Research Project Work Plan

for

STRATEGIES TO INCREASE THE SERVICE LIFE OF EXISTING BRIDGE DECKS

SPR 780

Submitted by

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for

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1.0 Identification

1.1 Organizations Sponsoring Research

Oregon Department of Transportation (ODOT)
Research Section
555 13th St NE
Salem, OR 97301 Phone: 503-986-2700

(If federal funds are used)
Federal Highway Administration (FHWA)
Washington, D.C. 20590

1.2 Principal Investigator(s)

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1.3 Technical Advisory Committee (TAC) Members

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Craig Shike, ODOT Bridge Section
Bill Bennett, ODOT Construction Section
Tim Rogers, FHWA

1.4 Research Coordinator

Steve Soltesz, ODOT Research Section Phone: 503-986-2851

1.5 Project Champion

Ray Bottenberg, ODOT Bridge Section

2.0 Problem Statement

Corrosion of the steel in reinforced concrete (RC) bridge decks is an important issue for structures that are exposed to chloride-containing de-icing chemicals or marine salts. Once the amount of chloride at the steel reinforcement reaches a critical level, corrosion is likely to initiate. ODOT has a large number of bridges that are vulnerable to this form of deterioration. Pre-emptive actions that prevent corrosion initiation are more cost effective than repair or replacement of bridge decks that have already experienced corrosion. An obvious indicator of a corrosion problem is visible damage; unfortunately, if corrosion damage is visible, the window for preventive action is likely closed.

ODOT uses chloride depth profiling on occasion to provide quantitative insight into the corrosion risk of bridge elements, but the method is time consuming and relatively expensive. It is also not practical for routine monitoring of bridge decks with current limited ODOT resources. Other measurement technologies are at various stages of maturity and are likely to be useful either by themselves or when used in combination. Whatever measures are used, values need to be turned into predictions about time to corrosion damage and when to apply these pre-emptive actions. Much valuable research is already available on detection technologies and models to predict corrosion.

Every year, ODOT treats the riding surface of select bridge decks with sealers, coatings and thin overlays to protect the decks from deicing chemicals. Currently, the mitigation actions are selected based on the judgment of field personnel, occasionally with additional data from chloride profiles. There is no routine methodology in place to select decks based on quantitative measurements coupled with time-to-damage predictions.

2.1 Background and Significance of Work

In recent years, electrical resistivity of concrete has emerged as a durability-related quantitative performance indicator. Several investigations have shown the existence of relationships between electrical resistivity and other durability-related parameters such as corrosion rate of steel reinforcement and transport properties of concrete. Alonso et al. (1988), Lopez and Gonzalez (1993) and Gowers and Millard (1999) reported that concrete resistivity and corrosion rate are inversely proportional over a wide range of concrete resistivity values. The literature also shows that concrete resistivity is strongly affected by the concrete characteristics, the degree of concrete pore saturation, and the chloride concentration (Rasheeduzzafar et al. 1995;Vico et al. 2004; Song and Saraswathy 2007). Low resistivity values are associated with high *w/c* values and/or high moisture contents (Neville 1996; Morris, Vico et al. 2004).

Lately, surface resistivity (SR) measurements of concrete cores have been replacing the widely-used Rapid Chloride Permeability Test (RCPT) because both tests provide a measure of resistance of concrete to ionic movement under an applied electrical potential difference. In most cases, RCPT and SR measurements have nearly perfect correlation (Hooton et al. 2012); while RCPT takes many hours to complete, SR

measurements can be taken in seconds. Several researchers have also shown in studies on cores extracted from RC structures and laboratory-produced cylinders that SR measurements are also strongly correlated well with water permeability (Kessler et al. 2005) and bulk chloride diffusion coefficient (Hamilton et al. 2007; Sengul and Gjorv 2008) of concrete.

All these developments have led to increased efforts to standardize SR measurement procedures (AASHTO TP 095-11UL 2011; CAN/CSA A23.2 2009; ASTM WK37880 2014). A number of jurisdictions even started requiring resistivity measurements as part of ongoing construction and maintenance procedures (FM 5-578 2004; MTO LS-444 2013). Consequently, a number of companies producing SR measurement devices have been increasing, while the cost of units for SR measurements has been declining. The current cost of a typical SR probe ranges from $3,000 to $5,000.

