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Future Utilization of Electro-Osmotic Pulse Technology on Concrete Structures

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14. ABSTRACT
Electro-Osmotic Pulse (EOP) technology has the potential to stop water leaks in small cracks, move water to drainage locations, and dry out concrete. Previous research sponsored by the Research Office involved EOP installation in the Bonnet Chamber and headgate shaft at Trinity Dam. The reduced seepage and drying of the concrete walls show that EOP can mitigate many water-related problems from the interior of affected areas. It is an effective tool to consider when attempting to stop leaks through concrete. These trials were specific and limited in scope to solving the issue of leakage through cracks and pores. Further investigations at other Reclamation facilities to determine the effective limits of the technology have been recommended and to determine if the technology can remedy other issues at Reclamation. EOP may be useful in solving issues of freeze-thaw and alkali-silica reaction (ASR) damage at some facilities. It may also be effective in diverting water into a drainage system thus preventing or limiting ice formation on the downstream face of dams.

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Electro-Osmotic Pulse, EOP, Calcite, Water Leaks, Ice Formation

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Acronyms and Abbreviations

A	Amperage
ASR	Alkali-Silica Reaction
EOP	Electro-Osmotic Pulse
I	Current
MMO	Mixed-metal oxide
MPCO	Mid-Pacific Construction Office
NCAO	Northern California Area Office
Reclamation	Bureau of Reclamation
V	Voltage
V_{AC}	Alternating current voltage
V_{DC}	Direct current voltage
R	Resistance
Ω	Ohms

Measurements

ft	feet
hrs	hours
V_{AC}	Alternating current voltage
V_{DC}	Direct current voltage
Ω	Ohms

Executive Summary

Reclamation's concrete structures are unique, since they are usually large, older, and have water and power delivery requirements for many users. Uncontrolled water seepage through concrete can cause extensive damage to the structure and /or equipment, unscheduled downtime, increased risk to personnel, and can necessitate expensive repairs. This damage can include, but is not limited to, corrosion affecting the reinforcing steel causing cracks and potential structural failure, increased maintenance due to ice formation, and inoperable drains amongst others. Grouting has historically been used to mitigate leaks; however, it may only be a temporary fix and does not prevent seepage through the pores and very fine cracks.

The Research and Development Office's Science and Technology Program previously sponsored a project to test the technology at Trinity Dam in northern California which involved three phases. Phase 1 and 2 involved installing an EOP system in a small test area of the Bonnet Cover Chamber at Trinity Dam and evaluating the effectiveness of the system in drying out a thick section of concrete. This site did not involve any cracks but rather the water seepage was from leaking joints and cracks from the shaft above the chamber. Phase 3 involved installing an EOP system in the Intake Gate Shaft at Trinity Dam. This EOP system was installed as part of the Trinity Dam Intake Gate Shaft Refurbishing (Phase 1) project which involved cleaning a significant buildup of calcite off the walls, chemically grouting leaking cracks and joints, and EOP system installation. The EOP system was installed in the bottom 40 feet of the headgate shaft in a location where there were numerous cracks. A significant amount of crack repair was required prior to the installation of the EOP system both in the location of the system as well as other parts on the headgate shaft.

EOP is preventing most of the water from seeping through the concrete walls minimizing new calcite build-up. Several installation and operation issues became evident during installation and evaluation. Current issues include the existence of cracks not grouted and seepage from above the installation.

EOP appears to have stopped leaks in some small cracks that were not grouted, likely due to the slower leakage rate allowing calcite to plug the cracks. Resistance has increased over time at a constant voltage and total current decreased. Resistance of the concrete between the anode and cathode is inversely related to the moisture in the concrete, so as resistance increases moisture content decreases.

Results of research at Trinity Dam to reduce seepage show that EOP technology can mitigate some water-related problems. Based on the results of the installations at Trinity Dam, presented in MERL-2012-10 [1] and ST-2018-4553 [2] it was decided to investigate the limitations and other uses of this technology regarding other common Reclamation problems. EOP may also be useful in solving the issues of freeze-thaw and alkali-silica reaction (ASR) damage at several facilities. This technology may also be effective in diverting water into a drainage system thus preventing or limiting ice formation on the downstream face of dams such as

Yellowtail Dam in Montana and Angostura Dam in South Dakota. Issues such as inoperable drains or water moving through lift lines may not be mitigated solely with grouting. Electro-Osmotic Pulse technology has the potential to economically decrease the moisture content in the concrete and move water to drainage locations on a long-term basis.

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1 Introduction

Electro-Osmotic Pulse (EOP) is a technology which can be used not only in preventing water leakage through pores, cracks, joints but also has other potential applications. Initial field trials at Reclamation have successfully demonstrated the viability of EOP in reducing seepage through concrete in a gate chamber subject to high hydrostatic head [1, 2]. Details of this installation and results are summarized below. The current scoping-level study explores additional use cases related to Reclamation infrastructure and associated practical limitations. The goal of this project is to assess the feasibility of deploying EOP technology to solve other issues stemming from water leakage and moisture content.

1.1 Project Background

1.1.1 Overview of Electro-Osmotic Pulse

Electro-Osmotic Pulse (EOP) is a technology typically used in conjunction with grouting and concrete repair to be a long-lasting solution for water intrusion through concrete. In conversations with the U.S. Army Corps of Engineers in 2010, their staff indicated that EOP systems installed at their facilities (lock galleries, basements, munition bunkers, etc.) may have a lower life-cycle cost than conventional repair methods, such as chemical grouting. One important benefit of this technology is that excavation of a buried structure is not required which can be a major expense.

This technology uses current and electric fields to drive water away from the anode towards the cathode essentially forming a barrier to water intrusion from the external surface, or for thick sections of concrete, a barrier within the concrete. Figure 1 shows an illustration of a typical EOP system layout and operation. An illustration of the result of a properly designed system is shown in Figure 2. A more detailed discussion on the principles of EOP operation is presented in Chapter I of MERL-2012-10 [1].

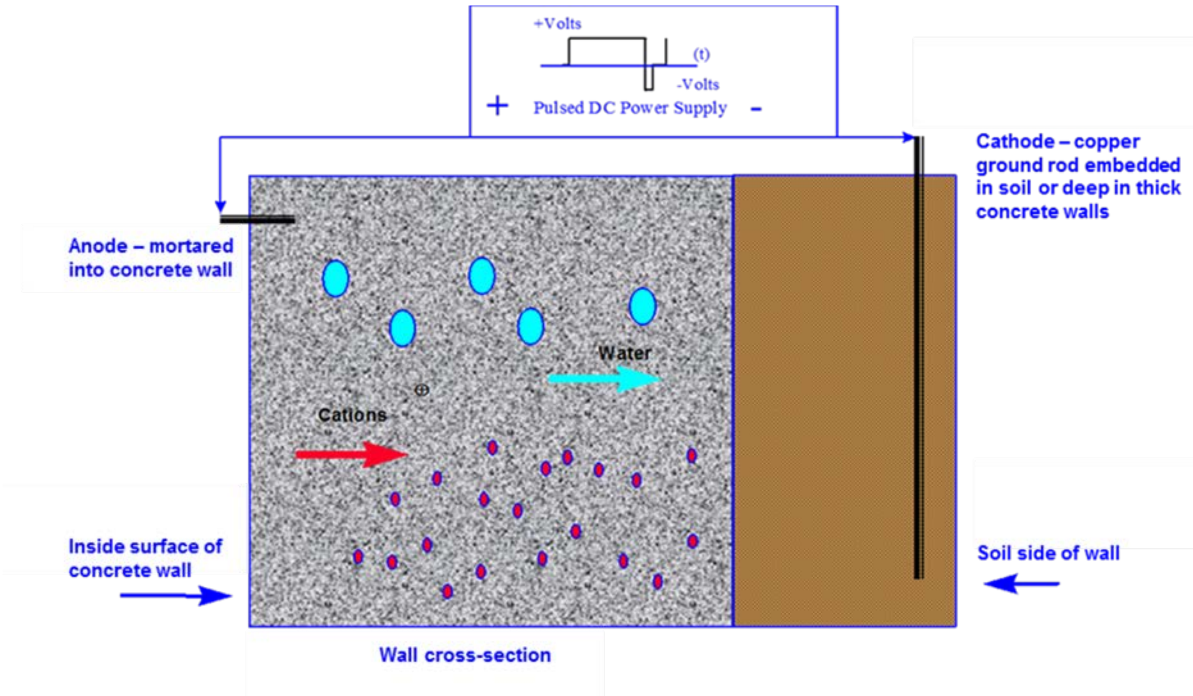

Figure 1. Illustration of cations and water molecules moving from anode to cathode on a macro scale with the application of EOP to dehydrate concrete.

