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DoD Corrosion Prevention and Control Program

Demonstration of Electro-Osmotic Pulse Technology in Earth-Covered Magazines at Fort A.P. Hill, VA

Final Report on Project FAR-01 for FY06

Orange S. Marshall, Jr.

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Construction Engineering Research Laboratory

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Final report

Prepared for Office of the Secretary of Defense (OUSD(AT&L))
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Under Military Interdepartmental Purchase Requests MIPR6FCERB1020 and MIPR6FCERB1023 (ACSIM/IMCOM), 23 March 2006; and MIPR6H6AG3CPC1 and MIPR6H6AG3CPC1R, 31 May 06 (AMC)

Abstract: In below-grade buildings and buried structures, such as hardened secure facilities used for munitions storage on U.S. Army installations, water intrusion can cause serious structural damage and destroy stored materiel. Standing water and high humidity inside the structures can interfere with operation of mission-critical equipment, corrode structural steel, and promote the growth of noxious molds. Electro-Osmotic Pulse (EOP) technology can reverse below-grade water intrusion through concrete pores. It has been successfully installed in military infrastructure ranging from family housing to steel-reinforced deep structures and tunnels. EOP has been shown to prevent below-grade moisture seepage through concrete and keep interior concrete spaces at or below 50 percent relative humidity. This project demonstrated the use of EOP technology to stop water intrusion into earth-covered ammunition magazines at Fort A.P. Hill, VA. This report describes the project objectives, equipment acquisition, setup, and system initialization. Preliminary observations of operation and lessons learned are presented.

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Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Control and Prevention Project FAR-01, "Electro-Osmotic Pulse Technology for Prevention of Water Intrusion and Corrosion of Munitions and Equipment in Ammunition Bunkers at Fort A.P. Hill." The proponent for the work was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), the stakeholder was the U.S. Army Installation Management Command (IMCOM), and the customer was Fort A.P. Hill, VA, U.S. Army Materiel Command (AMC). The project was funded under Military Interdepartmental Purchase Requests MIPR6FCERB1020 and MIPR6FCERB1023 (ACSIM/IMCOM), dated 23 March 2006; and MIPR6H6AG3CPC1 and MIPR6H6AG3CPC1R, dated 31 May 06 (AMC). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)Corrosion), Paul M. Volkman (IMPW-E), and David N. Purcell (DAIM-FDF).

The work was performed by the Materials and Structures Branch of the Facilities Division (CEERD-CF-M), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. The ERDC-CERL project manager was Orange S. Marshall, and the Project Officer was Vincent F. Hock. The ERDC-CERL CPC Program Manager was Dr. Ashok Kumar. Dr. Ghassan Al-Chaar, CEERD-CF-M, provided structural engineering support for the EOP design. The following installation personnel are gratefully acknowledged for their support and assistance in this project:

- Brian Robinson, Deputy Director of Public Works, Fort A.P. Hill
- John Hall, Director of Logistics, Fort A.P. Hill
- Charles Rupe, Ammunition Officer, Fort A.P. Hill
- Virginia Stokes, Quality Assurance Specialist (Ammunition Surveillance), Fort A.P. Hill
- Kenyon Williams, Associate Director, U.S. Army Technical Center for Explosives Safety, McAlister Army Depot, OK.

At the time this report was prepared, the Chief of the ERDC-CERL Materials and Structures Branch was Vicki L. Van Blaricum (CEERD-CF-M), the Chief of the Facilities Division was L. Michael Golish, (CEERD-CF),

and the Technical Director for Installations was Martin J. Savoie (CEERD-CV-ZT). The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

The Commander and Executive Director of ERDC was COL Richard B. Jenkins, and the Director was Dr. James R. Houston.

Executive Summary

This OSD Corrosion Prevention and Control project demonstrated the use of electro-osmotic pulse (EOP) technology to prevent water intrusion into the interior of earth-covered ammunition magazines. The usual method for preventing water intrusion is to remove the earth cover, replace the waterproofing membrane on the magazine, install a drainage tile system around the structure or affected area, and then replace the earth cover. This process is expensive, and it can be complicated by the fact that most contractors limit their warranties against future seepage in areas with high water tables. EOP technology offers an alternative to the conventional method by mitigating water-intrusion from the interior (negative side) of affected areas without the cost of excavation.

This interim report documents the design, installation, safety testing, and performance of an EOP system developed for use with ordnance storage structures. The report also documents the 9 months of EOP system operation in an earth-covered magazine at Fort A.P. Hill, VA. The EOP system was installed in 11 magazines, but was activated in only one until system approval for this application is obtained from the Department of Defense Explosives Safety Board (DDESB). Toward that end, safety testing has performed on the one magazine where EOP is operational. In terms of performance, the operating EOP system has successfully prevented water intrusion in the magazine.

Lessons learned related to EOP system installation, operation, and performance monitoring are discussed. Both the performance metrics and the safety testing procedures are also documented, along with performance data collected to date. Also included is a description of the different metrics used to determine EOP system performance and a description of the safety test procedures and test results to date that were performed. When the final safety testing tasks are completed, the results will be presented to the DDESB for approval. When EOP system safety for this application is approved, installations may begin using EOP technology in earth-covered magazines on military properties. Draft engineering criteria documents for implementation of EOP in earth-covered magazines are included in two appendices.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
mils	0.0254	millimeters
square feet	0.09290304	square meters

1 Introduction

1.1 Problem statement

Department of Defense and Army facilities constructed on grade or below grade are all susceptible to the problem of water intrusion and the damage it causes. Water intrusion, which is also a potential problem for nonmilitary government agencies and all other institutional building operators, causes corrosion, materials degradation, equipment damage, and growth of pathogens such as mold and microorganisms.

At Fort A.P. Hill, VA, large amounts of water seep through the concrete walls, floors, and wall/ceiling joints of earth-covered ammunition storage magazines. During periods of high rainfall, standing water inside these ammunition bunkers has reached a depth of 1.5 in. The earth-covered magazines (ECMs) are used for storage of a wide variety of explosive ordnance, from small arms to artillery rounds as well as fuses, shaped charges, hand grenades, and pyrotechnics. Water intrusion through the structure not only corrodes ammunition and equipment inside the magazines, it can also corrode the reinforcement steel embedded in the concrete floors and walls. Additionally, the propagation of mold and bacteria in these confined spaces causes respiratory distress (e.g., allergies, asthma) for Army personnel and contractors working inside the bunkers.

Water intrusion into ordnance storage facilities has a far-reaching impact on the Tri-Services and federal agencies such as the U.S. Bureau of Alcohol, Tobacco, and Firearms (ATF). The materiel stored in ECMs is used for training warfighters and law enforcement agents on a daily basis. Water inside an ECM will corrode medal ammunition cases and penetrate wooden crates, compromising their safety and utility. If standing water in the ECMs freezes, concrete structures can be cracked and severely degraded due to freeze/thaw cycling, further exposing the reinforcement steel to corrosive conditions. The frozen water on the ECM floor also is a safety hazard for forklift operators, and it seriously delays or prevents the delivery of munitions for troop training. These and other effects of water intrusion on soldiers and other ECM users will continue if water intrusion is not eliminated.

The conventional method for preventing water intrusion into ECMs is to remove the earth cover, replace the waterproofing membrane on the magazine, install a drainage tile system around the structure or affected area, and then replace the earth cover. This process is expensive, labor intensive, and time consuming. Also, it disrupts facility operations and has a high probability of failure. It also fails to address the difficult problem of water intrusion through the bunker floor — both the cracks in the concrete and permeation directly through the slab.

This type of difficult water intrusion problem has been successfully addressed in several government-sponsored field applications by an emerging technology called Electro-Osmotic Pulse, or EOP (Marshall 2007[1], Hock et al. 2006[2]). This technology uses embedded electrodes, a direct current (DC) power supply, and a pulsed electric field to counteract hydraulic pressure and reverse moisture seepage through concrete structures. EOP systems have direct applicability to ammunition storage facilities not only on military installations, but also in theaters of operations and other forward locations.

1.2 Objective

The objective of this work was to install EOP technology in eleven ECMs located at Fort A.P. Hill to eliminate water infiltration through concrete floor slabs and walls.

1.3 Approach

A multiphase approach was taken to accomplish the objective.

1. In-laboratory safety testing of a small-scale model of an ECM was performed. Laboratory test results were presented to the Department of Defense Explosives Safety Board (DDESB) to obtain their approval to go to the next phase.

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[1] Marshall, O.S. 2007. *Implementation of Electro-Osmotic Pulse Technology in Building P10000 at Fort Drum*, ERDC-CERL Technical Report TR-07-28. Champaign, IL: U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory.

[2] Hock, V.F., et al. 2006. Electro-Osmotic Pulse Technology for Control of Water Seepage in Various Civil Works Structures, ERDC TR-06-9. Champaign, IL: U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory.

2. An EOP system was installed in a full-scale ECM at Fort A.P. Hill. The effects of EOP system operation on magazine performance and on the materiel stored inside were investigated.

During installation of the full-scale EOP system, most of the moisture intrusion problems were solved before the system was energized. Consequently, installation officials approved implementing the system in the remaining 10 ECMs, but those systems were not powered up pending DDESB approvals. After testing of the magazine with the active EOP system was completed, the test results were presented to the DDESB for approval to implement EOP in all ECMs.

Performance metrics (Chapter 3) included monitoring the temperature and relative humidity inside the ECM with the active EOP system and comparing the results with outdoor ambient conditions and conditions inside ECMs with no active EOP system. Also, concrete internal moisture and corrosion coupon data were collected over time inside the EOP-protected ECM and compared with analogous data collected inside and outside an ECM without its EOP system energized.

Appendix A of this report is the project management plan developed for this demonstration. Appendix B is the contractor's planning and safety documentation. Appendix C is a report on laboratory testing performed for this project. Appendix D contains the EOP system design details. Appendix E is a report on the full-scale ECM testing. Appendix F includes the materials product sheets used in installing the EOP system, and Appendix G shows the as-built drawings for the EOP system. Appendix H is a draft Unified Facilities Guide Specification (UFGS) for EOP implementation in ECMs, and Appendix I is a draft Unified Facilities Criteria (UFC) design guidance document for EOP technology.

2 Technical Investigation

2.1 Technology overview

EOP technology offers an alternative to conventional water control techniques. It mitigates water-seepage problems from the interior of affected areas without excavation. EOP reduces corrosion damage to indoor materials and equipment and eliminates mold problems caused by moist or highly humid environments. EOP technology is based on the phenomenon of electro-osmosis, the directed migration of an electrically charged liquid using an external electric field. A system has been developed to apply electro-osmosis for control of water intrusion within concrete structures by applying a pulsed electric field, at cost savings of over 50 percent compared with conventional waterproofing methods.

Electro-osmosis is not a new technology, but new applications are still being developed. Research has shown that flow is initiated when *cations* (positively charged ions) in the pore fluid of a porous medium such as concrete migrate toward a *cathode*, carrying the surrounding water with them (McInerney et al. 2002[3]). Electro-osmosis has been used in civil engineering to dewater dredged material and other high-water-content waste solids (O'Bannon 1977[4]). It also has been used to consolidate clays, strengthen soft, sensitive clays, and increase the capacity of pile foundations (Chew et al. 2003[5]). Electro-osmosis has also received significant attention as a method for removing hazardous contaminants from groundwater or to arrest water flow (U.S. Patent 5074986[6]).

An EOP system was developed by ERDC-CERL and DryTronic, Inc., to apply electro-osmosis commercially within concrete structures using a pulsed electric field. This system uses two sets of electrodes — one set embedded just below the surface of concrete floors, walls, or ceilings, and the

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[3] McInerney, M., et al. August 2002. *Electro-Osmotic Pulse (EOP) Technology for Control of Water Seepage in Concrete Structures*, ERDC/CERL TR-02-21. Champaign, IL: U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory.

[4] O'Bannon, C. November 1977. *Field Study to Determine the Feasibility of Electro-Osmotic Dewatering of Dredged Material*. Vicksburg, MS: U.S. Army Waterways Experiment Station.

[5] Chew, S.H., et al. 2003. *A Field Trial for Soft Clay Consolidation Using Electric Vertical Drains*. Elsevier, Ltd.

[6] Probstein, Ronald F., Patricia C. Renaud, Andrew P. Shapiro. 24 December 1991. *Electroosmosis Techniques for Removing Materials from Soil*, U.S. Patent 5074986.

other set placed either in the surrounding soil or, if the wall is thick, deep within the concrete. Pulsed DC voltage is applied between the electrodes to produce an electric field in the walls. The field moves water from inside of a concrete structure toward the outside, reversing or preventing moisture seepage toward the interior space. A positive electrical pulse causes cations (e.g., Ca++) and surrounding water molecules to move from the dry side (anode) toward the wet side (cathode) against the direction of flow induced by the hydraulic gradient, thus preventing water penetration into a buried or submerged concrete structure (Figure 2.1).

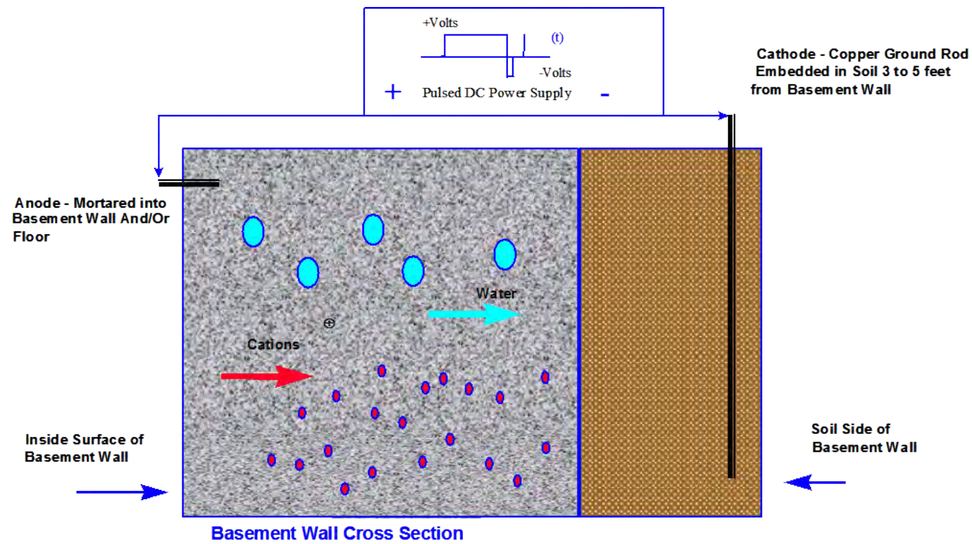

Figure 2.1. Schematic diagram of the EOP system.

The Drytronic system has received numerous technology awards both from the Army and industry, including the 2003 Army Research and Development Award and the 2003 NOVA Award from the Construction Innovation Foundation. It also was one of the three finalists for the Civil Engineering Research Foundation (CERF) Charles Pankow Award in 2004 and 2005. In addition, it has been published in technical journals and conference proceedings.

2.2 Safety testing for ECM applications

The Fort A.P. Hill safety office required that a safety text be performed in the laboratory before any system was energized in a full-scale ECM. The safety requirements were coordinated with the U.S. Army Technical Center for Explosives Safety at the Defense Ammunition Center, McAlester, OK. McAlester personnel in turn consulted with the DDESB and Army

Corps of Engineers Design Center, Huntsville, AL, for input to the safety requirements.

Safety testing consisted of initial laboratory testing, followed by full-scale testing in one of the smaller magazines at Fort A.P. Hill. Appendix C describes the in-laboratory testing, and Appendix E describes the full-scale testing. EOP system performance monitoring began with the full-scale test magazine. A draft UFGS (Appendix H) and UFC (Appendix I) were developed for ECM EOP applications. Also, an incidental revision was made to Technical Manual (TM) 5-622, *Maintenance of Waterfront Facilities*, to incorporate EOP technology.

2.3 Field installation

EOP technology was installed in 11 ECMs at Fort A.P. Hill, VA, between November 2006 and March 2007. The magazines are typical steel-arch earth-covered structures constructed in the 1950s. The magazines consist of a reinforced concrete floor with reinforced concrete head walls at each end. The side walls and ceiling consist of a reinforced knee wall approximately 15 in. high with a galvanized corrugated steel-panel arch bolted on top and at various points into the head walls. Figure 2.2 is a photograph of the exterior of a typical magazine. EOP systems were installed in magazines of two different sizes: two were 11 x 30 ft, and the remaining nine were 24 x 50 ft.

Figure 2.2. Typical steel arch earth-covered magazine.

2.4 Application design details

An application design for ECMs was developed, based on the principles detailed in the draft UFC reproduced in Appendix I. The floor section called for installation of *anodes* (positive electrodes) in the wall/floor juncture around the perimeter of the magazines, and also in the construction joints and cold joints in the floors and walls. Based on the anode placement, cathodes (negative electrodes) were located based on results of the laboratory investigations and guidance in the draft UFC.

Visual investigation of the magazines indicated that most of the water intrusion was coming from the back wall and the interface between the concrete and the corrugated steel arch. Some water was also entering through the bolt holes and joints in the steel arch. To stop water from entering through the rear wall, the design called for installing an additional anode part way up the rear wall. A structural analysis of the back wall was performed to determine the location of maximum wall moment in the event of an accidental explosion. Anode and cathode placement design in that wall avoided a section 2 ft on any side of the point of maximum moment. Appendix D shows the design calculations used in that determination.

2.5 Installation and calibration

The components of an EOP system are specialty electrodes (anodes and cathodes), a control unit (including power supply), and electrical wiring. Installing an EOP system involves the following steps:

- Locate reinforcing steel in the concrete.
- Saw cut or chip slots and grooves for anode placement.
- Drill holes through the concrete for cathodes.
- Drill holes in concrete to provide rebar connections for stray-current protection.
- Cut slots to embed wiring in the concrete.
- Seal cracks in the concrete.
- Install anodes.
- Install cathodes.
- Connect wires to reinforcing bars.
- Embed lead wires in the concrete.
- Mount connector box outside the magazine.
- Install the control unit.
- Connect power from the control unit to the magazine.

- Test the EOP installation and ensure that all of the water leaks are addressed.

Appendix E provides details for each of the steps listed above.

2.6 Technology operation and monitoring

The EOP application at Fort A.P. Hill is designed to remotely monitor system daily performance using a dial-up modem. To date, however, this feature of the system has not been used (see section 3.4). While approvals for system use in the subject application are pending, EOP system performance has been directly monitored by researchers and contract personnel on site. Monitoring procedures include measuring concrete moisture over time, installation of corrosion-rate coupons, and periodic measurement of relative humidity and air temperature inside the magazines. Appendix E provides a full description of the testing and monitoring performed, and the results.

3 Discussion

3.1 Metrics

The EOP system was installed in accordance with ANSI/IEEE 142-2007, *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*. Potential hazards posed by EOP system electromagnetic radiation were tested according to NAVSEA OP 3565, vol II, rev 16, *Electromagnetic Radiation Hazards (Hazards to Ordnance)*.

Performance metrics for the EOP system involved several parameters and measurement methods. Relative moisture was measured in the concrete using a Protimeter Surveymaster™ moisture meter and embedded relative humidity/temperature (RH/T) sensors. Additional RT/H sensors were used to measure the air moisture at surfaces both inside and outside the magazines, and were installed both in magazines with EOP and without EOP operating. Corrosion-rate coupons were installed inside magazines both with and without EOP operating, and also outside. Finally, the corrosion rate of the concrete reinforcing steel was monitored as described under "Reinforcing steel protection evaluation," page E9 in Appendix E.

3.2 Laboratory model testing results

The laboratory safety testing carried out on the ECM model (Figure 3.1) is described in Appendix C, and the results are summarized below.

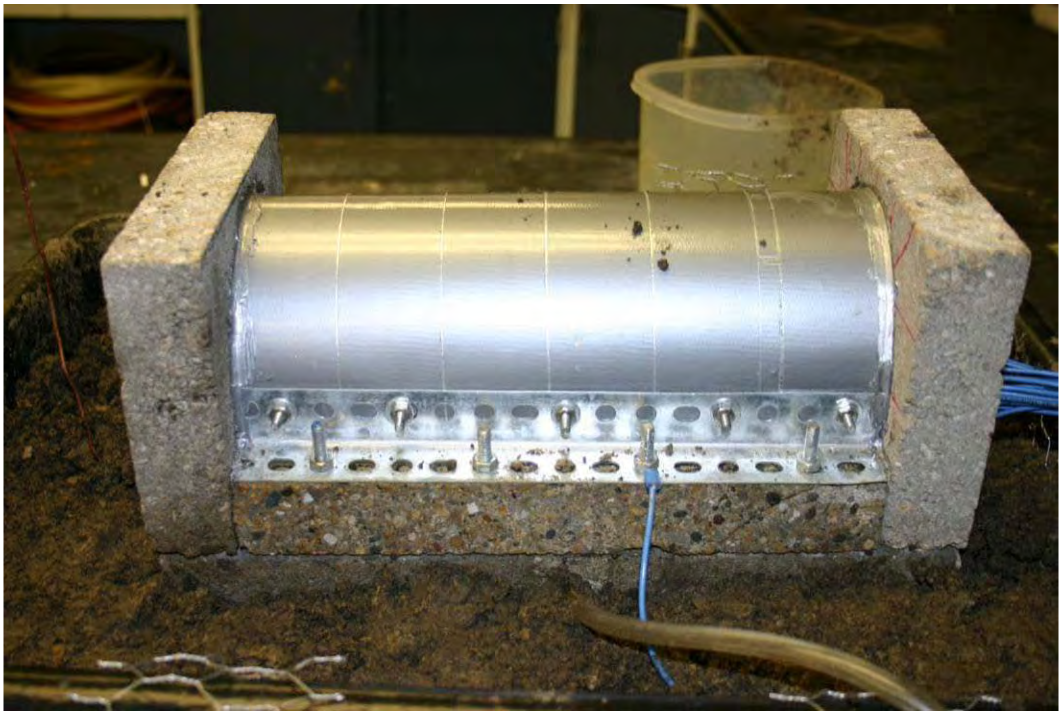

Figure 3.1. Laboratory model of ECM used for initial safety testing.

3.2.1 Sparking potential

Laboratory tests indicated that there is no danger of a spark being generated in the ECM by the EOP system. Electrical potentials were measured at different locations in the model, but no measurable potentials were found. As long as the magazine is grounded well, there is no potential for an electrical charge to build up on the steel arch inside the magazine.

There was no detectable current flow onto metal objects stored inside the ECM with a functioning EOP system in the laboratory. Electrical potential between model steel pallets was zero.

3.2.2 Lightning grounding interference

It was found that there is no significant interfering effect between the EOP system and the lightning grounding system in the model ECM.

3.2.3 Concrete drying

The concrete in the ECM model was saturated and placed in saturated soil. The EOP system was able to dry the interior surface of the concrete in model ECM, replicating many previous laboratory and field observations.

3.2.4 Generation of hydrogen gas

By taking silver/silver chloride reference cell measurements on the concrete base of the model, it was determined that the EOP system will not produce hydrogen gas. The electrochemical potential of the EOP system DC voltage in the concrete is not sufficient to produce hydrogen gas (i.e., below -0.981 v measured with reference to a saturated calomel electrode).

3.3 Full-scale ECM testing results

As in the laboratory tests, much of the testing performed on the full-scale ECM was to ensure that the EOP system would not introduce new safety risks to personnel, materiel, or ordnance. Appendix E describes the testing results in detail, and a summary is presented below.

3.3.1 Sparking potential

Sparking potential in a full-scale ECM was determined by measuring electrical potential differences between different locations on the corrugated steel arch, differences between the arch and metal pallets positioned inside the magazine, and between different metal pallets positioned on the floor of the magazine. Tests show that the voltage potential at 1 mil separation is only 40% of the value necessary to produce a spark.

3.3.2 Interaction with existing lightning protection system

The EOP system was installed in accordance with IEEE practices for lightning protection, as noted above in “Metrics.” The control unit is well grounded and all exterior wiring is run underground in non-conductive conduit.

3.3.3 Generation of hydrogen gas

Silver-silver chloride half-cell measurements were taken inside the magazine with the EOP system operating. As with the laboratory tests, the electrical potential measured in the concrete is not high enough to generate hydrogen gas; the lowest measured value is above the potential that will produce hydrogen gas in concrete.

3.3.4 Water intrusion protection

Concrete moisture was measured before the EOP system was energized and for a period following system activation. The relative concrete moisture was measured at four different depths at three different locations around the magazine: on the surface, 1 in. deep, 5 in. deep, and 10 in. deep in 11 in. concrete walls. Figure 3.2 – Figure 3.4 are graphs of the moisture measurements at the three locations in the ECM with operational EOP (illustrated in Appendix E, Figure E-43.

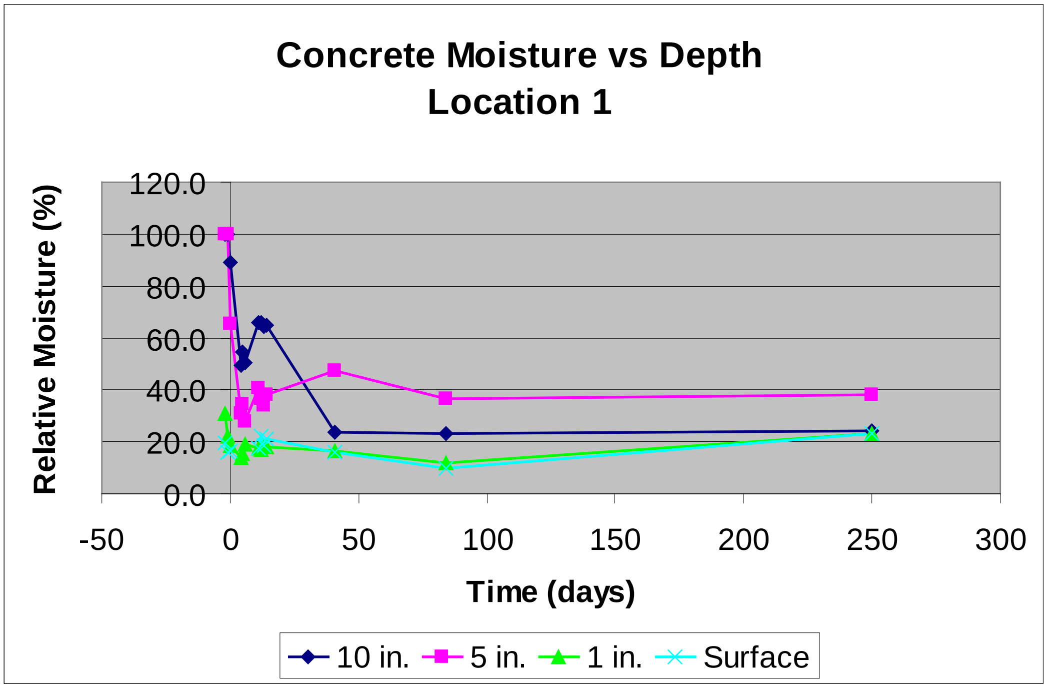

Figure 3.2. Plot of concrete moisture over time at location 1 (Figure E-42).

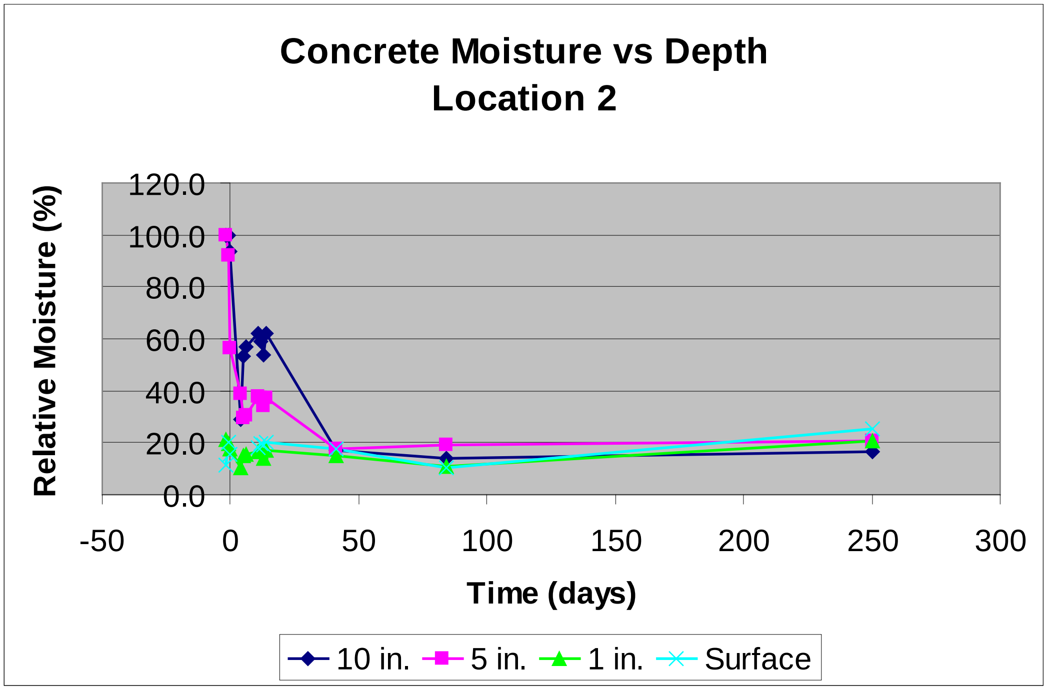

Figure 3.3. Plot of concrete moisture over time at location 2 (Figure E-42).

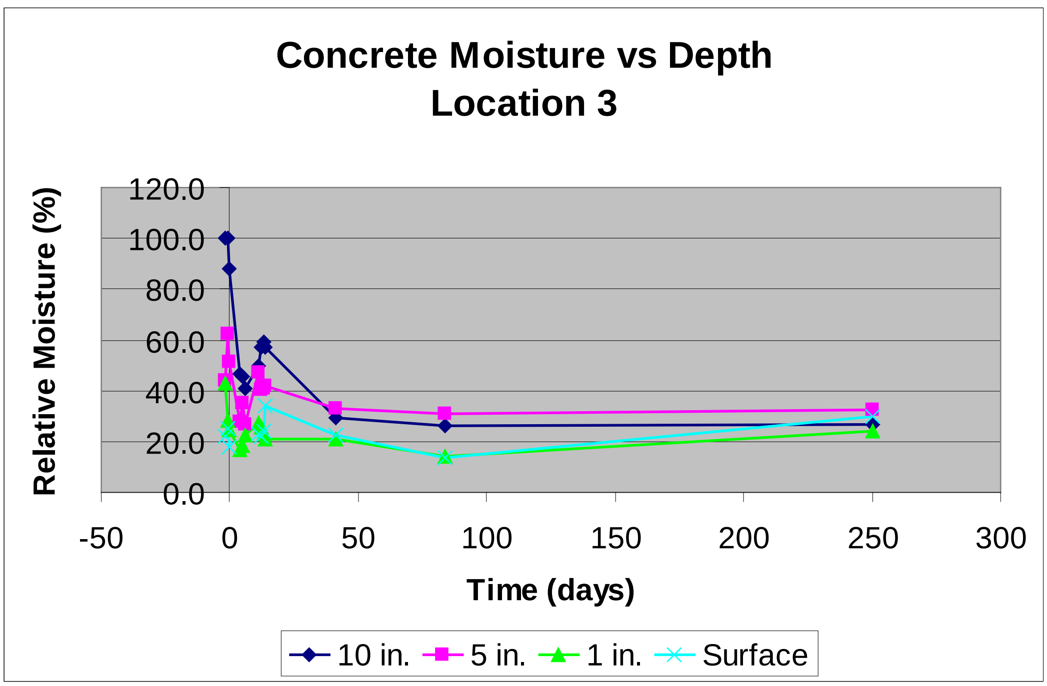

Figure 3.4. Plot of concrete moisture over time at location 3 (Figure E-42).

Data also were collected with an RH/T sensor embedded in a concrete knee wall near the midpoint of the ECM side wall. The EOP monitoring system collects the relative humidity and temperature of the concrete and logs it for download and analysis.

Two RH/T sensors and data loggers are located in the magazine with the EOP system activated and in three other magazines where the system is not yet energized. In addition, there is an RH/T sensor and data logger located approximately 200 yards from the magazines in the ammunition turn-in yard, exposed to the outside weather conditions.

3.3.5 Corrosion protection of reinforcement steel

There is potential for an EOP system to induce stray-current corrosion of the reinforcing steel in the concrete floor and walls of an ECM, as illustrated in Appendix E, Figure E-37. To prevent stray-current corrosion from occurring, a special circuit was included in the EOP system to apply a positive charge to the rebar and provide a route for current reaching the rebar to return to the controller. A test was developed to determine whether there is any stray current corrosion taking place in the structure. Tests of the effectiveness of the stray-current protection circuit are still under way.

3.3.6 Testing for electromagnetic radiation hazards

As noted under "Metrics" above, hazard testing was performed on magazines to measure electromagnetic radiation from the anodes and cathodes installed in the magazines and to detect any radio frequency (RF) emissions produced. Because of the arched form of the magazines, RF energy can be intensified when it reflects from the vault ceiling, similar to the way a parabolic reflector collects and focuses relatively weak light or radio signals.

Analysis of the tests was recently completed. Although the official test report has not been furnished to ERDC-CERL at the time of this writing, it has been communicated verbally that the EOP system produces no electromagnetic or RF emissions that would be hazardous to ordnance[7].

3.3.7 Corrosion-rate sampling and measurement

Battelle corrosion-monitoring test samples were used to measure interior and exterior corrosion rates. Coupons were placed in two ammunition bunkers (magazines 2 and 12) and outdoors. These samples were replaced

[7] Personal communication to Orange S. Marshall from Marquette Poston, principal investigator, Naval Surface Warfare Center Dahlgren Division, E3 Assessment and Evaluation Branch, Dahlgren, VA, 22 April 2008.

about every 3 months. The first group of coupons was exposed from March – June 2007, and the second group was exposed June – August 2007. These coupons were standard metallic specimens used by Battelle in worldwide corrosion monitoring activities. In addition, Battelle provided corrosion sensors based on the same copper and steel designs used in other OSD corrosion monitoring activities, including CPC Project FAR-15 (Development of Corrosion Indices and a Life-Cycle Prediction Method). Figure 3.5 shows the test rack from inside the magazine with active EOP for the June – August 2007 time frame, and Figure 3.6 shows the rack from outside exposure for that same time period.

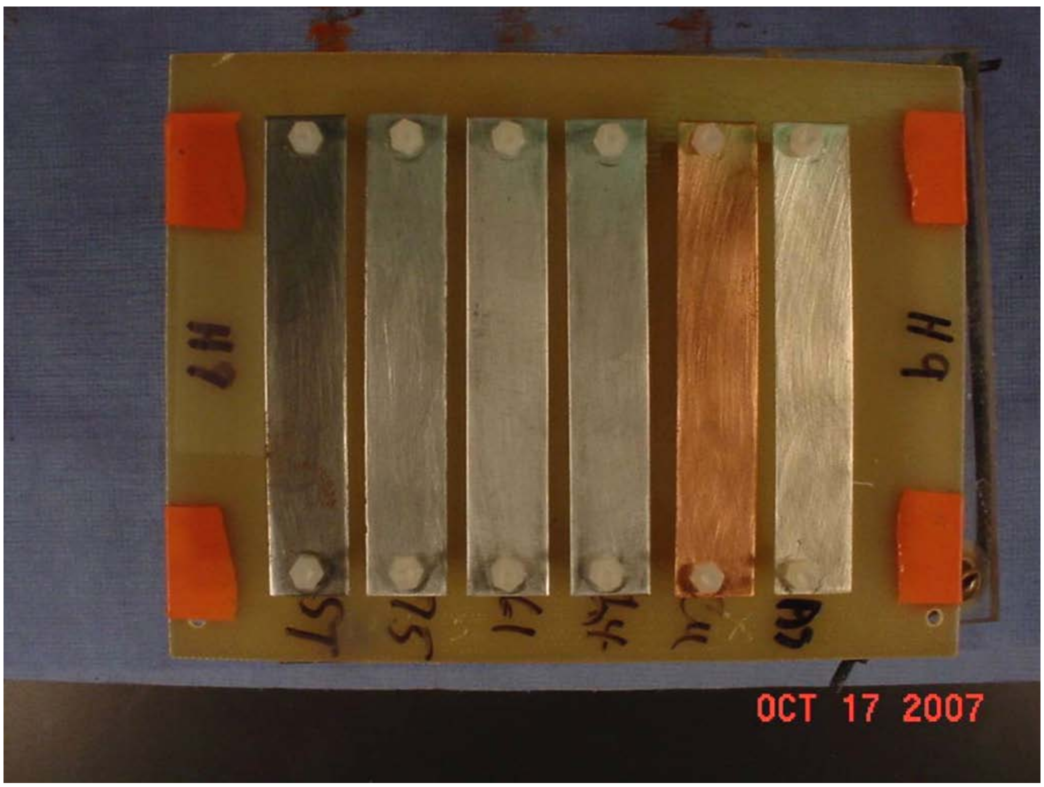

Figure 3.5. Test samples after 3 months inside ECM, June – August 2007.

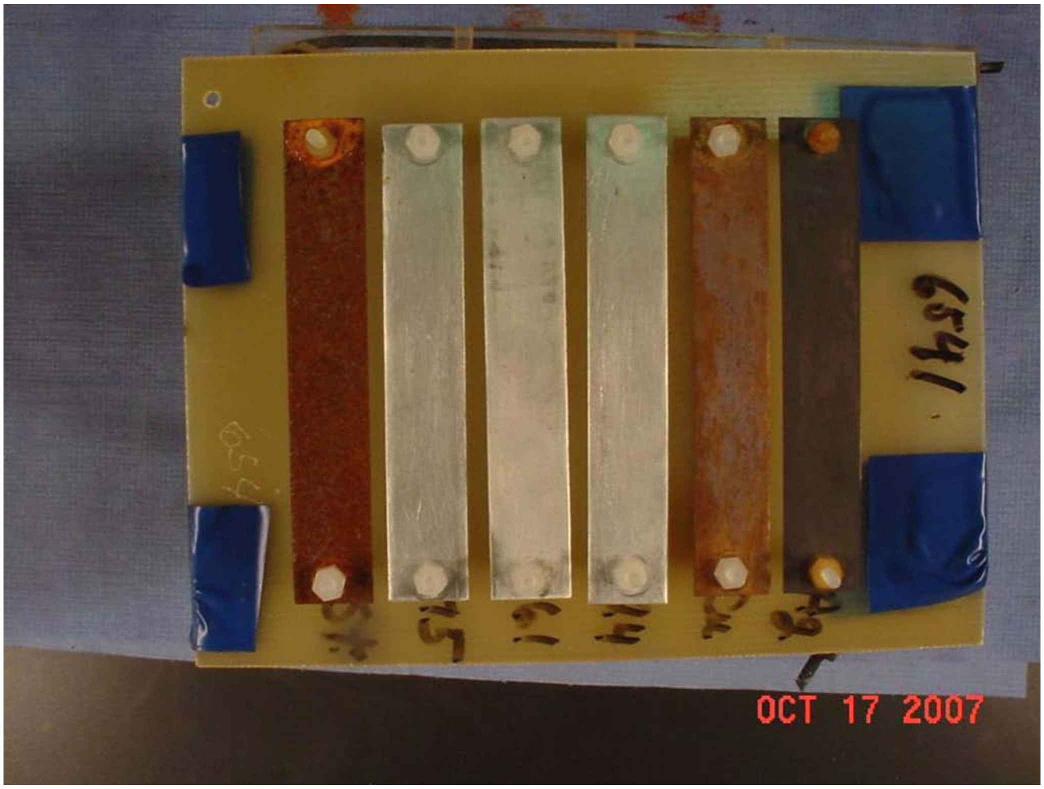

Figure 3.6. Test samples after 3 months exposure outdoors, June – August 2007.

Based on analysis of the first two 3-month samples by Battelle, it was evident that the corrosion rates inside magazines 2 and 12 were low. In fact , the only samples worth analyzing were the silver coupons (chlorides) and steel coupons since the latter had a very small amount of rust. There was no corrosion on the aluminum samples in the bunkers, and there was detectable corrosion outdoors. Table 3.1 shows the chloride film thickness for these two periods, and Table 3.2 shows the weight losses in the 1010 steel coupons.

Table 3.1. Chloride film thickness (angstroms of silver chloride).

Location	Months 0 – 3	Months 3 – 6
Magazine 2	67	76
Magazine 12	84	50
Outdoors	1267	846

Table 3.2. The weight loss on 1010 steel.

Location	Weight loss (µm/cm²)
Magazine 2	1755
Magazine 12	1784
Outdoors	5097

The results for the first set of Battelle coupons show a typical attenuation of corrosion (and corrosion-causing chlorides) by the structure as compared with outdoor ambient conditions. The corrosion rates outdoors at Fort A.P. Hill would be considered low-severity. The rates inside the two monitored bunkers were lower, but sufficient to allow a small amount (2 – 5% surface coverage) of rust formation on steel in 3 months. The results for the second Battelle sample set showed absolutely no corrosion on any coupons inside the ECMs (see section 3.4, “Lessons learned,” below).

These results indicate that corrosive conditions are not a significant factor inside the two monitored ECMs without operational EOP. At this point in time not enough data are available to conclude whether there are any significant differences in corrosion rate between the two magazines.

The Battelle coupon results were confirmed by exposure of copper and steel corrosion sensors. Corrosion activity could be seen on both types of coupon. The corresponding sensor output values obtained (in voltage) are shown in Table 3.3.

Table 3.3. Corrosion sensor voltage.

Location	Steel	Copper
Magazine 2	0.052	0.0
Magazine 12	0.296	0.053
Outdoors	1.533	0.133

These data are useful as a demonstration of a simple alternative corrosion monitoring technique. The typical uncertainty in these measurements on the scale used here is about +/-0.01.

The data for the second 3 month period through November 2007 were essentially the same (see Table 3.1).

3.4 Lessons learned

The ammunition storage magazines at Fort A.P. Hill were not the ideal site for this demonstration in terms of documenting impacts on corrosion. The atmosphere at Fort A.P. Hill is relatively noncorrosive, the relative humidity is typically not extremely high, the ordnance stored in the magazines is not of high value, and the turnover of inventory is high so that the ordnance is not generally stored there for long periods of time.

The EOP system was energized on 2 November 2006. On 25 January 2007, during field testing, the system quit pulsing. The system was deenergized and a new control unit was designed. The new control unit was designed so that (1) EOP in all the magazines could be controlled by a single, centrally located control unit instead of a separate controller in each ECM, (2) it could store, on an internal data logger, date, time, voltage, current, temperature, and relative humidity for each magazine, and (3) contained a telephone modem for notifying the installer of system failures and downloading of stored data. The new control unit was manufactured and installed in June 2007. During a site visit on 2 October 2007, it was discovered that the EOP system had quit working. Examination of the control unit showed that the main bus card in the controller had failed. Data retrieved from the controller data logger contained data starting 19 June and ending 29 July 2007. The card was removed and shipped to the manufacturer for repair. The repaired card was installed in on 29 November 2007 and the EOP system reactivated. In January 2008, permission was granted to connect the modem to a telephone line.

The RH/T sensor and data logger in the rear of the test magazine with EOP was apparently damaged or dislodged while material was being moved inside the ECM sometime around 2 March 2007; data from 3 March – 10 July 2007 are missing. A replacement sensor and data logger were installed on 10 July.

The RH/T sensor and data logger collecting outdoor data failed to operate from 13 December 2006 – 8 March 2007 because the sensor had not been reinitialized according to manufacturer instructions after the previous data download. Because some brands of RH/T sensor need to be reinitialized after data download while others do not, the responsible individual must be aware of each sensor's specific reinitialization requirements in order to avoid data loss. Extra care is needed to reinitialize the sensor following data downloads.

Because of the applicable safety requirements and approvals, the EOP system has been operational in only one empty ECM. After all of the data have been analyzed, it will be reviewed by the U.S. Army Technical Center for Explosives Safety and the Department of Defense Explosives Safety Board. Once the safety of EOP technology is approved for use in ECMs, the EOP systems will be activated in the other magazines at Fort A.P. Hill, and the technology will be cleared for use in other ECMs worldwide. At this writing, the expected date of approval is on or about 8 May 2008.

