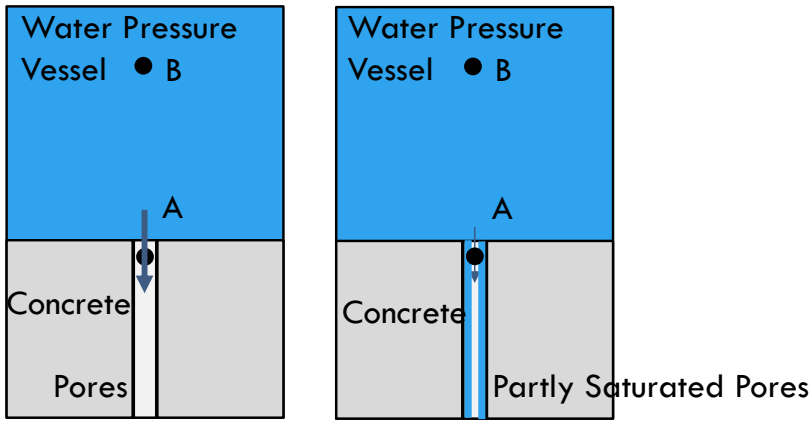


Figure 7. Schematic of Idealized Water Transport through Concrete.

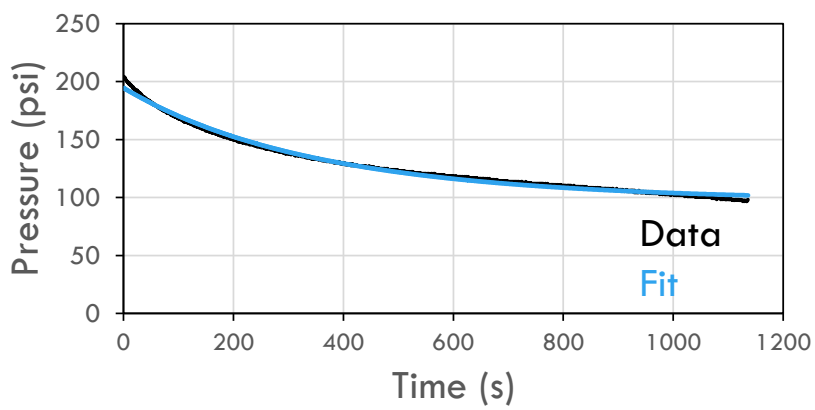


Figure 8. Example of Data Fitting.

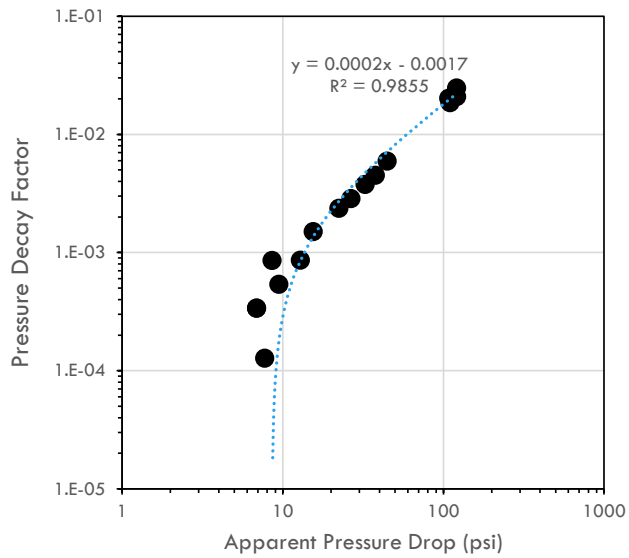


Figure 9. Correlation of Measured Apparent Pressure Drop to Pressure Decay Factor.