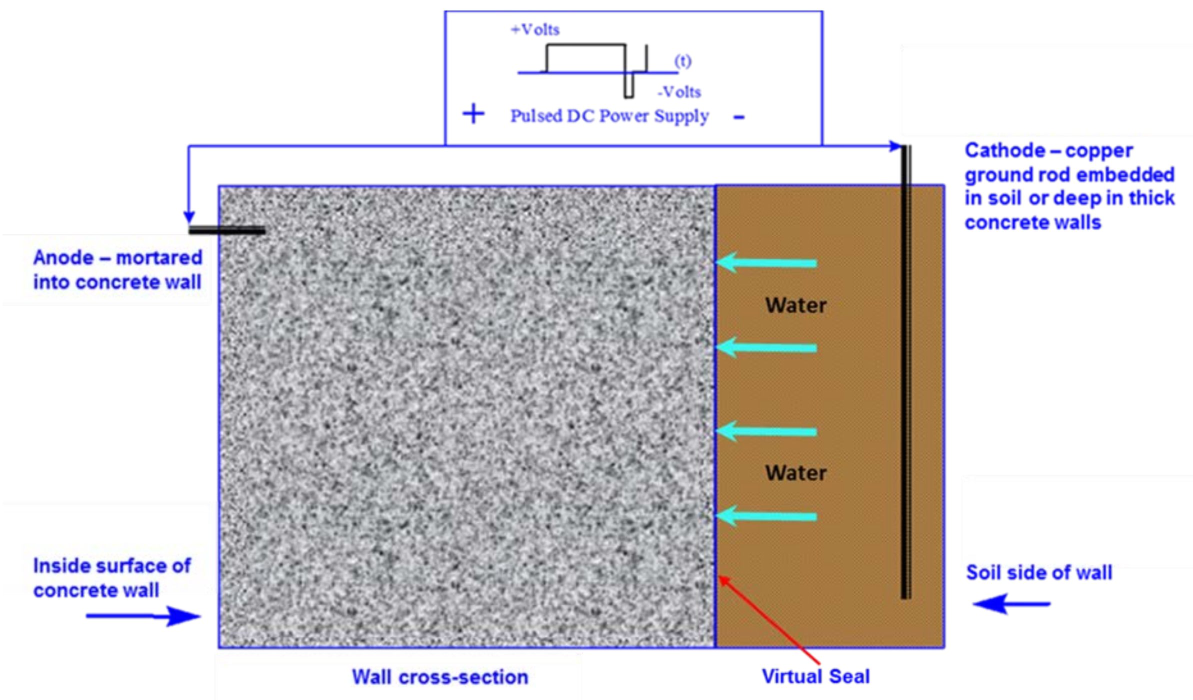

Figure 2. Illustration of the effects of the application of EOP to create a virtual seal or barrier to prevent water from entering the concrete on a macro scale.

1.1.2 Previous Research Performed

Problem

Electro-Osmotic Pulse systems were installed at Trinity Dam near Redding, California, to test the technology's ability to stop water leaking into the headgate shaft. Standing water on the bonnet chamber floor was causing corrosion of the headgate bonnet cover, air inlet pipe, and other metal structures, as shown in Image 1a and b. Failure of the air inlet pipe would result in complete flooding of the chamber and cause water to flood the tunnel to the powerplant yard if the door was not sealed shut. Sealing this door was difficult due to the corrosion and calcium carbonate build-up on the walls and door hinges. The leaks are mainly from cracks and joints in the shaft. The specific cause of the cracks was not determined; however, it was determined the cracks are not from a concrete deterioration mechanism and most likely from initial concrete shrinkage.

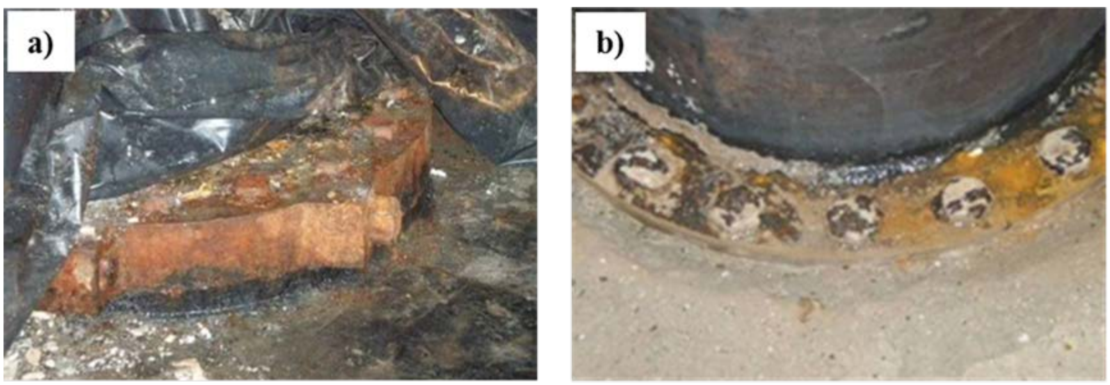

Image 1. Corrosion of the bonnet cover and air inlet pipe due to the standing water [1,2].

Water leaks had caused significant calcite build-up in the shaft, preventing removal of the headgate for maintenance and repair. Calcium carbonate (calcite) forms when water containing calcium ions reacts with carbon dioxide in air. In some areas, the seepage over time resulted in stalactite formation. The walls of the shaft were covered with calcite as shown in **Error! Reference source not found.**Image 2a - f. In some areas of the shaft it was reported that the calcite was as thick as 6 to 8 inches [3]. Calcite in the gate shaft guides prevents removal of the headgate for inspection and maintenance. The upstream face of the gate has not been inspected since installation other than an underwater inspection utilizing a remotely operated vehicle in October 2016 [4]**.**

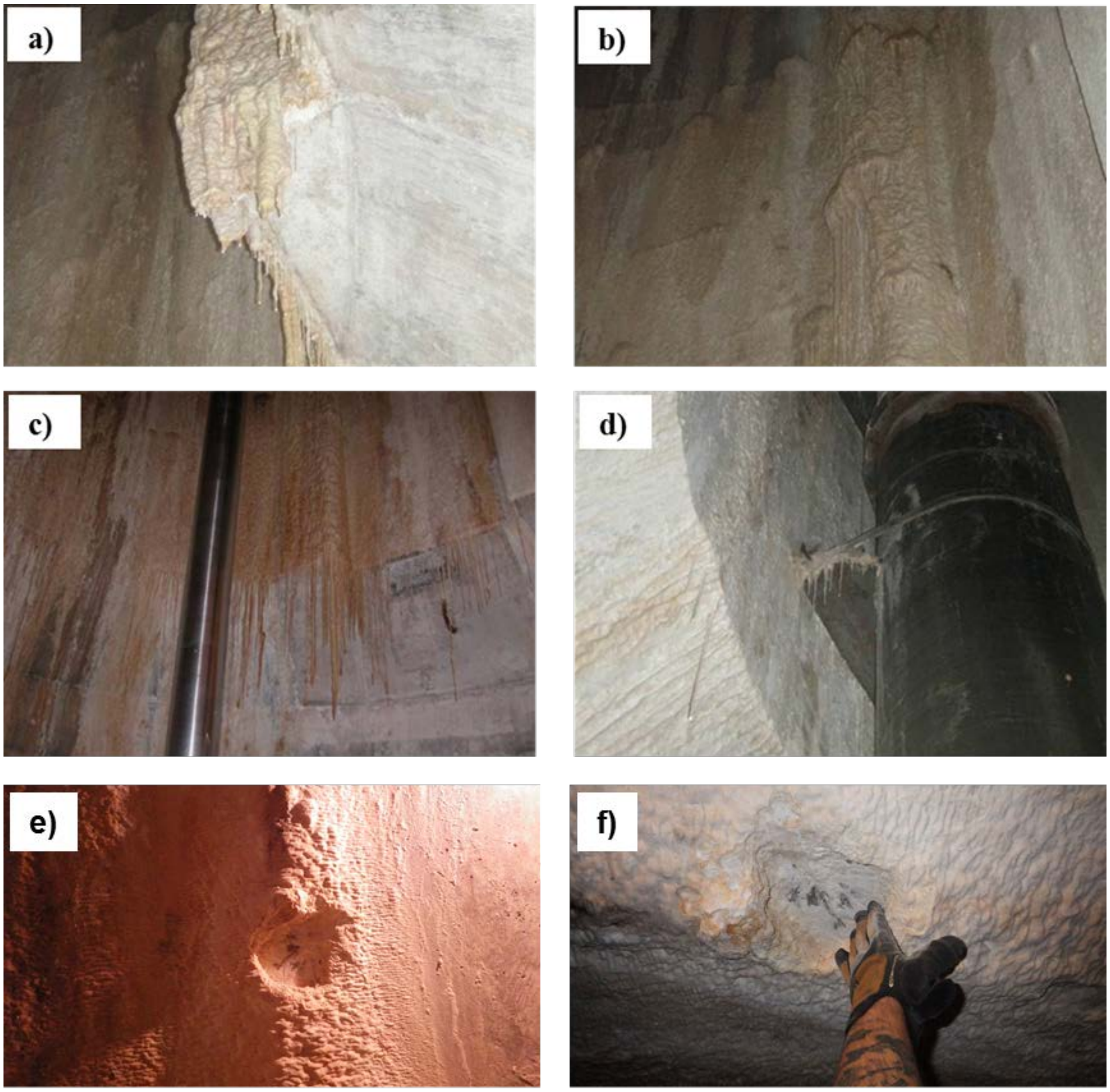

Image 2. Calcite deposits observed on the walls of the headgate shaft. Excessive seepage over time has resulted in stalactites and corrosion of air vent supports [1,2].

Synopsis of Previous Installations

Installation Typical anode materials for EOP installations are Mixed-metal oxide (MMO) coated titanium mesh strips, shown in Image 3a and b. Anodes for both Phase 2 and Phase 3 were installed in 1-inch wide by 1-inch deep (Image 4**Error! Reference source not found.**). Phase 2 also used MMO coated titanium mesh strip cathodes, installed in holes drilled approximately 20 inches deep. Phase 3 cathodes were copper coating steel rods installed in holes approximately 27-inches deep. Cathode installation for Phase 2 is shown in Image 6 and a schematic of the installation for Phase 3 is shown in Figure 3.