During testing for HERO it was discovered that nearby buried 60 Hz electrical cable was inducing an electromagnetic field onto the DC leads for the EOP system. The EOP DC leads must not be installed near other buried power lines and must not run parallel to them. There should be a minimum of 1 ft separation between the DC leads and buried power cables, or the power cables should be adequately shielded to avoid electromagnetic induction on the DC leads.

4 Economic Summary

4.1 Costs and assumptions

The cost to remove the soil cover and add a waterproofing membrane is estimated by the Fort Hill Director of Logistics to be $500,000 for three ECMs, or $167,000 each. Eleven ECMs at the demonstration site were subject to water intrusion problems, so it would cost $1,837,000 to address water intrusion in all 11 magazines using conventional methods. Based on experience with waterproofing membranes, it is estimated that the waterproofing will fail and need replacement within 7 years due to materials degradation, damage during construction, and damage by groundhogs.

The contract cost to install an EOP system in 11 ECMs was $565,659. An additional cost of $16,670 was incurred to redesign and assemble the control unit, bringing the total cost of the EOP system installation to $582,329. The electrical power to operate the EOP systems for a year is estimated to be less than 0.5 kilowatts, for an estimated cost of $120 per year (2008 dollars). EOP system maintenance and repair consists of changing a circuit breaker every few years and the system controller around year 20, at a cost of $1,500 net present value.

Installation of an EOP system will provide a cost avoidance for corrosion-related maintenance and repair to doors and hardware in the ECMs of $24,000 every 2 years. An additional cost avoidance of $1,000 per ECM, or $11,000, can be realized every year by eliminating the need for water cleanup and preventing losses to pallets and other dunnage needed to keep materiel dry. In addition, it is estimated that prolonged heavy rains could result in $600,000 losses in materiel stored in ECMs per year, and $75,000 of delayed or lost training due to water (or ice if the weather is cold enough) in the igloos.

Because of the structural degradation of the ECMs resulting from water intrusion, it is estimated that the magazines have a useful remaining life of less than 15 years. The replacement cost of an ECM is estimated to be $425,000, or $4.675 million for all 11 magazines. Assuming that the ECMs are replaced at year 10 and an EOP system is installed at that time, the risk of materiel replacement due to water damage will end at that time, as will costs associated with cleanup and training loss.

4.2 Projected return on investment (ROI)

Based in the costs and assumptions stated above, the projected return on investment is 38.04. Table 4.1 is a summary of the ROI computation.

Table 4.1. Estimated ROI computation sheet.

Return on Investment Calculation

Investment Required				230
Return on Investment Ratio	38.04		Percent	3804%
Net Present Value of Costs and Benefits/Savings	547		9,298	8,750

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	1,837		582	686	544	2,358	1,814
2			0	710	0	620	620
3			0	686	0	560	560
4			0	710	0	542	541
5			0	686	0	489	489
6			0	710	0	473	473
7			0	686	0	427	427
8			0	710	0	413	413
9			0	686	0	373	373
10	5,275		0	710	0	3,042	3,042
11			0		0		0
12			0		0		0
13			0		0		0
14			0		0		0
15			0		0		0
16			0		0		0
17			0		0		0
18			0		0		0
19			0		0		0
20			0		0		0
21			0		0		0
22			0		0		0
23			0		0		0
24			0		0		0
25			0		0		0
26			0		0		0
27			0		0		0
28			0		0		0
29			0		0		0
30			0		0		0

5 Conclusions and Recommendations

5.1 Conclusions

- Implementation of EOP technology stops water intrusion through concrete into ECMs.
- There is no danger of a spark being generated in an ECM due to the operating EOP system.
- The EOP system will not cause hydrogen gas formation at the reinforcing bars.
- The EOP system will maintain a dry interior concrete surface in ECMs.
- An operating EOP system does not have any impact on the existing lightning protection systems in an ECM.
- Electromagnetic and RF energy produced by the EOP system is being evaluated, but no hazardous effects have thus far been detected.

5.2 Recommendations

5.2.1 Applicability

The results of this demonstration show the capability of EOP to dry underground concrete structures. It is recommended that EOP be applied to ECMs where water damage to the storage bunker or the ordnance is known to be caused by water intrusion. The fullest potential ROI for implementing this technology will be realized, however, only where atmospheric or interior conditions are known to be corrosive at the location of the ECM.

5.2.2 Implementation

The implementation of EOP in ECMs should be formalized in Unified Facilities Guide Specifications (UFGS) and Unified Facility Criteria (UFC). Draft language for a proposed UFGS is provided in Appendix H, and draft language for a proposed UFC is provided in Appendix I.

Appendix A: Project Management Plan for CPC Project FAR01

TRI SERVICE PROGRAM

U.S. Army Facilities

CORROSION PREVENTION AND CONTROL PROJECT PLAN

Electro-Osmotic Pulse Technology for Prevention of Water Intrusion and Corrosion of Munitions and Equipment in Ammunition Bunkers at Fort A.P. Hill (RDT&E, FY06)

15 June 2005

Submitted By:

Vincent Hock

U. S. Army Engineer Research & Development Center (ERDC)

Construction Engineering Research Laboratory (CERL)

Comm: 217-373-6753

(Project Number to be *assigned by OSD when approved*)

1. **STATEMENT OF NEED**

PROBLEM STATEMENT: The Army and DoD facilities as well as the Federal Government and private sector all experience the problem of water intrusion with on grade and below grade structures such as basements and other buried structures. Fort A.P. Hill has a severe moisture intrusion problem with large volumes of water seeping through concrete walls, floors, and wall-ceiling joints of Ammunition Storage igloos at that location. During periods of high rainfall, the water depth inside the bunkers has reached 1½ inches in the past. The igloos are used for storage of a wide variety of explosive ordinance from small arms to artillery rounds as well as fuses, shape charges, hand grenades, and pyrotechnics to name a few. The water intrusion through the structure not only causes corrosion of the ammunition and equipment within the igloos, it corrodes the steel reinforcement in the concrete (Figure 1). **The moisture intrusion not only promotes severe corrosion but also contributes to poor air quality aggravating asthma and allergies of soldiers working in these confined spaces through promotion of mold and bacteria growth and propagation.** The conventional trench and drain tile method is very labor intensive, time consuming, disruptive, and prone to failure. It can not address water intrusion through floor cracks.

IMPACT STATEMENT: If this project is not funded, **the severe corrosion of vital, mission essential munitions and other metal equipment in the ammunition storage igloos will continue. In addition, the corrosion of the steel reinforced concrete will result in structural degradation.** According to Mr. John Theis and Mr. Hilton Mills of AMC, this project has the potential for far-reaching impact across the Army. In addition the project also has far reaching impact on the Tri-services, as well as other federal agencies including the Department of Alcohol, Tobacco, and Firearms (ATF). The technology has direct applicability to ammunition storage facilities in Theater of Operations and other forward locations. The igloos store materiel that is used for training soldiers, marines and ATF agents on a daily basis. The water intrusion results in ammunition boxes getting wet or damp and corrosion of metal boxes. The dampness promotes mold growth on the boxes and the materiel inside. Cracks in the floors and walls are affected in freezing weather causing further crack growth from freezing water further exposing steel reinforcement in the concrete to corrosion. The frozen water on the floor also becomes a safety hazard for fork lift operators and prevents or severely impacts delivery of munitions for troop training. These and other effects of water intrusion on soldiers and users of this structure will continue if the water intrusion is not properly eliminated. Electro-osmotic pulse (EOP) is capable of maintaining the level of interior humidity at or less than 55% RH to prevent corrosion and mold growth in and around the equipment.

2. PROPOSED SOLUTION

TECHNICAL DESCRIPTION: Electro-osmotic pulse (EOP) technology offers an alternative to conventional water control techniques. EOP mitigates water-seepage problems from the interior of affected areas without excavation. This results in reduced corrosion damage to indoors materials and equipment and elimination of mold problems caused by the moist, humid environment. EOP technology is based on the concept of electro-osmosis; the movement of an electrically charged liquid under the influence of an external electric field. A system has been developed to apply electro-osmosis for control of water intrusion within concrete structures by applying a pulsating electric field, with a savings of over 50 percent over conventional waterproofing methods. The calculated return on investment (ROI) for this project, which is based on current best practices, projected maintenance and rehab cost, is 8.32 with estimated savings of $8.7M. If this technology is not implemented, these benefits for the Tri-services will not be realized.

Figure 1: Corrosion on ammunition inside ammunition storage igloo.

Safety is an important issue with application to ammunition storage structures. Based on previous studies of EOP and experience using EOP, there is no risk of spark associated with the use of the system. The electric field generated by the EOP system is between the anode, embedded in the concrete and the cathode, embedded in the soil outside the structure. As a part of the project ERDC-CERL will perform a safety hazard study to reconfirm that there is no risk of sparking to occur. In addition the system will be designed and installed in accordance with the provisions in DA PAM 385-64, U.S. Army Explosive Safety Program, and Articles 500-503 of the National Electrical Code that deal with electricity in explosive environments.

Since the electric field generated by EOP occur between the anode and cathode the EOP system will not have any effect on metal or other material in contact with the concrete inside the igloos.

Technical Maturity:

Electro-osmosis is not a new technology although new applications are still being developed. Research has shown that flow is initiated by the movement of cations (positively charged ions) present in the pore fluid of a porous medium such as concrete; and the water surrounding the cations moves with them. Electro-osmosis has been used in civil engineering to dewater dredgings and other high-water content waste solids, consolidate clays, strengthen soft sensitive clays, and increase the capacity of pile foundations. It has also received significant attention as a method to remove hazardous contaminants from groundwater or to arrest water flow.

A system has been developed by CERL and DryTronic, Inc., to apply electro-osmosis commercially within concrete structures by applying a pulsating electric field. It is called electro-osmotic pulse (EOP). It uses two sets of electrodes; one set is embedded just below the surface of the concrete walls and the other set is placed either in the surrounding soil or if the wall is thick, deep in the concrete wall. A pulsing DC voltage is applied between the electrodes to produce an electric field in the walls, which moves water from the dry side (interior) of the walls toward the wet side, preventing moisture from reaching the interior surface of the concrete. The positive electrical pulse causes cations (e.g., Ca++) and surrounding water molecules to move from the dry side (anode) towards the wet side (cathode) against the direction of flow induced by the hydraulic gradient, thus preventing water penetration through a buried or submerged concrete structure (Figure 2). Field tests were conducted to assess the feasibility and cost effectiveness of this EOP technology in comparison with conventional dampness mitigation techniques, on selected concrete structures concluding that significant cost savings can be realized using the technology.

The Technology has received numerous awards both by the Army and industry including the 2003 Army R&D Award and the 2003 NOVA award for innovation. It was one of the three finalists for the CERF Charles Pankow Arard in 2004 and 2005. In addition, it has been published in a variety of journals and conference proceedings.

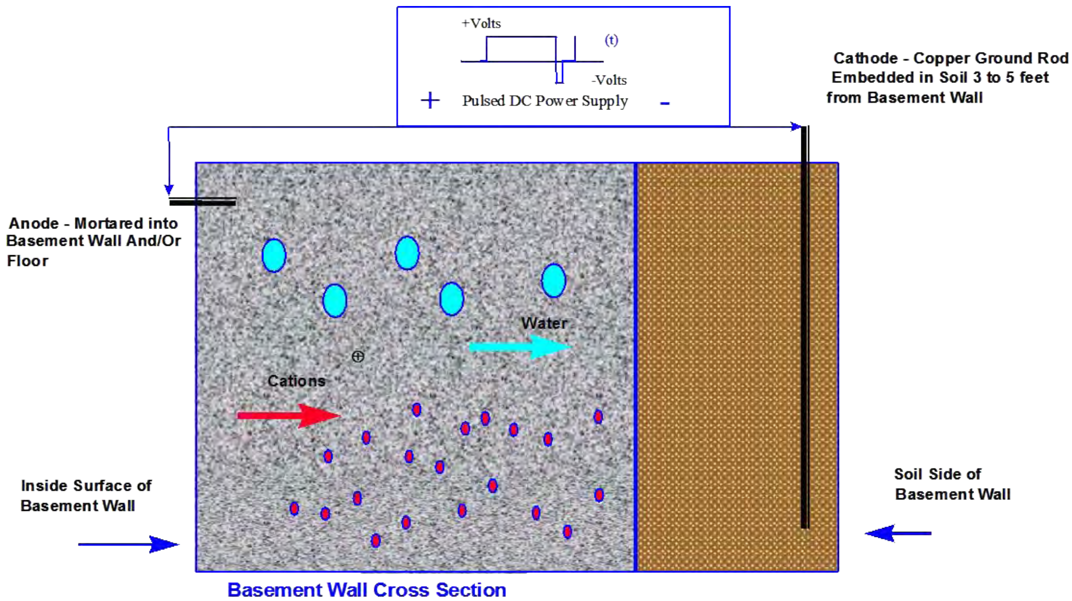

Figure 2: Schematic diagram of the Electro-Osmotic Pulse system.

Users of this technology will be Directorates of Public Works and other building maintenance and management officials.

References

1. "Evaluating Performance of the Electro-Osmotic Pulse Basement Dewatering System", Vincent Hock Sean Morefield and James B. Bushman, Journal of Materials Performance, August 2004

2. "Control of Water Migration through Concrete Using Electro Osmosis", Vincent Hock, Sean Morefield, Michael McInerney, Orange Marshall, Charles Marsh, Sondra Cooper, Philip Malone and Charles Weiss, Jr., Journal of Materials Performance, August 2004

3. "Electro-Osmotic Pulse (EOP) Technology for Prevention of Water Intrusion: Rising Damp and Moisture in Historic Buildings" Michael McInerney, Sondra Cooper, Vincent Hock, and Sean Morefield, APT Bulletin, The Journal for Preservation Technology, ART XXXIII-4-02

4. Electro-Kinetic Techniques for Moisture Control in Subgrade Structures, Vincent F. Hock, Michael K. McInerney, Sean W. Morefield, Sondra Cooper, Ann VanBlaricum, Orange S. Marshall, Jr., Philip G. Malone, and Charles A. Weiss, Jr., Proceedings:Association of State Floodplain Managers 2003 Conference, May 2003

5. "Control of Water Migration Through Concrete Using Electro-Osmosis", Sean Morefield, Vincent Hock, Michael McInerney, Orange Marshall, Charlie Marsh, Sondra Cooper, Proceedings: Corrosion 2003

6. Electro-Osmotic Pulse Technology For Corrosion Prevention and Control of Water Intrusion in Below Grade Concrete Structures, Vincent Hock, Orange Marshall, Michael McInerney, and Sean Morefield, Proceedings: 1st Congress of Corrosion in the Military, June 2005, Sorento, Italy

7. Patent: "Electro-osmotic pulse (EOP) system incorporating a durable dimensionally stable anode and method of use therefore", (COE Case # 506) published 13 Nov 2003, Publication # 2003-0209437 A1

RISK ANALYSIS: This is a **low risk** project in that the technology is commercially available and has been demonstrated to be effective in controlling water intrusion in both government and private applications. The project will be implemented in eleven ammunition storage igloos at Fort A.P. Hill, VA.

EXPECTED DELIVERABLES AND RESULTS/OUTCOMES: An EOP system will be installed in eleven ammunition storage igloos at Fort A.P. Hill. These buried structures have concrete walls on the front and back and corrugated steel arch ceilings mounted on top of fifteen inch high concrete side walls. Water seeps through the concrete rear and side walls, the concrete floors and at the concrete-steel ceiling juncture creating an environment for active corrosion to occur in the ammunition and other explosives components stored in the igloos. This is a problem, not only at Fort A.P. Hill, but at many military installations, arsenals and other underground structures where munitions are kept. As the structures age, the original waterproofing deteriorates and cracks develop in the concrete allowing water to enter. The waterproofing approach of excavating to expose the wall area and the base of the foundation, and then to install or replace damp-proofing on the wall and ceiling surface and a drain tile system around the igloos is not a practical solution to the problem since these are buried structures.

It is expected that the outcome will be permanently dry interiors for the igloos resulting in reduced corrosion and extended life, safety and reliability of the munitions and equipment stored in them. To verify the moisture reduction, temperature-humidity sensor will be installed to record changes in humidity and corrosion rates will be determined and tracked by installing metal coupons and monitoring corrosion rates of those coupons. Unified Facilities Guide Specifications (UFGS), Engineering Instructions (EI), Technical Instructions (TI), and Technical Manuals (TM), including updates, along with a final report describing the details of the project, will be developed and posted on the OSD Corrosion Exchange website under “Spec & Standards” and “Facilities SIG.” In addition, the draft documents will be posted on the ERDC-CERL Corrosion Control Program Technology Program (CCTP) website.

PROGRAM MANAGEMENT: The Project Manager will be: Mr. Vincent Hock (ERDC-CERL Senior Researcher and Materials Engineer). The Associate Project Manager will be: Mr. Orange Marshall. Mr. Martin Savoie is the ERDC/CERL Branch Chief. The stakeholders will be: Mr. John Hall (Fort A.P. Hill DPW POC), Mr. Bill Dancy (IMA-NERO), Paul Volkman (HQ-IMA), David Purcell (HQ-ACSIM), John Theis (AMSRD-AAR-AEE-P), Hilton Mills (AMC-G3), as well as Tri-services WIPT representatives, Mr. Tom Tehada (NFESC), and Ms. Nancy Coleal (AFCESA/CESM). The initial customer is: Directorate of Public Works, Fort A.P Hill, VA. The technology has been requested by Fort A.P. Hill to help prevent water intrusion and improve corrosion control inside their ammunition storage igloos.

The Army has provided matching funds ($500K) through HQ-IMA (See Memorandum from ACSIM Director for Facilities and Housing in Appendix 2). Coordination with the Army Corrosion Program Office will be through Mr. Hilton Mills (HQ-AMC).

This is a Tri-service Project. Funds have been requested for travel of Air Force and Navy representatives to participate in the evaluation of technology implementation. The approach will include contacting mechanisms such as Indefinite Delivery Indefinite Quantity (IDIQ) Contract.

3. **COST/BENEFITS ANALYSIS**

a. **Funding ($K):**

Funding Source	**OSD**	**Matching**
Labor	265	295
Materials	25	55
Travel	15	10
Report	15	10
Air Force/Navy Participation	15	---
SUBTOTAL	335	370
Overhead	165	180
TOTAL ($K)	**500**	**550**

Development Project Budget

The $1000K budget is realistic and adequate for the project scope. This budget has been developed based on a detailed needs assessment for the EOP Technology in cooperation with the Fort A.P. Hill DPW Office, including Mr. John Hall, Director of Logistics. Also, HQ-IMA and HQ-ACSIM have reviewed this project and have provided matching funds ($500) for FY06. ERDC-CERL has conducted a market survey to validate the costs for this project, which have also been extrapolated from ERDC-CERL's extensive previous experience in the area.

This project has a high discounted potential ROI>8, as shown below.

b. **Return-On-Investment Computation**

1) Useful Life Savings (ULS) is equal to the "Net Present Value (NPV) of Benefits and Savings" calculated from the Spreadsheet shown in Appendix 1 that is based on Appendix B of OMB Circular A94.

   ULS = 8,736K (from OMB Spreadsheet in Appendix 1. Assumptions for this calculation are also given in Appendix 1).

2) Project Cost (PC) is shown as "Investment Required" in the OMB Spreadsheet in Appendix 1; **PC=$1,050K**.
3) ROI – Computation

ULS 8,736K

ROI = ------------ = ------------- = 8.32

PC 1050K

The calculated ROI for this project, which is based on current best practices, projected maintenance and rehab cost, has the potential to increase over the multiple year implementation due to reduction in down time, which will result in increased indirect savings.

c. Mission Criticality

The operational benefits of implementation of this technology for these mission critical systems are reduced corrosion, enhanced life cycle costs, increased life-safety of soldiers, and greater reliability of ammunition and equipment.

4. SCHEDULE

MILESTONE CHART

EVENT	**TIME (months after receipt of funds)**
Award Contract	1

Site Visit to construction site	2
Perform Safety Study	3
Develop final EOP design	3
Begin EOP installation	4
Complete EOP installation	8
Perform Follow Up Assessment	10
Complete Documentation (includes Final Report, Procurement Specification, Ad Fliers)	12
Complete ROI Validation	12

a. Note: If project is approved, *bi-monthly status reports will be submitted* (i.e. starting the first week of the second month after contract award and every two months thereafter until final report is completed). This report will be submitted to the DoD CPC Policy & Oversight office. Report will include project number, progress summary (and/or any issues), performance goals and metrics and upcoming events.

b. Examples of performance goals and metrics: include achieving specific milestones, showing positive trend toward achieving the forecasted ROI, reaching specific performance quality levels, meeting test and evaluation parameters, and/or successfully demonstrating a new system prototype.

Development Project Schedule

This project to implement an EOP installation project will be completed, including final report, within 18 months. **The goals of the project are: elimination of water in the ammunition storage igloos, eliminate corrosion and equipment problems and potential problems associated with water intrusion into the igloos, and improve the air quality in the igloos. The objectives are installation of EOP and elimination of water seepage through the concrete walls and floor.** Detailed milestones are given in the schedule section. Contractors will provide implementation of the EOP system. ERDC-CERL will provide overall management, contract monitoring and provide bi-monthly reports. Existing contract mechanisms, such as IDIQ and BAA will be used. ERDC-CERL will be able to award the contracts within 60 days of receipt of funds. The schedule has been coordinated with Fort A.P. Hill DPW. Potential contractors have been identified.

5. IMPLEMENTATION

a. Transition approach: Unified Facilities Guide Specifications (UFGS), Engineering Instructions (EI), Technical Instructions (TI), and Technical Manuals (TM), including updates, along with a final report describing the details of the project, will be developed and posted to the OSD Corrosion Exchange website under “Spec & Standards” and “Facilities SIG.” In addition, the guidance will be ERDC-CERL Corrosion Prevention and Control Program (CPCP) website. Coordination with potential users will be an essential part of the transition of the technology.

It is the intent of the Project Management Plan (PMP) to implement this corrosion prevention and control technology at multiple regions and installations over the next 6 years, according to the schedule shown below. The UFGS, EIs, TIs, and TMs, including updates to existing guidance documents, developed for Army-wide implementation during the FY06 project, will be utilized to facilitate implementation at other DoD installations. ERDC-CERL will seek support from the Army to transfer the technology to other military installations around the world.

b. Potential ROI validation: Potential ROI will be validated by comparison of the building upgraded with the EOP system, versus the existing building and equipment. A panel of representatives from CERF, NFESC and HQAFCESA will conduct ROI validation. The calculated ROI for this project, which is based on current best practices, projected maintenance and rehab cost, has the potential to increase over the multiple year implementation due to reduction in down time, which will result in increased indirect savings.

c. Final Report: A final report will be written 60 days after the project is completed. The report will reflect the project plan format as implemented and will include lessons learned.

Projected Benefits:

Based on the past record of implementing these technologies at Army installations, the EOP system upgrades are projected to provide the benefits of elimination of water intrusion in ammunition storage igloos, resulting in reduced corrosion of munitions and equipment. Energy and maintenance requirements for sump pumps will also be realized. **The return on investment for this implementation was calculated to be 8.3 using discounted dollars with projected lifetime savings of $8,736K.**

Operational Readiness

The EOP system is commercially available and ready for implementation as solutions to the corrosion problems caused by water seepage through concrete walls and floors at Fort A.P. Hill. Based on previous experience, this project will eliminate water seepage, corrosion associated with it, eliminate the risk of loss of munitions and equipment and enhance the air quality in the interior of buried structures at Fort A.P. Hill.

Management Support

This project enjoys the support of the Fort A.P. Hill DPW Office, specifically, Mr. John Hall, Director of Logistics, IMA-NERO Region has also provided its support. Signatures have been obtained from representatives of Fort A.P. Hill DPW, IMA-NERO Region, HQ-IMA, HQ-ACSIM supporting this project, as shown on the coordination sheet. **Moreover, the Army (HQ-IMA and HQ-ACSIM) have reviewed this project and provided matching funds ($500for FY06 See attached Memorandum from ACSIM Director for Facilities and Housing in Appendix 2.**

6. COORDINATION SHEET

ORGANIZATION	SIGNATURE	DATE
Associate Project Manager	[illegible]	14 Jun 05
Project Manager	[illegible]	14 June 05
ERDC/CERL Branch Chief	[illegible]	14 June 05
Installation DPW POC		
IMA Region		
HQ IMA		
HQ ACSIM		
HQ AMC		
Tri Services Facilities WIPT Chair		

4. COORDINATION SHEET

ORGANIZATION	SIGNATURE	DATE
Project Manager		
ERDC/CERL Branch Chief		
Installation DPW POC		
IMA Region	Bill Daney	9/21/05
HQ IMA		
HQ ACSIM		
HQ AMC		
Tri Services Facilities WIPT Chair		

This is a Tri-service Project. Funds have been requested for travel of Air Force and Navy representatives to participate in the evaluation of technology implementation.

COORDINATION SHEET

ORGANIZATION	**SIGNATURE**	**DATE**
Project Manager		
ERDC/CERL Branch Chief		
Installation DPW POC		
IMA Region		
HQ IMA	[signature]	6/15/05
HQ ACSIM		
HQ AMC		
Tri Services Facilities WIPT Chair		

This is a Tri-service Project. Funds have been requested for travel of Air Force and Navy representatives to participate in the evaluation of technology implementation.

TRI SERVICE PROGRAM
ARMY FACILITIES
CORROSION PREVENTION AND CONTROL PROJECT PLAN
Electro-Osmotic Pulse Technology for Prevention of Water Intrusion and Corrosion of Munitions and Equipment in Ammunition Bunkers at Ft. A.P. Hill

COORDINATION SHEET

ORGANIZATION	SIGNATURE	DATE
Project Manager		
ERDC/CERL Branch Chief		
Installation DPW POC		
IMA Region		
HQ IMA		
HQ ACSIM	[signature]	15 Jun 05
HQ AMC		
Tri Services Facilities WIPT Chair		

This is a Tri-service Project. Funds have been requested for travel of Air Force and Navy representatives to participate in the evaluation of technology implementation.

6. COORDINATION SHEET

ORGANIZATION	SIGNATURE	DATE
Associate Project Manager	[signature]	14 Jun 05
Project Manager	[signature]	14 June 05
ERDC/CERL Branch Chief	[signature]	14 Jun 05
Installation DPW POC		
IMA Region		
HQ IMA		
HQ ACSIM		
HQ AMC		
Tri Services Facilities WIPT Chair	[signature]	6/15/05

APPENDICES

APPENDIX 1: RETURN ON INVESTMENT (ROI) CALCULATIONS

Based on OMB Circular A-94

ARMY FACILITIES

CORROSION PREVENTION AND CONTROL PROJECT PLAN

Electro-Osmotic Pulse Technology for prevention of Water Intrusion and Corrosion of Electrical and Mechanical Equipment at Fort Drum

Assumptions:

The cost to remove the soil cover and add a waterproofing membrane is estimated by Mr. Hall to be $500,000 for three ammunition storage igloos or $167,000 each. There are eleven igloos that are experiencing water intrusion. This translates to $1,837,000 to address the problem in all eleven igloos. It is estimated that the waterproofing will fail due to materials and workmanship and need replacement every 7 years.

The cost to install an EOP system in eleven igloos is estimated to be $600K and the electrical power to operate the system is 0.58K per year. EOP system maintenance and repair consists of changing a circuit breaker every few years and the system controller around year 20.

Installation of an EOP system will provide a cost avoidance for corrosion related maintenance and repair to doors and hardware in the igloos of $24K every other year and $1K every year for each igloo for water cleanup and losses to palletsand other dunnage required to keep materiel stored in the igloos dry, a total of $11K per year. In addition, Heavy prolonged rains could result in $600K losses in materiel stored in the igloos per year and $75K of delayed or lost training due to water, or ice if the weather is cold enough, in the igloos.

Because of the water intrusion and the structural degradation of the structures as a result, It is estimated that the igloos have a useful remaining life of less than 15 years. The replacement cost of an igloo is estimated to be $425K or $4.675M for all eleven igloos. Assuming that the igloos are replaced at year 10 and an EOP system is installed at that time, the risk of materiel replacement will end at that time as will water damage and cleanup and training loss costs.

Return on Investment Calculation

Investment Required			1,050
Return on Investment Ratio	8.32	Percent	832%
Net Present Value of Costs and Benefits/Savings	562	9,298	8,736

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	1,837		600	686	561	2,358	1,797
2				710		620	620
3				686		560	560
4				710		542	542
5				686		489	489
6				710		473	473
7				686		427	427
8				710		413	413
9				686		373	373
10	5,275			710		3,042	3,042
11							
12							
13							
14							
15							
16							
17							
18							
19							
20			5		1		-1
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

Year	B - Baseline			D - New System Cost				E - New System Benefits/Savings				
	Installation of Traditional Waterproof	Replace Igloos	Total	Installation	Energy to run system	Controller Replacement	Total	Materiel Replacement	Door / Hardware Replacement	Water Damage and Cleanup	On Time Training	Total
1	1837		1,837	600	0.58		600	600		11	75	686
2			0		0.58		0	600	24	11	75	710
3			0		0.58		0	600		11	75	686
4			0		0.58		0	600	24	11	75	710
5			0		0.58		0	600		11	75	686
6			0		0.58		0	600	24	11	75	710
7			0		0.58		0	600		11	75	686
8			0		0.58		0	600	24	11	75	710
9			0		0.58		0	600		11	75	686
10		5275	5,275		0.58		0	600	24	11	75	710
11			0		0.58		0					0
12			0		0.58		0					0
13			0		0.58		0					0
14			0		0.58		0					0
15			0		0.58		0					0
16			0		0.58		0					0
17			0		0.58		0					0
18			0		0.58		0					0
19			0		0.58		0					0
20			0		0.58	5	5					0
21			0		0.58		0					0
22			0		0.58		0					0
23			0		0.58		0					0
24			0		0.58		0					0
25			0		0.58		0					0
26			0		0.58		0					0
27			0		0.58		0					0
28			0		0.58		0					0
29			0		0.58		0					0
30			0		0.58		0					0

APPENDIX 2

DEPARTMENT OF THE ARMY
ASSISTANT CHIEF OF STAFF FOR INSTALLATION MANAGEMENT
600 ARMY PENTAGON
WASHINGTON DC 20310-0600

25 MAR 2005

DAIM-FD S: 15 Oct 2005

MEMORANDUM FOR DIRECTOR, INSTALLATION MANAGEMENT AGENCY, 2511 JEFFERSON DAVIS HIGHWAY, ARLINGTON VA 22202-3926

SUBJECT: FY 06 Army Corrosion Control Program

1. OSD has tentatively allocated a total of $15.0M in FY 06 matching funds for implementation of corrosion prevention and control projects for equipment and facilities. The enclosed list of Army projects, totaling $13.3M, will be presented for approval to OSD in April 05.

2. The Army programming target is not less than $10.0M of facility related projects in an effort to obtain a minimum of $5.0M of the OSD matching funds. To participate in OSD's funding augumentation, HQIMA will reserve $5.0M in FY06 OMA funds, to be released to ERDC-CERL upon confirmation by this office that OSD matching funds are available. Further instructions on the actual distribution of funds will follow at that time.

3. POC for this action is Mr. David N. Purcell, or (703) 601-0371, David.Purcell@hqda.army.mil.

4. Quality Facilities for Quality Soldiers!

FOR THE ASSISTANT CHIEF OF STAFF FOR INSTALLATION MANAGEMENT:

Encl
as

MARK A. LORING
Colonel, GS
Director, Facilities and Housing

CF:
DACSIM

Appendix B: Contractor Planning and Safety Documents

Work Plan/Pre-Performance/Installation Schedule

Plan/Procedure:
1. Sweep entire floor of ECM to remove any ammunition residue.
2. Perform depth of cover survey to locate and mark any high steel.
3. Perform continuity testing of all rebar.
4. Saw anode and control wire slots.
5. Drill holes for cathodes.
6. Implant reference electrodes.
7. Install cathodes.
8. Install anodes.
9. Install and terminate all D/C wiring.
10. Grout the anode and control wiring slots.
11. Grind and epoxy floor cracks.
12. Saturate ECM, and locate all water penetrations.
13. Repair all water penetrations with urethane grout and/or hydraulic cement.
14. Install controller and connect all control wiring.
15. Energize system.

Special Notes:
1. Anode and cathode placement will be determined by Orange Marshall.
2. All employees must wear OSHA approved respirator, hearing protection and safety glasses.
3. A fire extinguisher must be available within 25 feet of the electric generator.
4. Dig permits must be applied for 30 days in advance.
5. All debris must be contained, bagged and disposed of in authorized receptacles.
6. No photos are allowed without permission.

Important Numbers:

Emergency: 911
Fire Department (Chief Dan Glembot): 804-633-8117
ASP Office (Charles Rupe): 804-633-8801
DPW (Brian Robinson): 804-633-8262
Safety (Matthew Ewoldt): 804-633-8268
COTR (Orange Marshall): 217-373-6766
Drytronic, Inc.
Paul Femmer 636-346-7379
Patrick Reedy 612-508-1104
Ken Meyer 608-385-2075
Cathodic Technology Limited 905-857-1050

Appendix C: Laboratory Evaluation of EOP Technology on a Model Steel Arch ECM

Background

ERDC-CERL has been provided funding to investigate, demonstrate, and implement Electro-Osmotic Pulse (EOP) Technology in eleven ammunition storage igloos at Fort A.P. Hill, Virginia. These underground steel arch storage magazines have or have had water intrusion through the concrete walls and floors. The IMA region suggested to the DPW at Fort A.P. Hill that EOP could be a remedy for the water intrusion. The DPW contacted ERDC-CERL to evaluate the feasibility. ERDC-CERL inspected several igloos and concluded that much of the water intrusion was through the concrete walls; the rear wall in particular. These are the conditions under which EOP technology is most effective.

ERDC-CERL proposed to DoD and IMA, through the DoD Corrosion Prevention and Control (CPC) program, to address this problem. FY06 funds were provided to ERDC-CERL to conduct necessary developmental R&D and to demonstrate the technology. Monitoring of system performance will continue into FY07.

Objective

There were several safety issues that required evaluation before the EOP systems could be installed in the ammunition storage igloos at Fort A.P. Hill. The objectives of these evaluations were to conduct laboratory testing of a scale model earth-covered magazine (ECM):

- to determine if there is a sparking potential from the EOP system,
- to design the EOP system hardware to prevent interference with lightning protection systems installed in the igloos,
- to determine optimum cathode locations in order to minimize their impact on the existing installed ECM grounding systems,
- to determine and quantify the hydrogen gas generation potential, and
- to determine the effects of DC electrical current induced by the EOP system in the concrete floors on metallic pallets inside the structure.

Approach

A scale model of a steel arch earth-covered ammunition storage magazine was constructed in the laboratory. The model had an EOP system installed in it similar to the planned design for the full scale magazines at Fort A.P. Hill. The model included the ECM lightning protection and grounding systems. The model was buried in a laboratory test bed using a sandy clay backfill. The backfill was kept damp during the testing period.

Model Construction

A simplified scale model ammunition bunker was constructed based on the floor plans shown in Figure C-1. A single ground loop and a single air terminal at the rear of the concrete were installed as part of the system. Space limitations prevented installation of the double ring system illustrated in Figure C-1. The rings of a double ring ground system would have been so close together as to equate to the single ring. For the purposes of these tests a single ring ground was considered adequate.

Figure C-2 is a photograph of the assembled ECM model used for laboratory testing. The base and walls of the model were constructed from concrete paving blocks, 1½ inches thick and the roof from galvanized roof flashing. To simulate existing waterproofing, standard duct tape was applied to the roof section with approximately 1/16 in. gap between strips. The roof was attached to the walls using galvanized steel angles. The angles were held in place using screws going through the wall and base with nuts to keep them secure. The front and rear walls were attached by pinning them through the floor section, concrete screws into the side walls and a ¼ in. threaded rod between them at the apex of the arch and held in place using nuts. Figure C-10 shows the completed model under testing.

Prior to assembling the model grooves were cut in the floor and back wall sections for placement of anodes (Figure C-3 and Figure C-4). The anodes were embedded in a cementitious grout and the same grout was used during assembly as a mortar between the wall sections and the floor section. After curing for 24 hours, the assembly was placed in 2 inches of standing water for four days to completely saturate the concrete. Each anode segment in the floor was instrumented to monitor the current. The rear wall was a separate anode segment. Figure C-5 shows the rear wall section with the anode grouted in place. Moisture (Protimeter) probes were embedded in the floor section at three locations to measure concrete moisture during the testing period (Figure C-6).

Leads to monitor voltage at the four corners of the steel arch were attached to screws attaching the steel arch to the angle iron. A lead wire runs from the angle iron to the ground ring (Figure C-2) on each side of the model. A rubber hose was attached to the floor section near one of the screws in order to measure the steel electric potential in the concrete using a copper-copper sulfate half-cell. (The standard method of measuring steel potential in concrete is to place a copper-copper sulfate half-cell in the concrete surface nearest to the steel and measure the voltage. Since the model was covered in clay, the concrete surface was not accessible. The hose was installed to provide a way to make electrical contact with the concrete from outside the clay. The hose was filled with tap water, which was electrically conductive, and the half-cell was placed in the water.)

Before placing soil in the test bed, a wire mesh was laid on the bottom to act as an earth ground for the lightning protection system. Figure C-7 shows the test bed with the wire mesh in place.

The construction stage shown in Figure C-8 shows most of the items of interest for the lightning study. The copper wire in the soil forms the ground ring, the chicken wire represents the earth ground and the metal cylindrical structure models the metal roof of the actual structure. The blue insulated wire is the electrical connection between the metal building member and the ground ring.

Figure C-9 shows the test bed before being embedded in clay. The vertical copper wire is a part of the lightning protection system. The completed structure was covered with earth (clay) and is shown in Figure C-10. Again note the copper wire “lightning rod” at the rear of the structure and the chicken wire “earth ground” underneath. The blue insulated wires are the EOP anode leads and moisture measurement instrumentation leads.

Results

Sparking Potential Evaluation:

Electrical potential variations were monitored on the steel arch at the four corners and the ceiling. Any build-up of charge, which would be indicated by a voltage increase, can provide potential for a spark.

A potential measurement was taken using a digital multimeter. The potential was measured between the two screws on each side of the ceiling (i.e. left, right, front, and back). No potential difference was measured between each of these points throughout the testing period.

If a charge had built up, special circuitry would have been incorporated into the EOP system, modifying it to prevent charge accumulation on the steel arch.

Lightning Protection System Evaluation:

When the EOP system was running at steady state the ground system was monitored to determine the degree of coupling between the EOP system and the lightning protection system.

The “lightning” simulation was produced by driving a Kepco Bipolar operational power supply/amplifier, Model BOP50-4M with a repetitive pulse from a Wavetek Model 147 HF Sweep Generator. Figure C-11 shows the drive pulse from the Wavetek and the resulting voltage and current waveforms applied between the model lightning rod and the chicken wire earth ground. Signals were monitored and recorded with a Tektronix TDS 5104. After accounting for the current probe calibration factor, 2 Amps was injected into the “lightning rod.”

An initial voltage measurement was made on the EOP source being applied to the model EOP system (total voltage between the anodes and cathodes). This reading was taken with a high voltage differential probe. A second voltage reading was taken between the lightning rod and the earth ground to determine the degree of coupling between the two systems. The results are shown in Figure C-12. The ratio of the peak magnitudes of the signal measured on the lighting rod system to that applied by the EOP system is miniscule, approximately 0.004.

Figure C-13 shows the applied voltage signal and the measured EOP voltage and current. It can be seen that at the scale factors necessary to monitor these signals, there is no detectable response on the EOP signal.

Cathode Placement Evaluation:

To minimize impact on the existing grounding system, yet maintain EOP system efficiency, the EOP cathode placement was evaluated. It was not clear whether the EOP cathodes should be placed inside the ground ring or outside, or if it made any difference. Tests to determine cathode placement influence on the grounding system were conducted by monitoring potentials on the ground ring with several cathode placements around the model. See Figure C-14. EOP system efficiency was evaluated by monitoring the current in the anode and cathode circuits: see Figures C-15, C-16, and C-17.

The potential was measured between the ground ring and three other positions including the wire mesh (earth ground), the anodes, and the cathodes. The potential between the ground ring and the earth ground did not change whether the cathodes were placed inside or outside of the ground ring (Figure C-14). It was always less than 1 Volt.

The potential between the ground ring and the cathodes increased when the cathodes were moved from inside the ring to the outside. The potential between the ground ring and the anodes decreased when the cathodes were moved from inside to outside. Total potential always equaled the power supply voltage as one would expect. Since the ground ring is acting as a voltage probe between the anodes the cathodes.

The magnitude and distribution of current in the anode and cathode circuits is a measure of EOP system efficiency. The magnitudes of the anode currents should be as close to the design value (mA/foot) without exceeding it and the current should be evenly distributed over the cathode circuits. The anode current measurements are shown in Figure C-15. Cathode placement inside the ground ring resulted in higher currents and therefore higher EOP system efficiency. Cathode measurements are plotted in Figure C-16. The back cathode current is nearly twice as high as the left and right side cathodes. This indicates that another cathode should be added to the back side to equalize the current distribution. Figure C-17 shows the total anode and cathode current when cathodes are placed inside and outside the ring ground.

Potential for Hydrogen Gas Generation:

Appendix A is an analysis of the likelihood for generating hydrogen gas by the EOP system. The electrical potential of the steel was evaluated by installing reference electrodes and measuring/monitoring the steel (rebar) potential to ensure that it does not go less than -0.918 V. The worst case would be in completely saturated concrete due to reduced oxygen in the pores.

Figure C-18 is a plot of the steel potential over time. Note that the potential reaches a steady state condition of around 4.25 Volts and never goes negative.

DC Current Field Effects on Interior Materiel:

EOP utilizes an electrical field induced in the concrete to move water away from the anode side of a concrete surface. The field is created between the anode, buried in the concrete interior and the cathode, buried in the soil outside the structure. Other objects not between the anode and cathode are only minimally affected. However, the potential for current flow onto and through metal objects placed on top of a floor with EOP protection is not known. If the metal objects are tied to a ground it is not clear if current will flow from the floor, through the object and to the ground. A test was conducted in the model to monitor and measure current and voltage flow to simulated metal pallets on top of a floor and also when the pallets are tied to the structural ground. Two steel frames constructed from wire mesh were placed on the model floor and current and voltage potentials measured between them. They were then tied to the grounding system and the current and voltage potentials determined.

The potential was measured between the two pallets and also between the pallet and the screws in the four corners of the ceiling. The current was found by measuring the potential across a 0.1 ohm resistor. Potential and current measurements showed that the metal pallets were not affected by the EOP system. The potential was 0.0 mV for the entire test period.

Concrete moisture:

Concrete moisture data was collected with a Protimeter. The Protimeter measures the relative percent moisture concentration of the concrete at the depth the probes are placed. Three sets of probes were grouted into the floor section at a depth of approximately 1 inch. Because the steel half-cell measurement required adding moisture to the concrete, the moisture readings for all of the probe locations were 100% throughout the duration of the testing. The readings for all of the probe locations were 100% throughout the duration of the testing. On day 13 of the test period, collection of surface moisture data was begun. Figure C-19 is a graph of surface moisture indicating that the surface of the concrete on the interior of the model is drying out while the exterior is remaining wet.

Figure C-20 is a graph of the concrete subsurface moisture. Moisture content remained at 100% while the steel half-cell measurements were conducted. This is because water was added to the system in order to this measurement. When the steel half-cell measurement was discontinued the concrete began drying out.

Discussion

Sparking Potential Evaluation: Measurements to detect a differential build-up of electrical charge on the interior of the model indicated that a charge will not build up. Based on observations inside the magazines and on the construction drawings provided to ERDC-CERL, the interior steel arch of the magazines are electrically connected to the ground. As long as this ground is achieved, there is no potential for differential charge build-up on the steel arch.

Lightning Protection System Evaluation: The experiments conducted in this study discovered no significant interfering effects between the lightning rod system and the EOP system in the model. There were no obvious indications that the systems will interfere.

Examination of the floor plans for the bunker indicates that interfering effects will likely be minimized if EOP cathodes are placed inside the foundation footing ground loop. The lightning current will tend to spread out into the surrounding earth away from the metal structure and the EOP system currents (anode-to-cathode) will not flow directly across the lightning protection ground ring.

Cathode Placement Evaluation: Laboratory experiments evaluating the effectiveness of the EOP system on cathode placement when placed inside the grounding ring and outside the grounding ring further indicates that the cathodes need to be maintained inside the foundation footing ground loop.