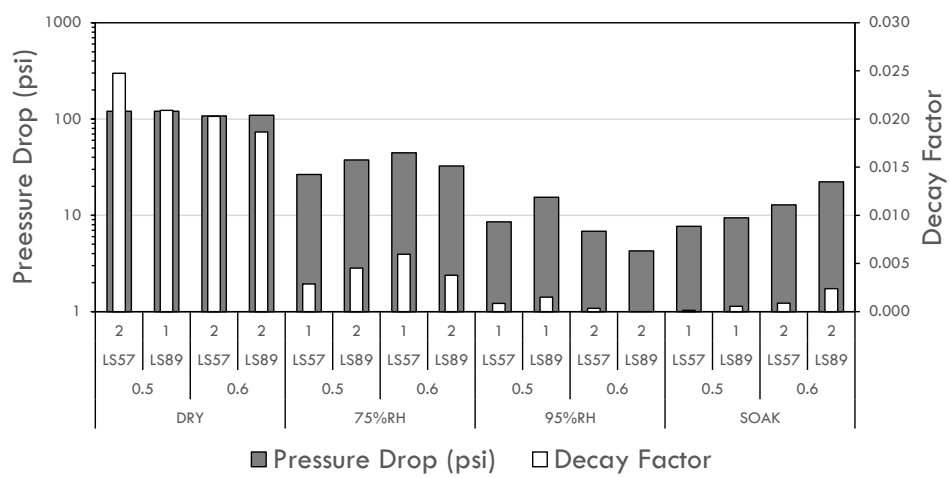


Figure 10. Results of Water Pressure Drop Test

Figure 22 shows the outcome of the water pressure drop test. The internal concrete moisture content had strong influence on the water transport and greater pressure drop was apparent for the concrete conditioned in <35%RH. Figure 23 shows the correlation of the pressure decay factor to the resolved concrete electrical properties.

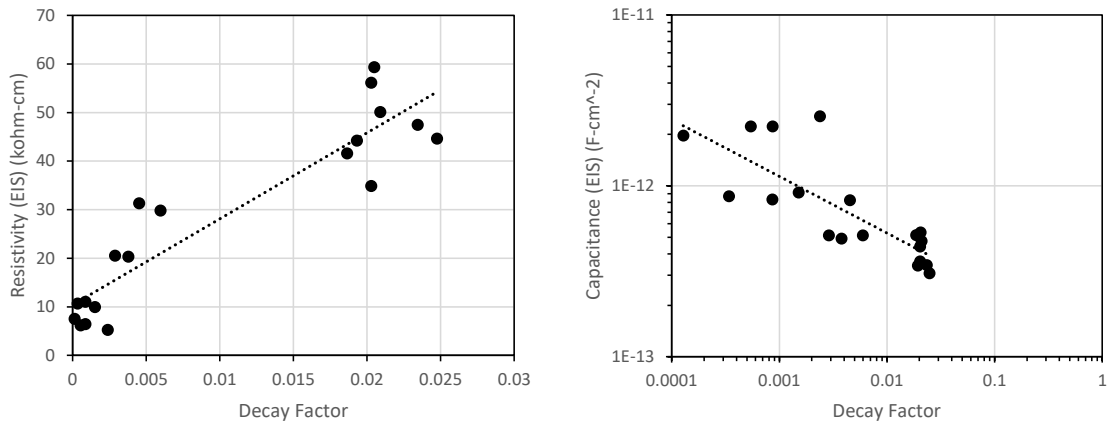


Figure 11. Correlation of Pressure Decay Factor to Concrete Electrical Properties

Concrete electrical properties have been promoted to characterize concrete permeability and overall durability. The bulk resistivity has been demonstrated by some researchers to characterize both the concrete solid microstructure as well as the pore water within. Likewise, the capacitance would be influenced by the microstructure as well as the amount of water within the pore spaces. For example, an increase in capacitance can be related to the presence of water that has a larger dielectric constant ε, than for the solids following the relationshiop $C = \varepsilon \varepsilon_o A/d$ where A and d are idealized area and lengths of pores and ε_o is the permittivity of free space.

Freeze/Thaw Testing

Accelerated freeze/thaw cyclic testing conforming to ASTM C666 was conducted for concrete cast with 0.5-0.6 w/c and with the #57 or #89 limestone coarse aggregate. Figure 7 shows the test specimens just prior to initiating the test within the freeze/thaw chamber. After freeze/thaw cycling, the test specimens were removed and the longitudinal resonant frequency was measured (as shown in Figure 8), using a James Instrument Emodumeter. Damage to the concrete due to the accelerate freeze/thaw cycling is shown in Figure 9.