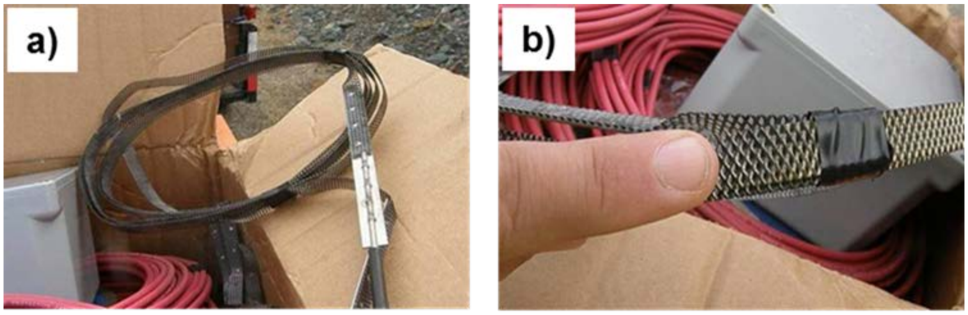

Image 3. Mixed metal oxide coated titanium mesh strip type anodes (a and b) and cathodes (c and d) installed in the concrete wall [1].

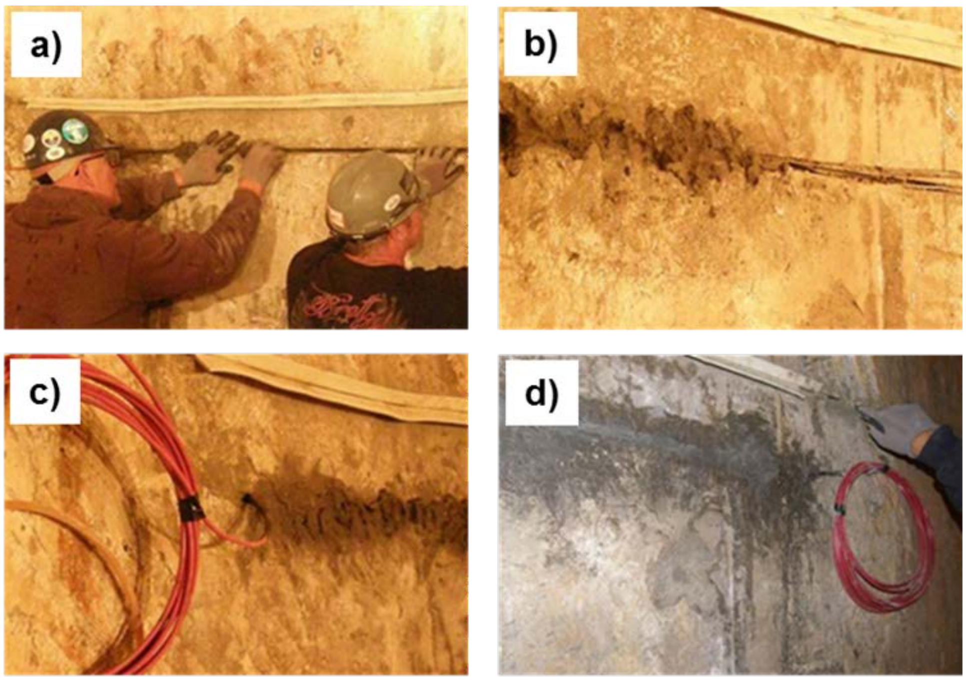

Image 4. Installation of upper strip anode and hand packing of Portland cement grout into the groove shown in photos a), b) and c). Photo d) shows finished installation of upper anode strips and cable [1].

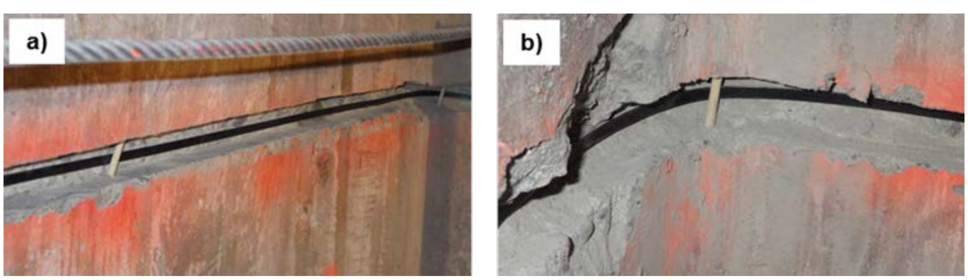

Image 5. MMO anode ribbons installed in grooves and held in place using wooden dowels [2].

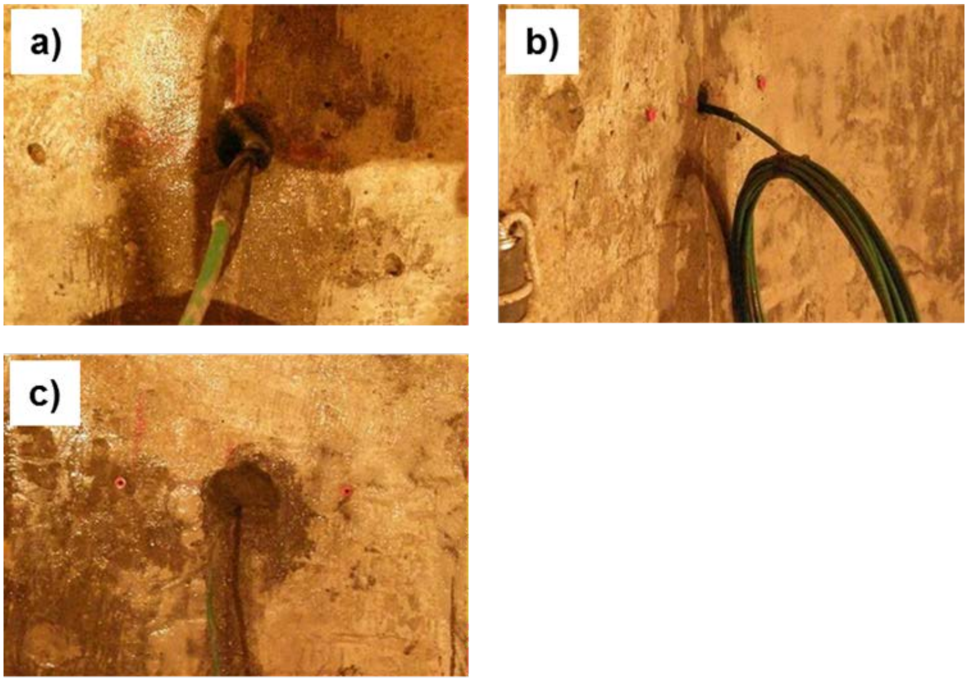

Image 6. Installation of strip cathodes into holes drill to a depth of ~18 inches shown in a) and b). Portland cement grout was poured in the holes around the cathodes, and the cathodes and cables were grouted in as shown in c) [1].

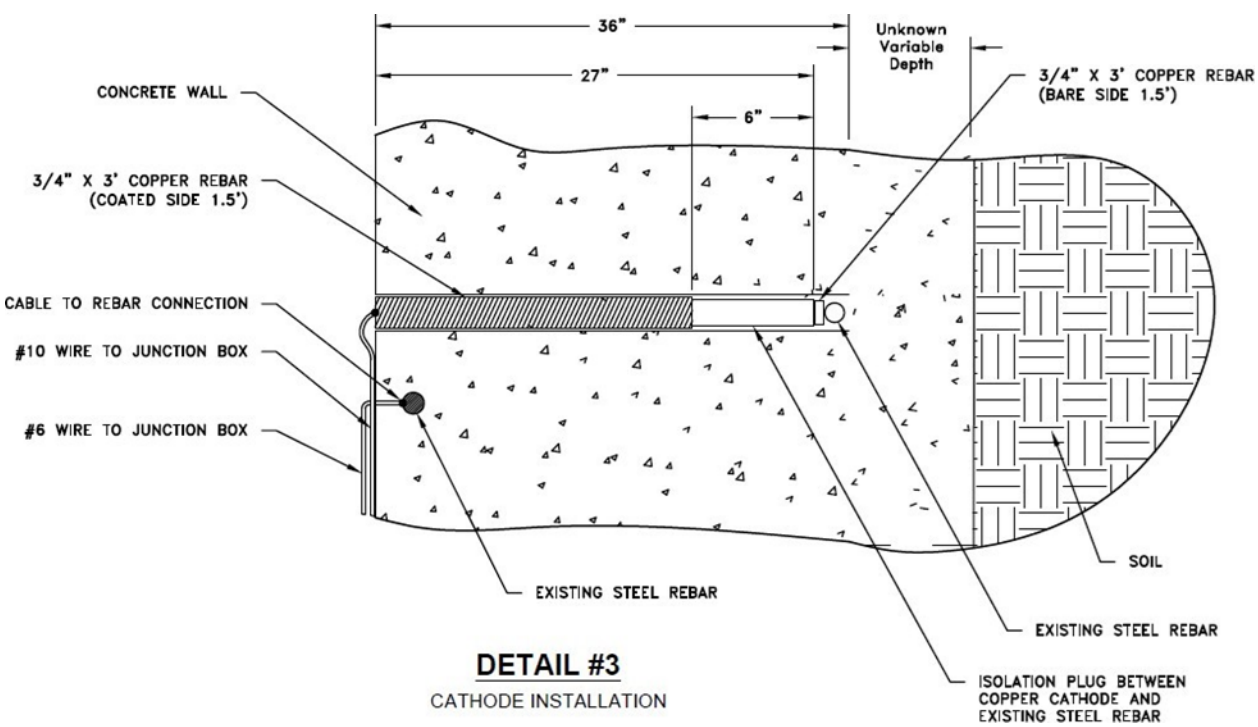

Figure 3. Schematic of cathode installation for isolation from rebar [2].