Hydrogen Gas Generation Potential: An engineering study of hydrogen gas generation potential for an EOP system indicates that there is no potential for hydrogen gas generation. Half-cell potential measurements indicate that the voltage levels produced by the EOP system will only produce hydroxyl ions in the presence of water, raising the pH and further reducing corrosion potential for the steel reinforcing.

DC Current Field Effects on Interior Materiel: No electrical current was detected on the model steel pallets placed in the model. The electrical current is directed away from the concrete surface toward the cathodes. As a result, there is no danger of current flowing onto the pallets or the materiel stored on them.

Concrete Moisture: As anticipated, moisture measurements of the concrete floors of the model showed a drying of the surface of the concrete while the deep cross-section of the concrete remained slightly wet. In saturated soil, the surface of the concrete adjacent to the soil will remain saturated, typically to the degree that the soil is saturated. The EOP system will effectively keep the surface of the concrete relatively dry, typically less that 15-20 percent relative moisture.

Conclusions

- There is no danger of a spark being generated in the ECM due to the EOP system.
- There is no significant interfering effect between the EOP system and the lightning grounding system in the ECM.
- There is no detectable current flow onto metal objects stored inside the ECM with a functioning EOP system.
- The EOP system will dry the interior surface of the concrete in ECMs where it is installed.

Recommendations

It is recommended, based on laboratory model investigations, that an EOP system be installed in a full scale ECM at Fort A.P. Hill for full-scale evaluation if these issues. If similar results are obtained in the full scale ECM, then EOP system installation should continue to the remaining ten proposed ECMs.

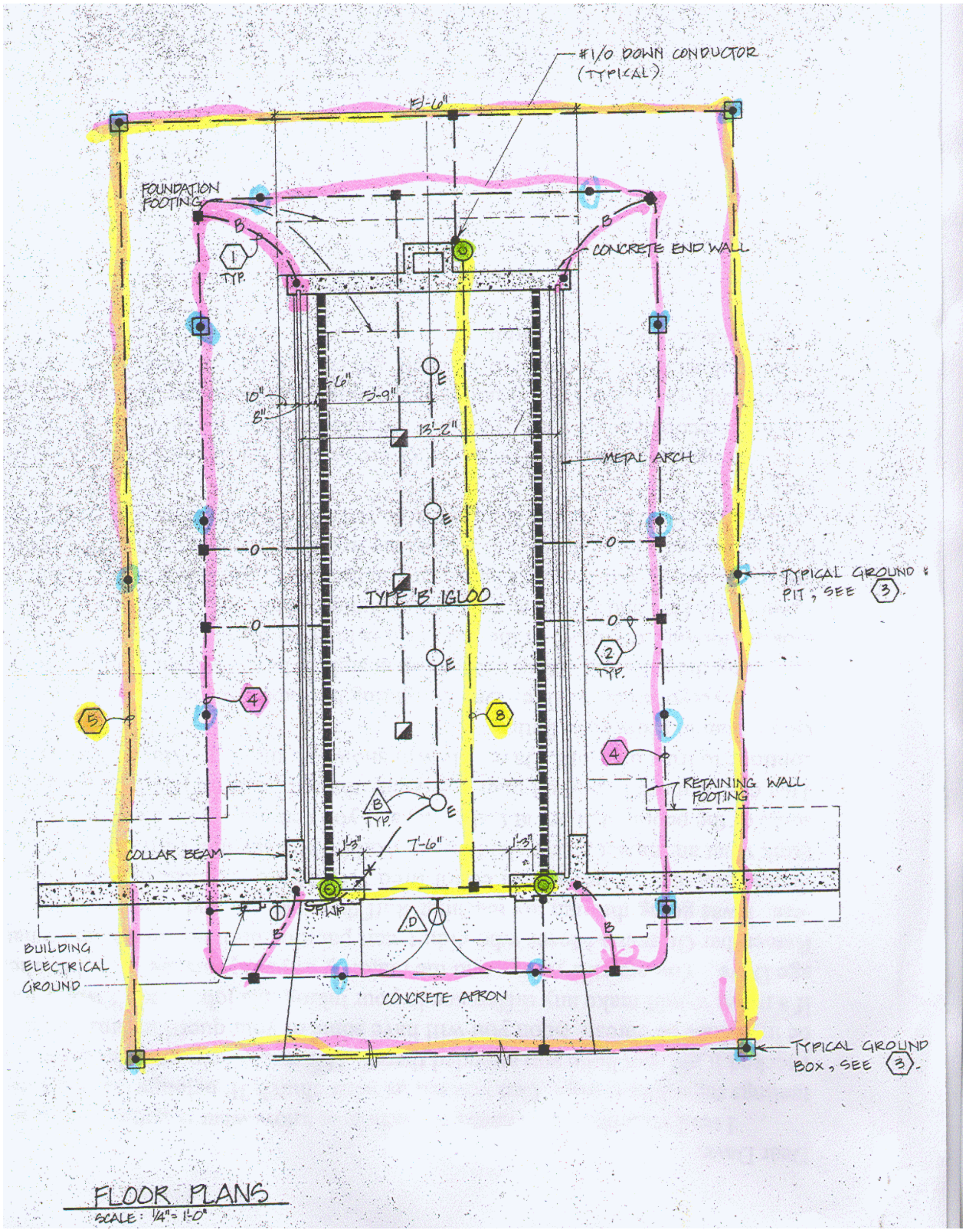

Figure C-1. Type 'B' Igloo Floor Plans. The pink highlighted ground loop approximates that installed in the model.

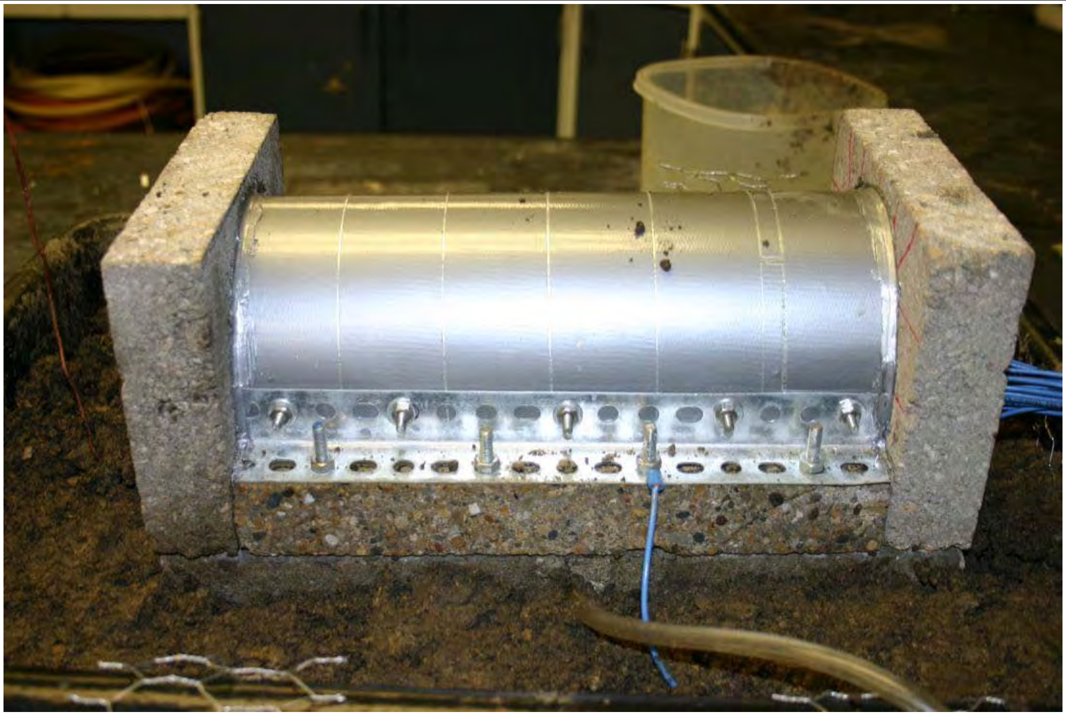

Figure C-2. Model of ECM used for testing.

Figure C-3. Floor section with grooves for anodes.

Figure C-4. Rear wall section with anodes in grooves.

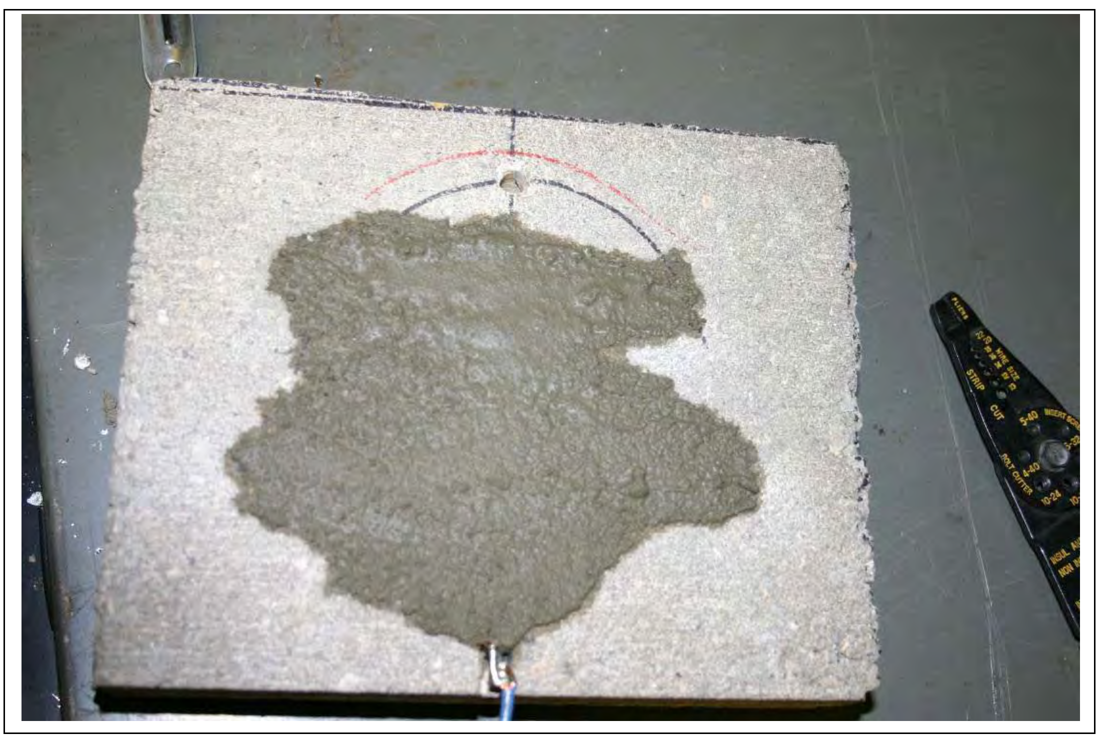

Figure C-5. Rear wall with grouted anode.

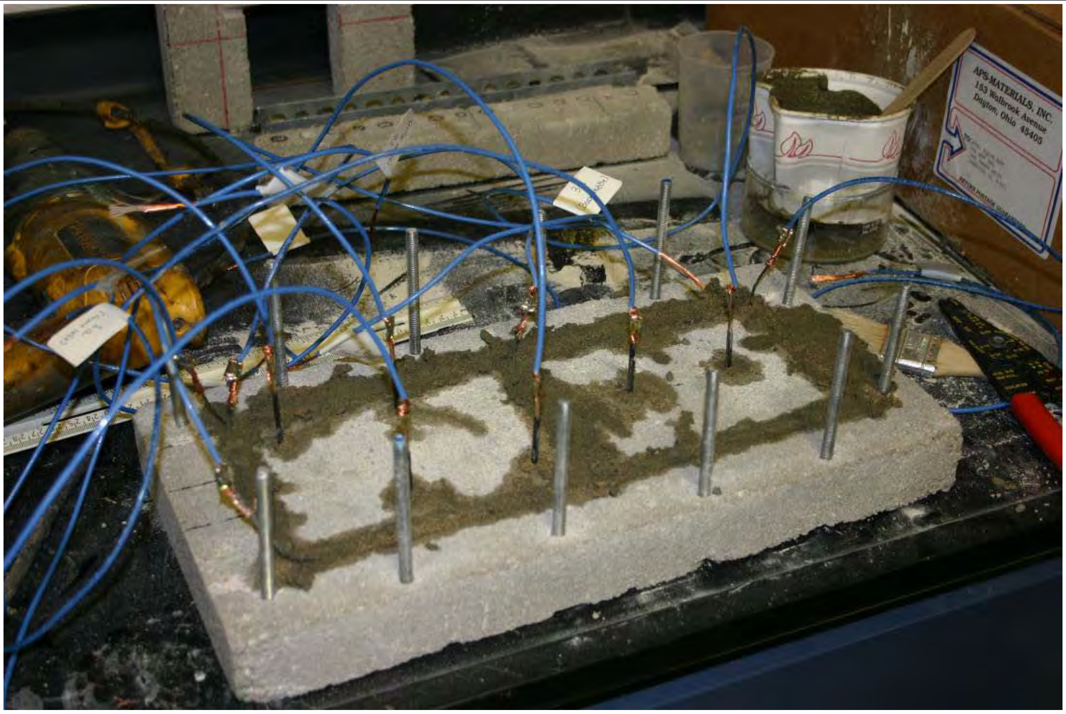

Figure C-6. Floor section with grouted anodes and moisture (Protimeter) probes.

Figure C-7. Test bed with “earth” ground.

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Figure C-8. ECM model with bare copper wire ground exposed.

Figure C-9. Model in test bed.

Figure C-10. ECM model with model lightning rod (pulse current injection point) at rear.

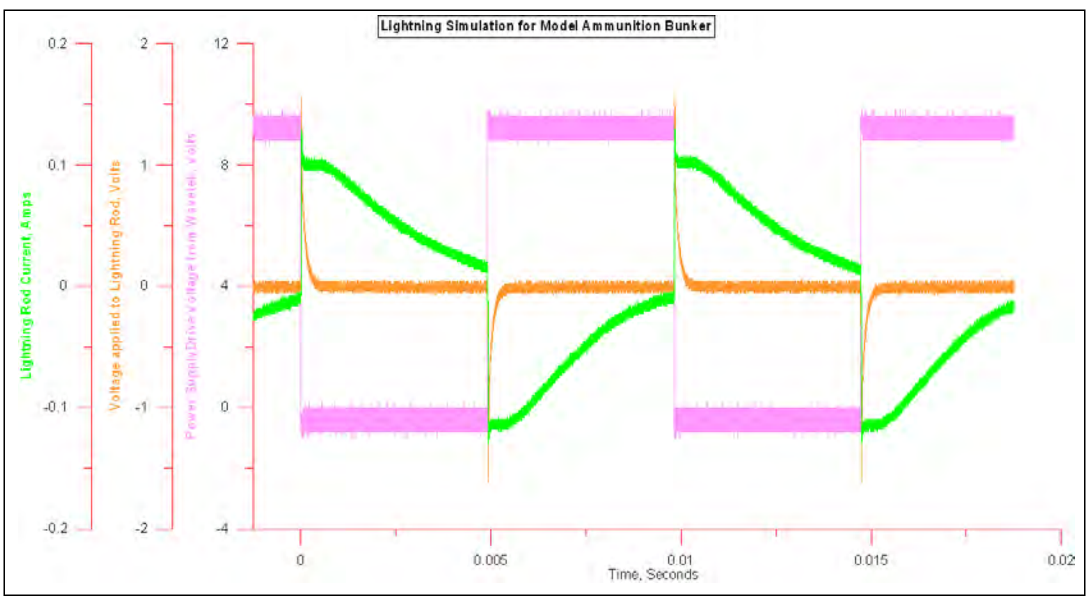


Figure C-11. Source signal for simulated lighting measurements on ECM model.

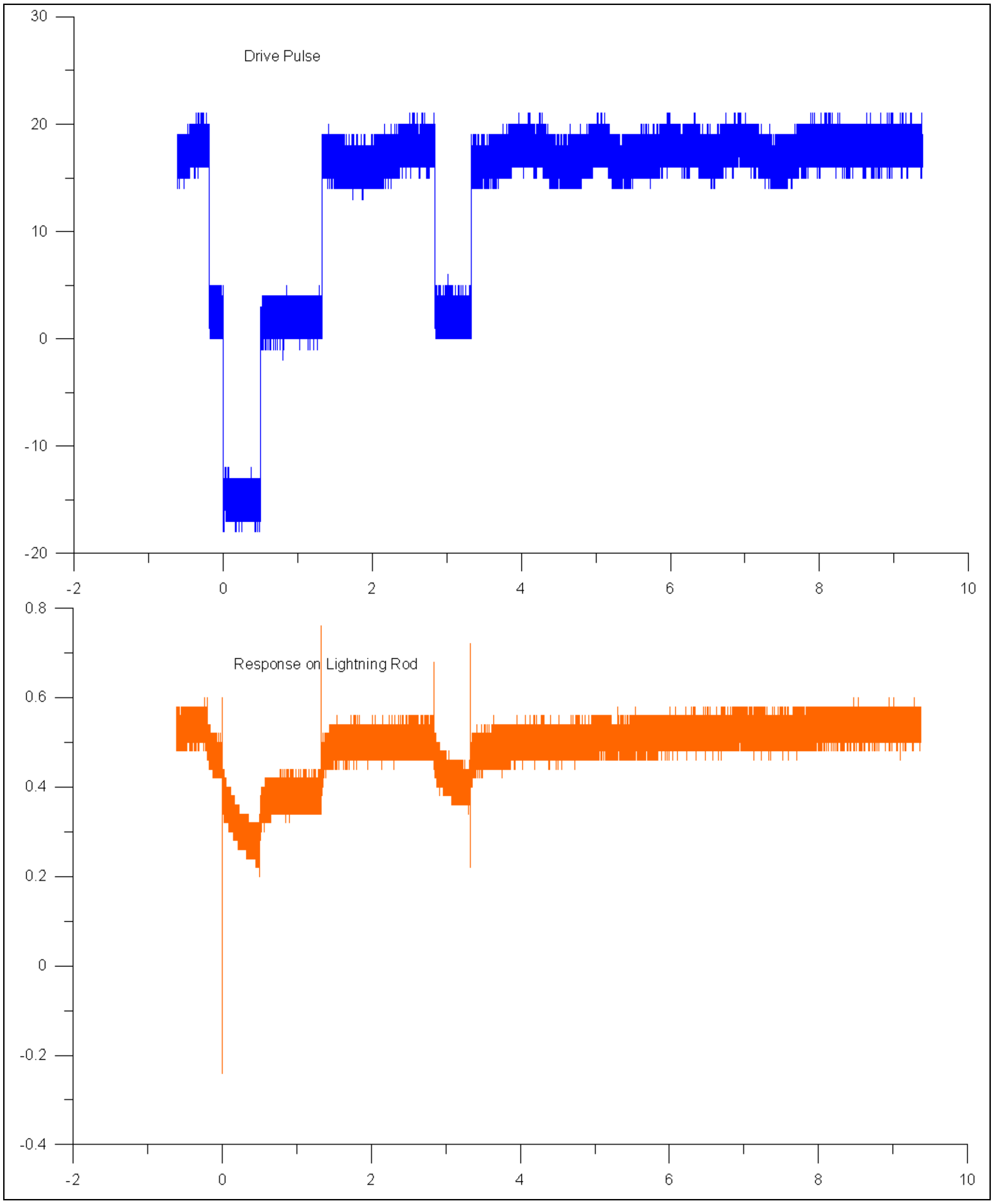


Figure C-12. EOP circuit current coupling to grounding system.

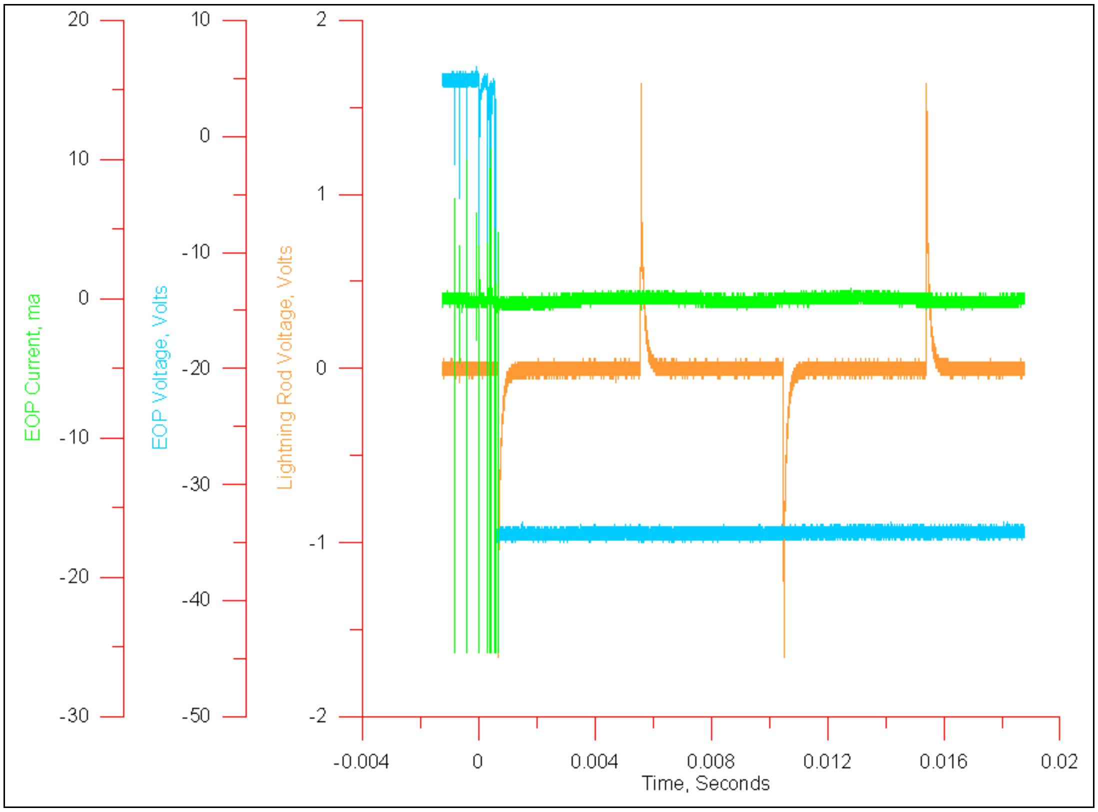


Figure C-13. "Lightning rod" induced grounding system current coupling to EOP circuit.

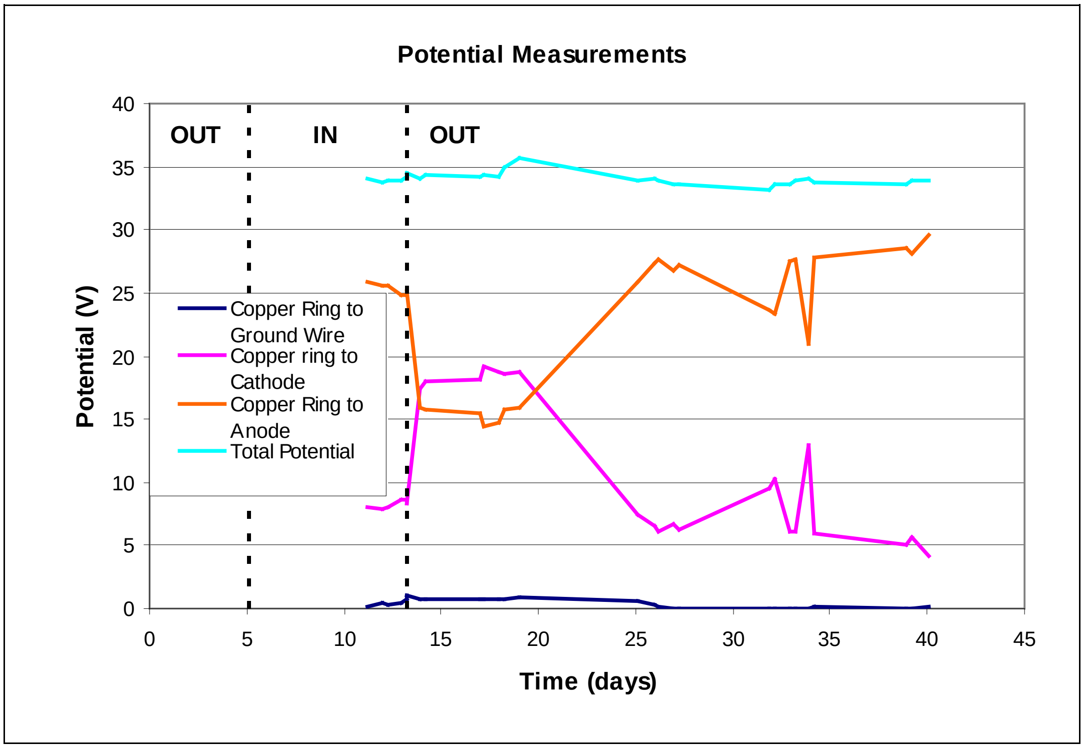


Figure C-14. Electrical potentials between conductors when cathodes are inside (IN) and outside (OUT) ring ground.

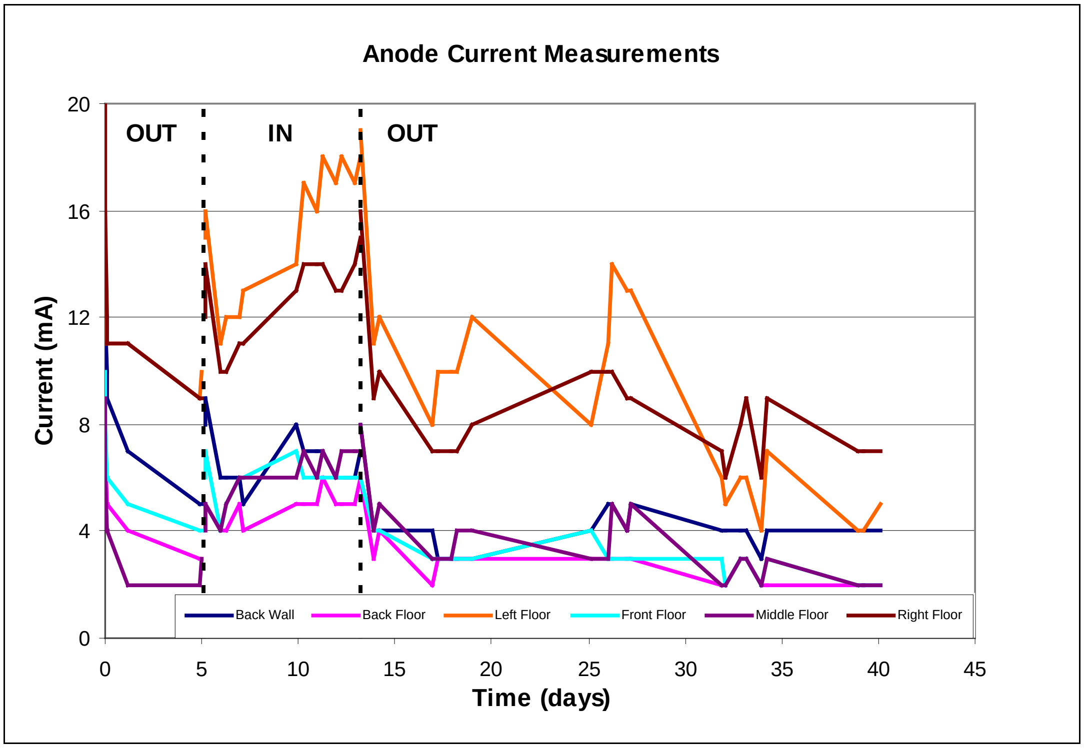


Figure C-15. Anode currents when cathodes are placed inside (IN) and outside (OUT) ring ground.

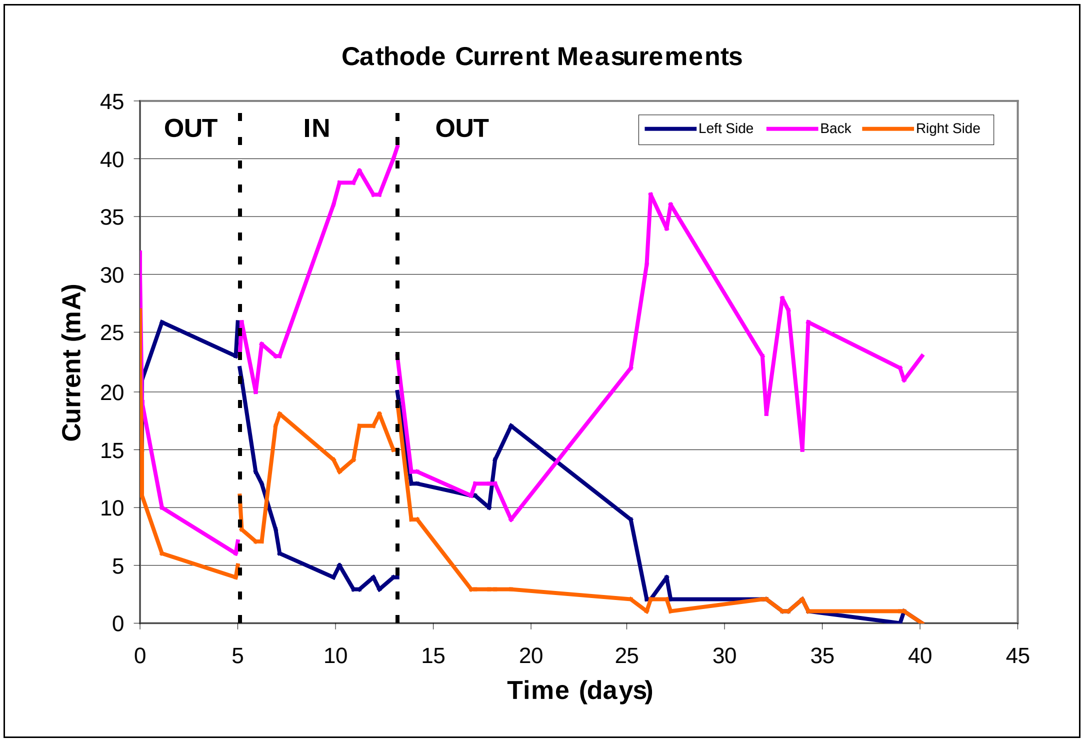


Figure C-16. Cathode currents when cathodes are place inside (IN) and outside (OUT) ring ground.

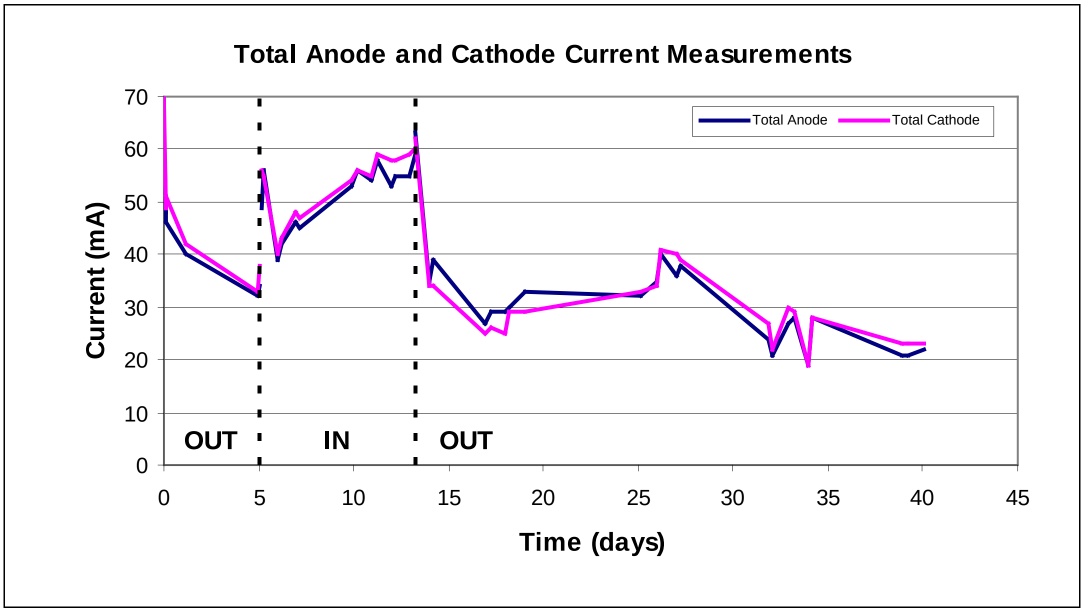


Figure C-17 Total anode and cathode current when cathodes are placed inside (IN) and outside (OUT) ring ground.

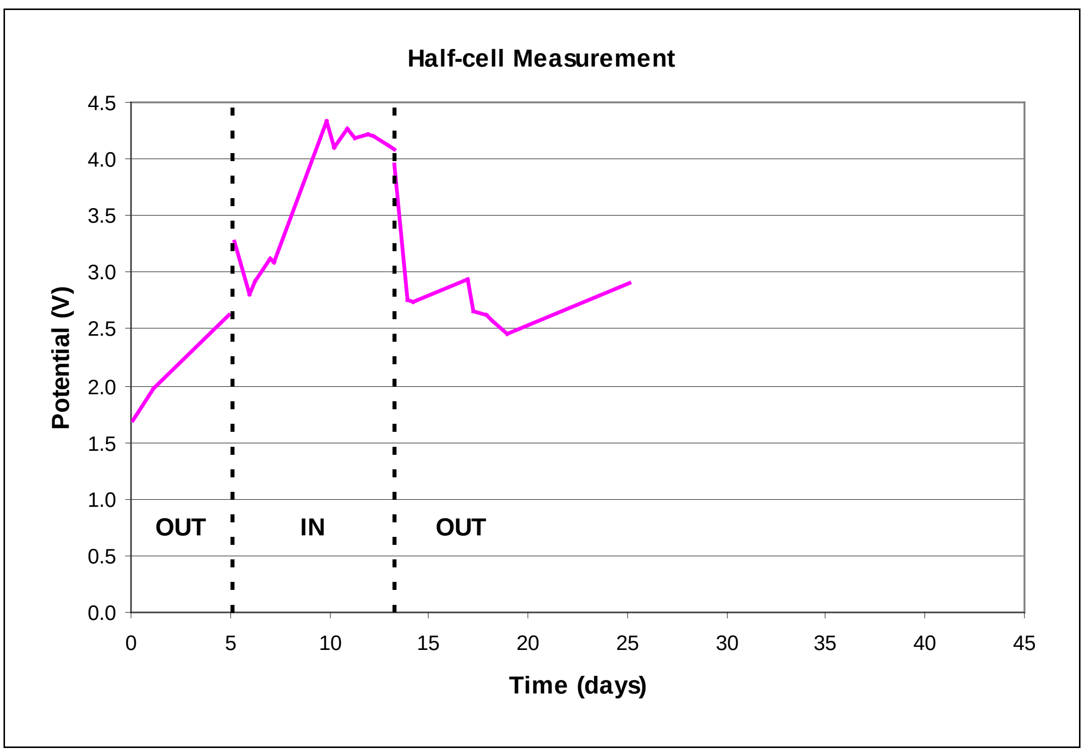


Figure C-18. Half-cell steel (rebar) corrosion and gas generation potential measurements when cathodes are placed inside (IN) and outside (OUT) ring ground.

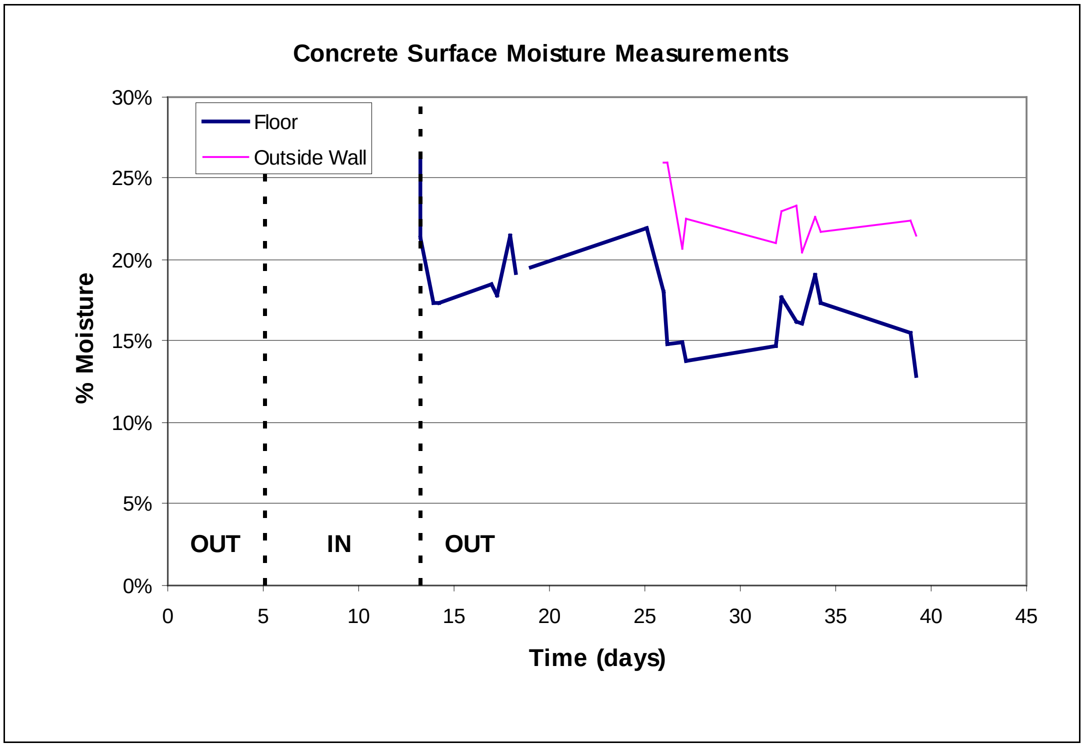


Figure C-19. Surface moisture (Protimeter) when cathodes are placed outside (OUT) of ring ground.

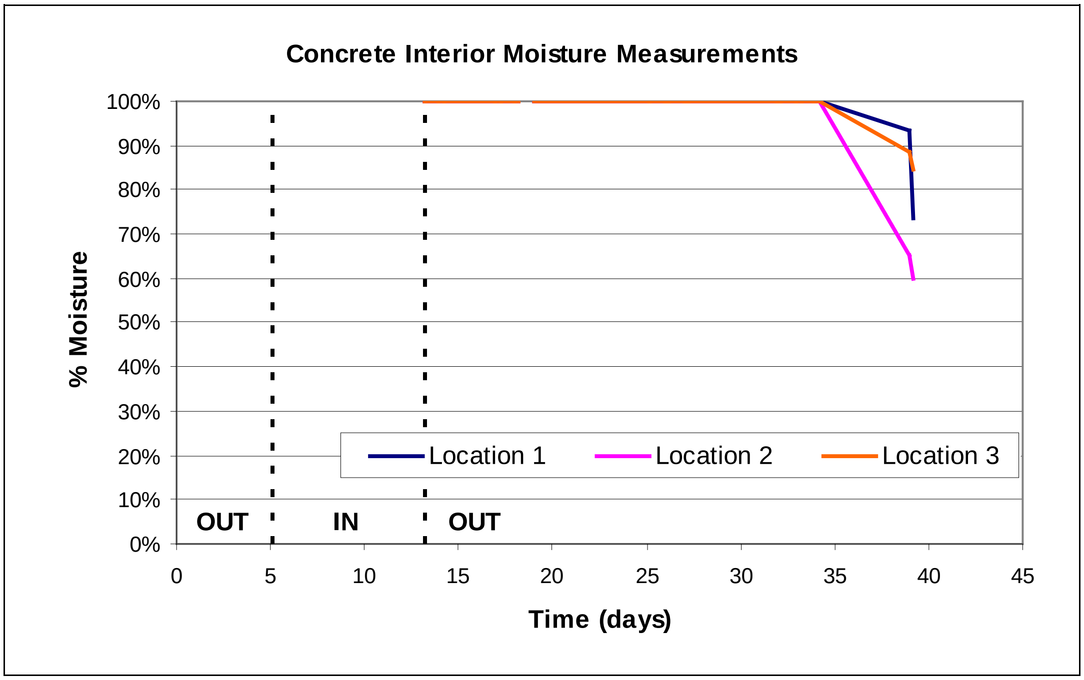


Figure C-20. Concrete interior moisture (Protimeter) when cathodes are placed outside (OUT) of ring ground.

Appendix D: EOP Design Details

Dr. Ghassan Al-Chaar

Technical Report on Back Wall Of Small Ammunition and Explosive Storage Magazines Constructed from Steel Semi-Circular Arch

Statement of the Problem:

An anode protection system is to be installed on the inside face of the back wall of an ammunition and explosive semi-circular magazine (igloos). ¾" wide and 1 ¼ " deep grooves will be cut on the face of the wall and it is required to identify the maximum moment on the back wall resulting from soil pressure combined with a hypothetical explosive load.

References:

1. Structural drawing S-5, S-6, and S-7.
2. The US Army Corps of Engineers Standard Design drawings on "Magazine, Steel, Semicircular-Arch Earth-Covered"
3. http://www.navfac.navy.mil, Building type "WBDG" Semi-Circular Arch 421-8--01

Description of the Structure:

An ammunition and explosive storage magazine is constructed from earth-covered one inch corrugated steel semi-circular arch. The magazine can be 26-80 ft. deep and the radius of the steel arch is about 12'-8" supported on 15" wide and about 2'4" deep portal walls. The slab is 6" reinforced concrete on gravel protected by water barrier. Typical transverse section details are shown in Figure D-1.

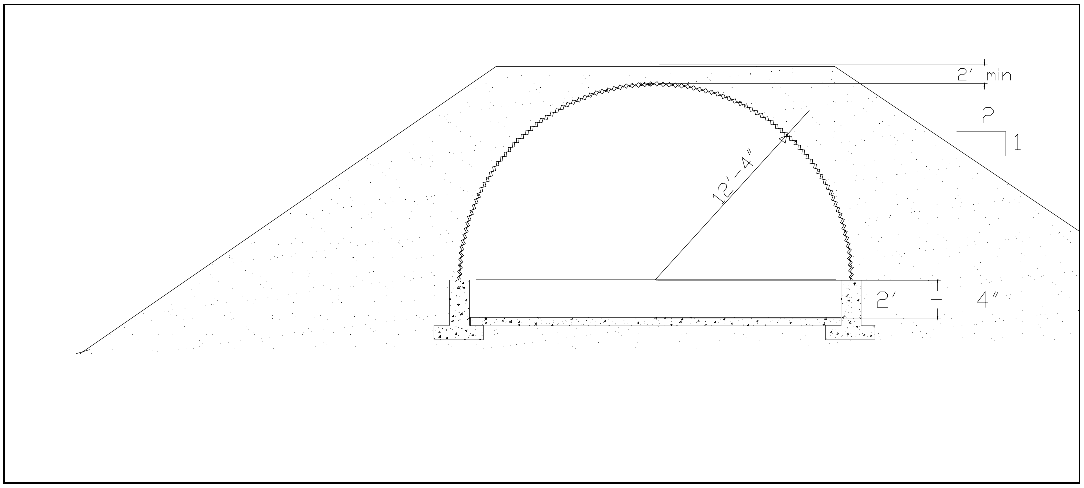


Figure D-1. Section in a typical ammunition and explosive storage magazine.