Figure 12. Freeze/Thaw testing in progress

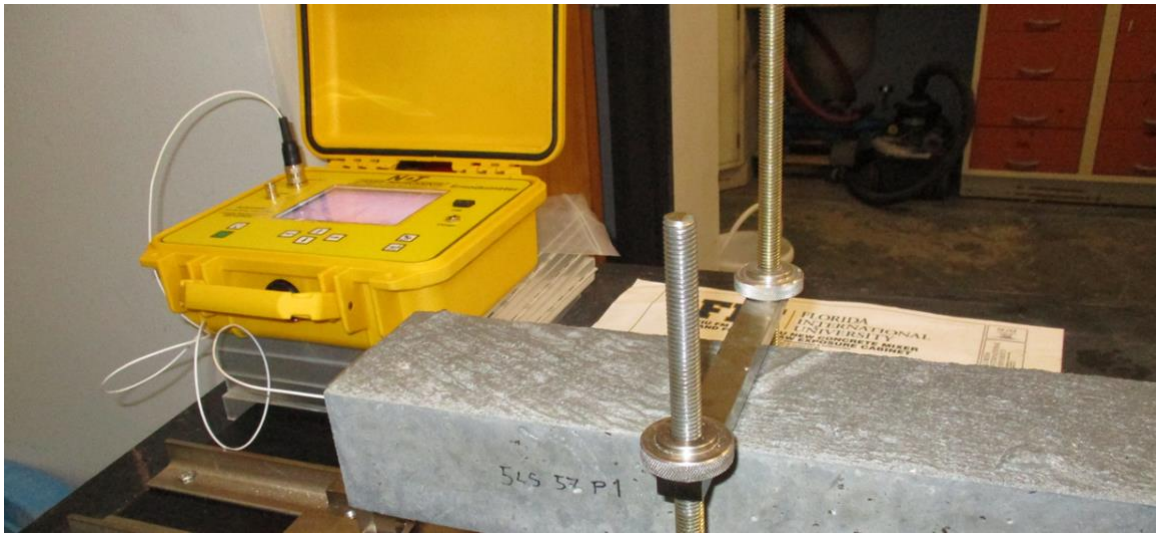


Figure 13. Resonant frequency testing

Figure 14. Damaged specimen after freeze/thaw testing

The relative dynamic modulus obtained from freeze/thaw testing was compared to concrete characteristics prior to testing including the water pressure test. As shown in Figure 10, comparison of the concrete electrical characteristics when in the wet condition showed better correlation to the outcomes of the freeze/thaw testing. Higher quality concretes with larger wet resistivity correlated to higher relative dynamic modulus, indicating that concrete quality provide better resistance to the physical stresses induced by the accelerated freezing and thawing cycling. Similarly, the concretes with higher capacitance (indicative of the higher internal moisture content) were more susceptible to damage by the freezing and thawing cycling.

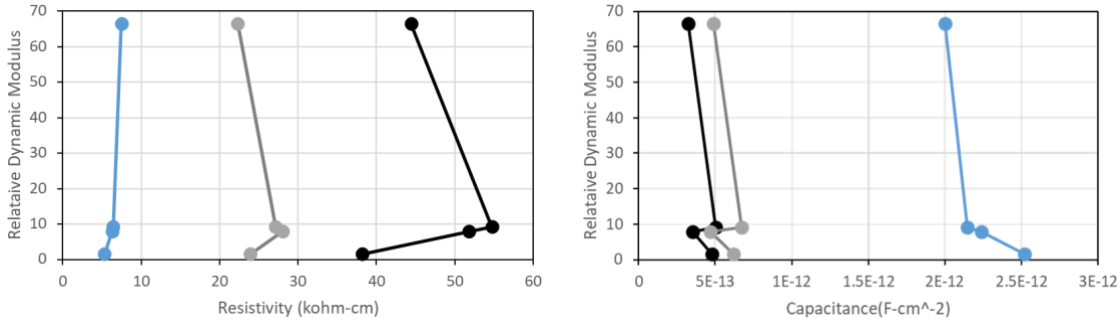


Figure 10. Comparison of concrete electrical characteristics to Relative Dynamic Modulus.

Blue: Wet Condition. Grey: 75%RH. Black: Dry Condition.

Figure 11, shows comparisons of the pressure decay factor for concretes in the wet, 75%RH and dry condition with the outcomes from the freeze/thaw testing. Concretes with the higher water-to-cement ratio would have lower strength, greater porosity and greater internal moisture content. With these characteristics, the damage caused by the accelerated freeze/thaw cycling were most aggressive as indicated but the low resolved relative dynamic modulus. These poorer quality (0.6 w/c) concretes had lower air content than the others (0.5 w/c). When dried out in the low humidity environments, the former did not allow as much water permeation. The water pressure drop test for the dried concrete thus showed a lower pressure decay factor for the poor quality concretes that

had greater susceptibility to freeze/thaw damage. On the other hand, when the specimens were maintained in a wet condition, the higher quality concrete more intuitively showed lower water permeation and less susceptibility to freeze/thaw damage.