Operational Analysis

Visual Inspection The wall of the chamber prior to installation was wet both to sight and touch, as shown in Image 7a and b. These photos document the visual conditions to determine if the system was operating. The Phase 2 test area showed that after only two weeks of operation the concrete wall surface was dry both visually and to touch as shown in Image 7c and d.

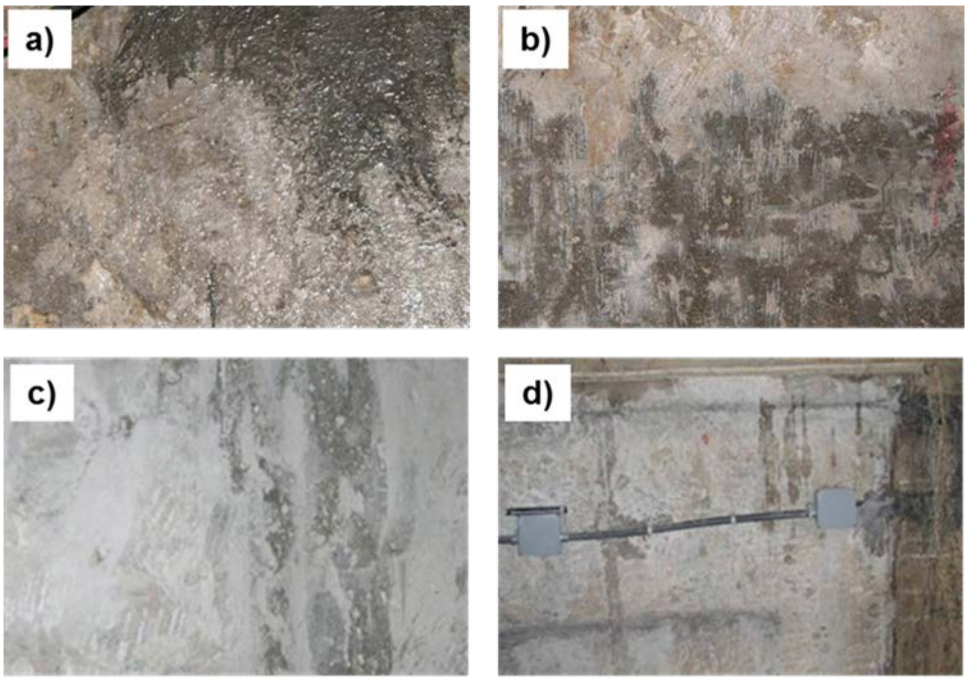

Image 7. Condition of wall at installation prior to energizing of the system is shown in a) and b). Note the wall was damp to sight and touch. The wall was dry to sight and touch over most of the test section after two weeks of system operation as shown in c) [1].

A visual inspection of the Phase 3 installation performed on September 13, 2017 by the Reclamation climb team indicated the continued presence of water seepage outside of the EOP installation (Image 8). These photos show locations where leaks were grouted and are still leaking, along with areas of cracks that were not grouted.

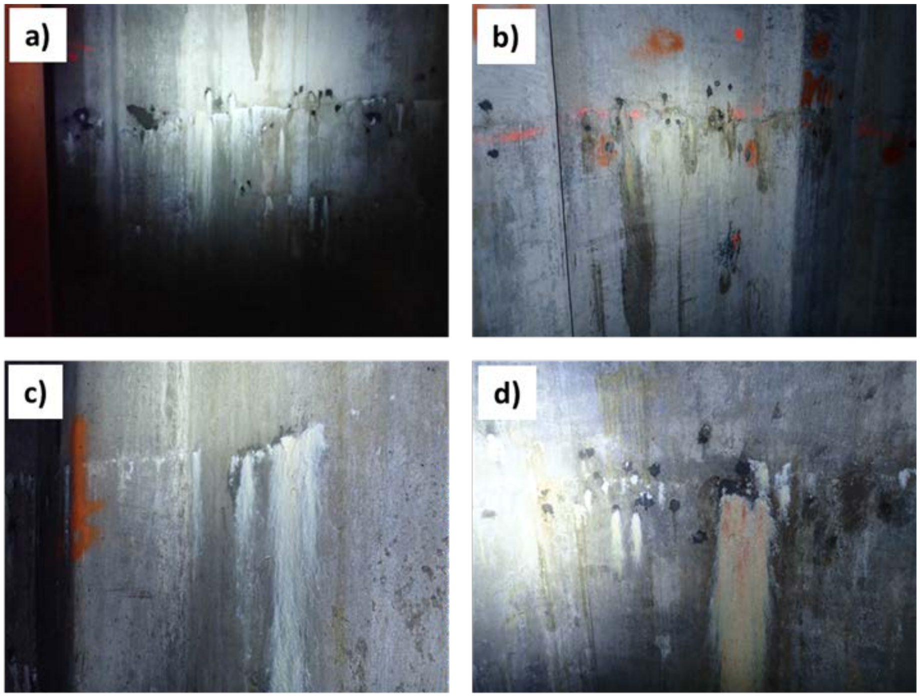

Image 8. Photos of areas above the EOP installation zones. Photos show locations where grouting was performed which are still leaking and areas of cracks which were not grouted [2].

Photos from the EOP zone indicated that water was still leaking in the area above the EOP installation zone causing calcite to build up on the drip tray installed above the EOP zone (Image 9a). Not all cracks were successfully grouted in the EOP zone (Image 9b, c, and d).

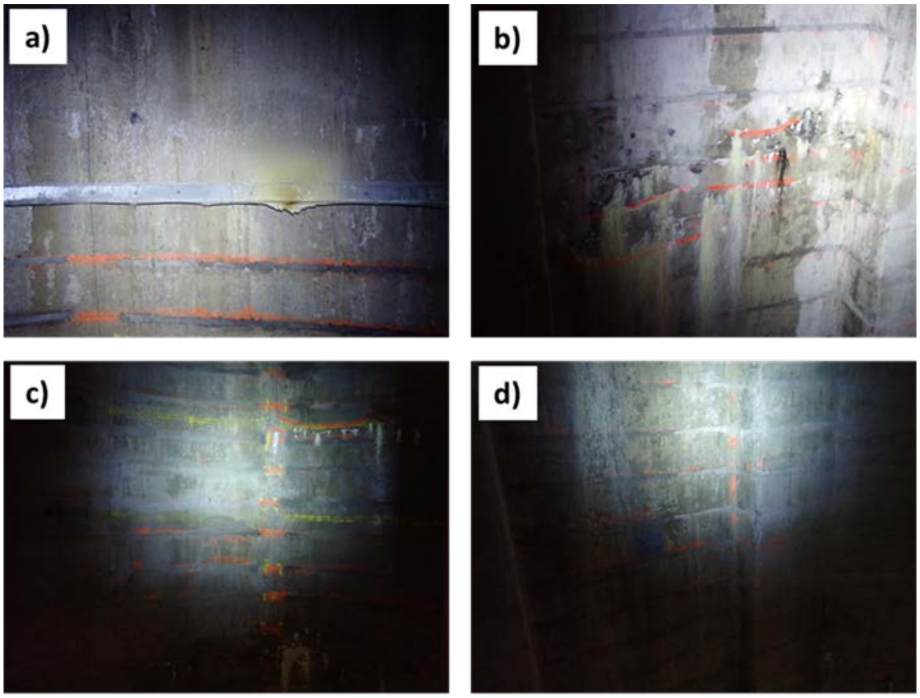

Image 9. Photos from the EOP zone indicating water coming from above and from cracks in the EOP zone. The photo in a) shows the calcite building up on the drip tray which was installed. The photos in b), c), and d) shows calcite build up due to seepage from the cracks which were not successfully grouted [2].

Data Results Data is analyzed using Ohm's law E = IR, where E is the potential (Voltage), I is the current (Amperage), and the R is resistance (ohms). The data presented in MERL-2012-10 [1] and ST-2018-4553 [2] show that at a constant applied potential, as the moisture level in the concrete decreases in the wall, the current will decrease and the resistance will increase. Figure 4 shows the analyzed data for total current output and resistance from Phase 2 after 15 weeks of operation. The increase in resistance indicates that the system is operating and moving water through the concrete towards the cathodes.