Location of Maximum Soil Pressure:

Assumption: The angle of internal friction Φ= 33 degrees

C= 0

Ka = (1- Φ) / (1+ Φ)

= 0.3

Area of the soil section above the wall:

Top edge = 3'

Bottom edge = 3' + 4' (for slop 1:2 the horizontal distance is twice the vertical distance. The vertical distance is assumed to be 2'. There fore the horizontal is 4' + 3' = 7'

Assumption: assume the unit weight of the soil γ= 120 lbs/ft ^{3}

Pressure at the top of the wall: Pa = 0.3 [(7' + 3')/2] 2' x 120

= 360 psf

The clear height of the wall: H = (17'-6") - (2'-6")

= 15'

Pressure at the bottom of the wall: Pb = 360 + (15 x 120 x 0.3)

= 900 psf

Location of maximum moment from the slab = h (max. moment)

= 15 [(360/900)]

= 6 ‘

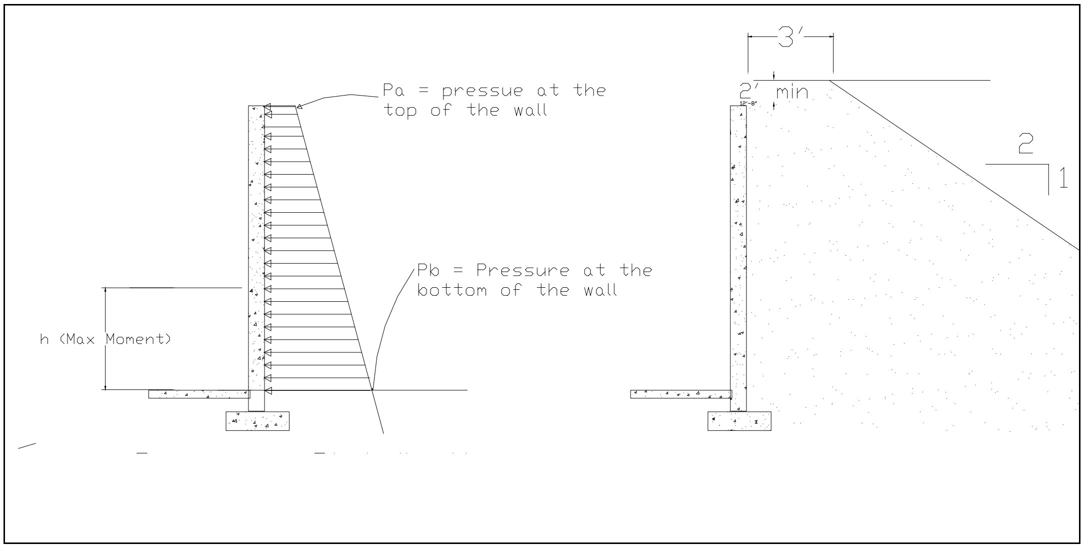


Figure D-2. Pressure distribution of the soil on the back wall of the igloo.

Conclusion:

As shown in Figure D-3, the theoretical maximum pressure due to the soil pressure is at about 6 ft. height from the bottom of the wall along the line of symmetry. Adding load of equal distributive pressure on the wall due to explosive will cause the location moment to move upward depending on the magnitude load. It is a judgment that the location of the maximum pressure for reasonable magnitude of pressure (before failure) due to explosion will be at height between 6 and 7 ft. Also, the moment decreased as we move away from the line of symmetry on each side. Therefore, area of maximum moment is roughly from 6 to 7 ft height and 4 ft. wide (2 ft on each side of the line of symmetry).

Note: the groove of 1 ¼ “ deep is within the concrete cover and shall have no significant structural impact on the wall.

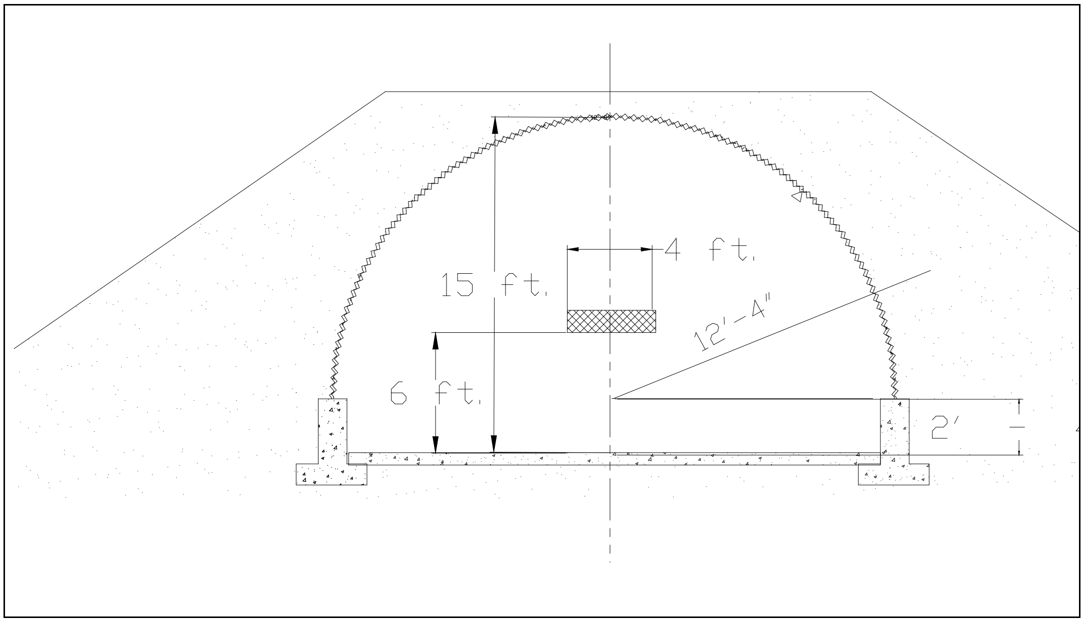


Figure D-3. Area of maximum moment on the back wall.

Dr. Ghassan Al-Chaar

Technical Report on Back Wall Of Large Ammunition and Explosive Storage Magazines Constructed from Steel Semi-Circular Arch

Statement of the Problem:

An anode protection system is to be installed on the inside face of the back wall of an ammunition and explosive semi-circular magazine (igloos). ¾" wide and 1 ¼ " deep grooves will be cut on the face of the wall and it is required to identify the maximum moment on the back wall resulting from soil pressure combined with a hypothetical explosive load.

References:

1. Structural drawing S-5, S-6, and S-7.
2. The US Army Corps of Engineers Standard Design drawings on "Magazine, Steel, Semicircular-Arch Earth-Covered"
3. http://www.navfac.navy.mil, Building type "WBDG" Semi-Circular Arch 421-8--01

Description of the Structure:

An ammunition and explosive storage magazine is constructed from earth-covered one inch corrugated steel semi-circular arch. The magazine is 24 ft. wide by 50 ft. deep and the radius of the steel arch is about 24'-6" supported on 15" wide and about 11" deep knee walls. The slab is 6" reinforced concrete on gravel protected by water barrier. Typical transverse section details are shown in Figure D-4.

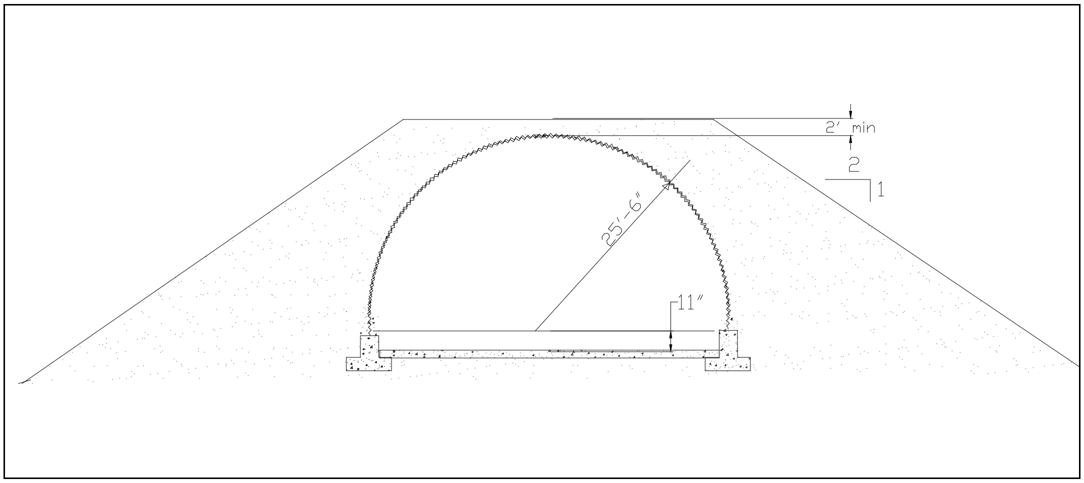


Figure D-4: Section in a typical ammunition and explosive storage magazine.

Location of Maximum Soil Pressure:

Assumption: The angle of internal friction Φ= 33 degrees

C= 0

Ka = (1- Φ) / (1+ Φ)

= 0.3

Area of the soil section above the wall:

Top edge = 3'

Bottom edge = 3' + 4'

(For slop, 1:2 the horizontal distance is twice the vertical distance.) The vertical distance is assumed to be 2'. There fore the horizontal is 4' + 3' = 7'

Assumption: The unit weight of the soil γ= 120 lbs/ft ^{3}

Pressure at the top of the wall: Pa = 0.3 [(7' + 3')/2] 2' x 120

= 360 psf

The clear height of the wall: H = (24'-6") + (11")

= 25'-5"

Pressure at the bottom of the wall: Pb = 360 + (25'-5" x 120 x 0.3)

= 1275 psf

Location of maximum moment from the slab = h (max. moment)

= (25'-5") [(360/1275)]

= 7'-2"

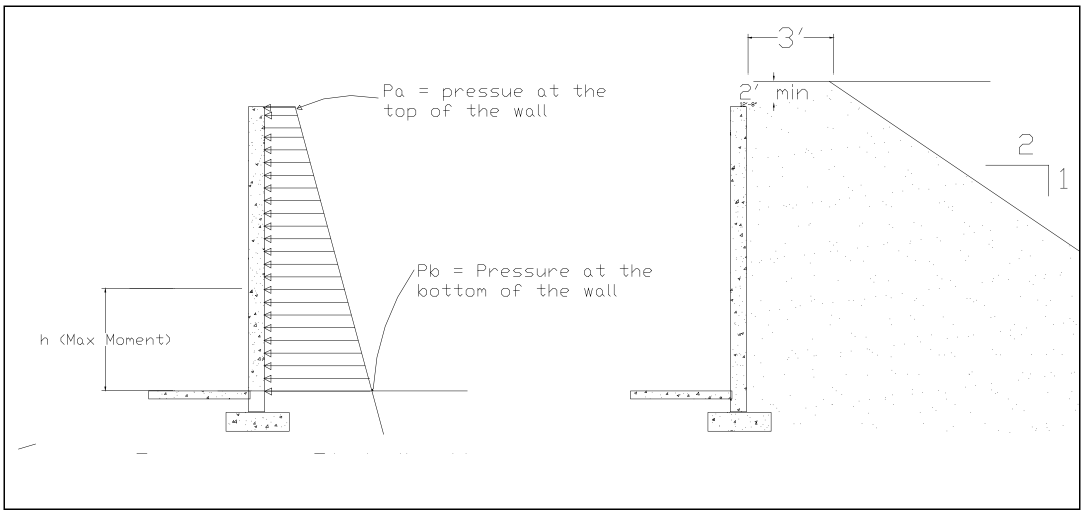


Figure D-5: Pressure Distribution of the Soil on the Back Wall of the Igloo.

Conclusion:

As shown in Figure D-6, the theoretical maximum pressure due to the soil pressure is at about 7'-2" height from the bottom of the wall along the line of symmetry. Adding load of equal distributive pressure on the wall due to explosive will cause the location moment to move upward depending on the magnitude load. It is a judgment that the location of the maximum pressure for reasonable magnitude of pressure (before failure) due to explosion will be at height between 7'-2" and 8'-5" ft. Also, the moment decreased as we move away from the line of symmetry on each side. Therefore, area of maximum moment is roughly from 7'-2" to 8'-5" height and 4 ft. wide (2 ft on each side of the line of symmetry).

Note: the groove of 1 ¼ " deep is within the concrete cover and shall have no significant structural impact on the wall.

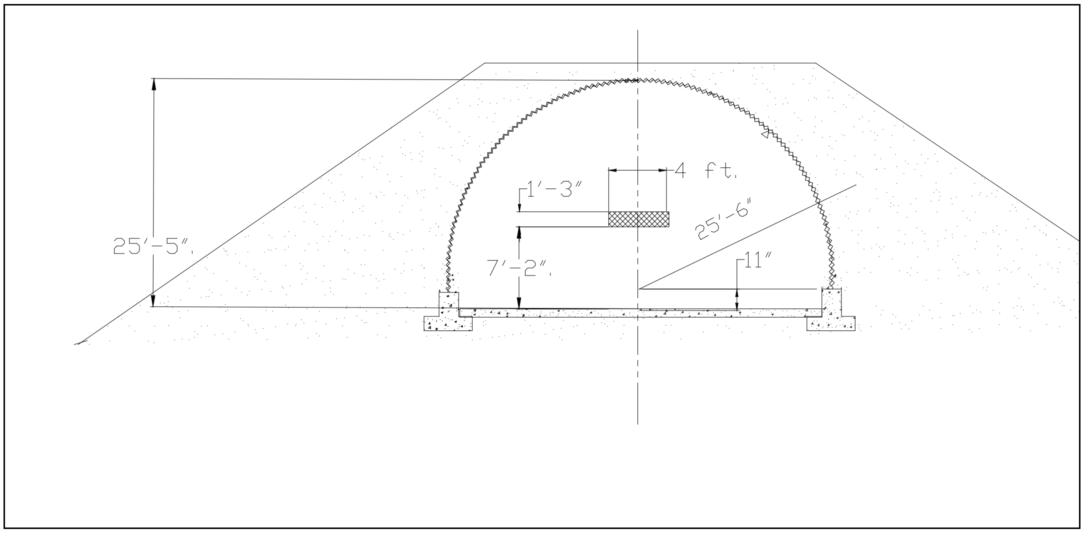


Figure D-6: Area of Maximum Moment on the Back wall.

Determination of Maximum Anode Segment Length for 11' X 30' Magazines

Design Calculations

Maximum Allowed Anode Length/Connection

A	Maximum Design Current Density	2	mA/ft^2		
B	Anode Spacing	11.000	ft		
C	Anode length/Cond. Bar	36.75	ft		
D	Anode width	0.75	in.		
E	Anode resistance	0.08	Ω/ft		
	2E=IR				
	IR_{tot}≤300 mV				
	Anode				
	R_A=	R_SL			
		R_S =	0.08	Ω/ft	
		L=	18.375	ft	
	=	1.47	Ω		
	I_A=	ρ_iS_AL			
		ρ_i=	2	mA/ft^2	
		S_A=	11.000	ft	
		L=	18.375	ft	
	=	404.25	mA		
	E_A=	$I_AR_A/2$			
	=	297.1238	mV	≤300 mV?	OK

Component Resistances		
Mesh Anode		
1/4"		Ω/ft
1/2"	0.12	Ω/ft
3/4"	0.08	Ω/ft
1"		Ω/ft
Conductor Bar		
1/4"	0.049	Ω/ft
1/2"	0.0175	Ω/ft
3/4"		Ω/ft
1"		Ω/ft

Determination of Maximum Anode Segment Length for 24' X 50' Magazines

Design Calculations

Maximum Allowed Anode Length/Connection

A	Maximum Design Current Density	2	mA/ft^2		
B	Anode Spacing	24.000	ft		
C	Anode length/Cond. Bar	25	ft		
D	Anode width	0.75	in.		
E	Anode resistance	0.08	Ω/ft		
	2E=IR				
	IR_{tot}≤300 mV				
	Anode				
	R_A=	R_SL			
		R_S =	0.08	Ω/ft	
		L=	12.5	ft	
	=	1	Ω		
	I_A=	ρ_iS_AL			
		ρ_i=	2	mA/ft^2	
		S_A=	24.000	ft	
		L=	12.5	ft	
	=	600	mA		
	E_A=	$I_AR_A/2$			
	=	300	mV	≤300 mV?	OK

Component Resistances		
Mesh Anode		
1/4"		Ω/ft
1/2"	0.12	Ω/ft
3/4"	0.08	Ω/ft
1"		Ω/ft
Conductor Bar		
1/4"	0.049	Ω/ft
1/2"	0.0175	Ω/ft
3/4"		Ω/ft
1"		Ω/ft

Appendix E: Field Evaluation of EOP Technology on a Full-Scale Steel Arch ECM

Background

ERDC-CERL has been provided funding to investigate, demonstrate, and implement Electro-Osmotic Pulse (EOP) Technology in eleven earth-covered ammunition storage magazines at Fort A.P. Hill, Virginia. These underground steel arch storage magazines have or have had water intrusion occurring through the concrete walls and floors. The Directorate of Public Works (DPW) for Fort A.P. Hill contacted ERDC-CERL to evaluate the feasibility of EOP stopping the water intrusion. ERDC-CERL inspected several magazines and concluded that much of the water intrusion was through the concrete walls; the rear wall in particular. These are the conditions under which EOP technology is most effective.

ERDC-CERL proposed to the Department of Defense (DoD) and Army's Installation Management Agency (IMA), through the DoD Corrosion Prevention and Control (CPC) program, to address this problem. FY06 funds were provided to ERDC-CERL to conduct necessary developmental R&D and to demonstrate the technology. Monitoring of system performance would continue through FY07.

This report describes the testing of an EOP system installed in an earth-covered magazine (ECM) at Fort A.P. Hill, VA.

Objective

The overall objective was to demonstrate EOP as a solution to the water intrusion problems in earth-covered magazines (ECMs) at Fort A.P. Hill, VA. In order to accomplish that objective, there were several safety issues with the use of EOP that required evaluation before the EOP systems could be installed in the ECMs. Initial laboratory evaluations were conducted on a small scale model ECM followed by installing an EOP system in a full scale magazine at Fort A.P. Hill and performing evaluations on it.

Approach

An EOP system was installed in an empty ECM. The following evaluations were then conducted over the next 15 month period to identify any ammunition safety hazards that may exist with the use of the EOP system. The following is a list of evaluations that were conducted.

- Sparking potential caused by the EOP system from any charge build up on the steel arch or on metal pallets inside the magazine,
- Potential for hydrogen gas being generated by the EOP system,
- Potential for corrosion to occur on the steel reinforcing in the concrete portion of the structure,
- Ability of the EOP system to stop water intrusion inside the magazine,
- Potential of the EOP system to compromise the ECM lightning protection system, and
- Potential radio frequency generation and electromagnetic field induction.

EOP System Installation

EOP Design

A design was developed based on the principles detailed in the draft UFC in Appendix I and laboratory model testing (Appendix C). The design for the floor section called for installation of anodes, positive electrodes, in the wall-floor juncture around the perimeter of the magazines, and also in the construction joints and cold joints in the concrete floors and walls.

Visual investigation of the magazines indicated that most of the water intrusion in the magazines was coming from the back wall and the interface between the concrete and the steel arch. Some water was also entering through the bolt holes and joints in the steel arch. To stop water from entering through the rear wall, the design called for installing an additional anode part way up the rear wall. A structural analysis of the back wall was performed to determine where the maximum wall moment in the event of an accidental explosion. Anode and Cathode placement design in that wall avoided a section, 2-feet on any side of the point of maximum moment. Appendix D shows the design calculations used.

EOP Installation Process

An EOP system consists of specialty electrodes, i.e. anodes (positively charged electrodes) and cathodes (negatively charged electrodes), a control unit, and electrical wiring. Installing an EOP system is comprised of the following steps:

1. Locate reinforcing steel in the concrete (Figure E-1). This serves two purposes: first to identify locations to tie into the rebar to protect it from stray current corrosion and second, to prevent damaging it while cutting or chipping the slots to embed the anodes during the installation process.

2. Saw cut or chip slots and grooves in the concrete for anode placement approximately 1¼ to 1½ inch deep. Figure E-2 shows the saw cutting of a construction joint. Figure E-3 shows chipping a groove for an anode.

3. Drill holes for cathodes. 3½ inch diameter cores were cut into the concrete approximately 2 inches deep. Centered inside the core holes, 1¼ inch diameter holes were drilled through the concrete to the exterior of the structure at the cathode locations, Figure E-4.

4. Drill holes for rebar connections. Two 3½ inch diameter cores were cut into the concrete and then the reinforcing steel exposed using a chipping hammer, Figure E-5. Electrical resistance measurements were made to ensure electrical continuity between the two points. Two locations were chosen for redundancy in the event that a lead wire should ever short out.

5. Wiring slots cut. Slots approximately ⅜ inch wide and 1 inch deep were cut in the concrete parallel to the anode slots to embed lead wires in, Figure E-6.

6. Concrete chips from the cutting and chipping operations were swept up and removed and the excess dust removed using a shop vacuum. Saws and chipping hammers were all equipped with vacuum attachments to minimize free dust in the work area.

7. Seal floor cracks. There was no evidence of water penetrating the magazines through cracks in the concrete. However, visible floor

concrete cracks were sealed by routing them first approximately ½ inch deep. Dust and concrete chips were removed and the grooves further cleaned by spraying water on them. The grooves were dried using a propane torch (Figure E-7). The cracks were then filled with epoxy sealant, Figure E-8 and Cut Sheet 1 in Appendix F.

8. Install anodes. Mesh style anodes (see Cut Sheet 2 in Appendix F for Manufacturer's Data Sheet) were prepared beforehand by cutting them to a predetermined length and exothermically welding a titanium wire connector, Figure E-9 in the center of the section. These prepared anodes were placed in the prepared slots according to the EOP design. The lead wires were connected to the anode and the connection sealed using heat shrink tubing. Cut Sheet 3 in Appendix F describes the lead wires used and Cut Sheet 4 the heat shrunk tubing used. Figure E-10 is a drawing of the connection. The anodes were tested for shorts onto the reinforcing steel. Where shorts occurred, the anode was wrapped with electrical tape approximately a minimum of ½ inch on each side of the short location. The lead wires were attached to each anode segment and the anodes grouted into place with cementious grout, Figure E-11. Masterflow 928 grout, Cut Sheet 5 in Appendix F, was used to grout in the anodes on horizontal surfaces and the Sika 223, Cut Sheet 6 in Appendix F, on vertical surfaces. These grouts are used for their electrical properties.

9. Install cathodes. The cathodes are standard 8 foot long copper clad steel grounding rods (See Cut Sheet 7 in Appendix F). The top 3-feet of the cathodes were wrapped using electrical tape and driven through the prepared holes into the soil outside the structure so the top half inch of the rod was above the bottom of the core cut. The bottom of the drilled hole was then packed with oakum, Figure E-12. The lead wire was attached to the cathode using an exothermic weld (Figure E-13). Cut Sheet 8 in Appendix F is the manufacturer's Data Sheet for the welding device. The top of the cathode and the lead wire connection was embedded in epoxy (Figure E-14). Once the epoxy was cured the hole was filled with the same cementitious grout used to grout in the anodes (Figure E-15).

10. Connect reinforcing bars. A ⅛ inch diameter hole was drilled through the exposed rebar. The hole was threaded using a threading

tap. A standard round wire connector was attached to the lead wire and attached to the rebar using a screw (Figure E-16). The rebar was embedded in epoxy and once it had cured the hole was filled using cementitious grout.

11. Embed lead wires. A hole was drilled at the floor level through the head wall to pass the lead wires out of the magazine, Figure E-17. The lead wires were placed in the prepared slots and fed through the hole in the head wall to the exterior of the magazine. The lead wires were then embedded in the concrete using the non-shrink cementious grout, Figure E-18. The Masterflow 928 grout was used on horizontal surfaces and the Sika 123 on vertical surfaces.

12. Mount connector box. A connector/distribution box with bus connectors was mounted on the exterior of the front end wall (Figure E-19). The lead wires were fed through PVC plastic conduit from the head wall hole in the magazine to the connector box (Figure E-20).

13. Install the control unit. The central EOP controller was installed centered between the eleven magazines (Figure E-21). Cut Sheet 9 is the manufacture's specification for the control unit box. A concrete pad was poured and a mounting frame assembled on it. The control unit was mounted to the frame, Figure E-22. 110 volt, 60 cycle power was provided through underground conduit to the control unit through a standard circuit breaker box (Figure E-23). The control unit is designed to convert the incoming AC power to the pulsed direct current and distribute it to each magazine. Figure E-24 shows the inside of the control unit.

14. Connect power to the magazines. PVC conduit was installed underground between the central controller to each connector box on the front end wall of each magazine. Lead wires were run and connected. Once connected, the power in the control unit was turned on. The pulse was then set on the control unit. Figure E-25 shows a plot of the EOP pulse produced at Fort A.P. Hill.

15. To test the EOP installation and ensure that all of the water leaks were addressed, water was sprayed on top of the magazines at a rate of 750 gallons per minute for 30 minutes, Figure E-26. This thoroughly saturated the soil cover. Leaks were then located and the

injected using a hydrophilic urethane material, Figure E-27. Cut Sheet 10 in Appendix F is the manufacturer's specification for the injection foam used.

Full-Scale Magazine Testing

An electro-osmotic pulse system was installed in Magazine 2 at Fort A.P. Hill, VA. Magazine 2 has a floor area 11-feet wide and 30-feet long. There is a 15 inch high concrete knee wall along the sides of the magazine on which the corrugated steel arch ceiling is mounted. The ceiling radius is approximately 5-feet 6½ inches. At the ends of the magazine are concrete head walls. All of the concrete is steel reinforced. The walls are approximately 11 inches thick and the floor 6 inches thick. The magazine has air vents in each door section (Figure E-28) and another in the ceiling at the rear of the magazine, Figure E-29. Figure E-30 is standard drawing showing the construction detail.

A series of tests were performed on this magazine to address ammunition safety concerns and to validate the effectiveness of the EOP system to dry out and keep the interior of the magazine dry. The following testing was performed.

Sparking Potential Evaluation

Sparking potential was determined in the full scale ECM by measuring electrical potential differences between different locations on the steel arch, differences between the steel arch and metal pallets positioned inside the magazine and between metal pallets positioned on the floor of the magazine.

The electrical potential was measured between six locations on the steel arch. Figure E-31 is a drawing of the magazine steel arch, the numbers indicate the locations the measurements were made between.

Electrical potentials were also measured between the steel arch and metal pallets positioned on the floor of the magazine. Measurements were made with the EOP system turned off and with the system turned on. Electrical potentials were also measured between the pallets. Figure E-32 is a drawing of the magazine floor showing the pallet locations and where measurements were made and Figure E-33 is a photo of the magazine with the metal pallets inside.

Hydrogen Gas Generation Evaluation

Mr. Jack E. Bennett of J.E. Bennett Consultants, Inc. installed the test apparatus in three magazines at Fort A.P. Hill. Once the apparatus was ready, Mr. Bennett conducted the testing and prepared the analysis and conclusions.

Thermodynamics

In order for hydrogen to be evolved from aqueous media, potentials at the steel surface must be more negative than –0.739 V versus Normal Hydrogen Electrode (NHE), or more negative than –0.981 V versus Saturated Calomel Electrode (SCE). This assumes a temperature of 25° C, pressure of 1.0 atmosphere, and a pH of 12.5, which are typical for steel in uncarbonated concrete. This is confirmed by an analysis presented on Page 114 of the "*Atlas of Electrochemical Equilibria in Aqueous Solutions*" by Marcel Pourbaix, NACE International, Houston, TX, 1974. Figure E-34 is a copy of the potential-pH equilibrium diagram for the system hydrogen-water on Page 114. This has been confirmed by several experimental studies.

Potentials more negative than –0.981 V_{SCE} can be achieved only in the absence of oxygen, since oxygen is reduced at potentials more negative than +0.247 V_{SCE}, making oxygen reduction the preferred cathodic reaction under normal conditions. This is also shown on the attached potential-pH equilibrium diagram by Pourbaix.

If hydrogen were generated, then that hydrogen would be effectively destroyed (oxidized back to water) if it came in contact with the surface of any anode, or with any steel surface less negative than –0.981 V_{SCE} within the concrete.

Cathodic Protection Experience

Cathodic protection (CP) experience is relevant since the environment and current densities used for CP are roughly the same as those used for EOP. CP current densities range from about ¾ to 2 mA/ft^2 of steel. Hydrogen evolution at the surface of cathodically protected steel has been a concern in the field of cathodic protection since atomic hydrogen could diffuse into high-strength prestressed or postensioned steel, resulting in hydrogen embrittlement of the steel and possible structure failure. This possibility was examined under FHWA Contract DTFH61-92-C-00030, performed by

ELTECH Research Corporation, in 1991-1997. That contract found that potentials sufficiently negative to generate hydrogen were rarely achieved during cathodic protection in steel reinforced concrete. Steel potentials more negative than –0.981 V_{SCE} were found to be limited to instances where the concrete was saturated with water, in which case the cathodic reaction was not depolarized by oxygen reduction. Even then, post analysis did not reveal any hydrogen content in the steel, or any adverse effect on the mechanical properties of the prestressing steel.

Calculations of Relevance

Calculations were conducted to examine the relevance of hydrogen, if generated by the EOP process. Calculations were made for a bunker measuring 50 x 24 ft, and where ELGARD-150 anode ribbon was installed around the perimeter of the bunker and along a central construction joint. Operating current, maximum amount of hydrogen generated (assuming worst case, 100% efficiency for H_2), and time to reach the lower combustion limit (4% H_2 in air) was calculated. It was assumed that the void in the bunker was 50% occupied. Following are the results of those calculations:

- Interior volume of magazine: 11,322 ft^3, or 320,603 liters
- Air volume in the magazine: 5,661 ft^3, or 160,302 liters
- H_2 needed to reach combustion limit: 6,412 liters, or 286 g-moles
- Maximum design current : 258 milliamps (average current)
- Charge needed to generate H_2: (2)(26.8) = 53.6 A-hr/g-mole
- Time needed to reach combustion limit: 59,417 hours or 6.8 years

The calculations indicate that even if 100% of the cathodic current was to generate hydrogen, and if all of that hydrogen made its way into the air volume of the bunker, nearly 7 years would be needed to reach the lower combustion limit, assuming that the air volume was completely captive for that period of time. It is not likely that hydrogen generated at these very low rates would pool or segregate at the top of the magazine.

Significant generation of hydrogen as a result of the EOP process is unlikely. Even if hydrogen were generated, any adverse consequence of that generation is also extremely unlikely.

Test Setup

Tests were conducted at Fort A.P. Hill, Virginia, to assess the possibility of hydrogen evolution in a munitions bunker as a result of EOP. In order to generate atomic hydrogen from aqueous media, potentials at the steel surface must be more negative than −0.739 V versus Normal Hydrogen Electrode (NHE), or more negative than −0.981 V versus Saturated Calomel Electrode (SCE). The thermodynamics of this process are discussed in detail in a report entitled "*Hydrogen Risk Assessment*" by J.E. Bennett.

Four potential wells were installed in the back wall of the munitions bunker in which the EOP process had been installed. Each potential well consisted of a ¾" diameter hole drilled to the top surface of a reinforcing bar, and insertion of a ½" diameter plastic tube, which was then filled with Sika-223 cementitious grout. The plastic tube was allowed to extend beyond the concrete wall about ¼". Figure E-35 is a diagram of the test setup and Figure E-36 is a photograph of the test setup. A reference electrode placed on the end of the tube could therefore measure the half-cell potential of the reinforcing steel embedded in the concrete. The four potential wells were located in "most cathodic locations" immediately adjacent to the anode ribbons. Two were located 14" above the floor, and two were located 108" above the floor. A complete explanation of the nature and use of potential wells is given in NACE International Publication 11100, "*Use of Reference Electrodes for Atmospherically Exposed Reinforced Concrete Structures,*" published by NACE International, March 2000.

Reinforcing Steel Protection Evaluation

Mr. Jack E. Bennett of J.E. Bennett Consultants, Inc. also installed the test apparatus in three magazines at Fort A.P. Hill to evaluate the steel protection. Once the apparatus was ready, Mr. Bennett conducted the testing and prepared the analysis and conclusions.

When current is passed through steel reinforced concrete, there is a possibility for the reinforcing steel to become a bipolar element. This can occur because the passage f current generates a voltage gradient across the steel, and since the steel offers a "path of least resistance", some current will travel that path. This current, commonly called "stray current", is potentially harmful since one end of the steel element will become anodic, causing corrosion of the steel. This possibility is illustrated in the sketch Figure E-37.

As illustrated in the sketch, stray current will be greatest where there is at least a double mat of reinforcing steel and where the two or more mats are electrically continuous. Stray current will not likely be an issue for a single mat of steel, or where mats are electrically discontinuous. At a given current density, the amount of stray current flowing through the steel will be dependent mainly on two parameters: the dimension "X" and the resistivity of the concrete. Both of these parameters profoundly affect the magnitude of the voltage gradient across the steel.

EOP complicates things due to the fact that it undergoes a current-voltage reversal during its pulse cycle. To address this, the EOP system makes the steel element a partial cathode via the use of a diode and resistor network as shown in Figure E-38.

During the positive cycle the field is applied with a positive potential at the anode with respect to the cathode. In this case there is a path for current flowing onto the reinforcing steel to be diverted to the cathode via Diode 2 and Variable Resistor 2, which are forward-biased during this cycle and conducting. This provides a safe electron path to the cathode. The net result is that the steel does not corrode. In this cycle Diode 1 is reverse-biased and does not conduct. Diode 1 presents a large resistance to current flow compared to the resistance of the media between the anode and the reinforcing steel.

For the negative cycle, the applied electric field is reversed so that the anode is negative with respect to the cathode. In this case Diode 2 is reverse-biased and does not conduct. Diode 1 is forward-biased and conducts, allowing current that flows onto the rebar a safe path to the anode. The time period of the negative cycle is much less than half of the applied positive half cycle. For this reason, much less electro-osmotic current is observed in the bulk matrix.

For both of these cycles, only one diode conducts at a time. Thus, there is never a complete low resistance path which bypasses the entire matrix. If there were no diodes, and only resistors in the network, then there would be very little current that would flow through the matrix at all, resulting in little to no effective electro-osmotic current.

The values of the Variable Resistors 1 and 2 can be adjusted to create a balance between the steel protective current and the matrix electro-osmotic current. This is important in order to maintain a balance between protecting the reinforcing steel and controlling the moisture content of the matrix.

When designing an Electro-Osmotic Pulse system and employing stray current corrosion mitigation, the constraint of an allowable estimated corrosion of the reinforcing steel must be considered.

Test Setup

Five pieces of #4 steel rebar, 1 inch long, were grouted in the back wall of the magazine at various depths. Attached to each rebar piece was a lead wire and a grout filled plastic tube, ¼ inch in diameter. Figure E-39 shows the stray-current test cell, Figure E-40 shows the stray-current test setup, and Figure E-41 shows a photograph of the test setup once it was installed. The grout-filled tube is to allow measurement of the electrical potential at the various depths and the lead wired allows the rebar piece to be grounded during testing.

Moisture Intrusion Evaluation

Concrete moisture was measured before the EOP system was turned on and for a period following system activation. The relative concrete moisture was measured at four different depths at three different locations round the magazine: on the surface, 1 inch deep, 5 inches deep and 10 inches deep in 11 inch concrete walls. Figure E-43 illustrates the locations where the tests were performed, and Figure E-44 shows a photograph of a test station.

In addition to the depth measurements there is a RH/T sensor embedded in a concrete knee wall near the midpoint of the side wall (Figure E-45). The EOP system collects the relative humidity of the concrete and the temperature and logs it for download and analysis.

Two RH/T sensors and data loggers (Figure E-46) are located in the magazine with the EOP system activated and in three other magazines where the system is not yet activated. In addition, there is an RH/T sensor and data logger located approximately 200 yards from the magazines in the ammunition turn in yard exposed to the outside weather conditions.

Lightning Protection System Interference Evaluation

The EOP system was installed in accordance with practices for lightning protection. The control unit is grounded and all exterior wiring is run underground in non-conductive conduit.

Hazards of Electromagnetic Radiation to Ordnance (HERO) Evaluation

Tests were conducted on magazines to detect any radio frequency (RF) emissions produced and to measure electromagnetic (EM) radiation from the anodes installed in the magazines.

The detailed results of a HERO (Hazards of Electromagnetic Radiation to Ordnance) evaluation performed on the EOP installations in the Fort A.P. Hill ammunition bunkers is documented separately in ERDC/CERL Contract Report CR-09-2 (August 2009). That report is published under a restricted distribution statement because it contains information approved only for operational and administrative use. Authorized users from U.S. government agencies or their contractors may request a copy of the report directly from NSWCDD (Q52), Dahlgren, VA 22448-5153.

Radio Frequency Production Evaluation

Because of the arched shape of the magazines, RF energy can amplify due to reflections off of the arch. Using the device shown in Figure E-47, field measurements are within tolerable limits with the EOP system operating in an ECM.

Electromagnetic Field Induction Evaluation

EM radiation was measured on at stand-off distances of 1 inch, 4 inches, 8 inches and 12 inches from the anodes embedded in the concrete of the ECM using a magnetometer (Figure E-48).

Test Results

The following describe the test results for each test performed.

Sparking Potential Evaluation Results

Table E-1 contains the voltage values measured between the test points on the steel arch. Table E-2 contains the voltage values measured between the metal pallets and the steel arch and adjacent metal pallets with EOP activated. Table E-2 shows the difference in potentials which indicates the potential induced by the EOP system onto the pallets.

Hydrogen Gas Generation Evaluation Results

Potentials were taken at two current levels: the first, 0.20 A, is typical of design current for the EOP system installed at Fort A.P. Hill; the second, 2.30 A, is about 10 times design current. The higher current therefore represents worst possible case. The potentials in Table E-3 labeled "On Potentials" include some error due to resistance in the measurement circuit. The "Off Potentials" exclude IR, and therefore more closely represent the true half-cell potential at the surface of the reinforcing steel.

Reinforcing Steel Protection Evaluation Results

Test results from the rebar probes set in the concrete wall were at first confusing. All probes, regardless of depth, were being polarized cathodic with the passage of current, and current measured to the probes confirmed this. It appeared that the probes—and, by inference, both mats of reinforcing steel—provided cathodic portion to a bipolar element, but the anodic portion was not known. This theory was confirmed by the data taken from bunker on 2 July 14, 2008 (see Table E-4). Since the EOP system had been turned off prior to this visit, accurate static potentials could be taken on all rebar probes. Current was then applied with the reinforcing steel disconnected from the power supply, creating the maximum opportunity for stray current. All the probes became strongly cathodic, confirming that all of the steel acted as the cathode side of a bipolar element. When 40% of the cathodic current was routed to the reinforcing steel, the probes were less cathodic but still much more cathodic than their static potentials. These data verified the presence of strong stray current, but the location of the anodic portion of the element was unidentified at that time.

Review of drawings revealed that the bunkers at Fort A.P. Hill are protected by two ground loops, located approximately 5 ft and 10 ft outside each bunker. It was theorized that these ground loops, and possibly the steel shell of the bunker itself, were serving as the anode for stray current. A series of 10 test points was setup 1 ft below the surface of the ground surrounding bunker 2 to test this theory. The locations of the 10 test points are shown in Figure E-43 Test points 1, 2, 9, and 10 were located just above the grounding loops adjacent to the concrete apron in front of the bunker. These points were quite close to the ground loop locations indicated by the drawings. Test points 3, 5, and 7 were located above the inner loop, but very high on the soil above the bunker. Test points 4, 6, and 8 were located above the outer ground loop, but also relatively high on the soil surrounding the bunker.

A technician was present to locate the ground loops surrounding bunker 2. The technician first impressed a frequency to a lightning rod on top of the bunker. Sensitive equipment was then used to detect metallic elements embedded in the ground. The technician could find no evidence of the presence of ground loops as indicated on the drawings. It is possible that the ground loops were not installed as shown on the drawings, or that electrical connection to the ground loops had been lost. It is also possible that the EOP system, which was operating during these tests, confounded the operation of the locating equipment. In any case, this uncertainty makes the following data more qualitative and less quantitative.

In order to measure possible stray current, a piece of #5 reinforcing steel (5/8 in. diameter) was pounded approximately 12 in. into the ground at the test points indicated on Figure E-43. This piece of reinforcing steel was masked off to present an area 6 inches long (11.78 sq in or 0.0818 sq ft). The piece of reinforcing steel therefore acted as a rebar probe, which was intended to relate to the potential and polarization of the ground loops assumed to be located about 6 in. below the end of the rebar probe. Tests were taken at the points indicated in Table E-5, despite doubt about location of the ground loops, to relate to stray current data obtained on July 14, 2008. A half inch diameter hole was located next to the rebar probe to allow an SCE reference electrode to be placed adjacent to the rebar probe. Thus, half-cell potentials in mV could be taken of the active surface of the probe both connected and disconnected to the EOP system negative. The potentials shown in Table E-6 were "ON" potentials taken during the forward portion of the EOP cycle. Data taken on July 14, 2008 with 40% of cathodic current flowing to the reinforcing steel were obtained using a 12 VDC battery.

A 10 Ω resistor was connected to the rebar probe so that a digital voltmeter installed across the resistor could be used to measure current flowing to or from the probe. The currents shown in Table E-5 were recorded during the forward portion of the EOP cycle. Figure E-44 shows the test setup.

Figure E-49shows the polarization of the rebar probe in the anodic direction when the probe was connected to the EOP system negative as a function of percentage cathodic current flowing to the reinforcing steel. The balance of the current is directed to the remote cathode. The graph shows that the rebar probe shifted more anodic (corrosive) when more current was directed to the remote cathode. This clearly indicates that the field generated by the EOP system was causing stray current, and therefore stray-current corrosion. At first it was puzzling that the polarization of the rebar probe was still about 200 mV anodic even when 100% of the current was directed to the reinforcing steel, in which case the EOP system effectively became a cathodic protection (CP) system. This result is contrary to CP experience, as CP systems have not caused anodic shift of steel elements embedded in either the concrete or surrounding soil.

Figure E-50 shows the current measured to the rebar probe when the probe was connected to the EOP system negative as a function of percentage of current to the reinforcing steel. The direction of current flow indicates corrosion of the rebar probe. This result agrees with the anodic polarization shift shown on Figure E-49. Again, the data suggested that significant corrosion of the rebar probe was occurring even when 100% of the cathodic current was directed to the reinforcing steel. As noted above, this is not consistent with CP system behavior.

Additional tests were conducted 4 November 2008 to clarify the apparent corrosion of the probe when 100% of the cathodic current was directed to the reinforcing steel. Data taken at that time are shown in Tables E-6 and E-7. Especially significant are data taken with the EOP power supply off and disconnected, as shown in Table E-8 These data show corrosion of the probe unrelated to the EOP system. This corrosion is probably a result of soil conditions and/or the action of dissimilar metals in electrical contact. The polarization data points labeled (x) immediately to the right of the graph box on Figures E-49 and E-50 represent data taken 4 November 2008 with the EOP power supply off and disconnected. These data prove that corrosion of the probe observed with a large percentage of cathodic current directed to the reinforcing steel was not a result of EOP operation.

Moisture Intrusion Evaluation Results

Table E-4 lists the relative moisture of the concrete over time at the 1010, 5, and 1 in. depths and at the surface for each of the wall three locations in the magazine. Figures E-51 — E-53 are plots of the relative moisture data.

Figure E-54 is a plot comparing outdoor air temperature with the interior air temperature for the test magazine with EOP applied and another magazine without EOP over time. A portion of the outdoor data is missing because of a failure of the data logger. Figure E-55 is a plot comparing outdoor dew point with the dew points inside the test magazine and another without EOP over time, and Figure E-56 is a plot comparing the relative humidity values. Again, the gap in data for the outside dew point and relative humidity is a result of data logger malfunction. Figure E-57 is a plot indicating the condensation potential for the test magazine compared with a magazine without EOP activated over time. Where the plots go below zero, the dew point temperature exceeded the air temperature. Moisture in the air can condense out in those conditions.

Table E-5 lists the average temperature, dew point and relative humidity for the magazine with EOP installed and a magazine without EOP comparing them to the outside average temperature, dew point and relative humidity. It also indicates the standard deviations, maximum and minimum values for each parameter.

Lightning Protection System Interference Evaluation Results

Upon the recommendation of the U.S. Army Technical Center for Explosives Safety, lightning protection was added to the EOP System at the point where the leads enter the magazine. The intent is to prevent a power surge from a lightning strike from traveling back through the EOP system and propagating to other magazines. To accomplish this, a metal-oxide varistor (MOV) was added between the anode and cathode, the anode and rebar, and the cathode and rebar circuits. Figure E-58 shows a magazine terminal box with MOVs installed. Following a lightning storm, the MOV between the cathode and rebar was blown.

HERO Evaluation Results

Based on the data obtained from measurements and from the proposed guidance on Maximum Allowable Environment (MAE) limits for magnetic fields, it is concluded that the EOP system operating with current pulses less than or equal to 1A does not produce magnetic field transients that would pose a threat to HERO UNSAFE/UNRELIABLE ORDNANCE (ERDC/CERL CR-09-2). Furthermore, with linear extrapolation to the maximum 3A operating level of the system, a threefold increase in the EOP-generated magnetic field strength would be less than or equal to a factor of 3 increase in the 10 μT minimum detectable level in the oscilloscope traces in Figures 7 through 9 in ERDC/CERL CR-09-2. Therefore, even at this maximum 3A operating level, a maximum EOP field of 30 μT remains less than the 40 μT threshold for exceeding the MAE.