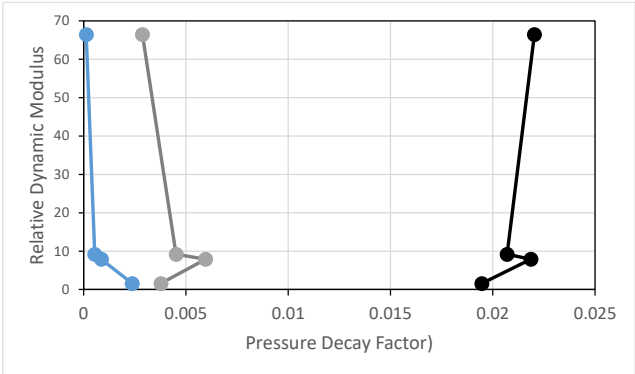


Figure 11. Comparison of Pressure Decay Factor to Relative Dynamic Modulus

Blue: Wet Condition. Grey: 75%RH. Black: Dry Condition.

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.

All experimental work completed, data processing and analysis in progress see section 4.

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.

Samples have been cast and conditioned. Samples are being prepared upcoming RCPT testing.

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.

All experimental work completed, data processing and analysis in progress see section 4.

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.

Preparing draft based on test results to be completed upon final analysis.

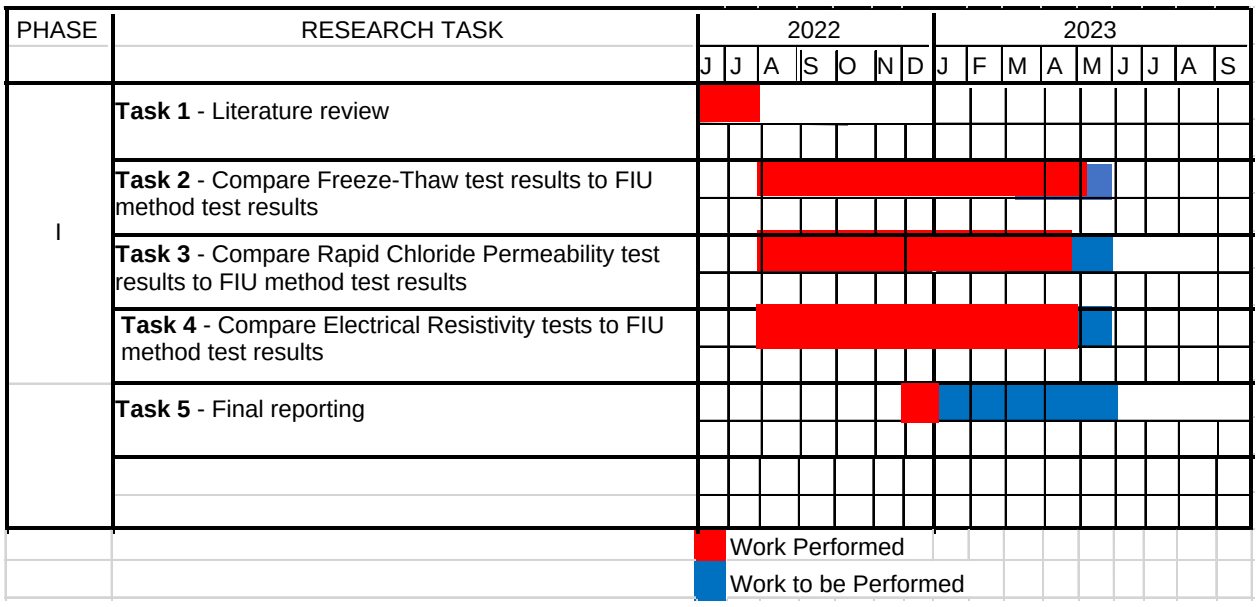
6. Expected Results and Specific Deliverables

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	95
Compare Freeze-Thaw test results to FIU method test results	90
Compare Rapid Chloride Permeability test results to FIU method test results	80
Compare Electrical Resistivity tests to FIU method test results	90
Final reporting	10



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.