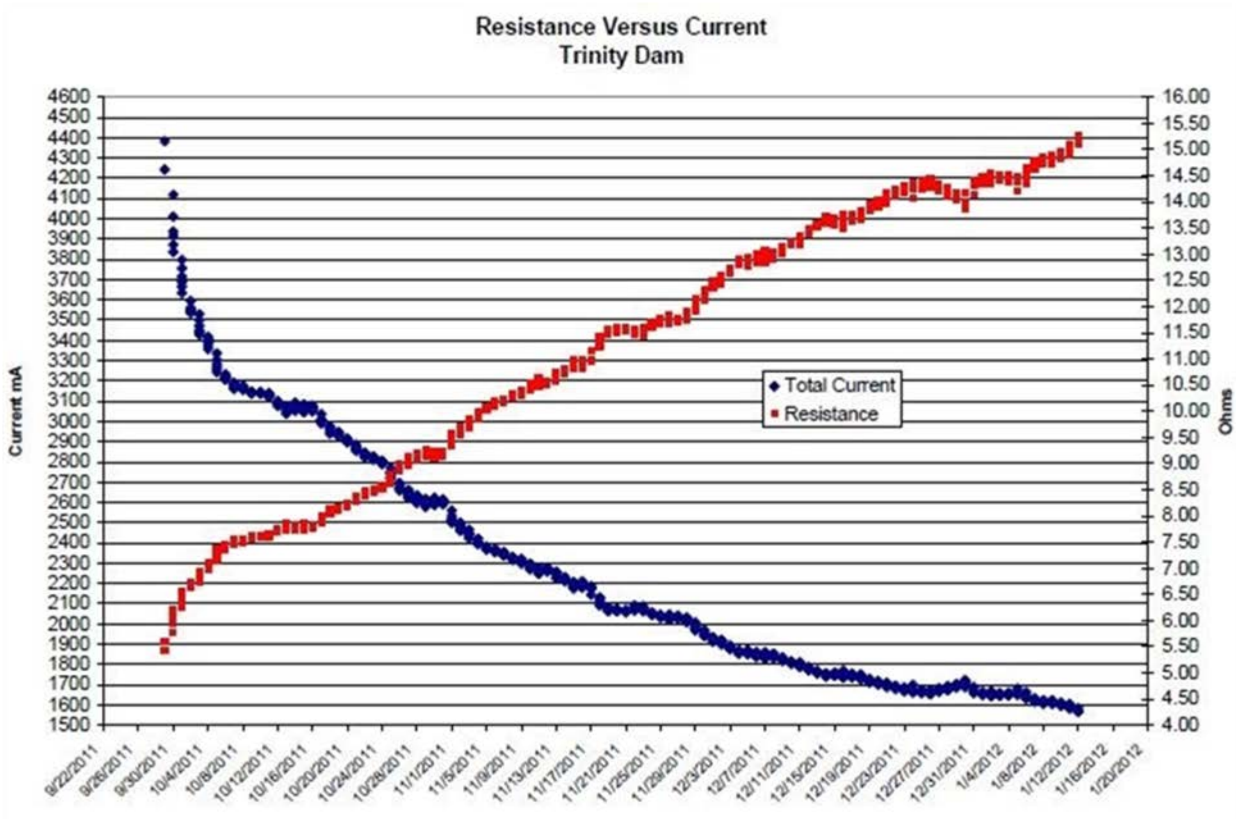

Figure 4. Data from the first 15 weeks of the Phase 2 system operation showing the current and resistance over time. The data shows that the moisture content in the concrete is decreasing [1].

Phase 3 data also showed increased resistance values over the first 12 months of operation as shown from the graph in Figure 5. The data indicate the effect of moisture leaving the structure. As the electrolyte (water) decreases in the concrete, it makes it more difficult for electrical current to flow, resulting in increasing resistance.

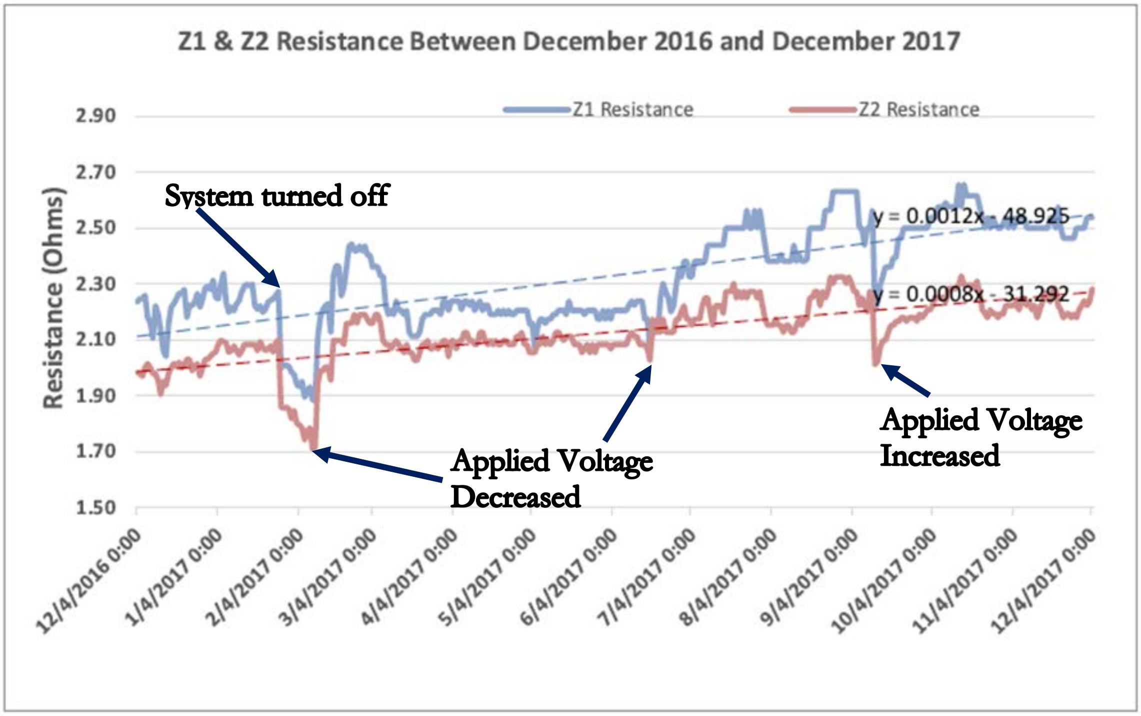

Figure 5. Graph of the first 12 months of data collected after energizing the Phase 3 EOP system. The resistance for each zone is increasing over time indicating that the water is moving away from the surface and the system is still operating as designed [2].

The applied voltage was decreased twice and increased once during the initial 12-month operational period. Adjustments to the applied voltage are required occasionally to establish an electric field gradient between the anode and cathode to maintain a force against the flow of water. As the system operates over time, a steady state or equilibrium will eventually be achieved; the system will stop driving the water and the resistance will stop changing. This change in the applied voltage essentially "jump-starts" the effect of the system by changing the electric field and the resistance increases again as desired. Since the forces due to pressure and electro-osmosis are generally the dominant components regarding the movement of water in concrete, the force due to electro-osmosis must balance or exceed that of the pressure force to prevent water seepage [1]. A minimum current density is required to create enough electric field strength in the concrete in order to overcome the force exerted on the water molecules by the hydraulic gradient [1]. The applied voltage when the system was energized was set at 40 V. The decrease in the resistance in January was the result of the system accidentally being switched off allowing water to migrate towards the anodes. The voltage was then decreased to 15 V in February, based on the initial steady state resistance measured prior to the system being off. Since after the voltage was decreased in February the resistance of the concrete started increasing again indicating that an equilibrium had not been obtained. The voltage was decreased again to 10 V in June due to the steady state measured by the controller which "jump-started' the system's ability of the system to drive more water out of the concrete. In September, the voltage was increased to 17 V to determine if an equilibrium had been reached and the resultant steady state resistance measured indicated that this was indeed the case.

1.2 Lessons Learned

Photos of the EOP zone, shown in Image 10 and Image 11 show moisture on the surface of the walls and new calcite formed over 12 months of operation. Calcite is due to water leaking from some of the cracks, grout ports, and anode and cathode locations. Some of the calcite is also due to the continued leakage from the walls getting past the drip try above the EOP system. These photos emphasize the importance of grouting all locations where water seepage is occurring and limiting the flow rate allowing EOP to operate more successfully. Work performed by USACE-ERDC-CERL to implement EOP did not address either the maximum head pressure limitations or the critical crack size. The critical crack size refers to the maximum size of crack opening and flow rate required for the technology to successfully mitigate water seepage without the need for grouting. Future EOP installations should prioritize data collection related to crack size i.e. size of the cracks not addressed during grouting repairs and quantifying leakage rate reduction.