Discussion

The EOP system was activated on 2 November 2006. On 25 January 2007 during field testing, the system quit pulsing. The system was deactivated and a new control unit was designed so that all of the magazines could be controlled by a single control unit which had the capability of logging data and communicating via modem for remote monitoring. The new control unit was developed and installed in June 2007. During a site visit on 2 October 2007 it was discovered that the EOP system had quit working. Examination of the control unit showed that the main bus card in the controller had failed. Data retrieved from the controller data logger contained data starting 19 June and ending 29 July 2007. The card was removed and shipped back to the manufacturer for repair. The repaired card was installed in on 29 November 2007 and the EOP system reactivated.

Sparking Potential

The test results indicate that the EOP system will not induce an electric charge on the steel arch or on metal pallets or other metal containers placed inside an ammunition storage magazine. In order to produce a spark, an electrical charge of 20 kV per inch is required. Tests indicated that that level of induced charge will not occur. The highest potential measured (Table E-2) is -7,420 mV. The highest potential induced by the EOP system (Table E-2) is 8,088 mV located directly over an anode. A second pallet positioned directly over an anode has 1/10th the induced voltage from the EOP system, 720 mV. For a separation of 1/1000 inch, a static charge of 20 volts (20,000 mV) is required to produce a spark. The EOP induced potential is 40% of the voltage necessary to produce a spark at a separation of 1/1000 inch. The EOP system will therefore not produce a spark from metal materials set on the concrete floor of a magazine.

Hydrogen Gas Generation

The above test results prove conclusively that neither atomic nor molecular hydrogen are being generated at the reinforcing steel as a result of operating the EOP system at Fort A.P. Hill. The most negative potentials measured were over 400 mV too positive to generate hydrogen. The dominant half-cell reaction at the reinforcing steel is therefore reduction of atmospheric oxygen.

Reinforcing Steel Protection

A variety of different metals come into play at this location. There are the galvanized steel arches, the carbon steel reinforcing in the concrete, and a copper grounding and lightning protection system. Because of the different potentials in the metals, stray current is being produced without the EOP system. Because these are 50-year-old structures, it is possible that grounding loops shown on the drawings for bunker 2 could not be located because they are corroding or corroded away in places. The exact status of the grounding loops is not known at this time. In addition to the varieties of metals in the magazines, there is old, abandoned electrical wiring in the ground. It is possible that these wires are not all dead. Based on the data obtained with the EOP system off and disconnected, the EOP system could potentially divert some of the stray current in the ground back to the EOP control unit and provide limited stray source current protection.

Moisture Intrusion

Over the period of 1½ years since the EOP system was installed, no moisture or dampness was observed in the magazine with EOP operating in it. Army personnel working at the ammunition supply point commented that the floors of magazines without EOP have gotten damp on occasion and becomes slippery for the forklift operations.

Figures E-55, E-56, and E-57 indicate that once the EOP system is turned on, the concrete moisture content is greatly reduced within a few days of operation. However, soil moisture outside the structure can affect the amount of moisture in the concrete closest to the soil. Rain and soaking of the soil for the first several weeks are reflected in the moisture measurements, but the concrete moisture content is unaffected. After 40 days the moisture level in the concrete becomes fairly uniform throughout and is not affected by external moisture, maintaining a level of 18–20%.

The air temperature inside the magazines are cooler than the outside temperature during warm weather (Table E-5) and warmer during cold weather. This is typical of underground structures. The relative humidity also follows that trend. However, the dewpoint is generally higher inside the magazines. This may be related to the temperature and ventilation.

There appears to be little difference between the temperature and relative humidity levels measured within the magazine with EOP and without EOP. Since the magazines are ventilated, the relative humidity, and temperature should be similar.

There is no clear difference in the condensation potential for a magazine with EOP and one without EOP. The advantage of the EOP is that it provides a mechanism for the water to be removed once it condenses.

Lightning Protection System Interference

The blown MOV between the rebar and cathode indicated that the MOVs selected were too small and needed a higher capacity. It also indicated that since the rebar is a part of the grounding system, an MOV to the rebar is not needed. They are only needed between the anode and cathode, and between the anode and rebar circuits.

HERO

One of the anomalies noted during HERO testing was a jump in emissions at cracks and joints in the magazine. Multiple magazines were evaluated at Fort A.P. Hill and this phenomenon was evident in all that were tested. This is likely a result of the stray current in the soil, as discussed above.

Conclusions

An EOP system was installed in a full sized earth-covered magazine. The EOP system was activated and the performance monitored and safety testing performed.

The electrical field produced by an EOP system in an ECM will not induce potential conditions for a spark to occur between materials stored inside the structure or between the materials and the ECM.

The electrical field produced by an EOP in an ECM will not generate hydrogen gas at the steel reinforcing in the concrete.

The electrical field produced by an EOP in an ECM prevents water from entering the ECM through the concrete. If moisture enters the structure it provides a mechanism to remove it from the interior surface.

EOP only minimally affects the relative humidity inside the ECM.

A properly installed EOP system will protect the reinforcing steel from stray-current corrosion by providing an electric charge on the reinforcement and cathodically protecting it.

The amount of current going to the rebar affects stray-current corrosion potential. This potential needs to be evaluated for all EOP system installations.

A properly installed EOP system works with the existing lightning protection system and will not propagate charge to other magazines.

EOP is HERO safe.

Recommendations

Based on the testing described in this report, electro-osmotic pulse technology should be incorporated in earth-covered magazines where water intrusion through the concrete ceiling, walls and floors. The system should be added to the standard ECM construction criteria for new construction in areas with high water tables or high rainfall or other precipitation.

Figure E-1. Locating reinforcing bars in concrete.

Figure E-2. Saw cutting of anode slot.

Figure E-3. Chipping of anode slot.

Figure E-4. Drilling of hole for cathode and cathode to be installed.

Figure E-5. Exposed rebar.

Figure E-6. Slot for lead wires.

Figure E-7. Routed of floor cracks being dried following cleaning.

Figure E-8. Crack being filled with epoxy.

Figure E-9. Titanium wire connector welded to anode.

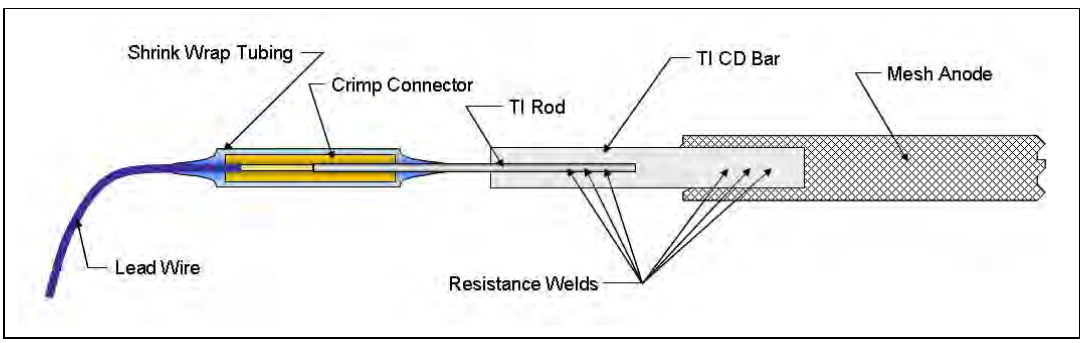


Figure E-10. Sketch of anode lead wire connection.

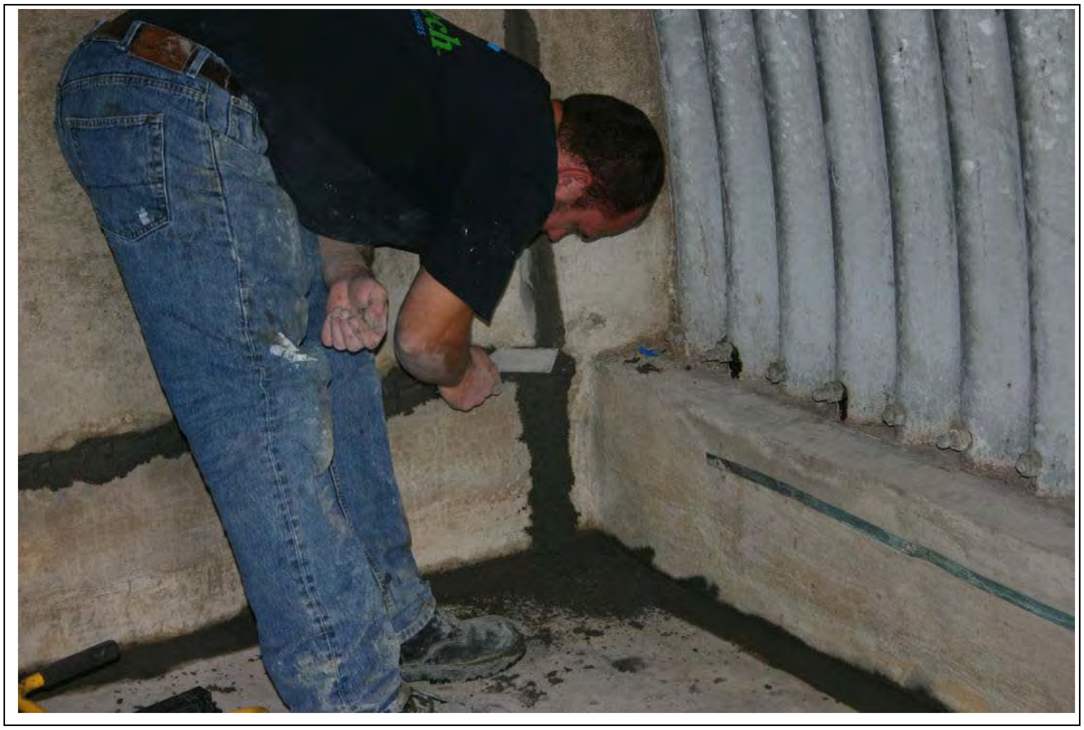


Figure E-11. Anode being grouted in slot.

Figure E-12. Installation of oakum around a cathode.

Figure E-13. Cathode lead wire exothermic weld connection.

Figure E-14. Epoxy potting of cathode.

Figure E-15. Grout finish over cathode.

Figure E-16. Rebar lead wire connection.

Figure E-17. Hole through head wall for lead wires.

Figure E-18. Grouting of lead wires in prepared slot.

Figure E-19. Connector box.

Figure E-20. PVC Conduit from magazine to connector box.

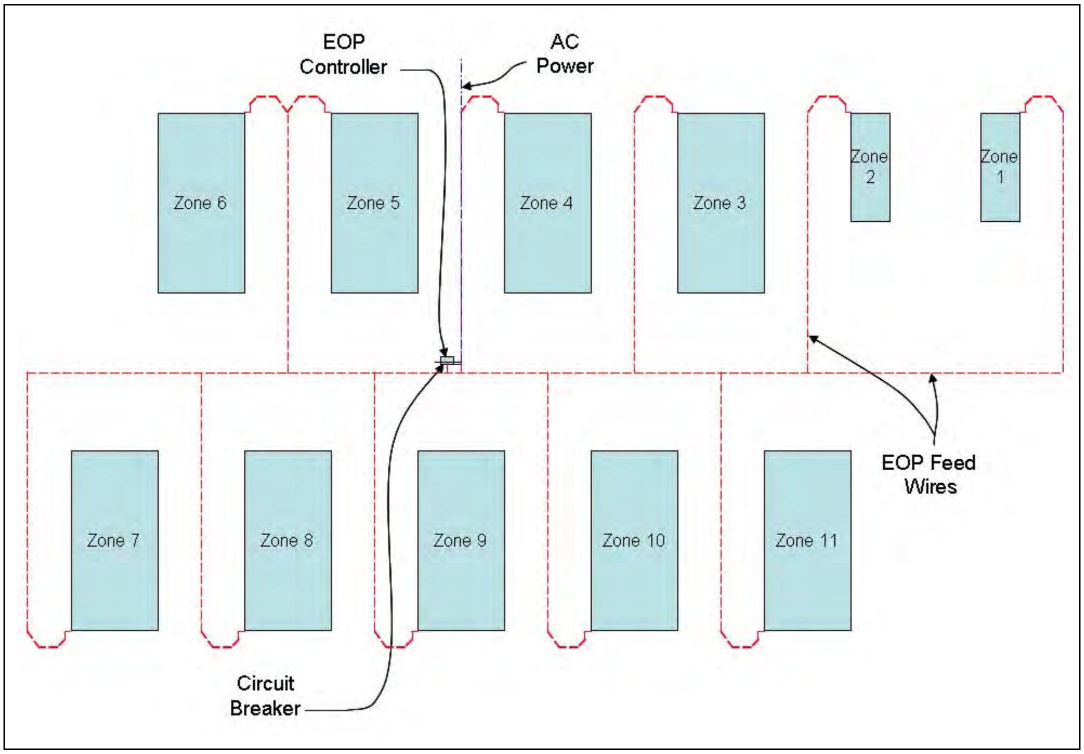


Figure E-21. EOP zone layout.

Figure E-22. EOP Control unit.

Figure E-23. Circuit breaker box.

Figure E-24. Interior of EOP control unit.

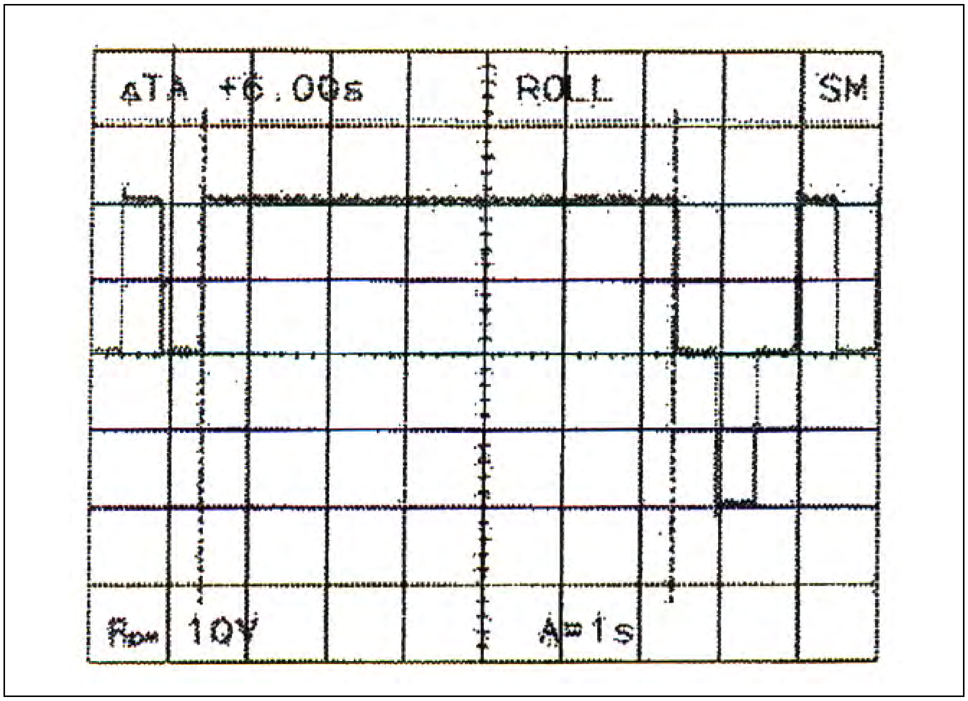


Figure E-25. Plot of EOP pulse (voltage along vertical axis and time along horizontal axis).

Figure E-26. Soaking of earth cover to test for leaks.

Figure E-27. Leak injection.

Figure E-28. Door air vent.

Figure E-29. Ceiling air vent.

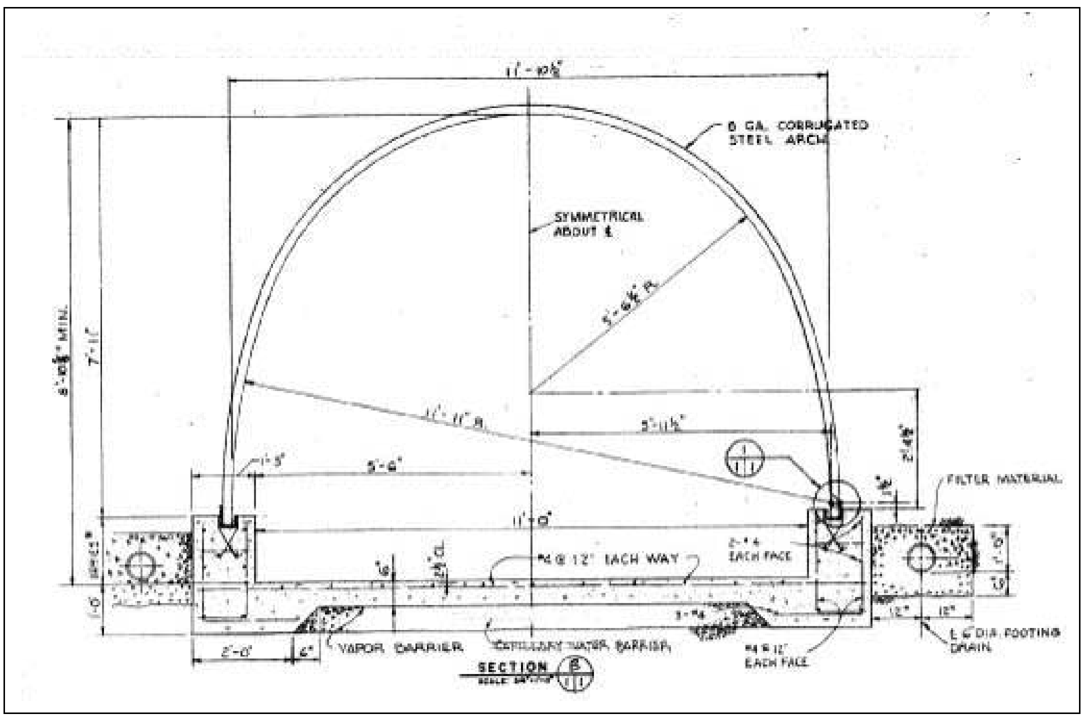


Figure E-30. Standard drawing for a steel arch ECM.

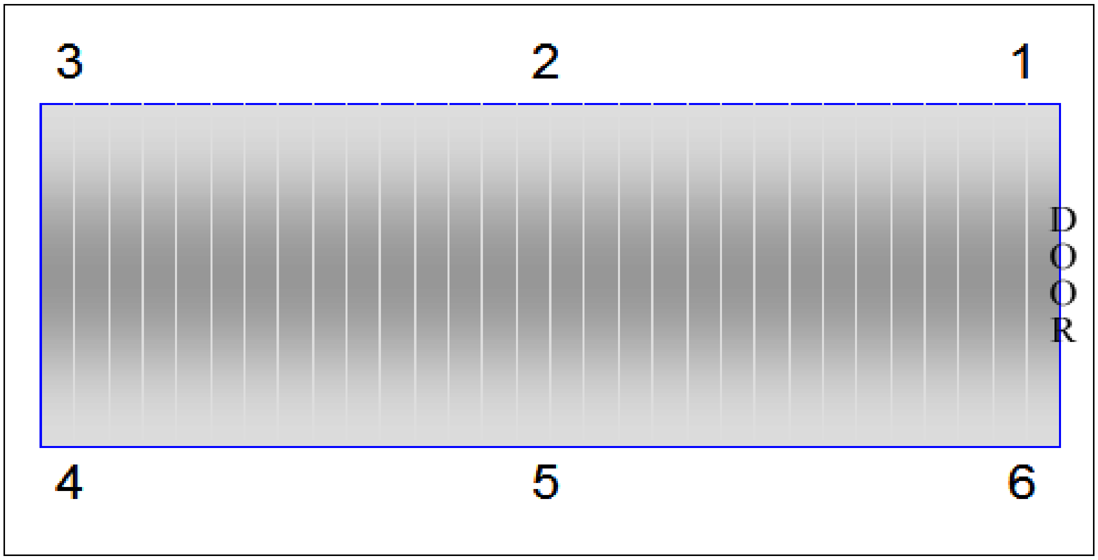


Figure E-31. Drawing indicating electrical potential measurement locations on steel arch ceiling of magazine.

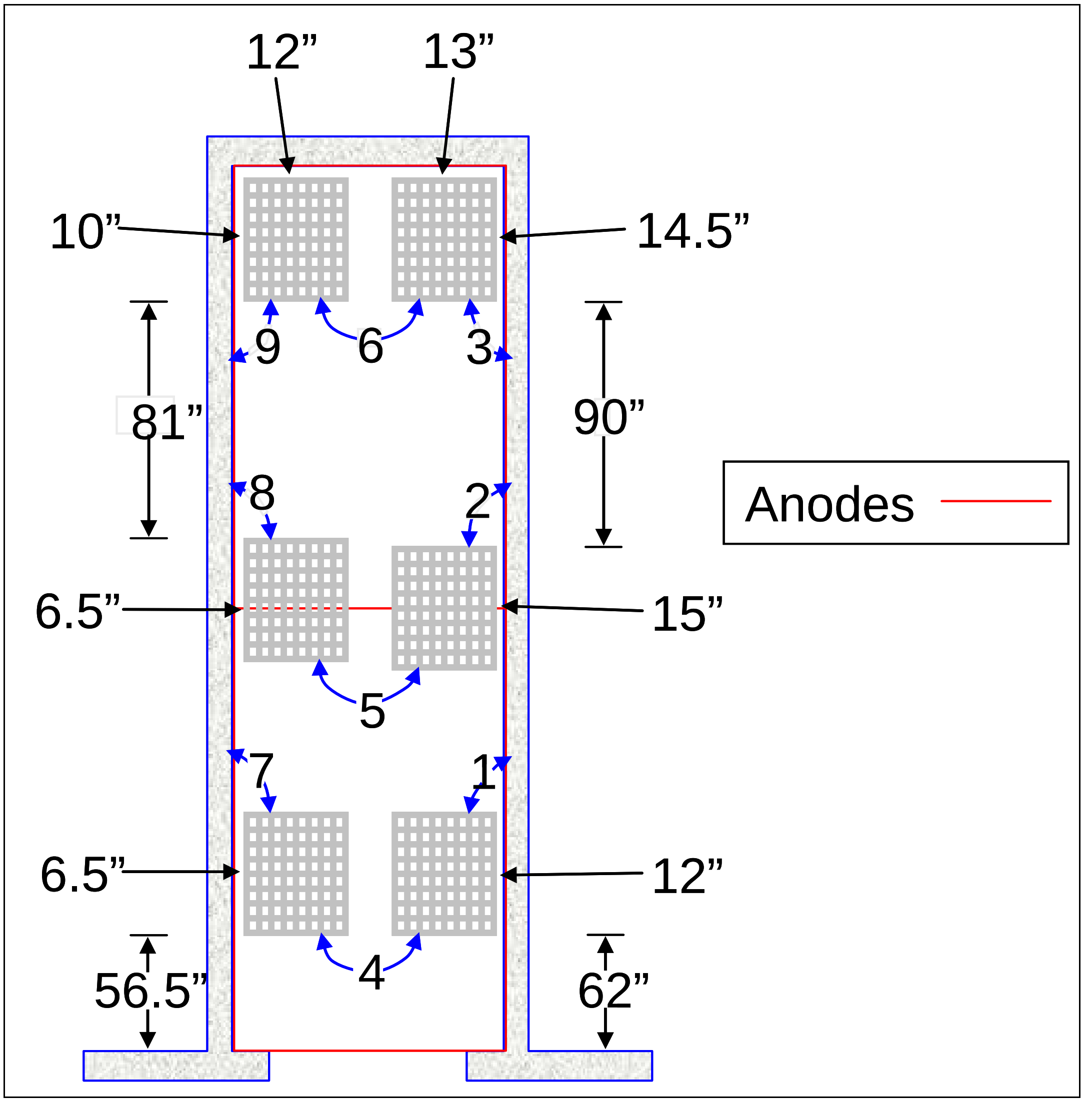


Figure E-32. Drawing indicating locations of metal pallets in magazine and electrical potential measurement locations.

Figure E-33. Photograph of metal pallets in test magazine.

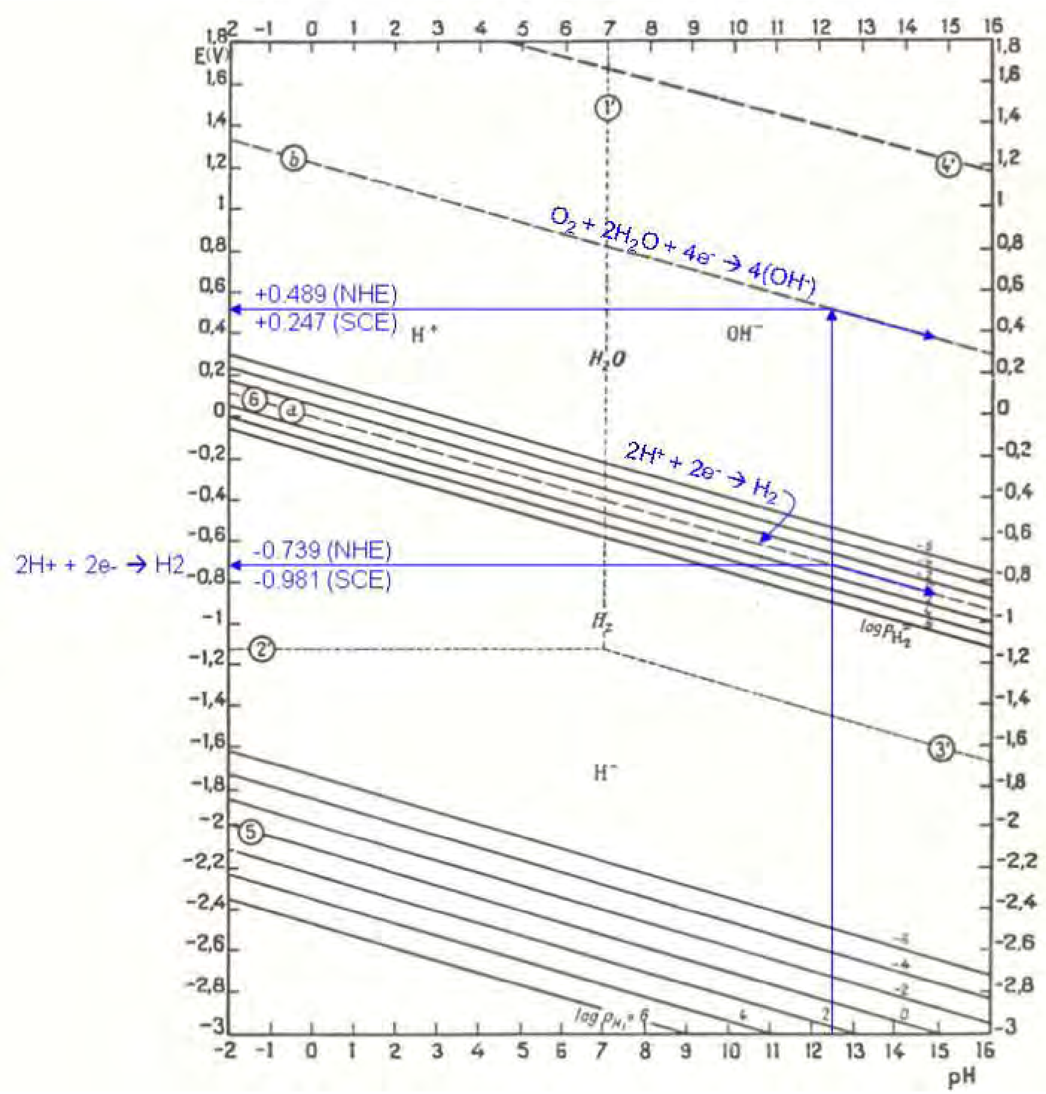


Figure E-34. potential-pH equilibrium diagram for the system hydrogen-water, at 25 °C.

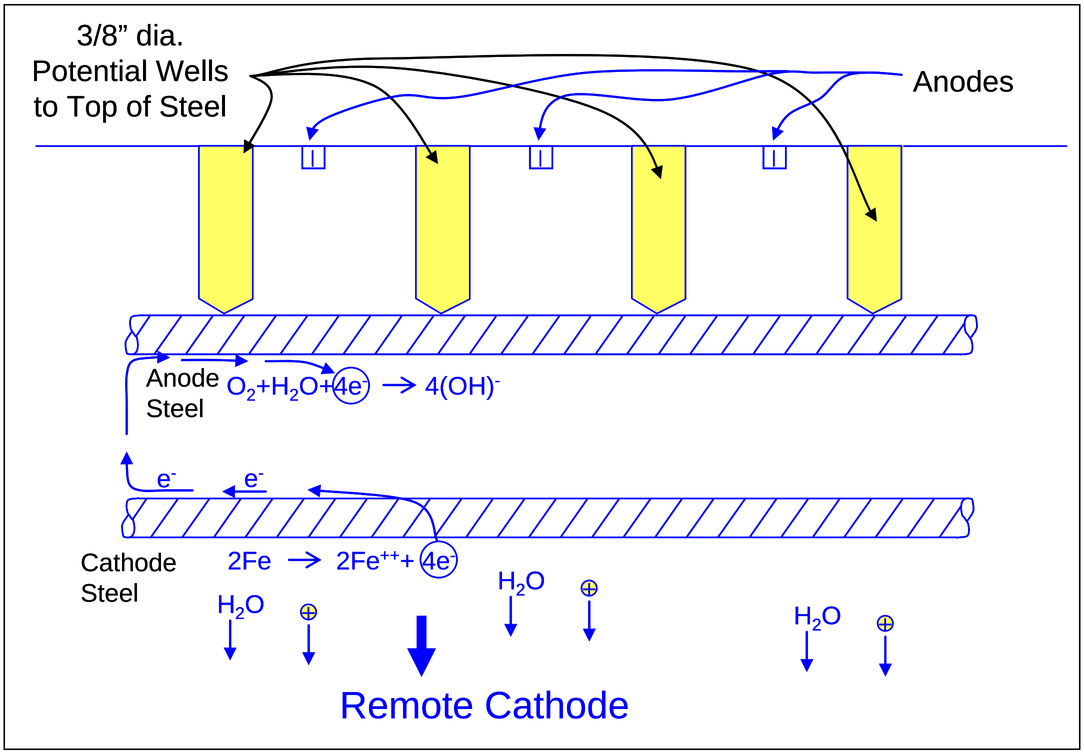


Figure E-35. Drawing of hydrogen gas generation test setup.

Figure E-36. Photograph of hydrogen gas test setup.

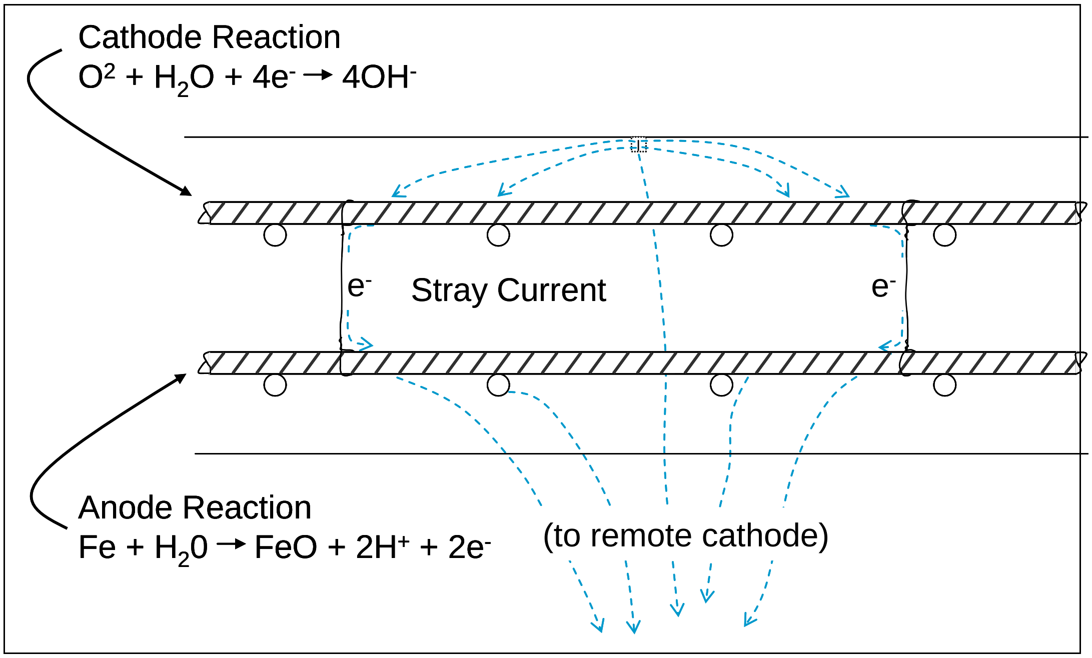


Figure E-37. Diagram of stray current corrosion mechanism.

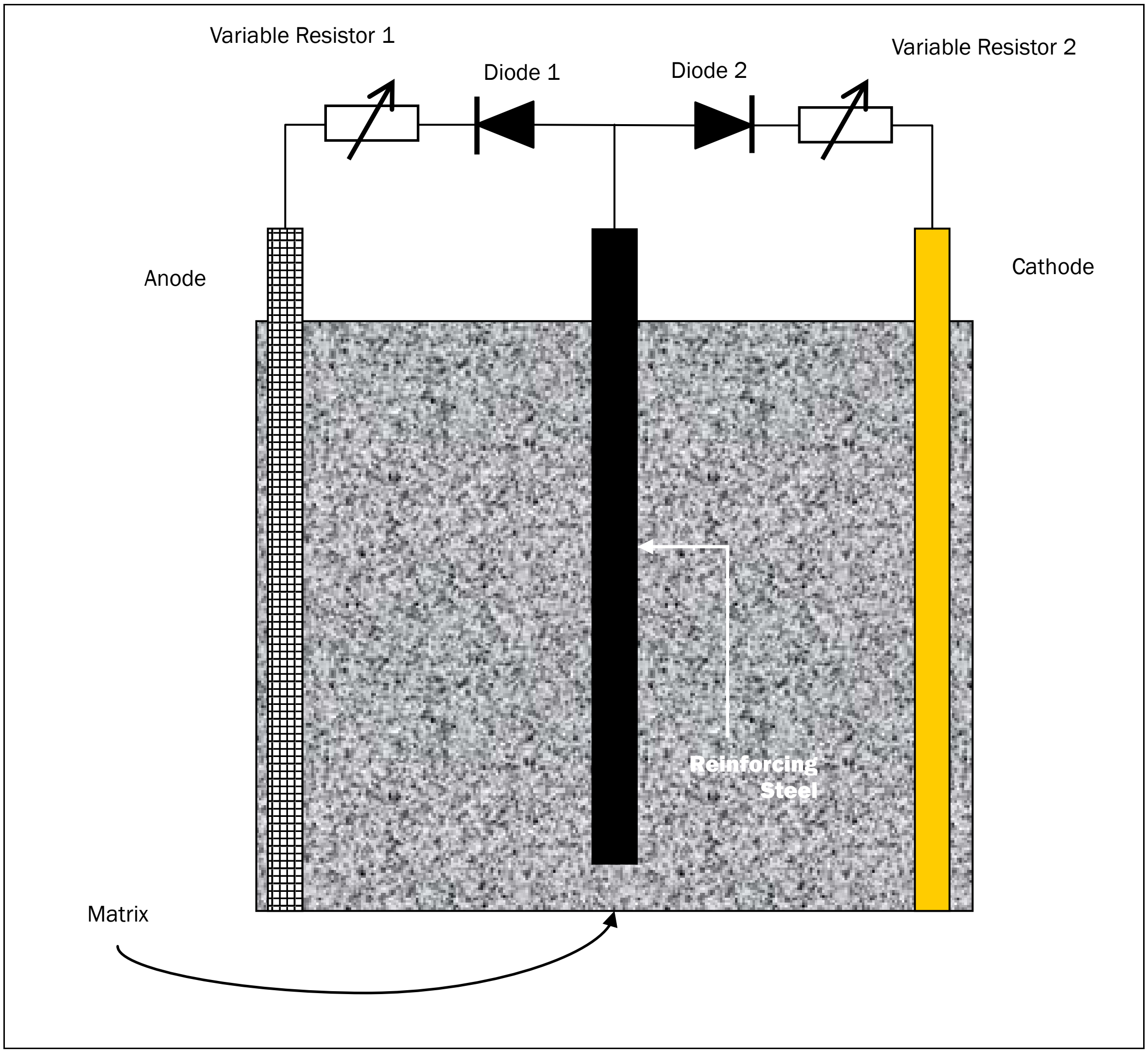


Figure E-38. Diagram illustrating stray current corrosion protection circuitry.

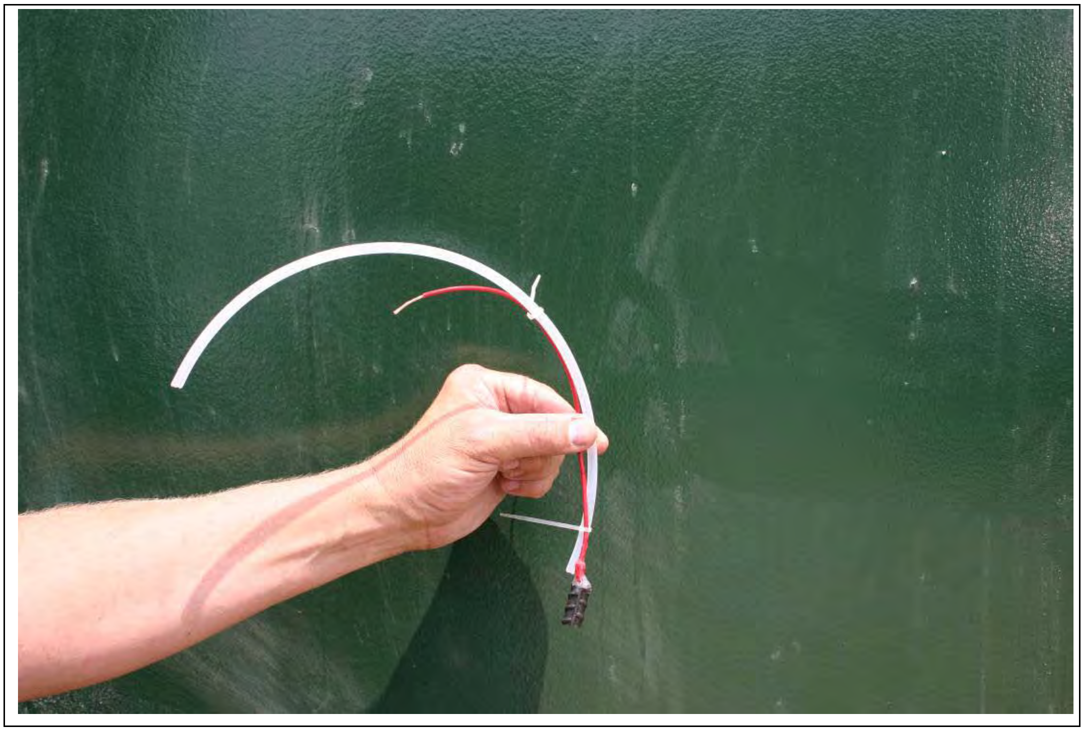


Figure E-39. Stray-current test cell.

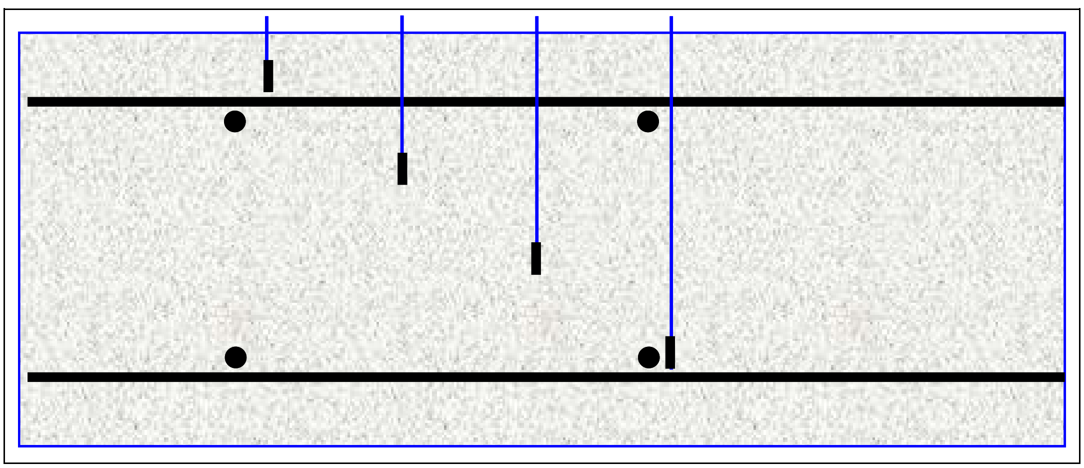


Figure E-40. Diagram of stray-current test setup.

Figure E-41. Photograph of stray-current test setup.

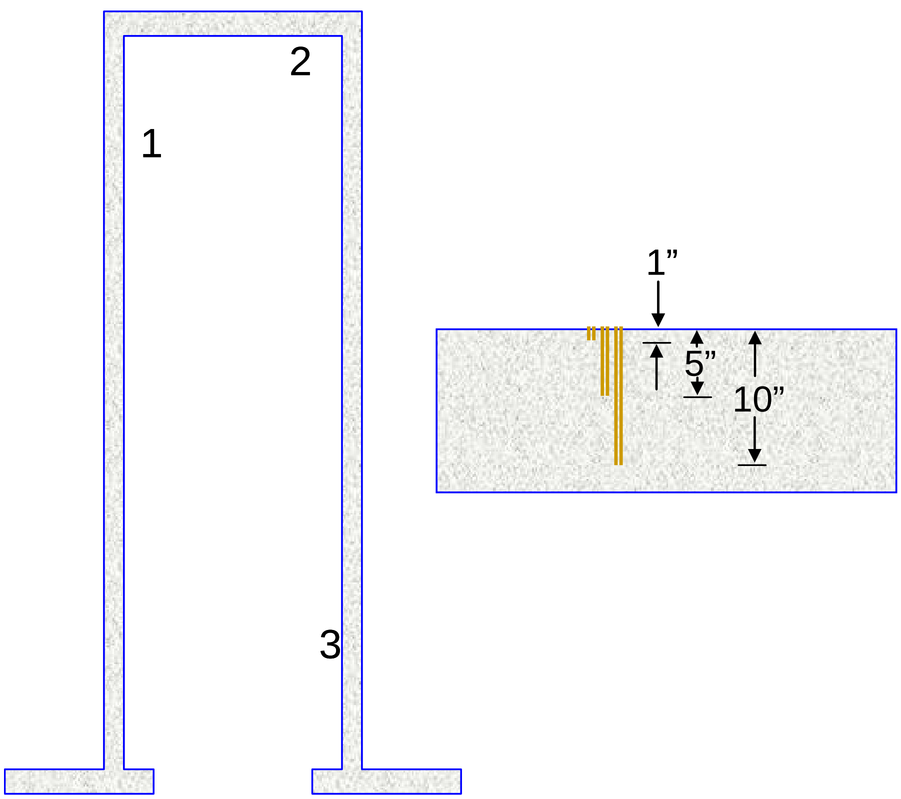


Figure E-42. Diagram of concrete moisture test locations and measurement setup.

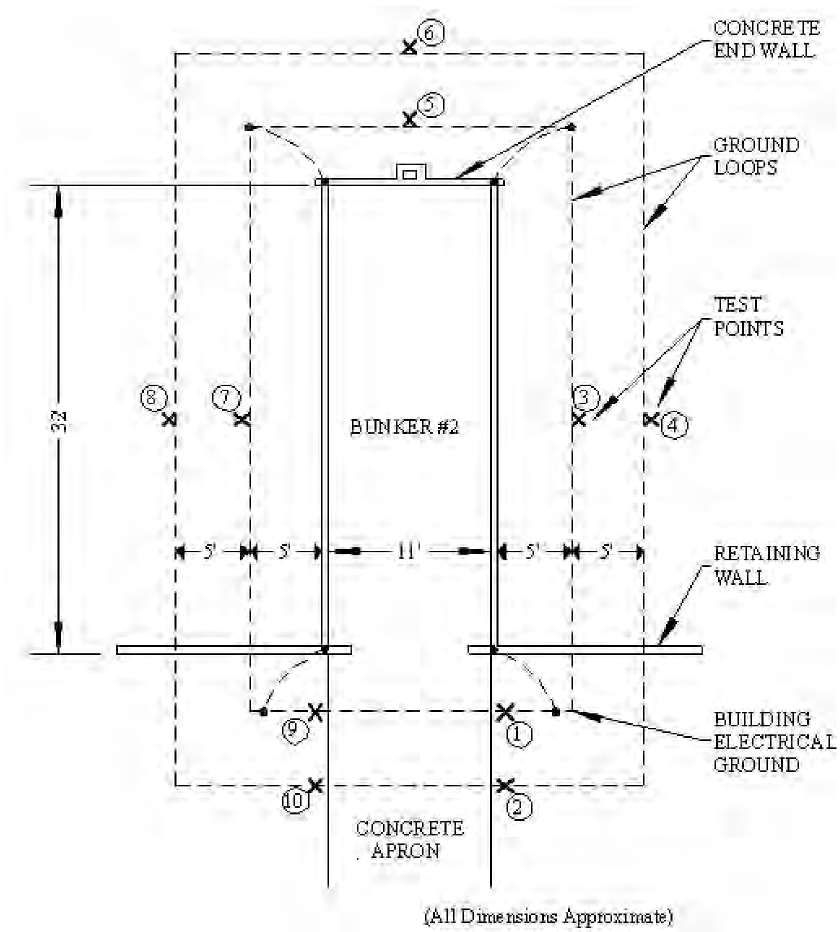


Figure E-43. Location of ground test points on bunker 2.