Resistivity of concrete can be measured in a number of ways; however, the four-point Wenner probe technique is the most commonly used approach for field application because of its speed, simplicity, and practicality. It can be used to measure resistivity of concrete cores extracted from concrete structures, but it can also be used directly on concrete surfaces without the need of coring or without the need for access (i.e., connect) to the steel reinforcement (as in the case of half-cell potential measurements). In all cases measurements are made in seconds. There are, however, a number of gaps in the literature and practical challenges before SR data can provide quantitative insight into the corrosion risk of bridge decks. These gaps and challenges are summarized as follows:

1. Most studies that demonstrated strong correlations between SR measurements and durability-related performance indicators (e.g. water permeability, RCPT data, and bulk chloride diffusivity) have been conducted on cores extracted from concrete structures or laboratory-produced concrete cylinders. However, establishing such correlations on riding surfaces of bridge decks can be confounded by the presence of reinforcement in the deck. It has been shown by a number of researchers (Millard 1991; Gowers and Millard 1999; Weydert and Gehlen 1999; Sengul and Gjorv 2009; Moreno et al. 2009, Salehi 2013) that electrical resistivity measurements can be affected by the density, depth, bar size, type, and orientation of steel reinforcement (with respect to the probe) in the deck. The use of SR data as a quantitative decision-making aid for selecting treatment options and timing for bridge decks will likely require correction of the measurements to minimize the reinforcement effect.

2. Moisture content of concrete affects electrical resistivity measurements; i.e., for the same concrete (with the same amount of chloride ingress), different resistivities will be measured depending on the degree of saturation of concrete (Neville 2011). To obtain consistent and comparable SR measurements, the moisture content of concrete needs to be relatively similar between different

measurements. This can be achieved relatively easily in extracted cores by always measuring SR after saturating the specimens; however, saturating the bridge decks before SR measurements will seldom be practical. Therefore, a new method for correcting for the effect of moisture content of concrete will need to be developed to ascertain that the SR values that are measured at different times are comparable even though moisture contents of the deck might be different in each measurement.

3. ODOT uses Polyester Polymer Concrete (PPC), Multi-Layer Polymer Concrete Overlays (MPCO) Silica Fume Concrete (SFC) overlays, crack sealers, and concrete sealers as methods of bridge deck preservation in Oregon (Lundy and Sujjavanich 1997). When the bridge decks have these overlays, SR measurements might need to be corrected for the thickness and the type of the overlay before values can be used as a quantitative indicator – particularly when the overlay is thin or applied partially over depth of the cover above the reinforcement.

4. Although SR measurements are highly correlated with water and chloride transport properties of concrete, they do not provide the actual chloride depth profiling. However, transport properties that are revealed by SR measurements can be used in chloride ingress models that can be used to predict chloride profiles in concrete. The accuracy of the predictions will improve with additional quantitative data such as environmental history (temperature, relative humidity, and precipitation) and amount of salt exposure. Some of these additional quantitative data are readily available, but in some cases educated assumptions might need to be made. These predictions, coupled with SR data, will also indicate if additional chloride profiling is necessary, and if so, at which locations on the deck it should be conducted.

5. Currently there is no routine methodology and decision matrix in place to select decks for pre-emptive action (e.g., use of sealers or coatings, or replacement of contaminated layers of the deck with SFC or PPC overlays). Methodologies should be based on quantitative measurements coupled with predictions regarding time-to-corrosion damage. A methodology based on Oregon service conditions is needed.

3.0 Objectives of the Study

The objective of the research is to provide ODOT with a protocol to select bridges for its ongoing bridge deck treatment operations using quantitative tools that are practical and quick. These quantitative tools will be in the form of concrete SR measurements, time-to damage predictions, and when necessary, strategically-selected chloride depth profiles. Specific objectives include the addressing of the five gaps and challenges that are identified in Section 2.1.

3.1 Benefits

For concrete bridge decks, the ability to measure the electrical resistivity of concrete directly from the deck surface without the need to extract cores could be extremely beneficial. Large surfaces can be mapped over relatively short durations with resistivity measurements. If a routine, quantitative methodology based on SR measurements can be coupled with time-to-damage predictions, ODOT will reduce the subjectivity and costs that are associated with the selection and timing of the treatments of the riding surface of bridge decks to protect them from deicing chemicals. Although SR measurements do not provide the actual chloride depth profile of the deck, the resistivity measurements coupled with time-to-damage predictions can indicate if chloride profiling is necessary, and if so, at which locations on the deck it should be conducted. ODOT will not have to spend valuable resources and time on excessive and unnecessary chloride profiling and will minimize the risk of not conducting chloride profiling at critical areas of the bridge decks. Overall subjectivity of the current practices will be replaced with quantitative and repeatable protocols.

4.0 Implementation

It is anticipated that the Bridge Design and Drafting Manual will be revised to detail acceptable corrosion test methods for concrete structures and identify corrosion mitigation actions for different levels of chloride exposure. The project investigators will provide workshops to ODOT personnel on using the techniques developed in the research. The project results will be broadly disseminated through the final report, journal articles, and conference presentations.