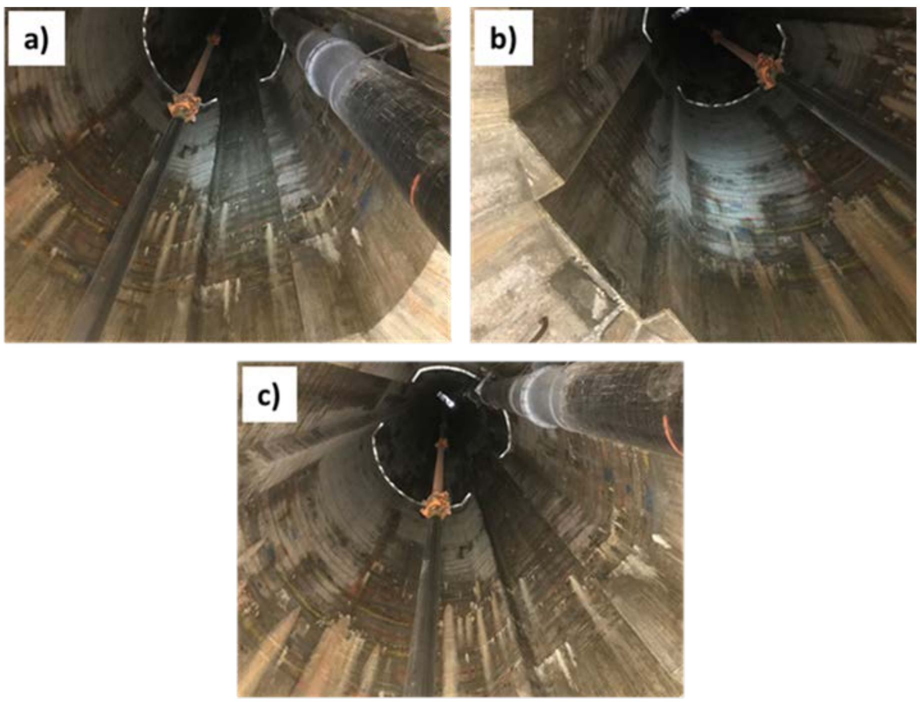

Image 10. Photos were taken looking up from the bottom of the shaft. The photos in a), b), and c) all show new calcite formation over the first 12 months after the installation of the Phase 3 EOP system [2].

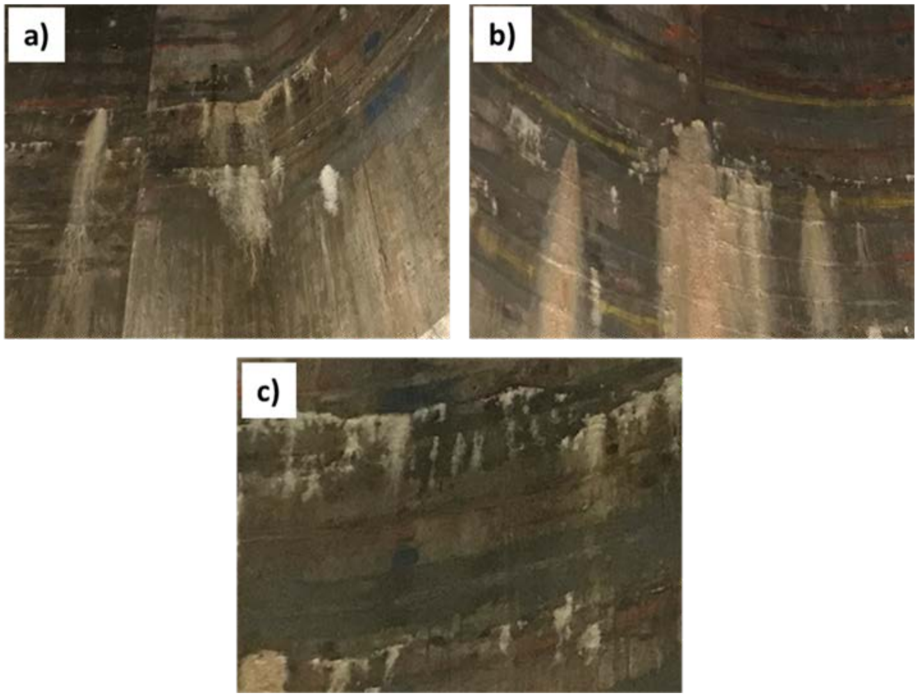

Image 11. Photos were taken of the shaft in various areas in the EOP installation zone. The photos in a), b), and c) all show new calcite formation over the first 12 months after the installation of the Phase 3 EOP system [2].

1.3 Economic Benefits of EOP

The Economic Analysis Group at Reclamation's Technical Service Center evaluated the economic benefits of installing EOP at Trinity Dam. This work looked at the costs associated with the Trinity Dam Intake Gate Shaft Refurbishing (Phase 1) project which involved cleaning a significant buildup of calcite off the walls, chemically grouting leaking cracks and joints, coating repair, and EOP installation. The total awarded cost of the project was about $2.6 million in 2016 dollars; however, due to additional grouting requirements this cost may have been higher. While most of this budget was for the grouting, platform, and calcite removal (approximately $1.8 million), installation of the EOP system itself was about $690,000. If EOP was not installed as part of the project, then it has been postulated that every 25 years significant calcite removal and grouting would need to be performed at a cost of approximately $1.8 million in 2016 dollars. Installation of the EOP system is expected to reduce the cost of calcite removal, grouting, and coating maintenance to approximately $550,000 every 25 years (includes the cost of the EOP maintenance); a savings of approximately $1.25 million per 25-year maintenance event (in 2016 dollars).

The Economic Analysis group also looked at the return on investment (ROI) regarding the research and development funds that have been spent on EOP implementation. As presented in the Science and Technology (S&T) FY2017 Program Impacts and Highlights [5], funds provided by S&T for the installations and investigation of EOP at Trinity Dam totaled $168,268 (2012-2017). It was calculated that the net present value (NPV) of avoided costs (Benefits) for installing EOP at Trinity is about $267,000 (in present dollars) over a 50-year period of analysis and this savings is achieved because of a $168,000 S&T investment, making net savings equal to $99,000. The ROI to S&T is equal to the net return [savings in this case] / total investment x 100; therefore, ROI for the EOP investment is 59%. The benefit-cost ratio (B/C) is equal to the gross benefit (savings in this case) / total cost, therefore B/C ratio is 1.6.

Realistically, the findings of the S&T work are applicable to multiple sites, and if this were accounted for both the ROI and B/C ratio would be significantly more favorable. For example, if there were 3 other locations like Trinity Dam where EOP was feasible and beneficial to their operation then the gross benefit would be 4 x $267,000 = $1,068,000, while the federal government's investment in the technology remains the same. The cost savings are also dependent on the specific use, case, and issue requiring mitigation.

2 Current System Outstanding Questions

There are still important unanswered questions related to EOP operation such as the effectiveness of EOP at higher water pressures and the critical crack size threshold that requires grouting. These were never investigated during the previous scope of work or during initial design of the technology. Information provided by the USACE states the maximum head pressure is 40 feet. However, this value was established during initial testing of the technology with setups that were limited to 40 feet of head. It was believed by installation contractors at Trinity that these systems will perform adequately at higher head pressure. This belief was supported by subsequent observations and test data at Trinity Dam.

The critical crack size is important to determine as it can reduce the amount of grout work which would be required for successful operation of an EOP system. The EOP system would aid in reducing the flow rate of the leaks allowing calcite to build-up in the cracks and essentially plug them. However, the critical crack size as it relates to head pressure was not determined during the investigations at Trinity Dam.

3 Additional Proposed Uses for EOP

3.1 Potential System Utilization

3.1.1 Alkali-Silica Reaction Mitigation

Alkali-silica reaction (ASR) is a reaction between the hydroxyl ions in the alkaline pore solution and reactive forms of some types of silica in the aggregate [6]. The reaction forms a gel, which has a strong affinity for moisture present in the concrete. If there is enough gel and moisture, the gel can swell and crack the concrete [6]. Sufficient moisture in the concrete is needed for the reaction, so EOP has potential to slow or stop the reaction if it can reduce the moisture content sufficiently. It is generally believed that a relative humidity of about 80% or higher in the concrete is needed for the reaction to occur [7]. Therefore, if an EOP system can decrease the moisture content below this threshold, it is hypothesized that ASR would slow down and potentially stop. While this would not reverse the existing damage to the concrete, it would prevent further degradation. Certain lithium compounds can inhibit ASR but getting the lithium deep into the concrete is a challenge [8]. It has been postulated by some in the EOP industry that the technology might be able to drive the lithium inhibitor into the concrete and if this can be accomplished then the inhibitor can be replenished periodically. While there are a limited number of facilities effected by this phenomenon it is important to note that this can be an issue due to the increased deterioration. Some of these dams include American Falls, Owyhee, Seminoe, Friant, Parker, and Stewart Mountain.

3.1.2 Freeze-Thaw Mitigation

Deterioration of concrete due to freeze-thaw weather cycles occurs due to the development of pressure in the pore spaces of the cement paste caused by expansion of water as it freezes [9,10]. At cold temperatures any water in the pores of the cement paste freezes, expands and the resultant pressure cracks the concrete. Water experiences volumetric expansion by approximately 10% as it freezes. If the moisture content in the concrete is below about 90%, then freezing moisture will not usually damage the concrete [9]. EOP has potential to reduce the moisture content sufficiently to mitigate freeze thaw by reducing the moisture content below that 90% level.

3.1.3 Ice Formation Mitigation

EOP may also be considered as a solution to another common problem observed at numerous concrete dams. Water may collect in lift lines in the dam. If it exits onto the downstream face of the dam rather than into internal drains, if can freeze into very large blocks of ice during cold weather. These large blocks of ice can represent a significant safety hazard for areas below them. This occurs at Angostura Dam in South shown in Image 12. Due to the location of these dams, this water can freeze and when it falls off the face of the dam could cause damage along with the risk of injuries to personnel (Image 13). Ice formation also occurs at Yellowtail Dam in Montana as shown in Image 14. Yellowtail Dam has a portion of its parking lot roped off to prevent cars from parking under areas where large ice blocks have been known to form.

Image 12. Water leaking through the lift lines on the downstream face at Angostura Dam Picture a) shows calcite formation emanating from the joints. Picture b) shows additional damage to the concrete due to the probable freeze-thaw.