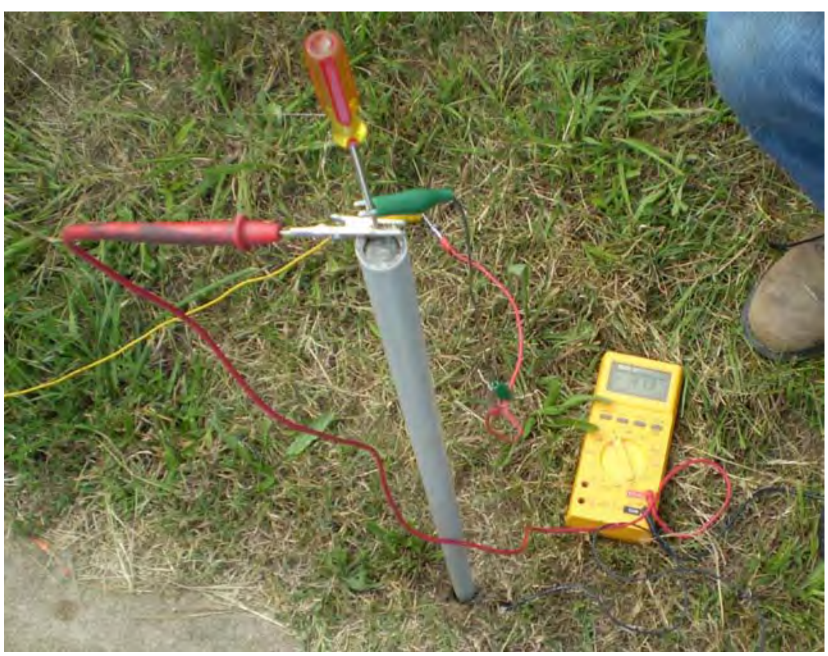


Figure E-44. Photo of test setup.

Figure E-45. Interior of EOP system relative humidity/temperature sensor wiring box.

Figure E-46. Relative humidity/temperature sensor and datalogger.

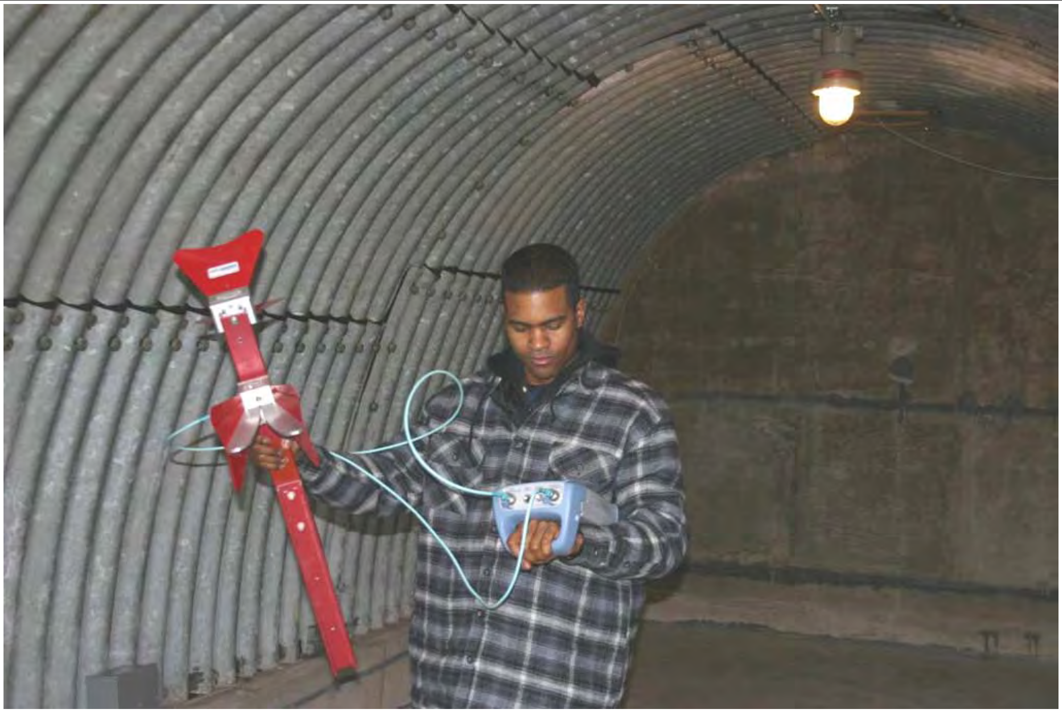


Figure E-47. Test apparatus to detect and measure radio frequency output.

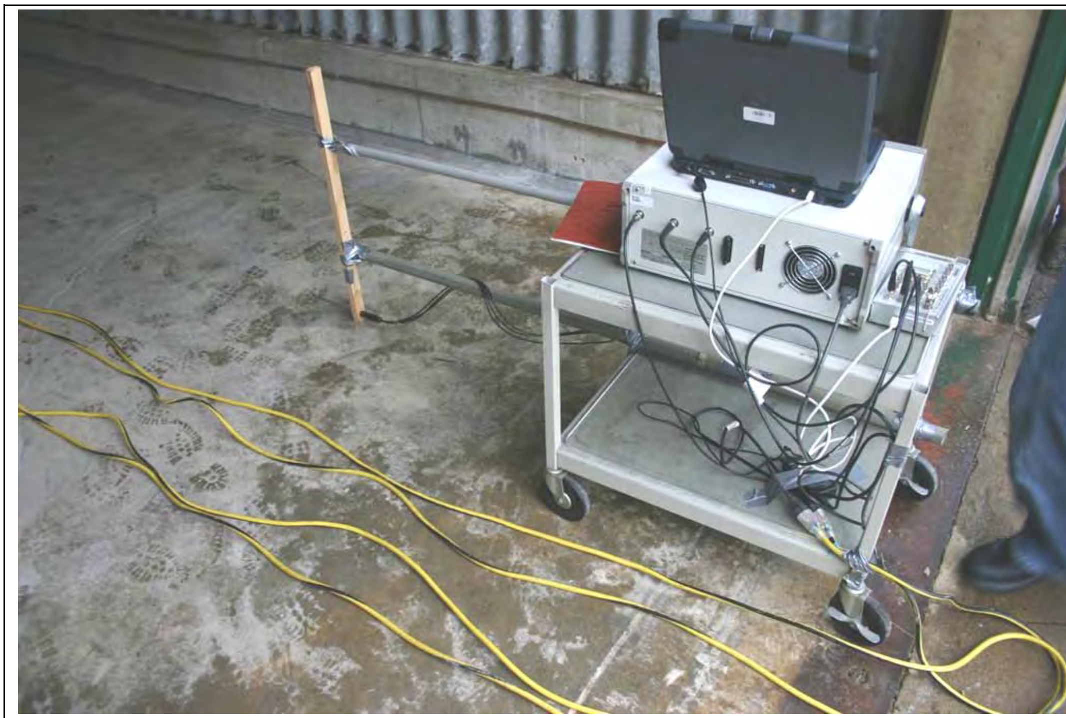
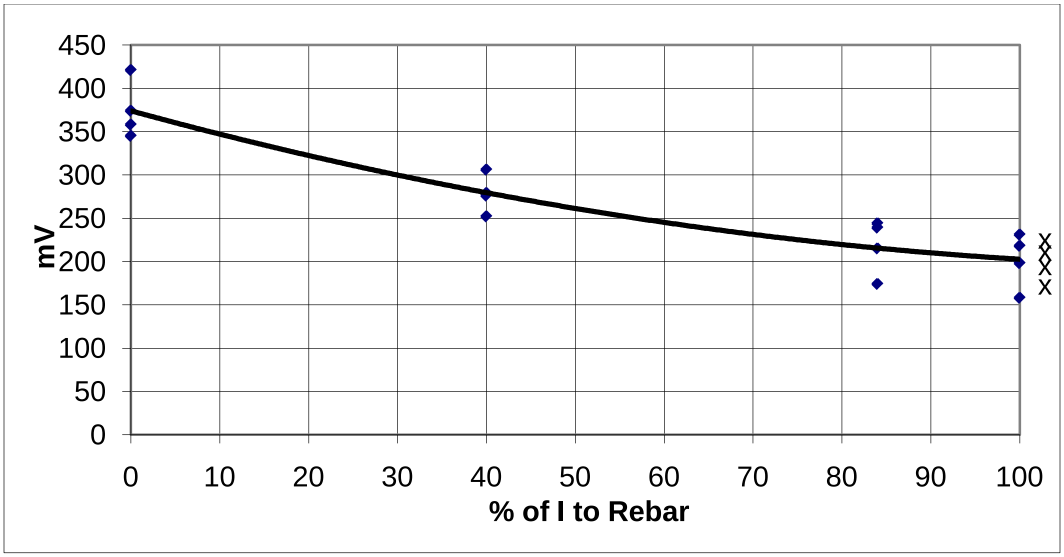
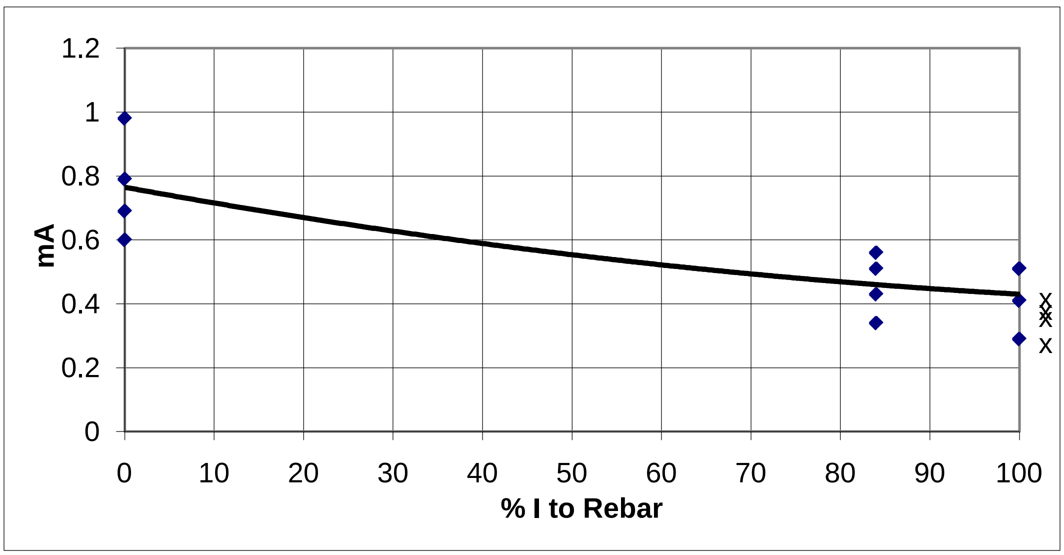


Figure E-48. Test apparatus for measuring electromagnetic radiation.



(x) Data Points Taken with the EOP power supply off and disconnected

Figure E-49. Anodic shift of rebar probe when connected to EOP system negative as a function of current flow.



(x) Data Points Taken with the EOP power supply off and disconnected

Figure E-50. Corrosion current on rebar probe when connected to EOP system negative as a function of current flow.

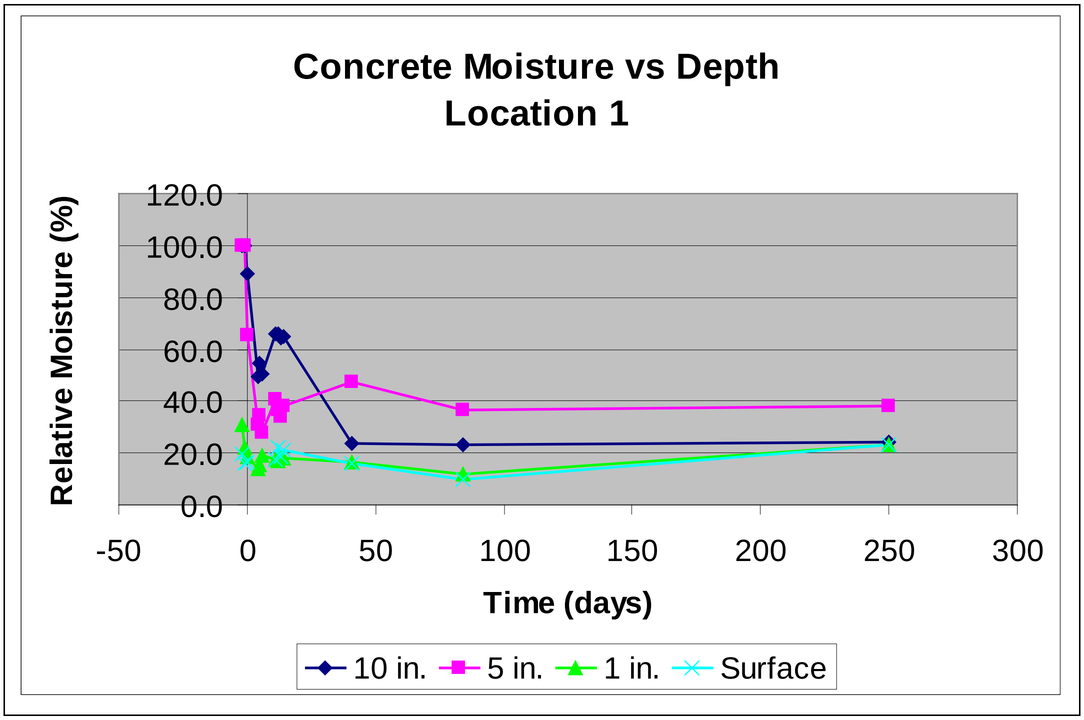


Figure E-51. Plot of concrete moisture over time at location 1, Figure E-43.

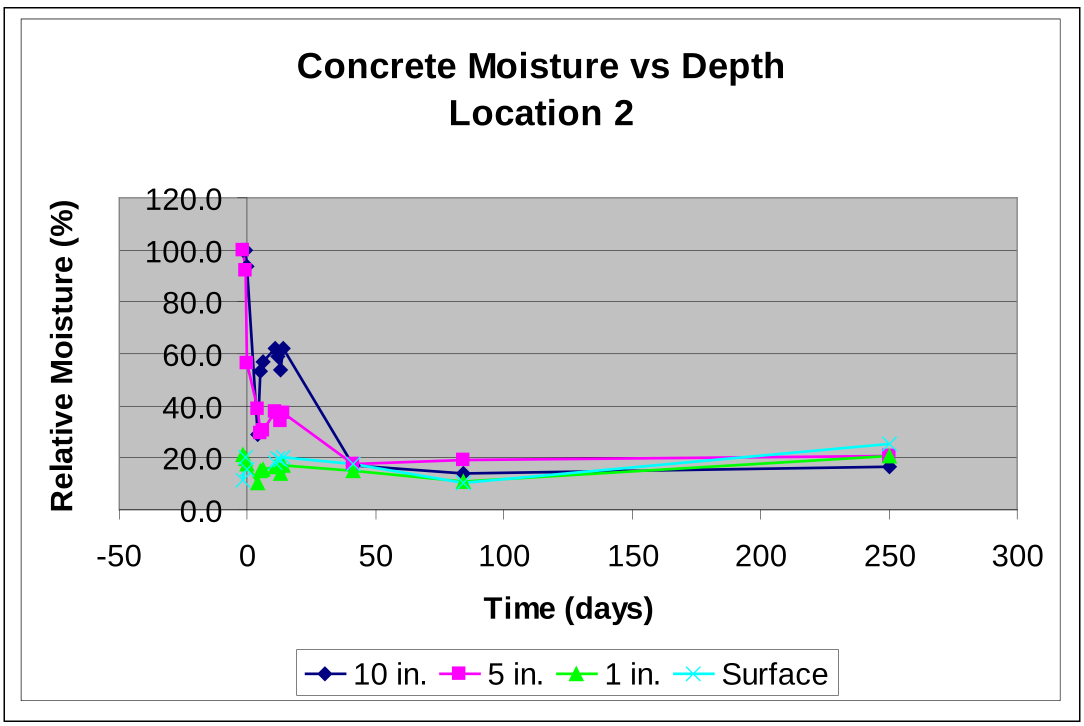


Figure E-52. Plot of concrete moisture over time at location 2, Figure E-43.

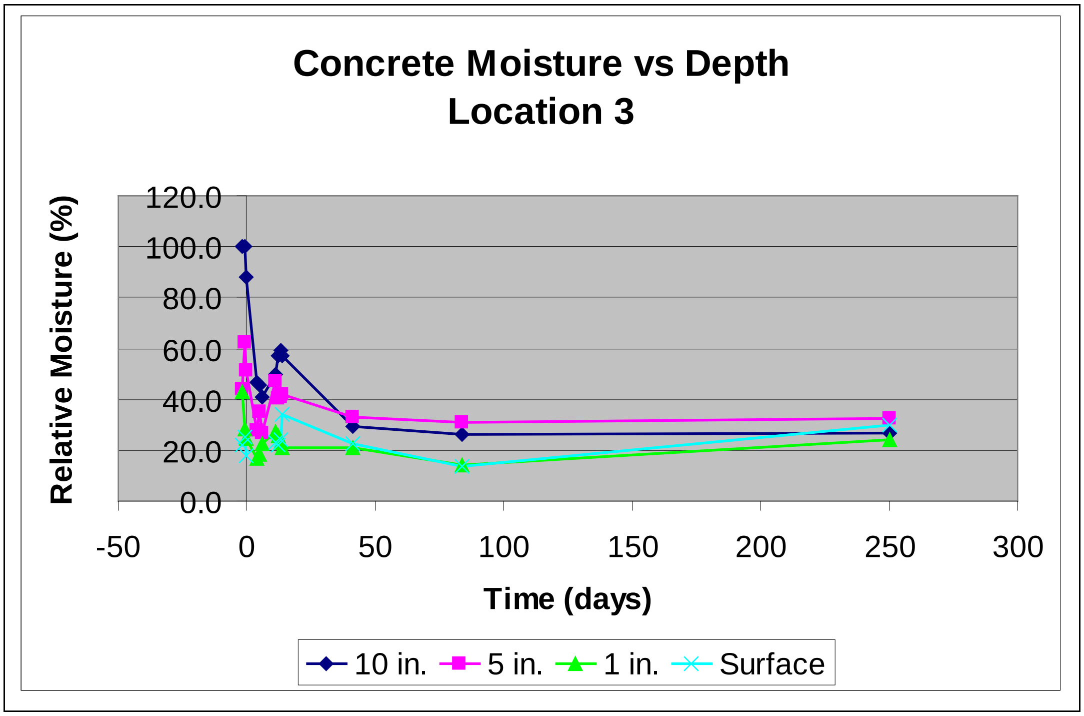


Figure E-53. Plot of concrete moisture over time at location 3, Figure E-43.

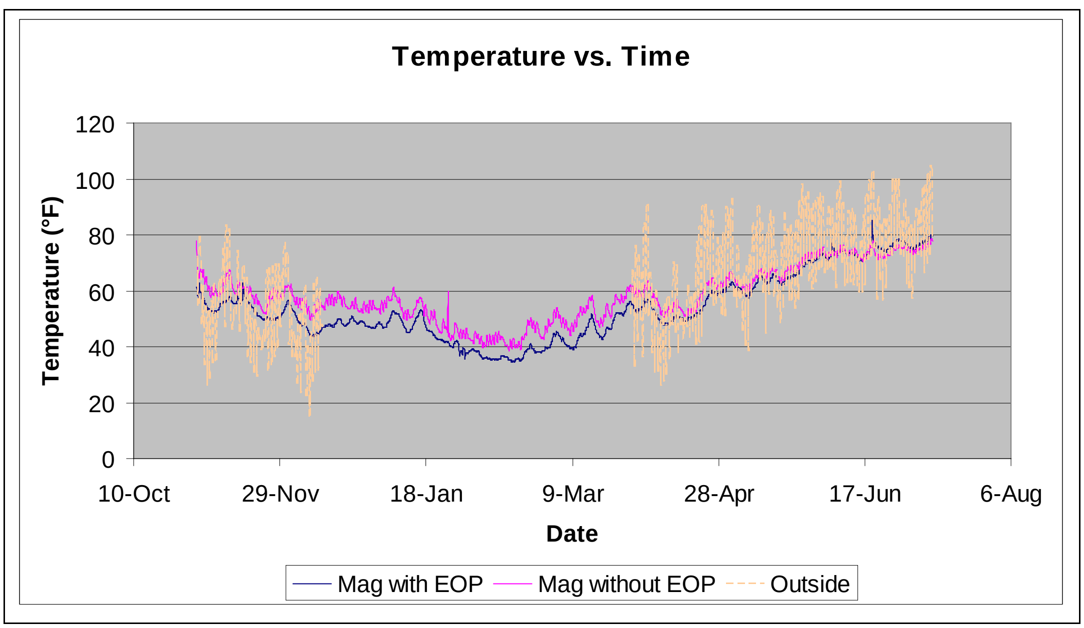


Figure E-54. Plot comparing outdoor temperature with interior temperature for magazine with and without EOP vs time.

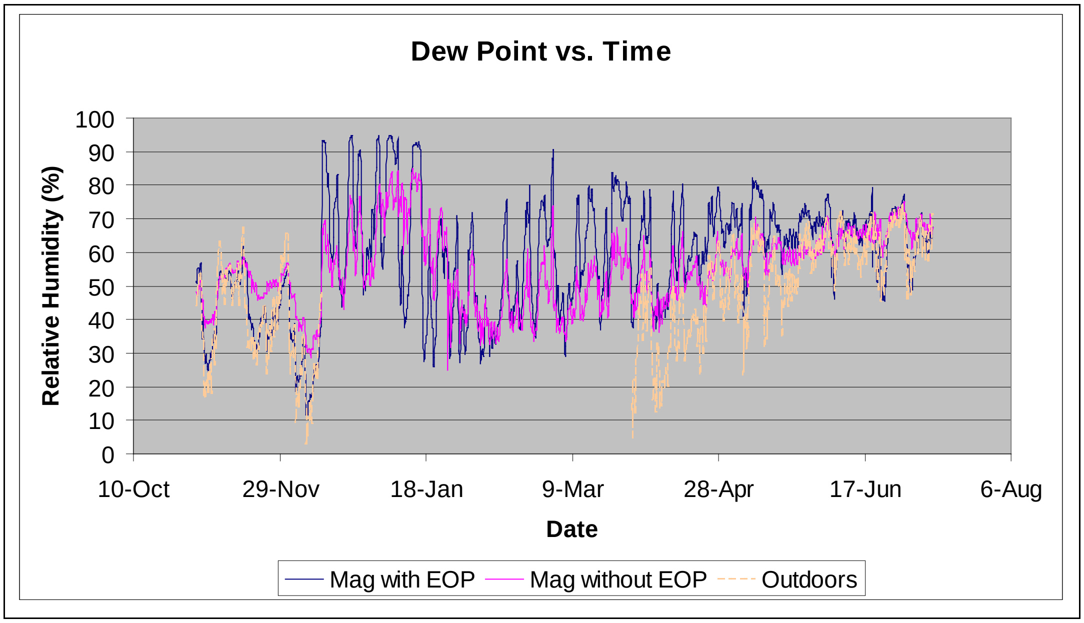


Figure E-55. Plot comparing outdoor dew point with interior dew point for magazine with and without EOP vs time.

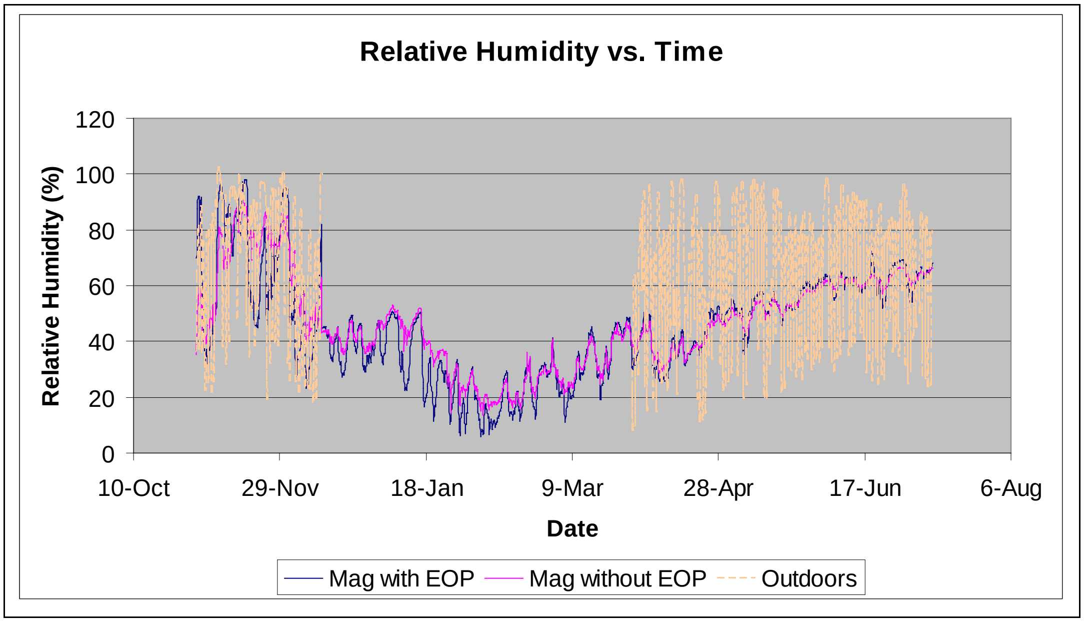


Figure E-56. Plot comparing outdoor relative humidity with interior relative humidity for magazine with and without EOP vs time.

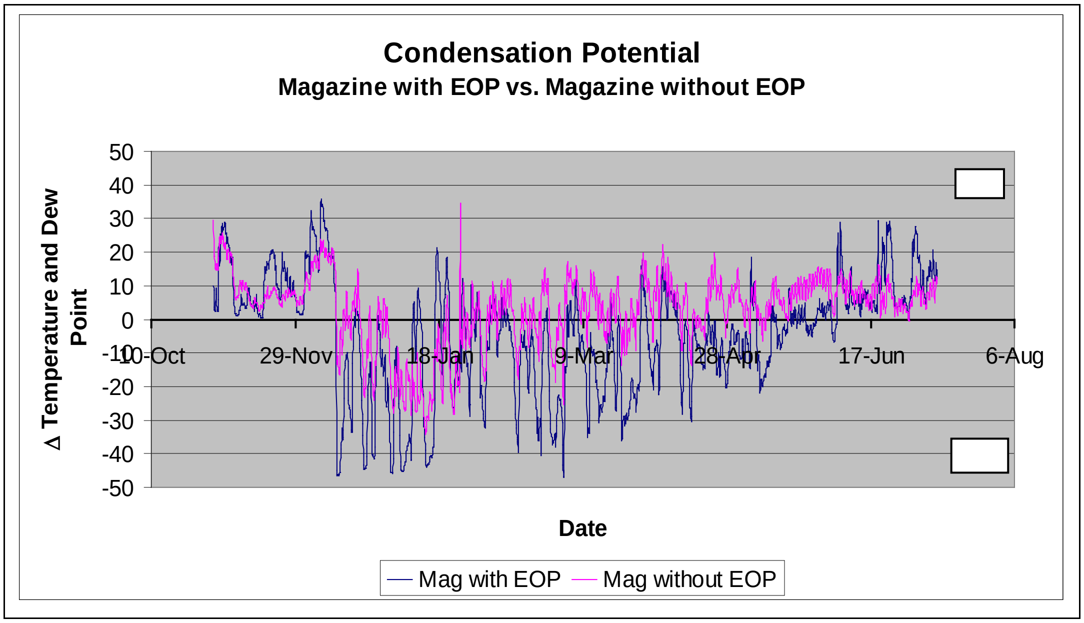


Figure E-57. Plot of condensation potential temperature for magazine with and without EOP vs time.

Figure E-58. Magazine connector box with MOVs installed.

Table E-1. Potentials between locations on steel arch.

Location*	Potential mV		Δ mV
	14-Nov-06	13-Dec-06	
1-2	0.3	-0.3	-0.6
1-3	0.5	-0.4	-0.9
1-4	0.6	-0.2	-0.8
1-5	0.3	-0.1	-0.4
1-6	0.3	0.0	-0.3
2-3	0.2	0.1	-0.1
2-4	0.1	0.0	-0.1
2-5	0.1	0.0	-0.1
2-6	0.1	0.0	-0.1
3-4	0.2	-0.3	-0.5
3-5	0.3	0.0	-0.3
3-6	0.1	0.0	-0.1
4-5	0.3	0.2	-0.1
4-6	0.3	0.2	-0.1
5-6	0.3	-0.1	-0.4

*From Figure E-31

Table E-2. Potentials between metal pallets and steel arch and between adjacent metal pallets with and without EOP activated.

Location	Potential mV		Δ mV
	14-Nov-06 w/ EOP	13-Dec-06 w/EOP	
1	-168	121	289
2	-7420	667.9	8087.9
3	223	-26.7	-249.7
4	-568	-2.8	565.2
5	-7370	-69	7301
6	-931	-210.8	720.2
7	-358	6.5	364.5
8	-159	396	555
9	-725	380.8	1105.8
10	- - -	452.5	- - -
11	- - -	278	- - -
12	- - -	299.5	- - -
13	- - -	-79.8	- - -

*From Figure E-32

Table E-3. Reinforcing steel potentials at Fort A.P. Hill, November 15, 2006 (mV vs SCE).

Potential Well	Potentials @ 0.20 A		Potentials @ 2.30 A	
	On Potential	Off Potential	On Potential	Off Potential
A.	-298 mV	-298 mV	-520 mV	-492 mV
B.	-190 mV	-190 mV	-583 mV	-536 mV
C.	-198 mV	-188 mV	-547 mV	-496 mV
D.	-32 mV	-25 mV	-601 mV	-529 mV

Table E-4. Relative moisture in concrete at various depths vs time.

Day No.	Location												Precip.
	1				2				3				
Depth (in)	10	5	1	0	10	5	1	0	10	5	1	0	
-2	100.0	100.0	31.0	19.4	100.0	100.0	21.0	11.6	100.0	44.0	43.0	22.0	22500 gal
-1	100.0	100.0	22.0	15.9	100.0	92.0	19.5	20.1	100.0	62.3	28.1	25.1	22500 gal
0	89.0	65.5	18.5	16.5	93.7	56.6	17.6	15.3	88.1	51.6	24.7	17.9	
4	49.4	30.7	13.8		28.9	38.6	10.5		46.4	27.7	16.7		
5	54.6	34.3	15.7		53.2	29.4	14.9		45.6	35.0	18.6		Rain
6	50.6	28.0	18.8		56.7	30.5	15.4		41.1	26.7	22.6		Rain
11	66.0	40.5	17.7	17.4	62.3	37.9	16.5	18.0	50.0	47.2	27.1	23.0	Rain
12	66.0	36.7	16.8	22.0	58.8	37.0	16.3	19.5	57.0	40.6	25.7	22.2	22500 gal
13	64.5	34.0	18.0	18.5	54.0	34.0	13.8	19.0	59.0	41.0	23.0	24.0	22500 gal
14	65.0	38.0	18.0	21.0	62.0	37.0	17.0	20.0	57.0	42.0	21.0	34.0	Rain
41	23.8	47.6	16.6	16.2	17.2	17.5	15	17.5	29.1	33.1	21.1	22.4	
84	23.1	36.4	12.1	9.9	13.8	18.9	10.7	10.5	26.2	30.9	14.2	13.7	
250	24.0	38.0	23.3	23.1	16.5	20.8	20.9	25.3	26.7	32.4	24.0	30.0	

*From Figure E-42

Table E-5. Temperature-relative humidity statistical data comparing outdoor conditions with indoor conditions in magazines with and without EOP.

Location	Statistic	Temperature (°F)	Dew Point (°F)	Relative Humidity (%)
Outdoors	Average	62.9	47.5	62.7
	Standard Deviation	17.5	15.7	23.4
	Maximum	105	74.7	100
	Minimum	15	3.1	8.2
Mag with EOP	Average	53.9	58.2	44.9
	Standard Deviation	12	16.8	19.2
	Maximum	85.2	94.9	98.1
	Minimum	34.5	11.6	5.8
Mag without EOP	Average	58.3	55.4	46.9
	Standard Deviation	9.8	11.4	16.6
	Maximum	78.6	85.1	91.4
	Minimum	38.4	25	13.6

Table E-5. Potentials and current to or from rebar probes to evaluate stray current, Bunker 2, November 11, 2006 (I = 0.20 A, mV vs SCE).

	P1	P2	P3	P4	P5
On Potential (mV)	-327	-223	-273	-166	-141
Off Potential (mV)	-318	-127	-248	-162	-127
Current (mA)	-0.23	-0.43	-0.67	-0.88	-1.80

Bunker 2, July 11, 2007 (I = 0.744 A, mV vs SCE)

	P1	P2	P3	P4	P5
On Potential (mV)	-294	-265	-268	-281	-309
Off Potential (mV)	-210	-224	-229	-228	-228
Current (mA)	-0.21	-0.08	-0.06	-0.09	-0.18

Bunker 2, July 11, 2007 (I = 0.50 A, mV vs SCE)

	P1	P2	P3	P4	P5
On Potential (mV)	-191	-176	-	-190	-340
Off Potential (mV)	-161	-118	-	-163	-326
Current (mA)	-0.05	-0.15	-0.34	-0.15	-0.17

Bunker 2, July 14, 2008 (Total I = 1.61 A, Steel I = 0.65 A, mV vs SCE)

	P1	P2	P3	P4	P5
Static Potential, No Current (mV)	-107	-105	-111	-110	-129
I-On Potential, Steel Disconnected (mV)	-324	-314	-315	-314	-324
I-On Potential, Steel Connected (mV)	-282	-295	-292	-298	-304

Table E-6. Test probe half-cell potentials at varying amounts of cathodic current to steel.

Test Point	Static Potential[1] (mV vs SCE)	On Potential[1] (mV vs SCE)	Polarization[2] (mV)	Rebar Current[3] (mA)
0% of Cathodic Current to Reinforcing Steel (Reinforcing Steel Disconnected)				
1.	-539	-118	421	0.79
2.	-540	-182	358	0.98
9.	-536	-162	374	0.60
10.	-516	-171	345	0.69
Ave.1,2,9,10[4]	-533 mV	-158 mV	375 mV	0.77 mA
40% of Cathodic Current to Reinforcing Steel (data taken 07-14-08 with battery)				
1.	-525	-219	306	
2.	-566	-287	279	
3.	-454	-422	32	
4.	-524	-363	161	
5.	-464	-396	68	
6.	-479	-264	215	

Test Point	Static Potential[1] (mV vs SCE)	On Potential[1] (mV vs SCE)	Polarization[2] (mV)	Rebar Current[3] (mA)
7.	-535	-458	77	
8.	-477	-336	141	
9.	-480	-228	252	
10.	-588	-312	276	
Ave.1,2,9,10[4]	540 mV	262 mV	278 mV	
84% of Cathodic Current to Reinforcing Steel				
1.	-615	-376	239	0.51
2.	-618	-403	215	0.56
5.	-562	-500	62	0.09
6.	-605	-421	184	0.13
9.	-604	-360	244	0.43
10.	-612	-438	174	0.34
Ave.1,2,9,10[4]	-612 mV	-394 mV	218 mV	0.46 mA
100% of Cathodic Current to Reinforcing Steel (Remote Cathode Disconnected)				
1.	-632	-401	231	0.51
2.	-625	-427	198	0.51
5.	-608	-536	72	0.09
6.	-636	-493	143	0.10
9.	-595	-377	218	0.41
10.	-605	-447	158	0.29
Ave.1,2,9,10[4]	-614 mV	-413 mV	201 mV	0.43 mA

1 Data in mV versus a saturated calomel reference electrode.

2 Data in mV. Polarization is in the anodic direction.

3 Data in mA. All currents represent corrosion of the probe.

4 Data from test points 1, 2, 9, & 10 were averaged since these points were similar.

Table E-7. Data taken November 4, 2008 with EOP power supply on.

Test Points	Static Potential1	On Potential1	Ground Potential	Rebar Current2
1.	-437	-315	-256	0.234
2.	-480	-348	-310	0.211
5.	-502	-413	-364	0.046
6.	-451	-382	-267	0.046
9.	-452	-314	-285	0.186
10.	-461	-342	-322	0.102

1 Data in mV versus a saturated calomel reference electrode.

2 Data in mA. All currents represent corrosion of the probe.

Table E-8. Data taken November 4, 2008 with EOP power supply off and disconnected.

Test Points	Static Potential[1] (Disconnected)	Potential[2] (Connected)	Polarization	Rebar Current[3]
1.	-494	-328	166	0.388
2.	-558	-350	208	0.385
5.	-538	-446	92	0.063
6.	-514	-440	74	0.055
9.	-546	-312	234	0.351
10.	-525	-346	179	0.204
Ave.1, 2, 9, 10[4]	-531 mV	-334 mV	197 mV	0.332 mA

[1] Data in mV versus a SCE reference, probe disconnected from reinforcing steel.

[2] Data in mV versus a SCE reference, probe connected to the reinforcing steel.

[3] Data in mA. All currents represent corrosion of the probe.

[4] Data from test points 1, 2, 9, & 10 were averaged since these points were similar.

Appendix F: Contractor Product Data Sheets

Cut Sheet 1

MICOR

PRODUCT DATA
MICOROX® JOINT FILLER

MICOROX™ Joint Filler (J.F.) is a two component, 100% solids epoxy resin based product designed to fill non-moving cracks and joints in concrete surfaces. MICOROX® "J.F." is a semi flexible liquid product that penetrates cracks and provides support to joint edges in traffic aisles.

AREAS OF APPLICATION:

- Concrete floors
- Secondary containment areas
- Warehouses
- Industrial facilities
- Paper Mills
- Food Processing Plants

FEATURES:

- Economic
- 1 to 1 Mix Ratio
- Protects joint edges
- Low temperatures brittle point
- Easy to place and trim

PACKAGING:

2 Gallon Units
20 Gallon Units

COVERAGE PER GALLON:

25 Lineal Feet - 1" wide x 3/4" deep
38 Lineal Feet - 1/2" wide x 1" deep
77 Lineal Feet - 1/4" wide x 1" deep

PHYSICAL/CHEMICAL CHARACTERISTICS:

Viscosity: 3000 CPS Mixed

Yield: 231 cubic inches per mixed gallon

Color: Grey, other colors by request

Working Life-Mixed Materials 25-30 minutes

Set Time. . . . 5 to 8 hours at 70°
Tensile Strength. . . 500 psi
Tensile Elongation . . . 110%
Compressive Strength . . 7600 psi
Tensile Bond Strength . . . 350 psi

STORAGE AND SHELF LIFE:
Stored at room temperature, the unopened materials should have a shelf life of one year.

MICOR CO., INC. • 3232 NORTH 31ST ST. • MILWAUKEE, WI 53216 • PHONE (414) 873-2071 1-800-284-4308

SURFACE PREPARATION:
Cracks and voids must be clean and free of loose material, dust, grease, oil, grout, or other contaminants. Chip or rout out cracks that are hard to clean. Notch or V cracks for maximum performance. Seal the bottoms of cracks through the slab, or where the Joint Filler will leak through, with a polyurethane rope. Concrete should be clean, dry and rough for best performance.

APPLICATION INSTRUCTIONS:

Mix **MICOROX® Joint Filler** by combining one part of hardener component with one part of resin component. A measuring cup, or a can may be used to measure the components.

Mix the two components together thoroughly for two to three minutes to a uniform color and consistency. Use a paddle or low speed drill - stirrer to mix the material.

To apply the material, a plastic squeeze bottle (like a ketchup bottle) works well. Dispense the liquid into the crack until penetration stops and the crack is full. To fill very fine cracks, pressure is required to force the sealer into place. A grease gun with grease fittings may be used. Pressure injection devices may also be used. Contact Micor for recommendations.

The **MICOROX® Joint Filler** may be thickened for application on vertical cracks. Mix the material as described above and add the dry thickening agent (sold seperately) to obtain the desired consistancy. Apply with a squeeze bottle, spatula, trowel or with pressure equipment.

CLEAN UP:
Clean tools immediately with hot soapy water or with solvents such as Xylene or MEK. These products are **HAZARDOUS** and must be used with **CAUTION** and **MUST** be used with appropriate **VENTILATION.** See their M.S.D.S. sheets for appropriate use.

WORKING LIFE:
Working life of mixed materials is very short. Mix only the amount of material that can be used in 30 minutes.

HANDLING PRECAUTIONS:
MICOROX® Joint Filler is intended for industrial and commercial use only! Prolonged contact with skin can cause irritation. **Wear protective clothing and chemical splash goggles to avoid eye contact. NEVER RECAP A CONTAINER OF MIXED COMPONENTS** as the continuing reaction may cause an **EXPLOSION.** READ THE M.S.D.S. SHEET BEFORE USING.

COMPLIMENTARY INFORMATION:
Our full service lab and technical engineers are available to assist you. For complete information on all systems, contact your local Dealer or our factory at 1-800-284-4308.

Micor Company, Inc. believes the information contained herein to be true and accurate. Information contained herein is for evaluation purposes only. Micor makes no warranty, express or implied based upon this literature and assumes no liability or responsibility for consequential or incidental damages as a result of the use of these products and systems described herein, including any warranty of merchantability or fitness.

THIS MATERIAL IS INTENDED FOR INDUSTRIAL USE ONLY!

6/6/95

Cut Sheet 2

Product Catalog

TO ORDER CALL UNITED STATES 1-866-CORRPRO (1-866-267-7776)
CANADA 1-800-661-8390
INTERNATIONAL 1-330-723-5082
or e-mail: corrpro@corrpro.com

ELGARD™ 150 ANODE RIBBON MESH

DESCRIPTION

ELGARD™ Anode Ribbon Mesh is a key component for Cathodic Protection systems in reinforced concrete structures. It is composed of a precious metal oxide catalyst sintered to an expanded titanium mesh substrate.