5.0 Research Tasks

Task 1: Literature Review and the Development of Detailed Research Plan

This task will involve reviewing the literature related to the objectives of the research and develop the detailed research plans for the laboratory and modeling studies. The task will be performed by the co-PIs of the project and a graduate student. The main goal of this task are to (1) establish current practices, (2) identify the main parameters of the laboratory study, (3) develop the framework for the modeling study, (4) establish a plan for merging laboratory and modeling work toward the development of a bridge deck evaluation protocol. A preliminary literature review will be performed during the preparation of the detailed research plan. A full literature review will be provided with the final report.

Time Frame: 3 months for the detailed research plan and preliminary literature review; 16 months for full literature review
Responsible Party: OSU Team at OSU Facilities
Cost: $18,500

Deliverable: Detailed research plan with preliminary literature review; full literature review as part of the final report
TAC Decision/Action: Review; comments; required modifications; and approval of research plans.

Task 2: Laboratory Study

This task will involve executing the experimental plan for the laboratory study. The laboratory study will investigate the factors affecting SR measurements on reduced-size reinforced concrete (RSRC) slabs (simulating bridge decks commonly used in Oregon). RSRC slabs will be cast at the OSU outdoor exposure site. The main parameters of the investigation will be (1) concrete type (selected ODOT types), (2) cover thickness, (3) reinforcement spacing, (4) moisture content (degree of saturation), (5) chloride content, and (6) the effect of freeze-and-thaw action. It is estimated that a total of 24 slabs will be cast for the laboratory study. The effect of cracking on SR measurements is currently studied under another project led by one of the PIs of the current work; therefore, cracking will not be considered as one of the investigated parameters. The results of the ongoing study on the effect of cracking on SR will be used in the current project.

The slab dimensions will be sized to accommodate multiple measurements from different locations on the concrete surface; therefore, replicate specimens are not required. The thickness of the slabs and rebar size will be constant representing typical ODOT bridge decks. Table 1 provides a draft listing of the test parameters and the number of specimens to be tested. It should be noted that measurements under different degrees of saturation do not warrant new samples; all specimens will be tested in wet, dry, and partially saturated conditions. Because the control of the degree of saturation is difficult in the field, the moisture content of the specimens will be determined at the time of the measurements. Specific mixture proportions for concrete types will be determined based on current ODOT practices and interests.

In Table 1, four types of concrete are listed for the purpose of estimating the number of specimens that will be cast in the laboratory study. ODOT will provide additional details about the required concrete types during the preparation of the detailed experimental plan. Slabs will have unreinforced sections from which cores can be extracted at regular intervals for detailed laboratory studies such as chloride profiling, moisture content and RH determination, bulk resistivity measurements, and mechanical testing. Throughout the testing duration, baseline measurements will be taken from control cylinders that will be cast during the production of the slabs for the purpose of normalizing the slab data.

Within the first three months after casting of the slabs, SR measurements (using Wenner probe and laboratory-grade techniques that are not vulnerable to the limitations of the Wenner probe) will be collected from wet, dry, and partially-saturated slabs. After three months and for the next 12 months, the slabs will be exposed to $MgCl_2$ solutions (concentration to be specified in detailed experimental plan) to simulate field conditions. The chlorides will be transported into the concrete via a cyclic ponding and drying

process (the durations of the cycles will be specified in the detailed experimental plan) to accelerate the chloride ingress realistically. Regular chloride depth profiling will allow the researchers to monitor the chloride ingress, and if it is deemed necessary to increase the rate of penetration, the exposure regime will be adjusted. Half-cell potential monitoring will be conducted regularly to check if corrosion has initiated. During this time surface resistivity data will be collected using the same aforementioned techniques, and cores from unreinforced parts of the slabs will be extracted regularly for detailed laboratory investigations.

As shown in Table 1, three slabs (and accompanying control cylinders) will be exposed to F/T cycles after different levels of chloride exposure. During the F/T cycles SR data will be collected to investigate the effect of F/T damage on SR measurements. One slab will be used as control (no chloride exposure); the second and third slabs will be exposed to F/T cycles after being exposed to chlorides for (approximately) 6 months and 12 months, respectively. The F/T exposure protocol will be specified in the detailed experimental plan.

Table 1 – Estimated Number of Specimens for the Laboratory Study

	Number of Cases			
Concrete Type / Parameter	Type 1	Type 2	Type 3	Type 4
Water-binder ratio	3	1	1	1
Concrete cover	3	1	1	1
Rebar spacing	2	1	1	1
F/T action	3	0	0	0
Number of Specimens	**18**	**1**	**1**	**1**
Total	**21**			

Time Frame: 22 months
Responsible Party: OSU Team at OSU Facilities
Cost: $110,000
Deliverable: Research report on the laboratory study
TAC Decision/Action: Review; comments.