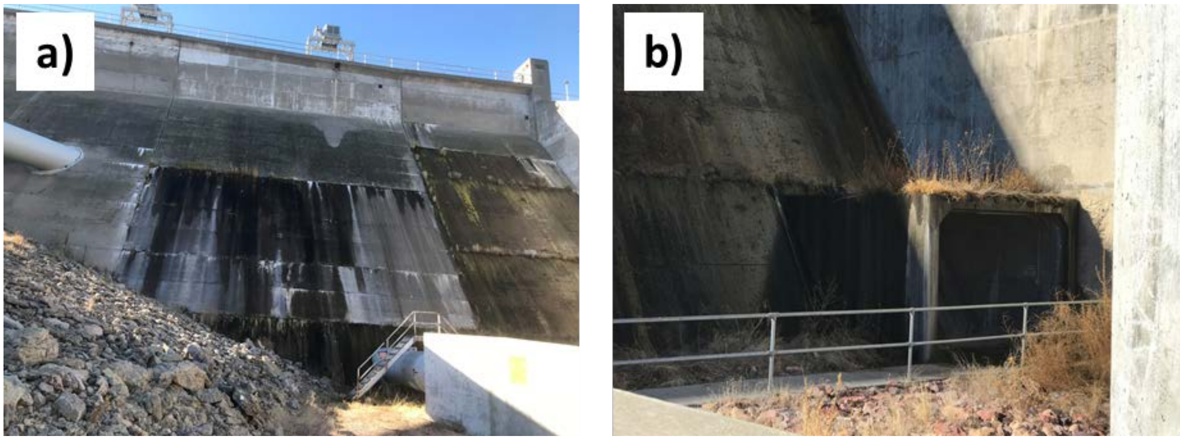

Image 13. Ice formation at Angostura Dam can lead to damage of the discharge pipe shown on the bottom of a) as well as damage to the entrance area shown in b). This also could lead to a risk of injury to dam personnel.

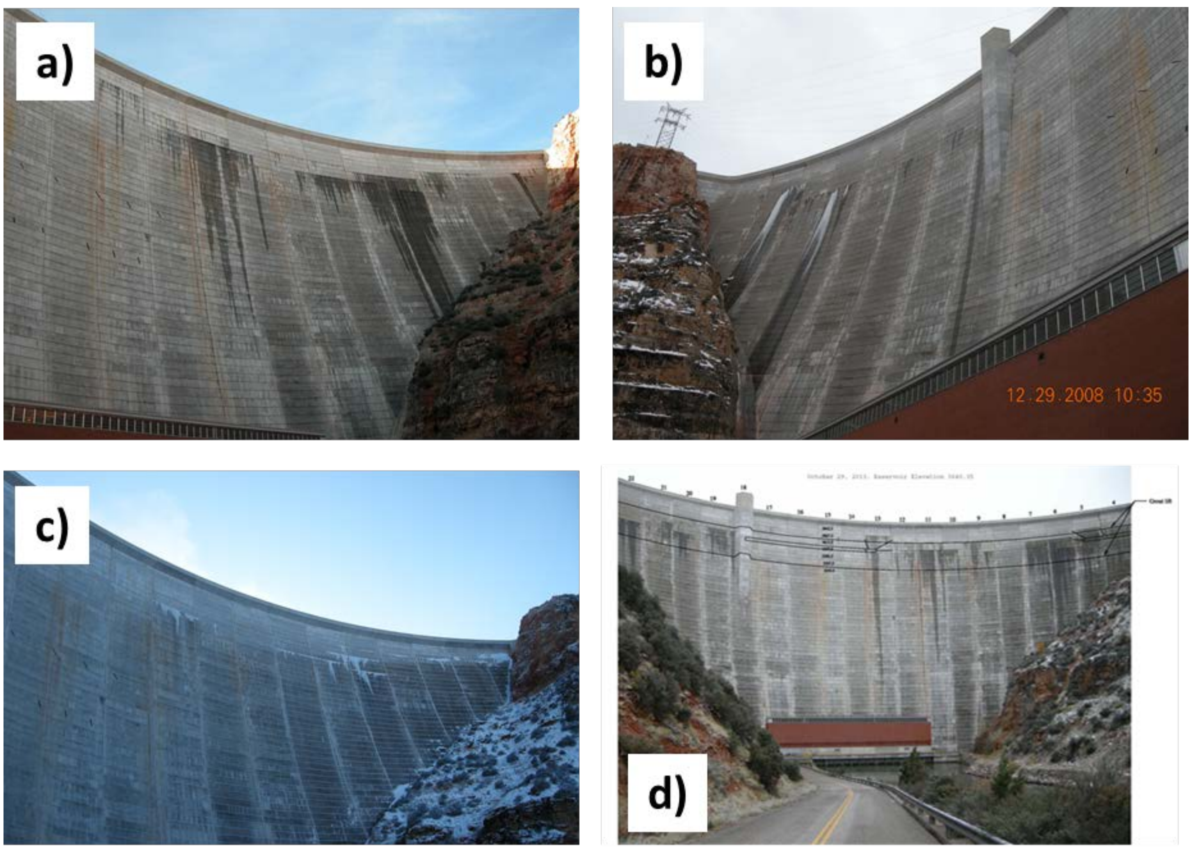

Image 14. Water leaking through the lift lines on the downstream face at Yellowtail Dam shown in a). The pictures in b) and c) show ice formation observed during the freezing winter months. An overall view of the leakage from the lift lines in shown in d).

The source of the water is primarily in the contraction joints between each block of concrete. The water leaks on the downstream face are due to water moving along these contraction joints and bypassing the internal formed drains which lead to the gallery. There are 5 drains between each contraction joint, roughly one every 11 feet. At some locations, the water is then entering the lift lines and emerges onto the downstream face. Some water leakage is occurring through other areas such as cracks and water is entering the gallery as shown in Image 15. As shown in Image 15, little to no water flow is exiting many of the internal drains while water is seen coming from these other locations like cracks.

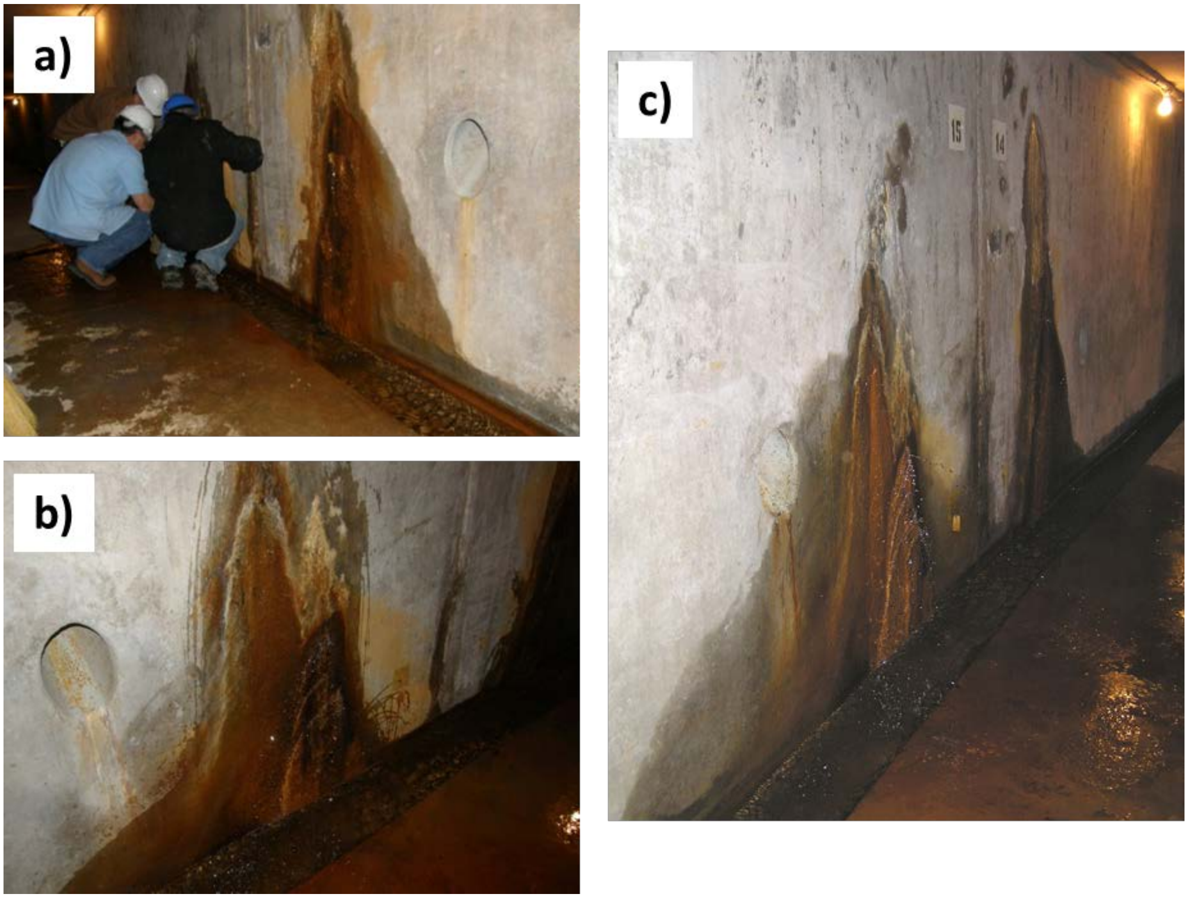

Image 15. Water leakage into the gallery through cracks in the walls. Note that little to no water is exiting through the drain as was originally designed. As shown in c) that water pressure and flow rate can be significant.