MATERIAL SPECIFICATIONS

Anode Performance:

Current rating at 110 mA/m^2 (10 mA/ft^2)	5.28 mA/m (1.61 mA/ft)
Expected life (NACE Standard TM02944-94)	75 years
Catalyst	Mixed Metal Oxide
Maximum anode concrete interface current density:	
FHWA limit	110 mA/m^2 (10 mA/ft^2)
Short-term limit	220 mA/m^2 (20 mA/ft^2)

Dimensions:

Width	19 mm (3/4")
Coil length	76 m (250 ft)
Actual anode surface per unit length of anode	0.048 m^2/m (0.157 ft^2/ft)
Expanded thickness	1.30 mm (0.051")
Diamond dimensions	2.5 mm x 4.6 mm x 0.6 mm (0.10" x 0.18" x 0.025")
Shipping weight per coil	2.7 kg (6 lbs)

Substrate:

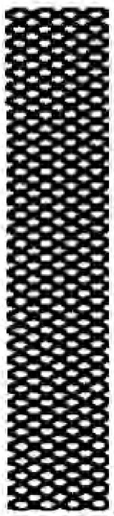
Composition	Titanium, Grade 1 per ASTM B265
Coefficient of thermal expansion	8.7 x 10^{-5}/°K (0.0000048/in/in/°K)
Thermal conductivity at 20°C	15.6 W/m^2-°K (9.0 BTU/hr/ft^2/°F/ft)
Electrical resistivity	0.000056 ohm-cm (0.000022 ohm-in)
Modulus of elasticity	105 GPa (14,900,000 PSI) minimum
Tensile strength	245 MPa (35,000 PSI) minimum
Yield strength	175 MPa (25,000 PSI) minimum
Elongation	24% minimum

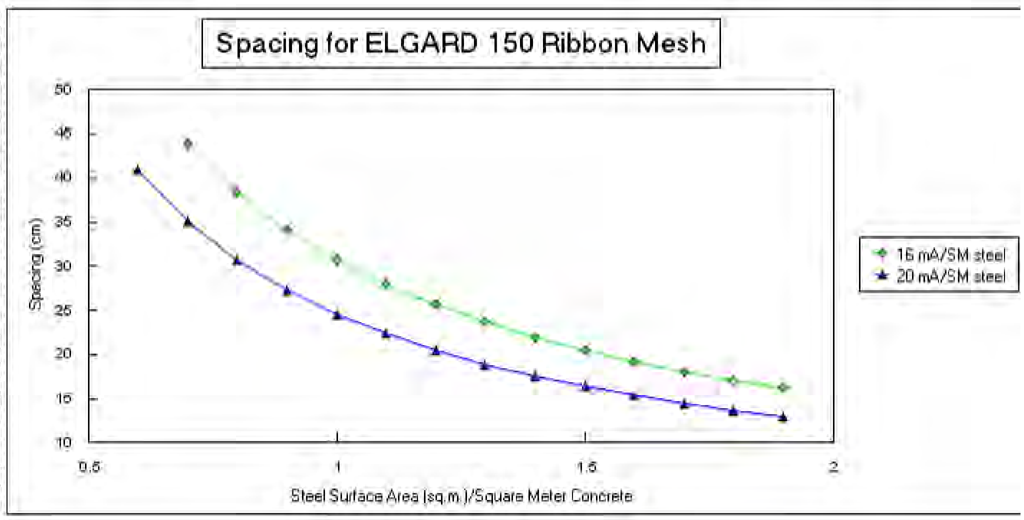
Current Distributor:

Width .... 12.7 mm (1/2")
Thickness .... 0.9 mm (0.035")
Coil length .... 76 m (250 ft)
Shipping weight per coil .... 3.9 kg (8.6 lbs)

Electrical Properties:

Anode ribbon mesh resistance lengthwise .... 0.26 ohm/m (0.08 ohm/ft)
Current distributor resistance lengthwise .... 0.049 ohm/m (0.015 ohm/ft)





Actual Size

Corrpro Companies, Inc. is the world wide licensee of the ELGARD System for Cathodic Protection of Reinforced Concrete Structures. ELGARD is a trademark of Eltech Systems Corporation.

Cut Sheet 3

ServiceWireCo.
Manufacturing quality. Delivering service.

XLP USE-2
RHH or RHW-2
600 Volt, Copper

Single Conductors

Description:
Single copper conductor, stranded, insulated with moisture and heat resistant, chemically cross-linked polyethylene insulation. Temperature rating 90° C in wet and dry applications. Colors available.

Standards:
UL 44 and UL 854, ICEA S-95-658/NEMA WC-70
Federal spec. A-A-59544
-40° C rated
Direct Burial/Sunlight resistant

Application:
Types USE-2, RHH/RHW-2 are suitable for use in general purpose wiring applications and may be installed in raceway, conduit, direct burial and aerial installations.

XLP USE-2, RHH/RHW-2

Size AWG or MCM	Strand (no.)	Insulation Thickness (mils)	Approx. Diameter Overall (inch)	Approx. Net Weight per 1000 feet (lbs.)	Ampacity* 90°C Wet/Dry
14	7	45	.169	22	35†
12	7	45	.188	30	40†
10	7	45	.212	45	55†
8	7	60	.272	73	80
6	7	60	.310	107	105
4	7	60	.358	161	140
3	7	60	.382	193	165
2	7	60	.419	244	190
1	19	80	.484	307	220
1/0	19	80	.523	379	260
2/0	19	80	.567	469	300
3/0	19	80	.617	582	350
4/0	19	80	.673	724	405
250	37	95	.773	873	455
300	37	95	.818	1027	505
350	37	95	.871	1200	570
400	37	95	.918	1349	615
500	37	95	1.011	1683	700
600	61	110	1.116	2014	780
750	61	110	1.226	2508	885

* Per NEC-Table 310-17.
The overcurrent protection for items marked with an obelisk (†) shall not exceed 15 amps for 14 AWG, 20 amps for 12 AWG, and 30 amps for 10 AWG per NEC 310-17 footnote.
NOTE: The data shown is approximate and subject to standard Industry tolerances. 2006

11

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Phoenix, AZ 877-623-9473 | Culloden, WV 800-624-3572 | Houston, TX 800-231-9473 | Pittsburgh, PA 800-778-9473

Cut Sheet 4

Current refinements (click ☒ to remove)

☒ Region › USA ☒ Product Line › Heat Shrink & Abrasion Protection › ☒ Heat Shrink › ☒ Thick Wall Adhesive Lined Polyolefin and End Caps for Wet Locations ☒ Product Family › Thick Wall Polyolefin Heat Shrink

- Shrink ratio of 3:1 insulates a wide range of diameters and irregular shapes, which reduces inventory costs
- Cross-linked, UV resistant material improves flame retardancy, chemical, and temperature resistance
- Thick wall product seals and insulates in one step to speed installation

* For red, add 2 to end of part number package suffix (Example HST0.4-3-Q2).
‡‡ Meets Mil Spec AMS-DTL-23053/15 Class 1.

Part Number:	HST0.4-48-5
Product Family:	Thick Wall Polyolefin Heat Shrink
Product Line:	Accessories
Product Line:	Thick Wall Adhesive Lined Polyolefin and End Caps for Wet Locations
RoHS Compliancy Status:	Compliant
Part Description:	Thick Wall Heat Shrink provides excellent protection above or below ground level and is suitable for wet locations and direct burial (UL486D)
Material:	Flame retardant polyolefin cross-linked with adhesive‡‡
Color:	Black
CSA Certified:	Yes
Military Specification:	AMS-DTL-23053/15 Class 1
UL Recognized:	Yes
Length (In.):	48.00
Length (mm):	1200.0
Copper Conductor Size Range:	#12 - #6 AWG
Conductor Size Range (mm):	4 – 10
Flammability Rating:	Flame Retardant
Max. Connector O.D. (In.):	.350
Max. Connector O.D. (mm):	8.9
Max. Recovered I.D. (In.):	.15
Max. Recovered I.D. (mm):	3.8
Min. Cable O.D. (In.):	.170
Min. Cable O.D. (mm):	4.3
Min. Expanded I.D. (In.):	.40
Min. Expanded I.D. (mm):	10.1

Nominal Recovered Wall Thickness (In.):	.090
Nominal Recovered Wall Thickness (mm):	2.3
Product Family:	Thick Wall Polyolefin Heat Shrink
Record Type:	Products
Shrink Ratio:	3:1
Std. Pkg. UOM:	PK
Temperature Range:	-85°F to 230°F (-65°C to 110°C)
UOM:	PC
Std. Pkg. Qty.:	5
Min. Order Qty.:	5
Part Number:	HST0.4-48-5
BOM Qty. (# of Pkgs.)	
Add to My Catalog	

Please register to utilize the 'Bill of Materials', 'Submit Quotes' and 'My Catalog' features.

View Content Details

Evaluate Design a Solution Install & Main

Installation Instructions:

Thick Wall Heat Shrink - Int

legal information | privacy policy | site map

http://www.panduit.com/search/product_details.asp?Ne=1&recName=HST0%2E4%2D48... 7/18/2006

Cut Sheet 5

degussa.
Construction Chemicals

MASTERFLOW® 928

High-precision mineral-aggregate grout with extended working time

PRODUCT DATA

3 03600 Grouts

Description

Masterflow® 928 grout is a hydraulic cement-based mineral-aggregate grout with an extended working time. It is ideally suited for grouting machines or plates requiring precision load-bearing support. It can be placed from fluid to damp pack over a temperature range of 45 to 90° F (7 to 32° C). Masterflow® 928 grout meets the requirements of ASTM C 1107, Grades B and C, and the Army Corp of Engineers' CRD C 621, Grades B and C, at a fluid consistency over a 30-minute working time.

Features / Benefits

Features	Benefits
Extended working time	Ensures sufficient time for placement
Can be mixed at a wide range of consistencies	Ensures proper placement under a variety of conditions
Freeze/thaw resistant	Suitable for exterior applications
Hardens free of bleeding, segregation, or settlement shrinkage	Provides a maximum effective bearing area for optimum load transfer
Contains high-quality, well-graded quartz aggregate	Provides optimum strength and workability
Sulfate resistant	For marine, wastewater, and other sulfate-containing environments

Yield

One 55 lb (25 kg) bag of Masterflow® 928 grout mixed with approximately 10.5 lbs (4.8 kg) or 1.26 gallons (4.8 L) of water, yields approximately 0.50 ft³ (0.014 m³) of grout.

The water requirement may vary due to mixing efficiency, temperature, and other variables.

Packaging

55 lb (25 kg) multi-wall paper bags

3,300 lb (1,500 kg) bulk bags

Shelf Life

1 year when properly stored

Storage

Store in unopened bags in clean, dry conditions.

Protection and Repair

Where to Use

APPLICATION

- Where a nonshrink grout is required for maximum effective bearing area for optimum load transfer
- Where high one-day and later-age compressive strengths are required
- Nonshrink grouting of machinery and equipment, baseplates, soleplates, precast wall panels, beams, columns, curtain walls, concrete systems, other structural and nonstructural building members, anchor bolts, reinforcing bars, and dowel rods
- Applications requiring a pumpable grout
- Repairing concrete, including grouting voids and rock pockets
- Marine applications
- Freeze/thaw environments

LOCATION

- Interior or exterior

How to Apply

Surface Preparation

1. Steel surfaces must be free of dirt, oil, grease, or other contaminants.
2. The surface to be grouted must be clean, SSD, strong, and roughened to a CSP of 5 – 9 following ICRI Guideline 03732 to permit proper bond. For freshly placed concrete, consider using Liquid Surface Etchant (see Form No. 1020198) to achieve the required surface profile.
3. When dynamic, shear or tensile forces are anticipated, concrete surfaces should be chipped with a "chisel-point" hammer, to a roughness of (plus or minus) 3/8" (10 mm). Verify the absence of bruising following ICRI Guideline 03732.
4. Concrete surfaces should be saturated (ponded) with clean water for 24 hours just before grouting.
5. All freestanding water must be removed from the foundation and bolt holes immediately before grouting.
6. Anchor bolt holes must be grouted and sufficiently set before the major portion of the grout is placed.
7. Shade the foundation from sunlight 24 hours before and 24 hours after grouting.

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Cut Sheet 6

Product Data Sheet
Edition 6.2003
Identification no. 553
SikaRepair 223

SikaRepair® 223

One component, early strength gaining, cementitious patching material

Description	SikaRepair 223 is a one-component, early strength gaining, cementitious, patching material for vertical and overhead repair of concrete.
Where to Use	• On grade, above, and below grade on concrete and mortar. • As a repair material for vertical and overhead concrete surfaces.
Advantages	• Easy-to-use. • Suitable for exterior and interior applications. • Easily applied to clean, sound substrate. • High early strengths. • Increased abrasion resistance. • Increased freeze/thaw resistance. • Not a vapor barrier. • Not flammable.
Coverage	Approximately 0.41 cu. ft.
Packaging	SikaRepair 223 - 50 lb. multi-wall bag. SikaLatex R - 1 gal. plastic jug; 4/carton, 5 gal. pails

Typical Data *(Material and curing conditions @ 73°F (23°C) and 50% R.H.)*

Shelf Life	One year in original, unopened bags.
Storage Conditions	Store dry at 40°-95°F (4°-35°C). **Condition material to 65°-75°F before using.**
Color	Concrete grey
Mixing Ratio	3/4 gal. to 1 gal. of liquid per 50 lb. bag
Application Time	Approximately 15 min. after adding powder to Latex or Latex R. Application time is dependent on temperature and relative humidity.
Finishing Time	20 to 60 min after combining powder and liquid: depends on temperature, relative humidity, and type of finish desired.

		with undiluted Latex R
Flexural Strength (ASTM C-293)		
28 days	850 psi (5.9 MPa)	1,200 psi (8.2 MPa)
Splitting Tensile Strength (ASTM C-496)		
28 days	550 psi (3.8 MPa)	700 psi (4.8 MPa)
Bond Strength * (ASTM C-882 modified)		
28 days	1,800 psi (12.4 MPa)	2,000 psi (13.8 MPa)
Compressive Strength (ASTM C-109)		
1 day	3,000 psi (20.7 MPa)	3,300 psi (22.8 MPa)
7 days	6,000 psi (41.4 MPa)	6,200 psi (42.8 MPa)
28 days	7,000 psi (48.3 MPa)	7,500 psi (51.7 MPa)

*Mortar scrubbed into substrate

How to Use

Surface Preparation - Remove all deteriorated concrete, dirt, oil, grease, and all bond-inhibiting materials from surface. Be sure repair area is not less than 1/4 inch in depth. Preparation work should be done by scabbler or other appropriate mechanical means to obtain an exposed aggregate surface with a minimum surface profile of ±1/8 inch (CSP-6). Saturate surface with clean water. Substrate should be saturated surface dry (SSD) with no standing water during application.

Priming For priming of reinforcing steel use Sika Armatec 110 EpoCem (consult Technical Data Sheet).

Concrete Substrate: Prime the prepared substrate with a brush or sprayed applied coat of Sika Armatec 110 EpoCem (consult Technical Data Sheet). Alternately, a scrub coat of Sika Repair 223 can be applied prior to placement of the mortar. The repair mortar has to be applied into the wet scrub coat before it dries.

Mixing

With water: Wet down all tools and mixer to be used. Add approximately 3/4 gal. of water to mixing vessel. Slowly add 1 bag of SikaRepair 223 while continuing to mix. Mechanically mix with a low-speed drill (400-600 rpm) and SikaTop Gel paddle. 1/4 gal. of water may be added to achieve desired consistency. Do not overwater. Maintain a mix temperature of 65°-75°F for maximum performance by using hot or cold water as needed.

With Latex R: Pour 3/4 gallon of SikaLatex R into the mixing container. Slowly add powder while continuing to mix mechanically as above. Add remaining SikaLatex R (up to 1/4 gal.) to adjust the desired consistency.

note: SikaLatex R must be protected from freezing. If frozen, discard.

With diluted Latex R: Sika Latex R may be diluted up to 5:1 (water:Sika Latex R) for projects requiring minimal polymer-modification. Pour 3/4 gallon of the mixture into the mixing container. Slowly add powder and mix as above. Add remaining diluted SikaLatex R (up to 1/4 gal.) to adjust the desired consistency.

Application & Finish

At the time of application, surfaces should be saturated surface dry (SSD) with no standing water. Mortar must be scrubbed into the substrate, filling all pores and voids. Force material against edge of repair, working toward center. After filling repair, consolidate, then screed. Material may be applied in multiple lifts. The thickness of each lift not to be less than 1/2 inch minimum.

Where multiple lifts are required score top surface of each lift to produce a roughened surface for next lift. Allow preceding lift to reach final set, 30 minutes minimum before applying fresh material. Saturate surface of the lift with clean water. Scrub fresh mortar into preceding lift. Allow mortar to set to desired stiffness, then finish with wood or sponge float for a smooth surface, or texture as required.

For repairs greater than 1 inch in depth, the use of SikaRepair 222 extended with coarse aggregate, and appropriate formwork is also recommended.

Important: Maximum bond is achieved with application of a scrub coat on properly prepared, saturated surface dry (SSD) substrate.

Curing

As per ACI recommendations for portland cement concrete, curing is required. Moist cure with wet burlap and polyethylene, a fine mist of water or a water based compatible curing compound. Curing compounds adversely affect the adhesion of following lifts of mortar, leveling mortar or protective coatings. Moist curing should commence immediately after finishing. Protect freshly applied mortar from direct sunlight, wind, rain and frost.

Limitations

- Application thickness: (with water and diluted Latex R) Minimum 1/4 inch (6 mm). Maximum in one lift 1.5 inch (38 mm)
- Application thickness: (with undiluted Latex R) Minimum 1/8 inch (3 mm). Maximum in one lift 1.5 inch (38 mm)
- Minimum ambient and surface temperatures 45°F (7°C) and rising at time of application
- Use only potable water.
- Do not use solvent-based curing compound.
- As with all cement based materials, avoid contact with aluminum to prevent adverse chemical reaction and possible product failure. Insulate potential areas of contact by coating aluminum bars, rails, posts etc. with an appropriate epoxy such as Sikadur Hi-Mod 32.

Caution

Irritant

Suspect carcinogen - Contains portland cement and sand (crystalline silica). Skin and eye irritant. Avoid contact. Dust may cause respiratory tract irritation. Avoid breathing dust. Use only with adequate ventilation. May cause delayed lung injury (silicosis). IARC lists crystalline silica as having sufficient evidence of carcinogenicity in laboratory animals and limited evidence of carcinogenicity in humans. NTP also lists crystalline silica as a suspect carcinogen. Use of safety goggles and chemical resistant gloves is recommended. If PELs are exceeded, an appropriate, NIOSH approved respirator is required. Remove contaminated clothing.

First Aid

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately with plenty of water for at least 15 minutes, and contact a physician. For respiratory problems, remove person to fresh air.

Clean Up

In case of spillage, scoop or vacuum into appropriate container, and dispose of in accordance with current, applicable local, state and federal regulations. Keep container tightly closed and in an upright position to prevent spillage and leakage. **Mixed components:** Uncured material can be removed with water. Cured material can only be removed mechanically.

KEEP CONTAINER TIGHTLY CLOSED
NOT FOR INTERNAL CONSUMPTION

KEEP OUT OF REACH OF CHILDREN
FOR INDUSTRIAL USE ONLY

CONSULT MATERIAL SAFETY DATA SHEET FOR MORE INFORMATION

Sika warrants this product for one year from date of installation to be free from manufacturing defects and to meet the technical properties on the current technical data sheet if used as directed within shelf life. User determines suitability of product for intended use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product exclusive of labor or cost of labor.

NO OTHER WARRANTIES EXPRESS OR IMPLIED SHALL APPLY INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. SIKA SHALL NOT BE LIABLE UNDER ANY LEGAL THEORY FOR SPECIAL OR CONSEQUENTIAL DAMAGES.

Visit our website at www.sikausa.com 1-800-933-SIKA NATIONWIDE

Regional Information and Sales Centers. For the location of your nearest Sika sales office, contact your regional center.

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Quebec H9R 4A9
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C.P. 76920 A.P. 136
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Fax: 52 42 25 0537

QUALITY ISO 9001 9002 ACHIEVEMENT

Cut Sheet 7

COPPER BONDED GROUND RODS

Copper Bonded Ground Rods

- Galvan's copper bonded rods have a heavy, uniform coating of copper metallurgically bonded to a rigid steel core.
- UL Listed rods have 10mil minimum copper plating. UL/RUS models have 13mils of copper.
- Galvan manufactures copper-clad rods under patent 6,527,934

Catalog Number	Nominal Diameter X Length	Sub & Master Bundle	Wt. per 100	NA UPC 632
3754	3/8" x 4'	10 / 100	132	613
3755	3/8" x 5'	10 / 100	165	613
3756	3/8" x 6'	10 / 100	200	613
5005	1/2" x 5'	5 / 100	305	611
5006	1/2" x 6'	5 / 100	370	611
5008	1/2" x 8'	5 / 100	500	611
5008L*	1/2" x 8'	5 /100	545	611
5010	1/2" x 10'	5 / 100	611	611
5010L*	1/2" x 10'	5 / 100	690	611
6254	5/8" x 4'	5 / 100	340	
6255	5/8" x 5'	5 / 100	424	615
6256	5/8" x 6'	5 / 100	508	615
6258*	5/8" x 8'	5 / 100	680	615
6258G13**	5/8" x 8'	5 / 100	700	612
6260*	5/8" x 10'	5 / 100	847	615
6260G13**	5/8" x 10'	5 / 100	860	612
7508*	3/4" x 8'	5 / 50	992	615
7510*	3/4" x 10'	5 / 50	1240	613
1010*	1" x 10'	25	2248	614

Notes:

*These rods are UL Listed

**These rods meet the requirements of UL & RUS (13 mils mimimum of copper).

Rods with less than 10 mils of copper, do not meet UL requirements, nor the N

Cut Sheet 8

ERICO

CADWELD® PLUS ONE SHOT

CADWELD

The CADWELD® PLUS ONE SHOT produces a pemanent exothermic connection to a ground rod that will not loosen, corrode or increase in resistance for the life of the installation. The convenient single-use package makes the connection to the ground rod without a mold or starting material. Thanks to the electronic CADWELD PLUS Control Unit, welds can now be completed up to 6 feet (1.8 meters) away, increasing flexibility in hard-to-reach areas. The new refractory ceramic body utilized with the CADWELD PLUS ONE SHOT system is more durable than conventional ceramic and resists breaking.

Features

- Easy-to-use electronic ignition. No starting material.
- Durable disposable ceramic body eliminates the graphite mold and frame.
- Produces a permanent connection that will not loosen or corrode.
- Fits both threaded and unthreaded copper-bonded and full size steel and stainless steel ground rods.
- NEC® compliant.
- cULus® Listed.

Applications

The CADWELD PLUS ONE SHOT is ideal for making permanent reliable connections to ground rods for electrical transmission and distribution, telecommunications and cable television applications.

More Information

CADWELD PLUS ONE SHOT part numbers for type GR (one conductor to ground rod) and type GT (two conductors to ground rod) connections:

GROUND ROD	CONCENTRIC CONDUCTOR		METRIC CONDUCTOR	CADWELD PLUS ONE SHOT PART NUMBER	
	SOL	STR	SQUARE MILLIMETER	TYPE GR	TYPE GT
1/2" (12.7mm)	6, 8 3, 4 1, 2	8 4, 6 2, 3	8 - 10 14 - 22 30 - 38	GR1141GPLUS GR1141LPLUS GR1141VPLUS	GT1141GPLUS GT1141LPLUS GT1141VPLUS
5/8" (14-16mm)	6, 8 3, 4 1, 2 2/0, 1/0	8 4, 6 2, 3 1/0, 1 2/0 4/0	8 - 10 14 - 22 30 - 38 50 - 60 70	GR1161GPLUS GR1161LPLUS GR1161VPLUS GR1162CPLUS GR1162GPLUS GR1162QPLUS	GT1161GPLUS GT1161LPLUS GT1161VPLUS GT1162CPLUS GT1162GPLUS -
3/4"	6, 8	8	8 - 10	GR1181GPLUS	GT1181GPLUS

http://www.erico.com/productPrint.asp?productid=1652 10/25/2005

(17-19mm)	3, 4 1, 2 2/0, 1/0	4, 6 2, 3 1/0, 1 2/0 4/0	14 - 22 30 - 38 50 - 60 70	GR1181LPLUS GR1181VPLUS GR1182CPLUS GR1182GPLUS GR1182QPLUS	GT1181LPLUS GT1181VPLUS GT1182CPLUS GT1182GPLUS -

CADWELD PLUS ONE SHOT part numbers for type NT (three conductors to ground rod) and type NX (four conductors to ground rod) connections:

GROUND ROD	CONCENTRIC CONDUCTOR		METRIC CONDUCTOR	CADWELD PLUS ONE SHOT PART NUMBER	
	SOL	STR	SQUARE MILLIMETER	TYPE NT	TYPE NX
1/2" (12.7mm)	6, 8 3, 4 1, 2	8 4, 6 2, 3	8 - 10 14 - 22 30 - 38	NT1141GPLUS NT1141LPLUS NT1141VPLUS	NX1141GPLUS NX1141LPLUS -
5/8" (14-16mm)	6, 8 3, 4 1, 2 2/0, 1/0	8 4, 6 2, 3 1/0, 1 2/0 4/0	8 - 10 14 - 22 30 - 38 50 - 60 70	NT1161GPLUS NT1161LPLUS NT1161VPLUS	NX1161GPLUS NX1161LPLUS NX1161VPLUS
3/4" (17-19mm)	6, 8 3, 4 1, 2 2/0, 1/0	8 4, 6 2, 3 1/0, 1 2/0 4/0	8 - 10 14 - 22 30 - 38 50 - 60 70	NT1181GPLUS NT1181LPLUS NT1181VPLUS	NX1181GPLUS NX1181LPLUS NX1181VPLUS

The CADWELD PLUS Control Unit, which is required to initiate the reaction, is ordered separately.

PLUSCU

Cut Sheet 9

CATH-TECH™ SRC-255

CATHODIC PROTECTION MANAGEMENT SYSTEM

Système de gestion de protection cathodique

نظام التحكم وادارة الحماية الكاثودية

FEATURES

- 1 to 255 individually controlled constant voltage/constant current or autopotential circuits
- 1 mA to 15 amps/circuit on board. Higher current capability available
- Fully programmable
- Remote monitoring built-in
- Full remote control

CARACTÉRISTIQUES

- 1 a 255 circuits individuels pour controle a courant constant tension constant ou potentiel constant
- Circuit de 1 mA a 15 A. Possibilite de capacite plus importante
- Completement programmable
- Controle a distance incorpore
- Completement controlable a distance

المزايا

- التحكم بعدد من ١ إلى ٢٥٥ فولتات ثابتة أو تيارات ثابتة أو دارات آلية
- التيار من ١ مل أمبير إلى ١٥ أمبير على الكروت ويمكن زيادتها بناءاً على الطلب
- مبرمج بشكل كامل
- بداخله نظام التحكم عن بعد
- التحكم عن بعد بشكل كامل

CATH-TECH™

Technical Specifications

Power
- 120/240V 50/60 Hz AC
- 347, 480, 600 Volts AC on special order

Logic
- CMOS technology
- Microprocessor controlled
- 12 bit data conversion
- 3.5" floppy drive for data storage

Control
- Switch mode technology
- Fully programmable, locally or remotely
- Constant current, constant voltage or auto potential control
- Records instant OFF potential of references
- Recorded readings are date and time stamped
- No special software required

Options
- Hayes compatible modem 1200/2400/9600 baud
- 128K to 2MB on board static RAM

Specifications Techniques

Aliment&ion
- 120/240 V CA, 50/60 Hz
- 347,480,600 V C A sur demande

Circuit logique
- Technologie CMOS
- Controle par microprocesseur
- Conversion de donnee 12 bits
- Lecteur de disquette 3.5"

Controle
- Mode impulsion
- Pleinement programmable sur site ou a distance
- Controle courant constant, tension constante ou auto potentiel
- Enregistrement des potentiels "Instant OFF" des references
- Enregistrement des donnees avec date et heure
- Pas de programme special requis

Options
- Modem compatible Hayes 1200/2400/9600 baud
- Memoire additionnelle de 128 k – 2 Mbytes

المواصفات الفنية

احتياجات الطاقة:
* ١٢٠/٢٤٠ فولت ٥٠/٦٠ هرتز
* ٣٤٧، ٤٨٠ و ٦٠٠ فولت تيار متناوب او طاقة خسية بطلب خاص

الدارات المنطقية
* تكنولوجيا CMOS
* التحكم بواسطة حاسب آلي
* تحويل المعلومات بسعة ١٢ بايت
* ذاكرة مساعدة بطاقة ١٢٨ كيلوبايت

التحكم
* تكنولوجيا نظام النصف
* يمكن برمجته بشكل كامل مباشرة او بواسطة التحكم عن بعد
* تيار ثابت وفولت ثابت او التحكم بالجهاز بشكل آلي
* تسجيل قراءات وحدات التحكم بعد القطع مباشرة
* تسجيل زمن وتاريخ القراءات
* لا تحتاج الى اية برامج خاصة

موديم اختياري
* موديم ذو ٣ هايز بسعة ١٢٠٠/٢٤٠٠/٩٦٠٠
* متوافق مع بيل ١٠٣ و٢١٢ وسوفت بسلك توصيل

Manufactured by:
(صنعت بواسطة)

Cathodic Technology Ltd.
10 McEwan Drive
Bolton, Ontario
Canada
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Fax ++1 (905) 857-3499

Cut Sheet 10

STRATA-TECH, INC.

ST-524

Return to ST-524

POLY-FOAM INJECTION RESIN

INTRODUCTION

Stratathane ST-524 Poly-Foam is a hydrophobic two component, flexible polyurethane resin based on MDI in combination with high-value polyether polyols. ST-524 Poly-Foam reacts with water and sets into a flexible closed-cell foam. ST-524 is mixed with ST-525 at the work site to form a single injection material whose reaction time is governed by the concentration of ST 525 in the blend.

The ST-524/525 mix reacting with water forms an inert barrier which is essentially unaffected by acids, gasses, and micro-organisms usually found in soil or the leak area. A minimum of reaction water is needed but larger amounts can be accommodated through displacement.

ST-524 is useful for a wide range of water control applications, including formation of grout curtains, stabilization of water-bearing soils, and sealing of cracks and joints in concrete, buildings, dams, and utility vaults.

ST-524 has NSF 61 approval for potable water contact and carries the Underwriters Laboratories UL seal.

ST-524 is injected directly from the can into the leak using either a single or a plural component high pressure pump. When 20 parts of ST-524 react with one part of water, the resulting mixture expands and quickly fills the leak path with an elastic seal that stops water entry but allows crack movement to protect against stress transfer. Concrete repaired with ST-524 will usually not crack again.

Stainless steel fittings are recommended but not strictly required because the ST-524/525 blend is only mildly corrosive. Cleanup of solidified material in the system, however, is often accomplished with caustic cleaning compounds, making stainless steel advisable.

The low-viscosity ST-524 mixture is easily injected. Once cured, its impermeability makes it an effective water shut-off system. The permeability of soil grouted with ST-524 depends on how well its voids are filled with grout. Values in the 10-5 cm/sec range should be obtained using ASTM Constant Head Permeability Test Method D-2434.

REACTION

A two stage reaction takes place when ST-524 comes in contact with water. The mixture first expands and quickly thickens. Then, as it cures, ST-524 solidifies into a strong impermeable water barrier in just minutes. Unrestrained ST-524 foam expands up to ten times its starting volume. However, a dense material is preferred for most applications. Greater density is obtained by controlling grout placed relative to void space and static head pressure.

The two stage reaction takes place continuously during injection as product exits the packer. Initial penetration is facilitated by the low viscosity of the mixture. After reaction begins, the expansive mixture pressure induces some further penetration of the grout zone depending on the amount of static head pressure. ST-524 creates a seal which is impervious to water yet is able to tolerate freeze-thaw, wet-dry cycling, extrusion, and compression.

CURE

The reaction and set time of ST-524 resin is a function of both temperature and the concentration of ST-525 in the blend. The following table shows the effect of ST-525 at different weight percentages at a temperature of 20C.

ST-525 WT %	CREAM TIME (SECONDS)	TACK FREE (MINUTES)
1.0	100	25.0
2.0	70	14.0
3.0	40	7.0
6.0	35	3.2
10.0	29	3.0

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CHEMICAL SEALANTS • WATER CONTROL MATERIALS • GROUTING EQUIPMENT

STRATA-TECH, INC.

PHYSICAL CONSTANTS

The primary physical constants for the ST-524 system are shown in the table which follows.

	ST-524	ST-525
Appearance	Pale Yellow	Grayish Liquid
Specific Grav	1.08 20 C	0.995 at 20 C
Viscosity	500 cps 25 C	25 cps at 25 C
Flash Point	>385 C	130 C

The low viscosity of the ST-524 Resin blend allows good penetration into cavities and cracks. After curing, water pressure will not affect the ST-524 resin seal at heads usually encountered in crack injection repair work. It has no preset "pot life" and does not cure as long as water or moisture vapor are not available to start the cure cycle.

TENSILE AND ELONGATION

Test samples were prepared by putting the reacting mixture into a plastic pressure mold and capping the opening. This procedure (per ASTM D-638) resulted in a closed-cell foam with a density of about 30 pounds per cubic foot as compared to a free rise density of about 6 pounds per cubic foot. Measured tensile strength was about 6 psi at 67% elongation. The samples subsequently showed no water absorption after 4 hour immersion. Flammability tests of the same samples showed that combustion self-extinguished when the flame source was removed.

To prevent condensation from forming on the liquid or in the can, the temperature of the ST-524 should be adjusted to match the ambient temperature of the work area. Protect uncured resin during application from exposure to water, moisture vapor, and direct sunlight.

CLEANUP

Cleanup of ST-524 is accomplished with a solvent or with a solvent and a cleaner used in sequence. The preferred solvent is ST-590 Kleen-Purge and the recommended cleaner is ST-522 Veri-Kleen Grout Cleaner. Use ST-590 for the liquid resin and ST-522 for solidified resin.

For heavy cleaning, push out ST-590 with ST-522 Veri-Kleen Grout Cleaner and follow the instructions for its use. Do not allow ST-590 or ST-522 to remain in the system for long periods. Properly dispose of used cleaning materials and do not reuse if contaminated or resin-loaded. See the pump manuals and the Technical Data Sheet for ST-522 and ST-590 for more information.

ENVIRONMENTAL

ST-524 is essentially non-toxic in its cured form, with an LD50 (rat) in excess of 5000 mg/kg. Freezing either the cured or uncured material is not harmful to the product and may prolong the shelf life of the uncured resin in an unopened container. At temperatures below 5 C, crystallization may occur but is reversible without damage to the material by indirectly warming and gently mixing the product.

Stratathane ST-524 contains no measurable amount of TDI as performed by the Modified Analysis for Diisocyanates. ST-524 is non-flammable, non-carcinogenic, and non-corrosive as defined by 40 CFR and as described in the *NIOSH Pocket Guide for Hazardous Materials.*

Back to ST-524 Urethane Grout

STATEMENT

Strata Tech believes that the information herein is an accurate description of the general properties and characteristics of the product(s), but the user is responsible for obtaining current information because the body of knowledge on these subjects is constantly enlarged. Information herein is subject to change without notice. Field conditions also vary widely, so users must undertake sufficient verification and testing of the product or process herein to determine performance, safety, usefulness, and suitability for their own particular use.

Strata Tech warrants only that the product will meet Strata Tech's then-current specification. NO WARRANTY OF SUITABILITY OR FITNESS FOR A PARTICULAR PURPOSE IS MADE. Users should not assume that all safety requirements for their particular application(s) have been indicated herein and that other or additional actions and precautions are not necessary. Users are responsible for always reading and understanding the Material Safety Data Sheet, the product technical literature, and the product label before using any product or process mentioned herein and for following the instructions contained therein.

