Scoping Level Project Completion Report

Project X0919 – Water Resistant Concrete

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Project Summary

While concrete is one of the most durable manmade materials, it has a fundamental flaw. Concrete was often formed with the evaporation of water beyond what is required for the hydration reaction, resulting in a porous concrete matrix with small capillaries and pores. Water from the environment may fill and occupy these voids. When the water freezes, the water occupying these voids expands and creates stresses leading to tiny cracks. Repeated freeze-thaw cycles may lead to ever-enlarging cracks causing the concrete to spall. This is a problem affecting older Reclamation concrete structures - typically those constructed prior to the use of air-entrainment admixtures.

Two research questions were posed for this project:

1. Is it possible to protect Reclamation concrete structures from damages due to freeze-thaw action and undesirable chemical reactions from reservoir water intrusion?

2. What is the best research strategy to investigate ways to prevent water intrusion resulting in freeze-thaw damages and undesirable chemical reactions in concrete?

The primary activities of this scoping level project were to perform a literature review, refine the research needs, and further develop research partnerships.

During literature research, one of the more promising means of preventing freeze-thaw damage appears to be various types of crystalline chemical reactions that can penetrate into the voids of the concrete matrix. This particular means of preventing water intrusion became the primary focus of this scoping level project. In simple terms, a solution of organic and/or ionic chemicals is applied to the surface of the concrete and allowed to penetrate into the concrete matrix, usually by capillary action or electro-osmotic flow. Through solid-liquid separation within the concrete matrix, solutes from the liquid react and transforms to an insoluble crystalline phase compatible with the concrete. As a result, voids within the concrete matrix are reduced to prevent further intrusion of liquid water from the environment and the crystalline phase becomes an integral component of the concrete adding to its strength and durability. A class of crystalline chemical reactions that appeared to be the most popular involves the use of lithium compounds. Various lithium compounds, such as lithium carbonate, lithium hydroxide, and lithium sulfate, are already used in the formulation of chemical admixtures for calcium-aluminate-cement concrete. Other lithium compounds, such as lithium nitrate, have been used to control alkali-silica reactions in Portland cement concrete. Lithium silicate has also been extensively used as a chemical “hardeners” for concrete.

In addition to freeze-thaw damage, water-intrusion chemical reactions may also contribute to the deterioration of the concrete. Examples of these chemical reactions include gypsum formation (e.g., sulfate attack) and alkali-aggregate reactions (i.e., alkali-silica and alkali-carbonate). While the focus of

this scoping project is prevention of freeze-thaw damage in older hardened concrete, it is possible that the prevention of water intrusion by crystalline chemical reactions may also prevent these undesirable water-intrusion chemical reactions.

Recommendations for Continuing Research

From the literature research performed during this scoping level effort, a number of questions or knowledge gaps were found. More research is required before the Technical Service Center can confidently recommend a particular means of preventing freeze-thaw damage on Reclamation concrete structures. Scientists from the Technical Service Center should actively seek out other scientists performing similar work to share and advance the state of the knowledge of freeze-thaw damage, such as those from the U.S. Army Engineer Research and Development Laboratories (ERDL). The Army Corps of Engineers maintains the largest inventory of critical concrete infrastructure in the nation and is also experiencing significant problems with concrete deterioration, including freeze-thaw damage. Individuals who expressed interest in collaborating on this research are Dr. Paul Mlakar from ERDL, Kurt Von Fay and Bret Robertson from the Technical Service Center (86-68180, Materials Engineering and Research Laboratory).

Below is a short listing of research experiments that can be readily performed in the Technical Service Center laboratories:

1. Laboratory Evaluation of Commercial Products. There currently exist a large number of commercial products that claim to provide “water-proofing” for pre-existing or hardened concrete. They are usually used as sealants, coatings, membranes or overlays. Of particular interest is a group of commercial products called “penetrants”, which rely on penetrating crystallization chemical reactions within the concrete matrix to seal off capillaries, hairline cracks, and shrinkage cracks. Much of the formulations available commercially are proprietary and claims vary widely across industry. It is recommended that the Technical Service Center undertake a standardized approach in testing commercial products that may be used on Reclamation facilities. One possibility is to perform a series of laboratory freeze-thaw durability testing. ASMT Method C-666/C-666M – 03 (2008) describes standard procedures for testing the resistance of concrete to an accelerated program of repeated freezing and thawing cycles in the laboratory. The Technical Service Center has laboratory equipment that can subject concrete specimens to 9 freeze/thaw cycles per day. Reclamation minimum criteria for acceptable concrete is 500 cycles before 25% weight loss of a 3-inch x 6-inch cylinder. The basic procedure would involve side-by-side comparison of treated and non-treated (control) concrete cylinders to test their relative durability.

2. Penetration Depth. In the literature, penetration depth appeared to be a critical parameter and well correlated with the effectiveness of crystalline chemical reactions in preventing freeze-thaw damage. In conjunction with the laboratory freeze-thaw testing described above, cross-sections of concrete cylinder specimens can also be tested by X-ray analyses (e.g., X-ray fluorescence) to measure penetration depths of commercial products under standard conditions. Penetration into the concrete matrix may be affected by simple capillary action (topical treatment only), electro-osmotic force, or vacuum impregnation.

3. Treatment of Older Concrete. Unfortunately, Reclamation currently has a large inventory of concrete structures that is not modern – made prior to the use of air-entrainment technology

that can be damaged by freeze-thaw. A key question to be answered is at what point during concrete freeze-thaw deterioration are cracks too far advanced to derive any benefits from crystalline chemical reactions. While capillaries and hairline cracks may be affectively sealed with the application of crystalline chemical technologies, it may not be as effective for concrete with advanced freeze-thaw deterioration. Testing of actual concrete specimens in varying stages of freeze-thaw damage would help further our understanding of the limits of using crystalline chemical reactions to prevent further freeze-thaw damage.

4. Effect of Treatment on Concrete Properties. The use of any treatment on hardened concrete to prevent freeze-thaw damage may affect the structural properties of the concrete, both negative and positive. In parallel with the laboratory freeze-thaw testing described above, treated and non-treated (control) concrete specimens should be tested to compare standard structural properties before and after the application of crystalline chemical reactions.