Yellowtail Dam has a powerplant at the base of the downstream face as observed in the photos in Image 16. The switchyard is located at the base and some of the areas where the lift lines are leaking are located above the powerline connections to the dam as can be observed on Image 16. Ice formation at the lift lines is common during the winter months and some of these formations require removal to prevent extensive damage. Leaks from lift lines on Blocks 11, 12, and 13 are all above the powerline connections and personnel must remove the ice manually by chipping (Image 17). In order to get to the ice, personnel must be lowered on a platform with a crane (Image 16). Therefore, there is the potential for ice to fall and damage critical power components. Leaks on Blocks 6-7 and 23-24 consistently have large amounts of ice build-up, and the leaks on 23-24 is one of the big contributors of ice fall on the parking area near the powerplant.

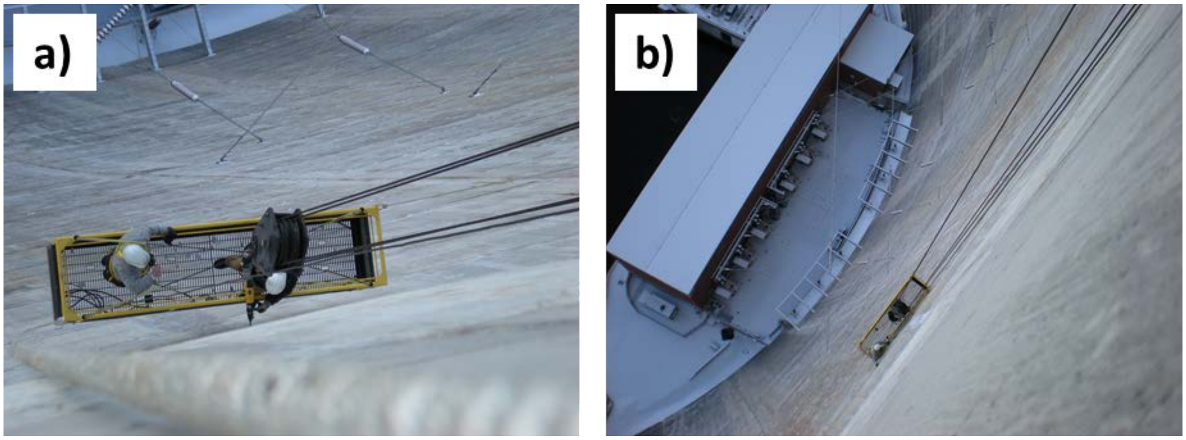

Image 16. Access required to remove the ice is performed using a man basket lowered from the top as shown in a) and b). These photos show the proximately of the ice formation in relation to both the powerline connections and switchyard.

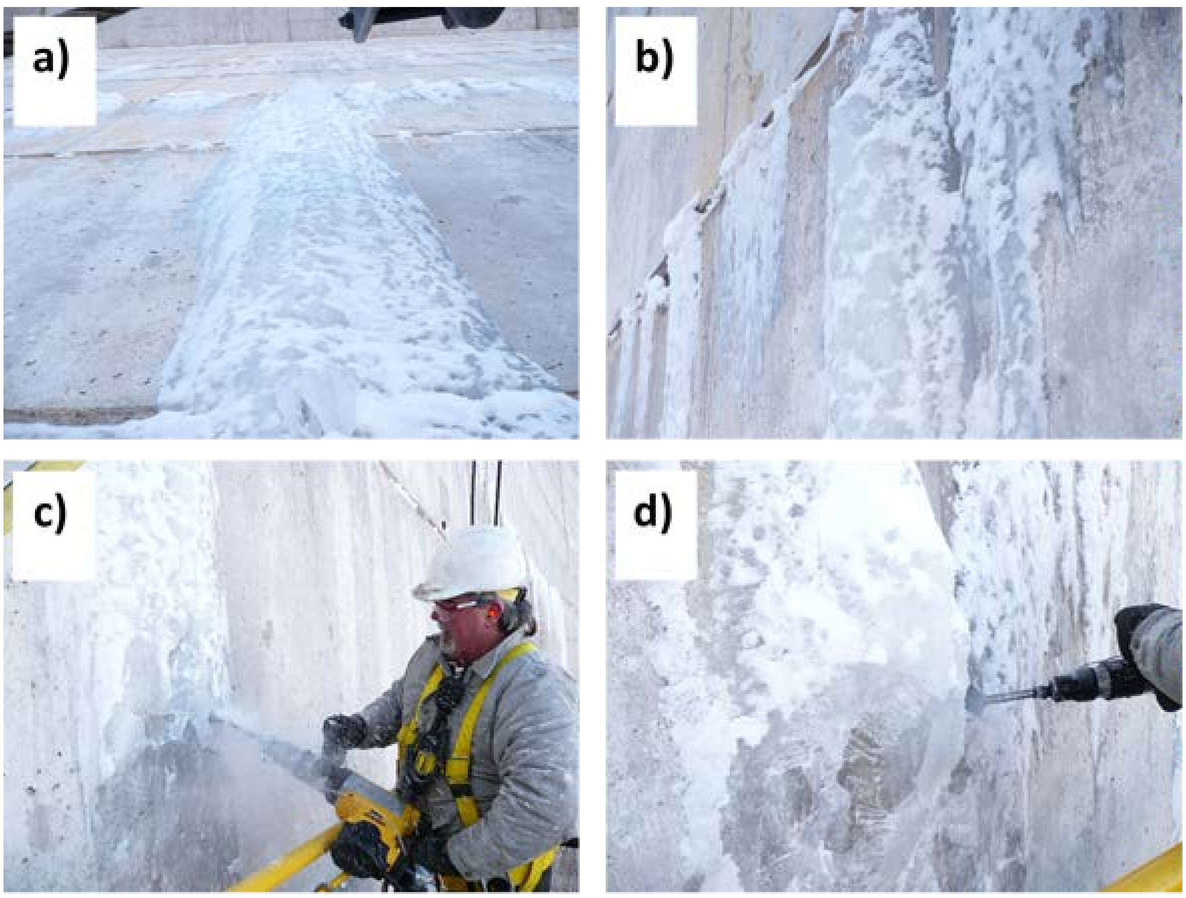

Image 17. Ice formation on the downstream face of the dam caused by water leakage at the lift lines as shown in a) and b). As shown in c) and d) the ice must be manually removed with a chipper.

It has been proposed to utilize EOP to direct water from lift lines into the internally formed drains designed to drain water from lifts lines and other areas into the galleries where the water can be directed to sump pumps. This work would involve possibly some grouting of the concrete in some areas and inserting the anodes into the gallery wall. Typically, anodes are only embedded about an inch from the surface however they would most likely be embedded deeper into the concrete structure upstream of the gallery. The internally formed drains would then be lined with a mesh style cathode material. The current issues being discussed with field staff are the length of some of the drains as well as the configuration and bends. The cathode material would have to be flexible. Another challenge is how to embed or attach the mesh to the wall of the drain and how the mesh might impact drain cleaning activities. While no answers to these challenges have been determined yet, discussions are on-going with field personnel, USACE, and contractors to address these issues.

4 References

[1] MERL-2012-10, Electro-Osmotic Pulse Leak Repair Method: Evaluation in Trinity Dam Bonnet Chamber, 2012.
[2] ST-2018-4553, Demonstration Project to Implement Electro-Osmotic Pulse Technology to Stop Water Leaks Through Concrete, 2018.
[3] Reclamation Travel Report dated Nov 21, 2005 – Rope inspection.
[4] ST-2016-7738-01, Photogrammetric Processing from Remotely Operated Vehicle (ROV) Data: Trinity Dam Intake Tunnel, 2016.
[5] Reclamation (Bureau of Reclamation), FY 2017 Impacts and Highlights, Science and Technology Program, https://www.usbr.gov/research/st/fy17brochure.pdf, Accessed 12/20/2019..
[6] Adeyemi Damilare, Adesina, "Influence of Moisture on Alkali Silica Reaction", Master of Applied Science Civil Engineering Thesis, Concordia University, Montreal, Quebec, Canada, December 2016.
[7] Olafsson, H., "The Effect of Relative Humidity and Temperature on Alkali Expansion of Mortar Bars," Concrete Alkali-Aggregate Reaction, Noyes Publications, pp. 461-465 (Proc. 7th Int. Conf. on AAR in Concrete, Ottawa, Canada, July 1986), 1987.
[8] Deschenes, R. Jr.; Murray, C. D.; and Hale, W. M., "Mitigation of Alkali-Silica Reaction and Freezing and Thawing through Surface Treatment," ACI Materials Journal, V. 114, No. 2, Mar.-Apr. 2017, pp. 307-314. doi: 10.14359/51689493
[9] Powers, T. C., "A Working Hypothesis for Further Studies of Frost Resistance of Concrete," ACI Journal Proceedings, V. 42, No. 4, Apr. 1945, pp. 245-272.
[10] Powers, T. C., and Helmuth, R. A., "Theory of Volume Changes in Hardened Portland-Cement Paste during Freezing," Proceedings of the Annual Meeting—Highway Research Board, V. 32, 1953, pp. 285-297.