Task 3: Modeling Study

This task will involve executing the modeling plans for the research program. The modeling study will address a number of challenges: (1) correction of concrete resistivity measurement for varying moisture content using available environmental data (temperature, relative humidity and precipitation) from the days prior to the SR measurement date as well as for the presence of reinforcement; (2) predicting chloride profiles in concrete using SR measurements, environmental data, and salt ($MgCl_2$)

exposure history, and; (3) making time-to damage predictions to guide the selection of bridge decks for pre-emptive corrosion mitigation procedures.

The main modeling studies to develop the procedures for correcting the variability introduced by cover thickness, concrete type, the degree of saturation, and steel reinforcement will be carried out using a commercial software package that is already available at OSU. However, models that will be delivered to ODOT will be in the form of easy-to-use, intuitive and user-friendly software tools for ODOT inspection engineers. Using these models ODOT personnel will be able to (1) decide if chloride profiling is necessary, and if so, on which locations on the deck these measurements should be performed, (2) predict chloride profiles using SR measurements, environmental data, moisture content predictions, and salt exposure history, and (3) make time-to damage predictions.

Time Frame: 20 months (overlapping with the laboratory study)
Responsible Party: OSU Team at OSU Facilities
Cost: $74,000
Deliverable: Research report on the model development; Software tools for (1) deciding if and where chloride profiling should be performed, (2) predicting chloride profiles, (3) predicting time-to-damage.
TAC Decision/Action: Review; comments; software testing.

Task 4: Development of Bridge Deck Evaluation Protocol

This task will involve merging the results of the laboratory and modeling studies to establish a routine methodology and decision matrix to select decks for pre-emptive action based on quantitative measurements coupled with predictions about time to corrosion damage. This task will also involve the execution and verification of the established bridge deck evaluation protocol for a selected bridge deck. The details of this field verification process will be decided in collaboration with ODOT during the preparation of the detailed experimental plan.

Time Frame: 12 months
Responsible Party: OSU Team at OSU Facilities, ODOT
Cost: $23,000
Deliverable: Bridge deck evaluation protocol; field verification; workshop for ODOT staff.
TAC Decision/Action: Review; comments.

Task 5: Final Report:

A final report will be developed to document the efforts undertaken in this research project.

Time Frame: 8 months

Responsible Party: OSU Team at OSU Facilities
Cost: $13,500
Deliverable: Final report
TAC Decision/Action: Review; comments.

5.1 Reporting

All reports shall be produced in the standard ODOT Research Section report format provided to the Project Investigator by the Research Coordinator unless some other format is deemed to be more appropriate. The Project Investigators shall be responsible for submitting reports of professional-level written composition equivalent to the writing standards of peer-reviewed journals. These writing considerations include grammar, spelling, syntax, organization, and conciseness.

The Project Investigators, in consultation with the TAC and Research Coordinator, shall deliver to ODOT in electronic format the data produced during the project. The Project Investigators shall assure the data are labeled and organized to facilitate future access. ODOT shall warehouse the data.

5.2 Safety and Related Training

OSU CCE Infrastructures Materials Group has written safety procedures to be followed in its laboratories and the outdoor exposure site. All OSU personnel who will be working in the project will complete safety training prior to their initial involvement.

Prior to accessing ODOT right-of-way (ROW), all personnel who will work on ODOT ROW shall complete safety training appropriate to the work to be performed within the ROW. The Project Investigator shall notify the Project Coordinator in writing (email accepted) prior to the first day of work within the ROW that all project personnel who will access ODOT ROW have been trained. Until all ROW work is completed, the Project Investigator shall notify the Project Coordinator in writing (email accepted) annually that safety training appropriate to the work to be performed within the ROW has been completed by all personnel who will work on ODOT ROW.

6.0 Time Schedule

Task	2014						2015												2016								
	FY15												FY16												FY17		
	Jul – Sep			Oct – Dec			Jan – Mar			Apr – Jun			Jul – Sep			Oct – Dec			Jan – Mar			Apr – Jun			Jul - Sep		
1. Plan			*																								
2. Laboratory																*											
3. Modeling																		*						W			
4. Protocol																				*							
5. Report																					R1			R2			F

*Deliverables
W - Workshop
R1 - Draft report submitted for ODOT for initial feedback.
R2 - Draft report submitted for ODOT for final review.
F - Revised report submitted to ODOT for publication. End of contract.

7.0 Budget Estimate

Task	FY2015	FY2016	FY2017	Total
Task 1: Plan	$18,500	0	0	$18,500
Task 2: Laboratory	$65,000	$45,000	0	$110,000
Task 3: Modeling	$39,000	$35,000	0	$74,000
Task 4: Protocol	0	$23,000	0	$23,000
Task 5: Report	0	$11,500	2,000	$13,500
Total for tasks (Contract amount)	**$122,500**	**$114,500**	**2,000**	**$239,000**
ODOT support/management	$5,000	$6,000	2,000	$13,000
Total for ODOT	**$127,500**	**$120,500**	**4,000**	**$252,000**

8.0 References

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