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CHEMICAL SEALANTS • WATER CONTROL MATERIALS • GROUTING EQUIPMENT

Appendix G: As-Built Drawings

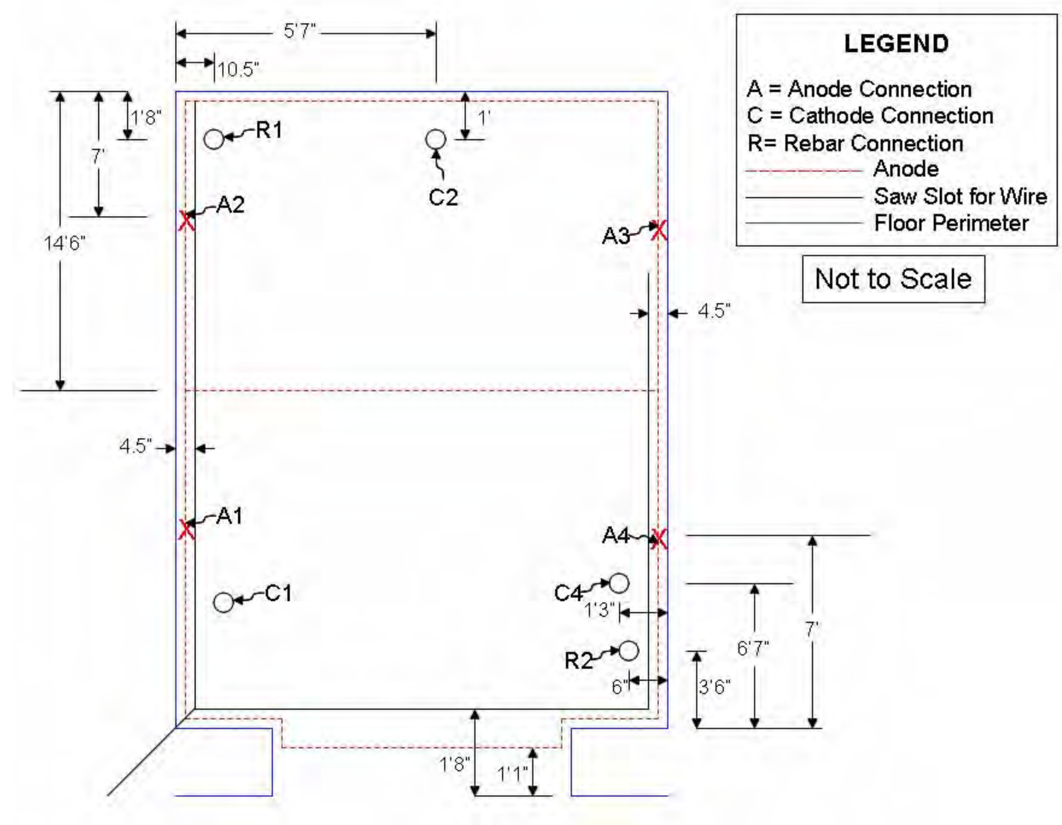

Figure G-1. As-Built Floor Plan Drawing for P02003

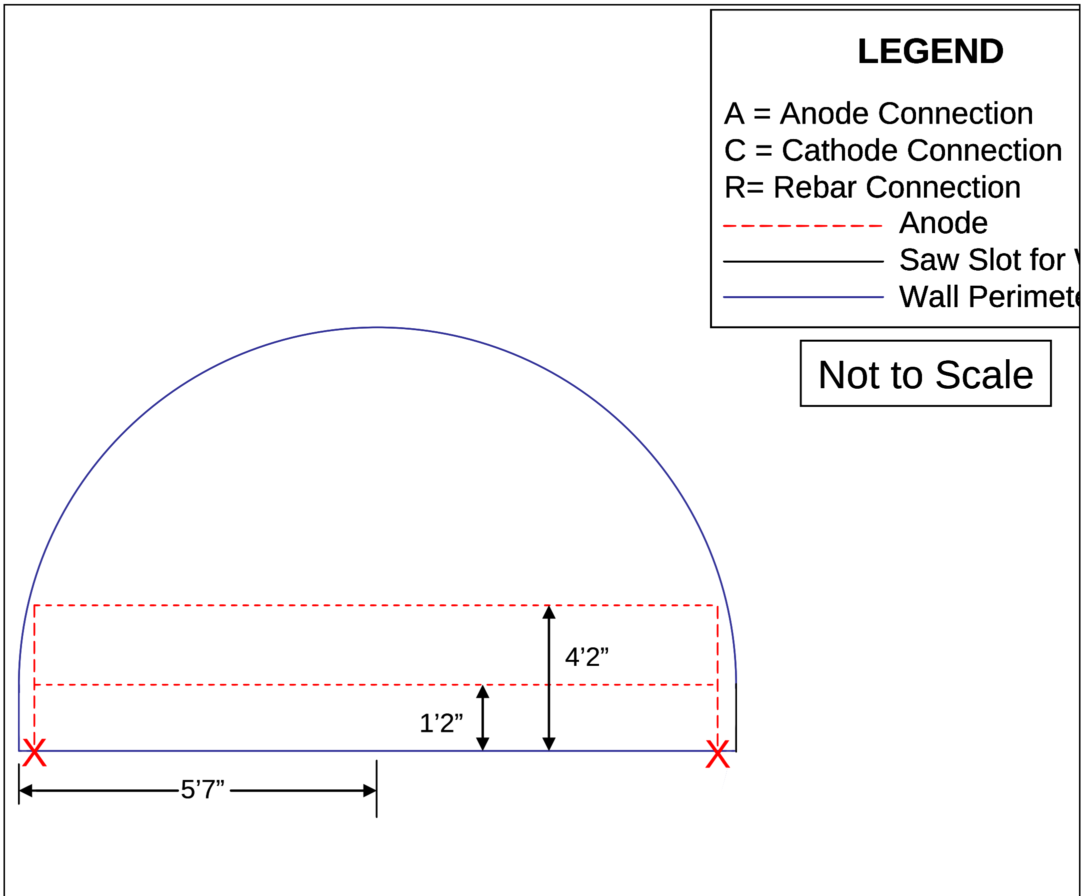

Figure G-2. As-Built Rear Wall Drawing for P02003

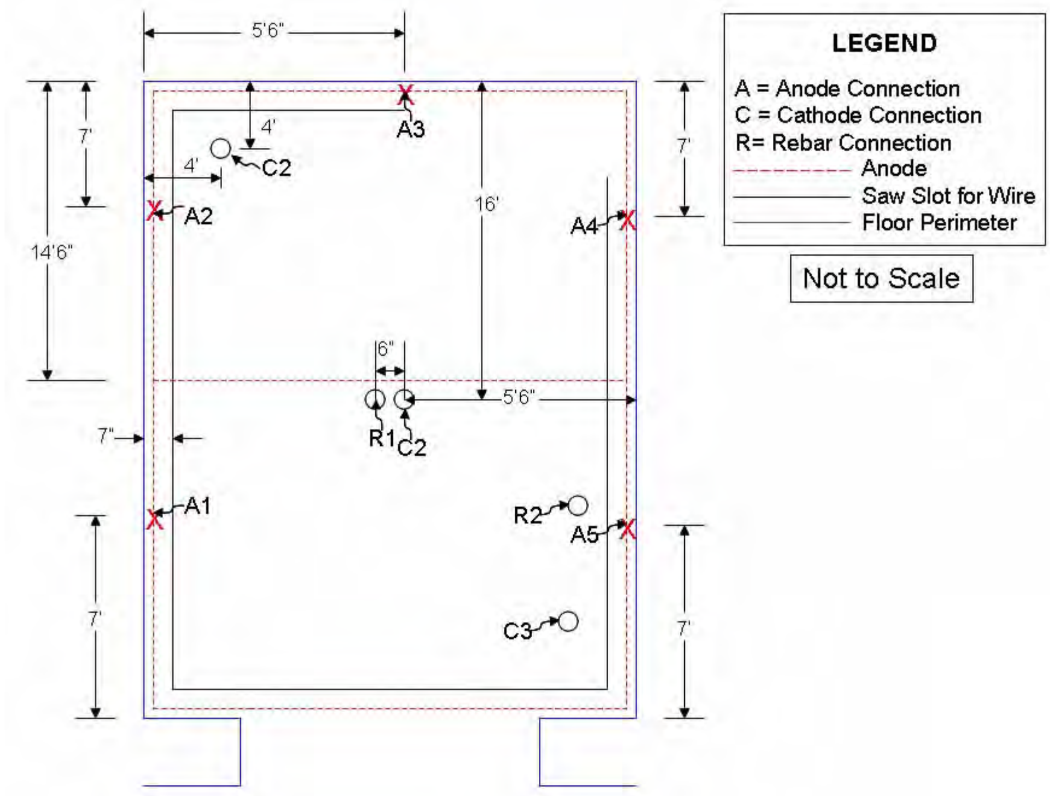

Figure G-3. As-Built Floor Plan Drawing for P02004

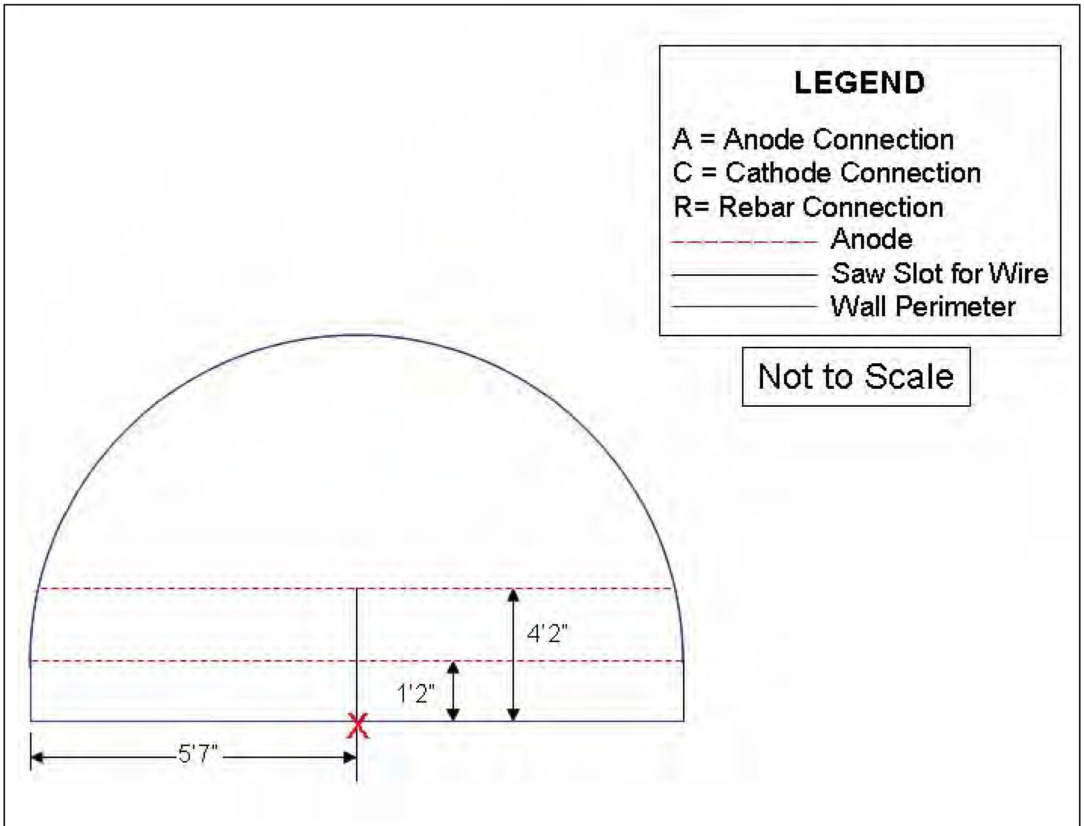

Figure G-4. As-Built Rear Wall Drawing for P02004

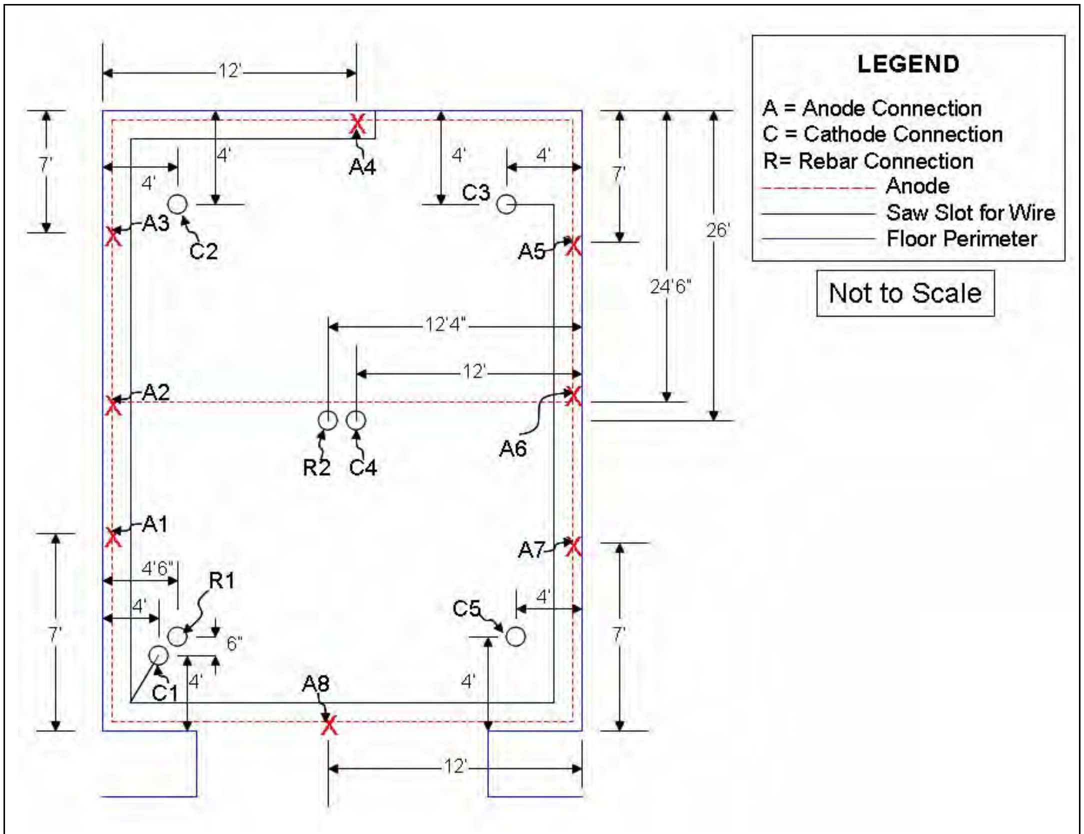

Figure G-5. As-Built Floor Plan Drawing for P02005

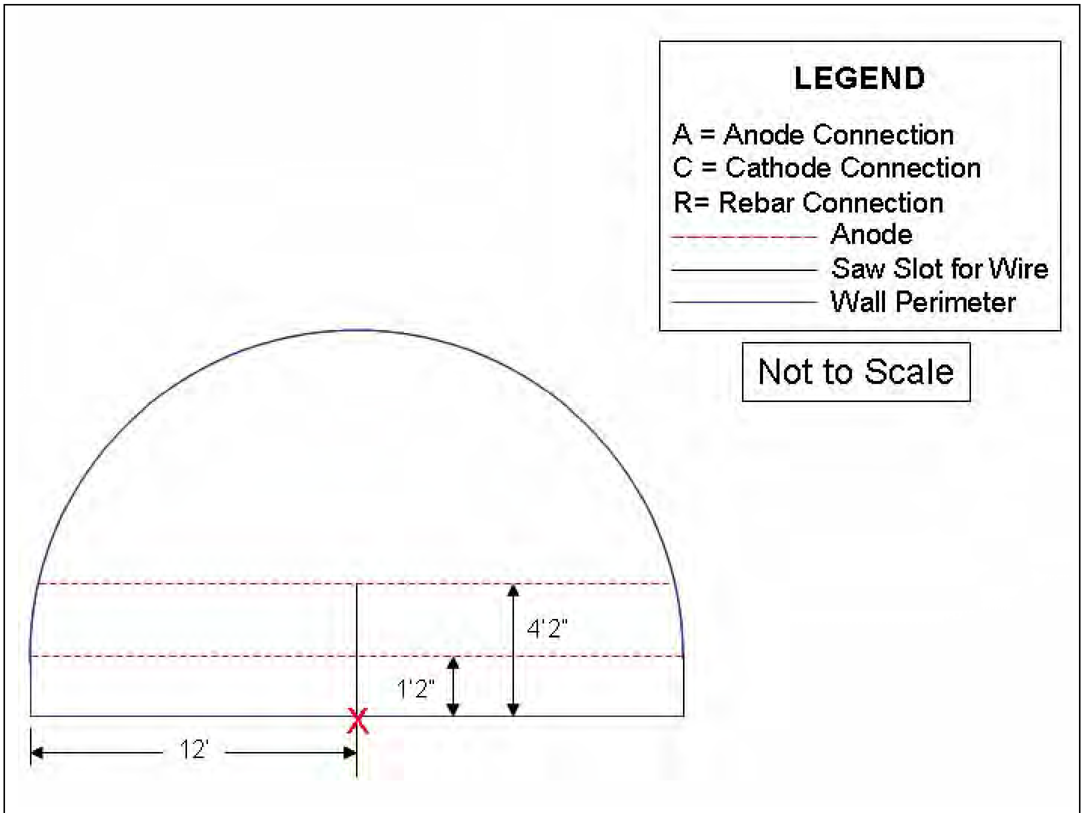

Figure G-6. As-Built Rear Wall Drawing for P02005

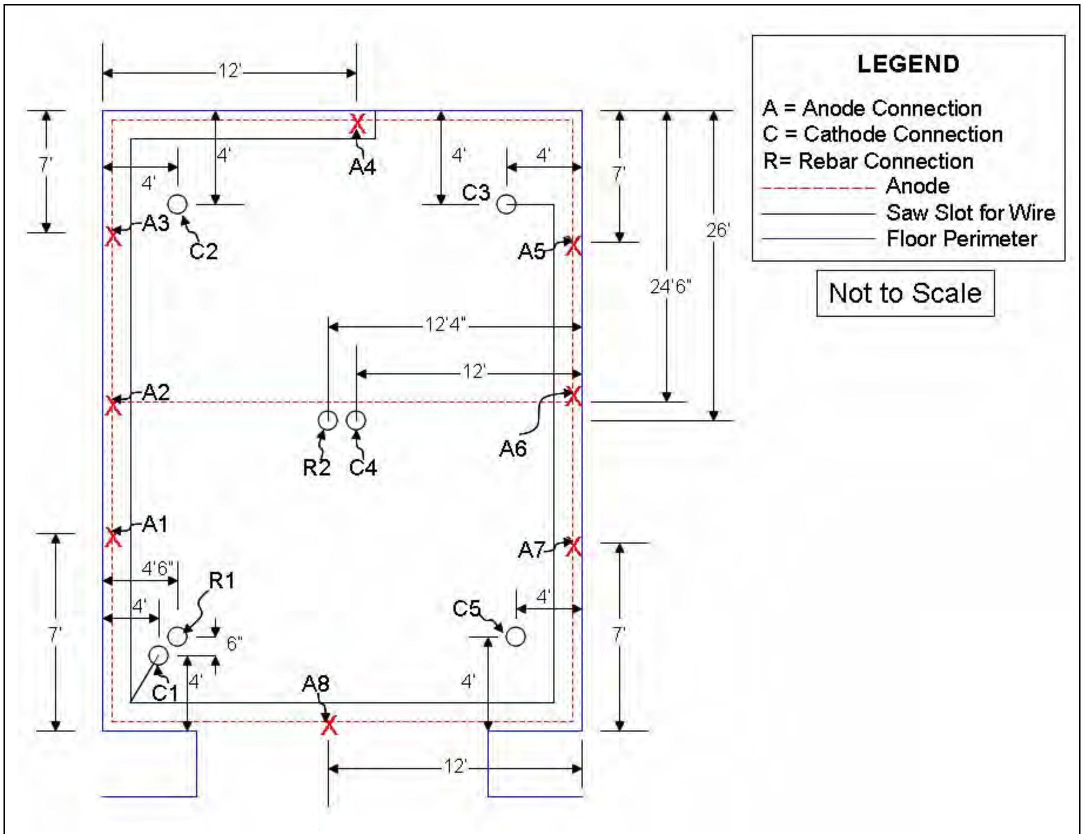

Figure G-7. As-Built Floor Plan Drawing for P02006

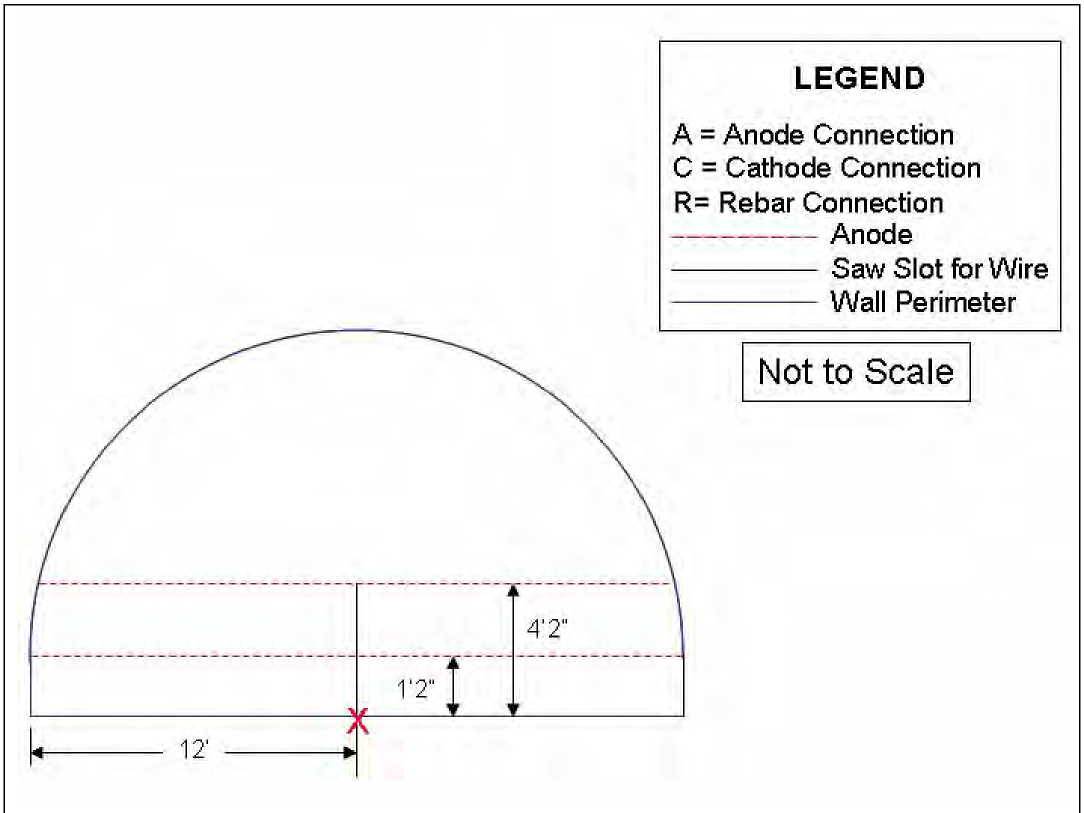

Figure G-8. As-Built Rear Wall Drawing for P02006

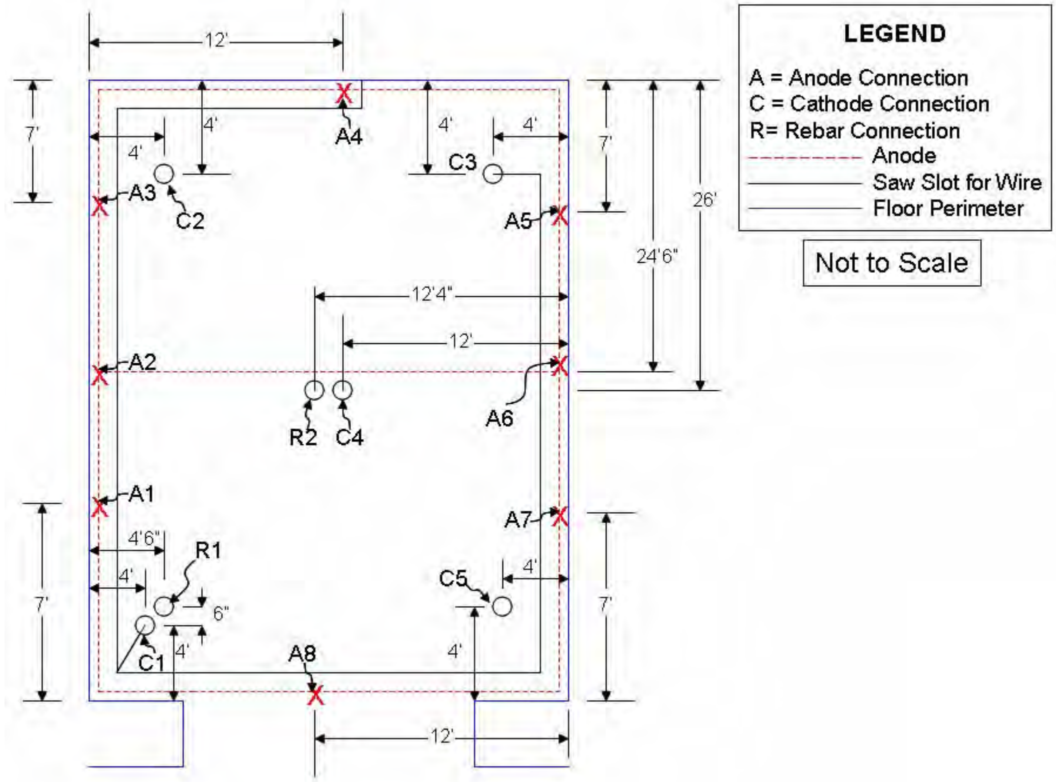

Figure G-9. As-Built Floor Plan Drawing for P02007

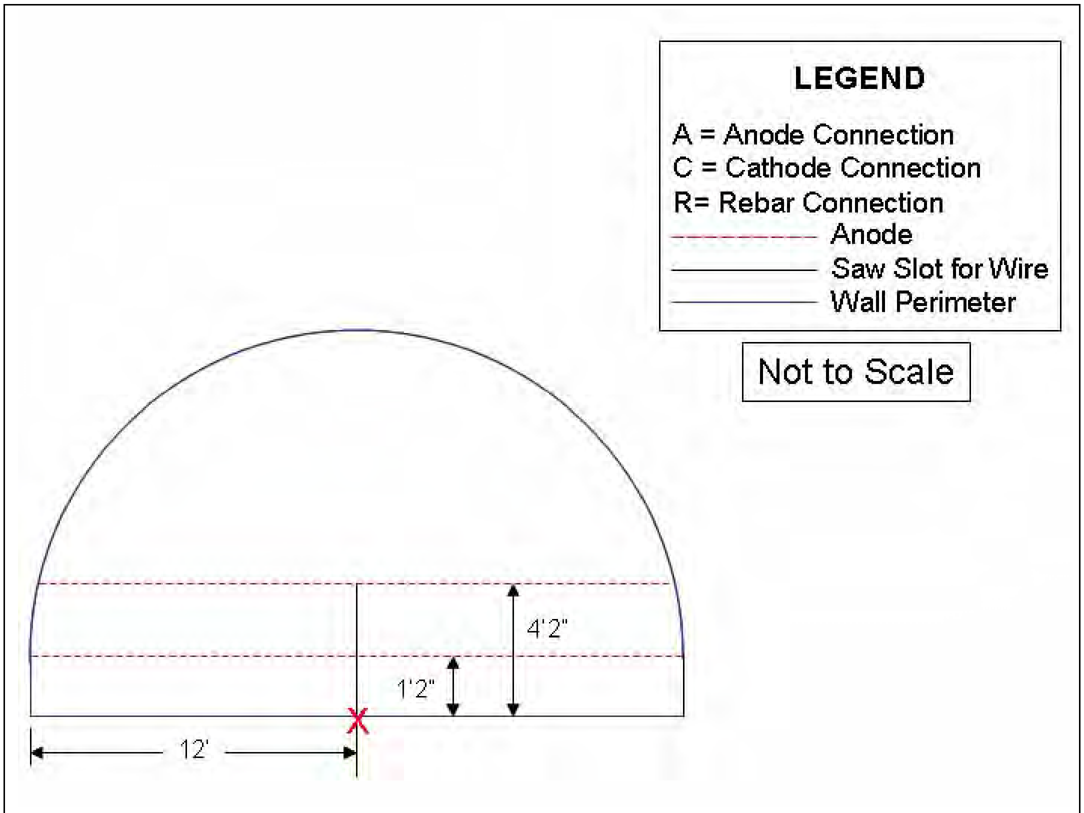

Figure G-10. As-Built Rear Wall Drawing for P02007

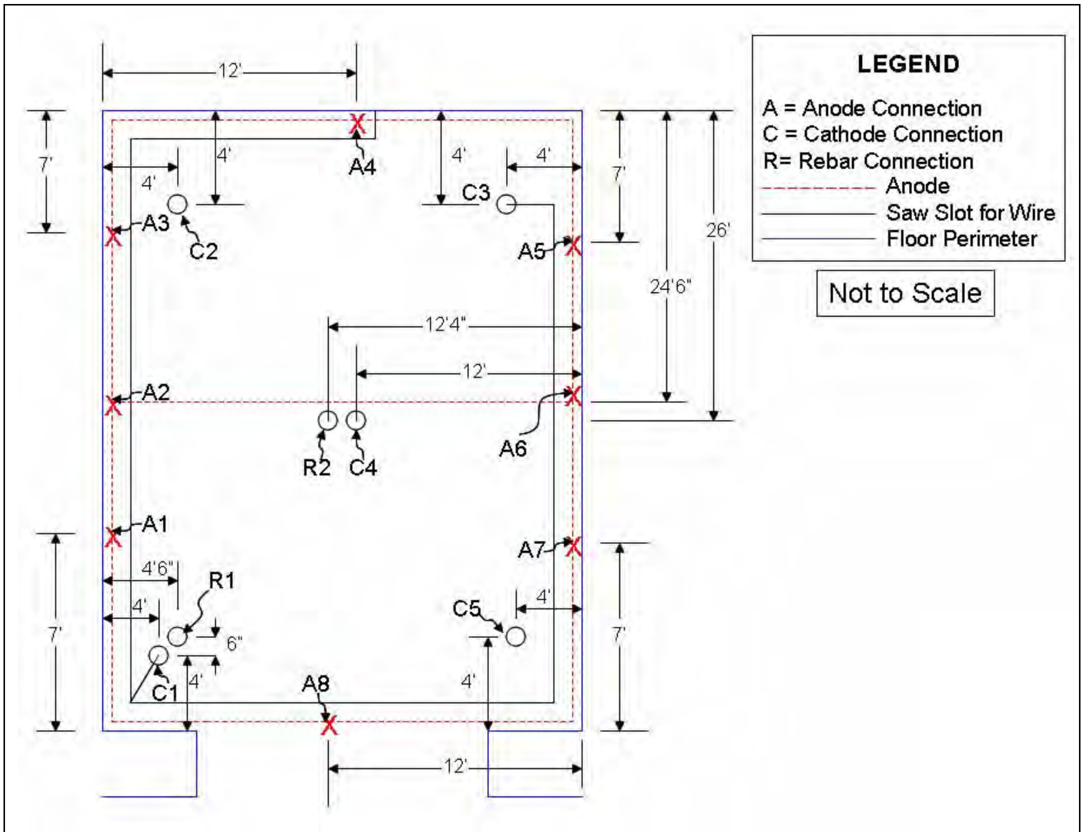

Figure G-11. As-Built Floor Plan Drawing for P02008

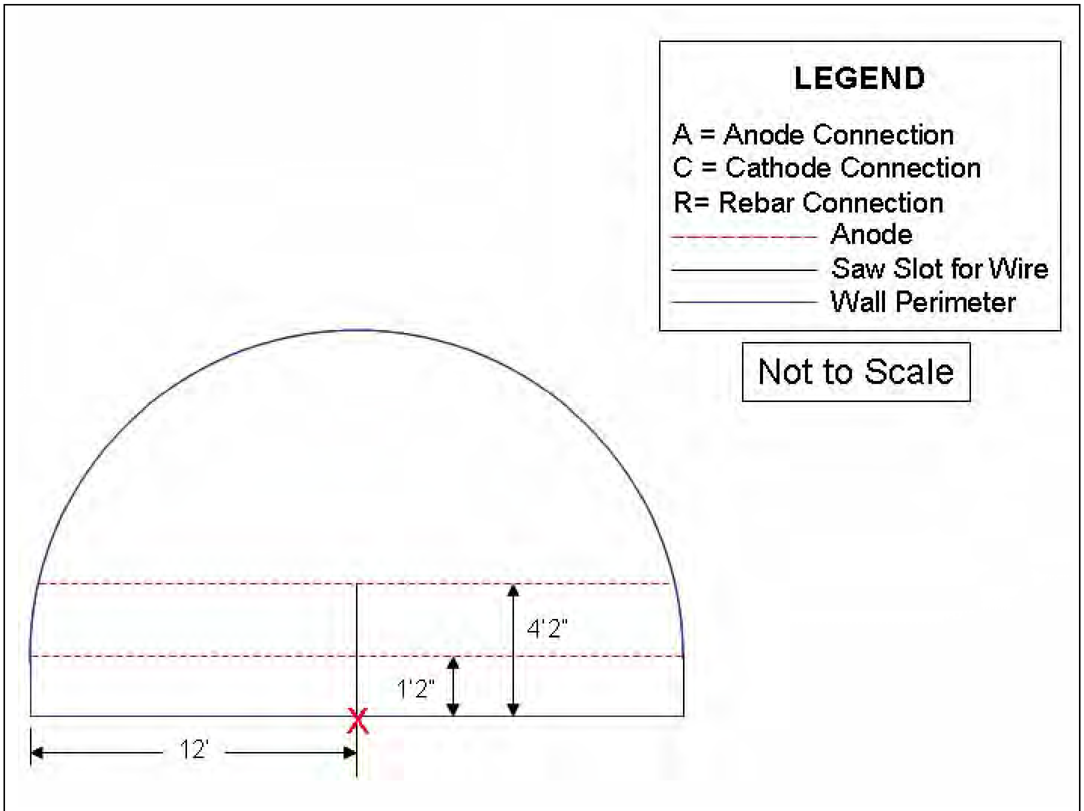

Figure G-12. As-Built Rear Wall Drawing for P02008

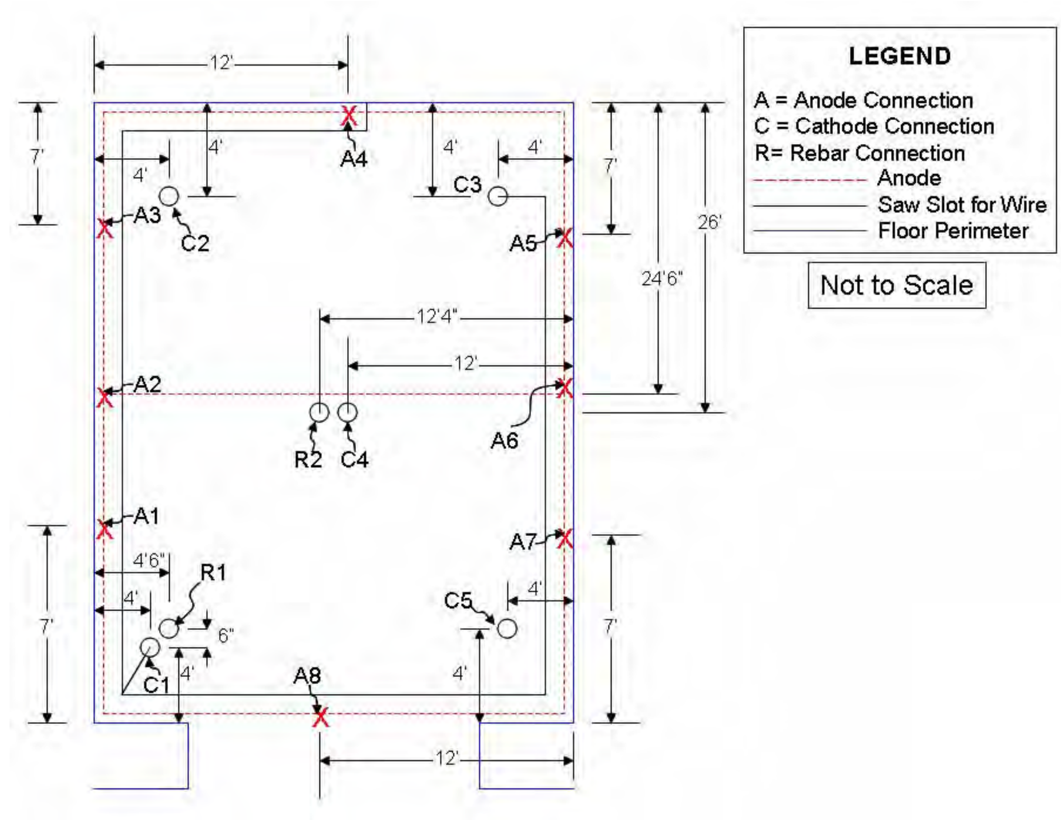

Figure G-13. As-Built Floor Plan Drawing for P02009

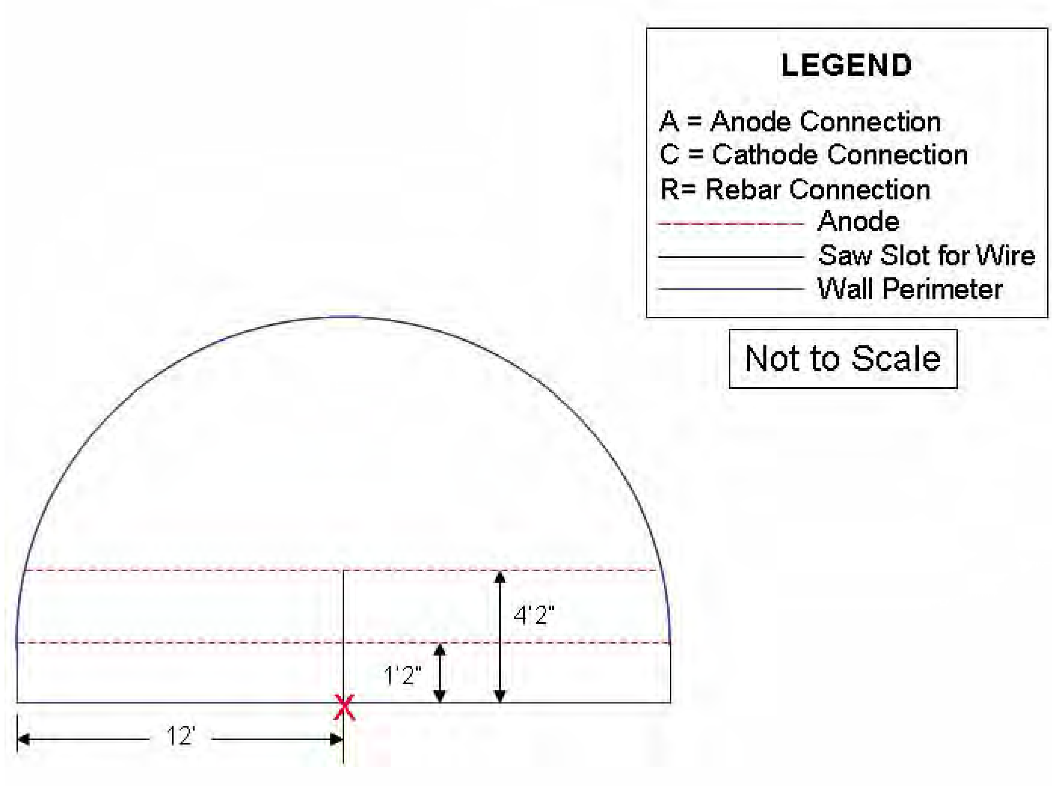

Figure G-14. As-Built Rear Wall Drawing for P02009

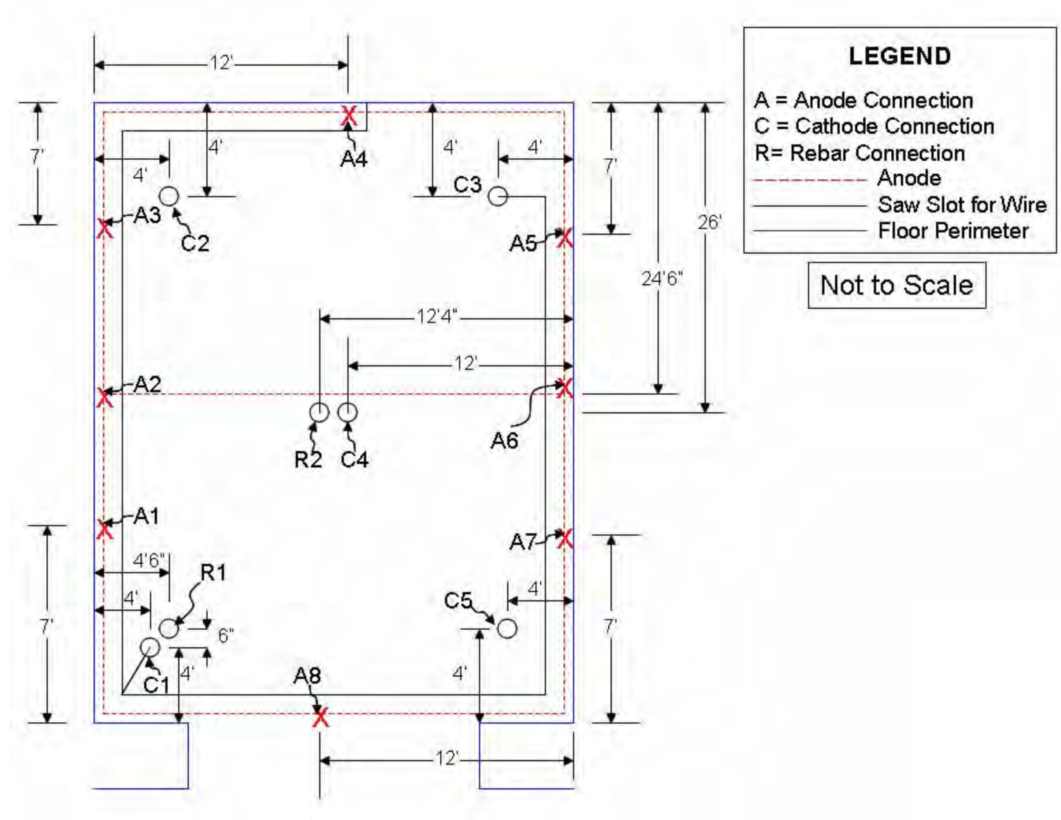

Figure G-15. As-Built Floor Plan Drawing for P02010

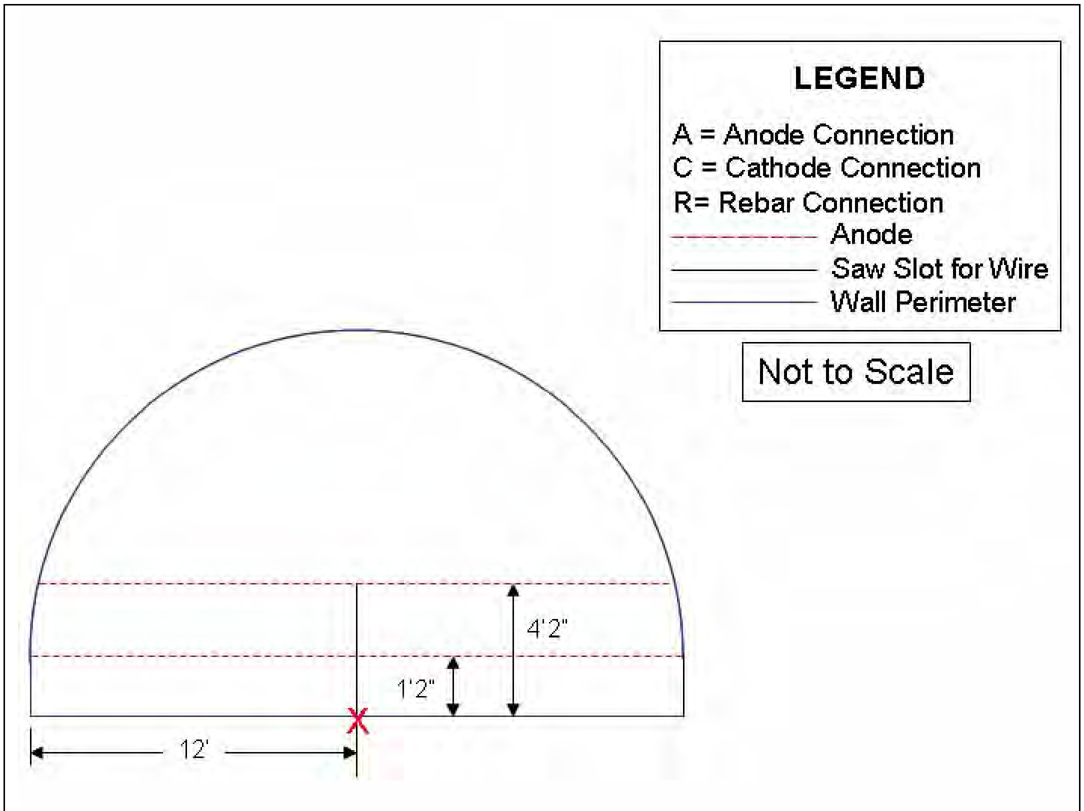

Figure G-16. As-Built Rear Wall Drawing for P02010

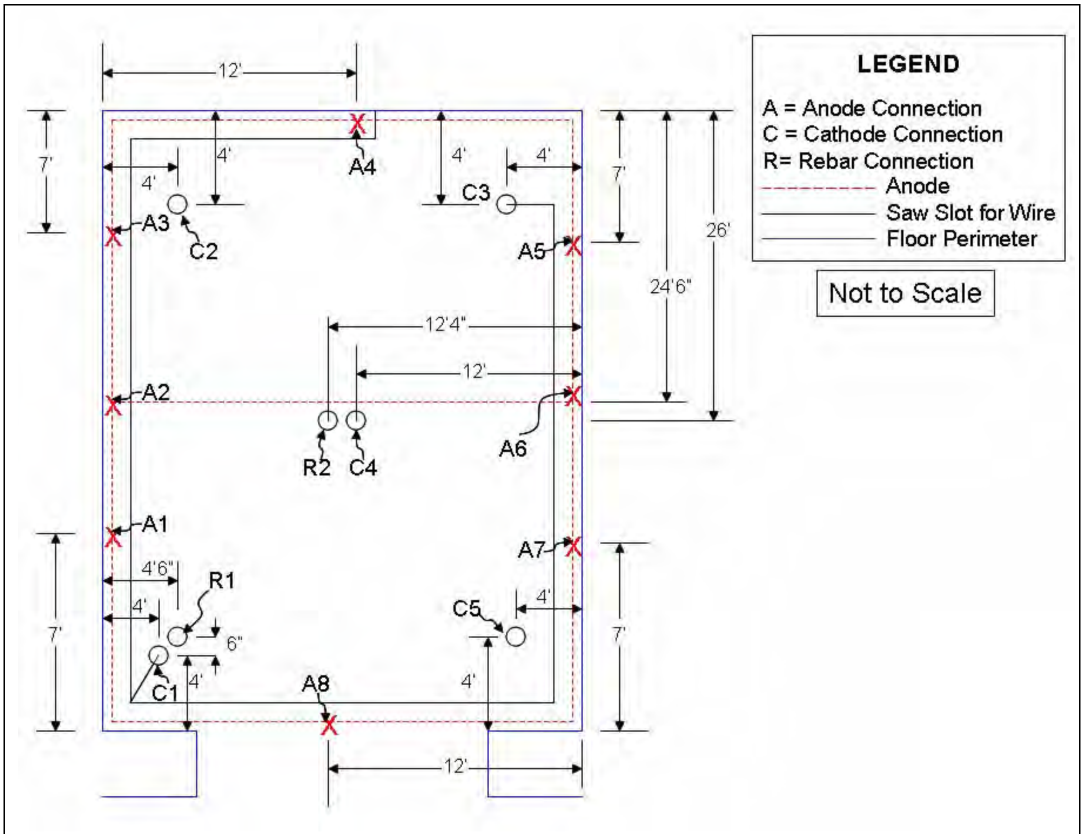

Figure G-17. As-Built Floor Plan Drawing for P02011

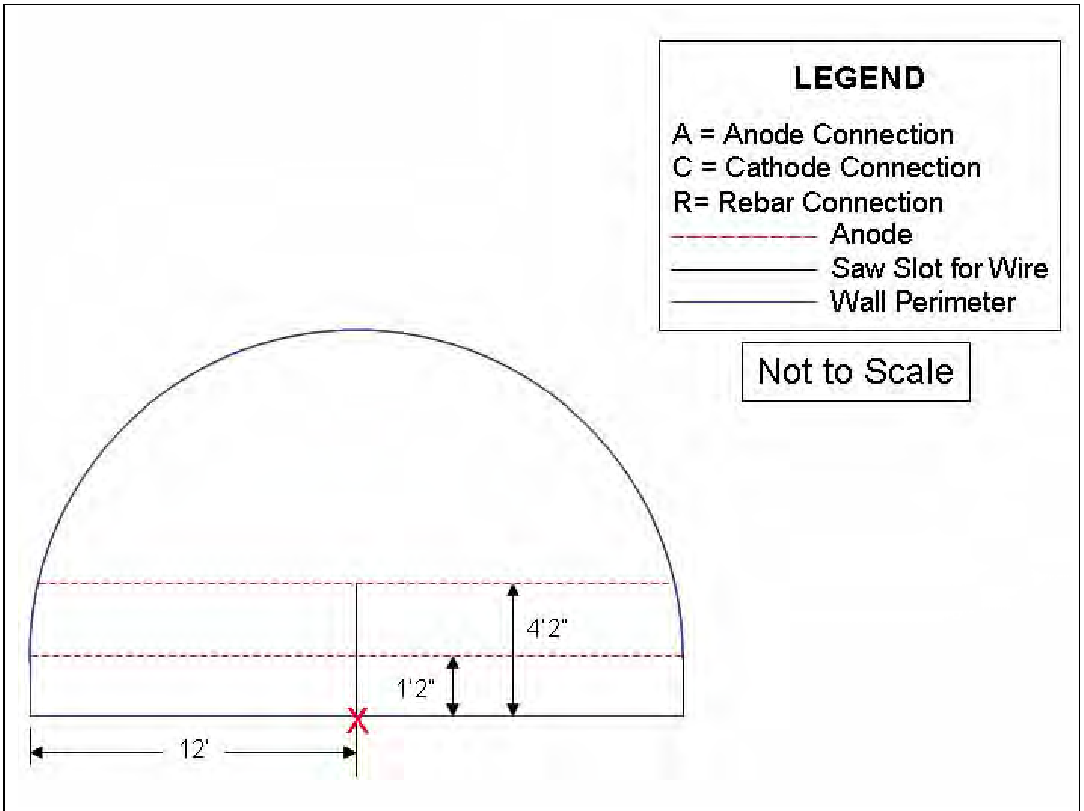

Figure G-18. As-Built Rear Wall Drawing for P02011

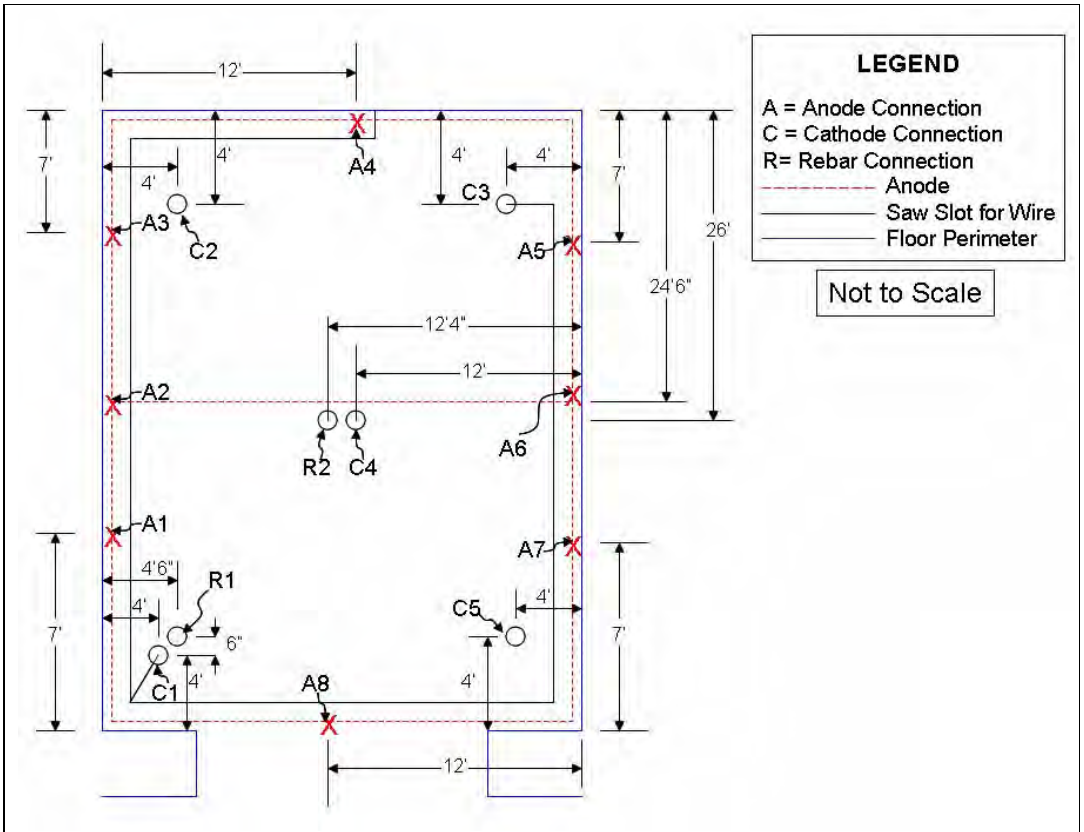

Figure G-19. As-Built Floor Plan Drawing for P02012

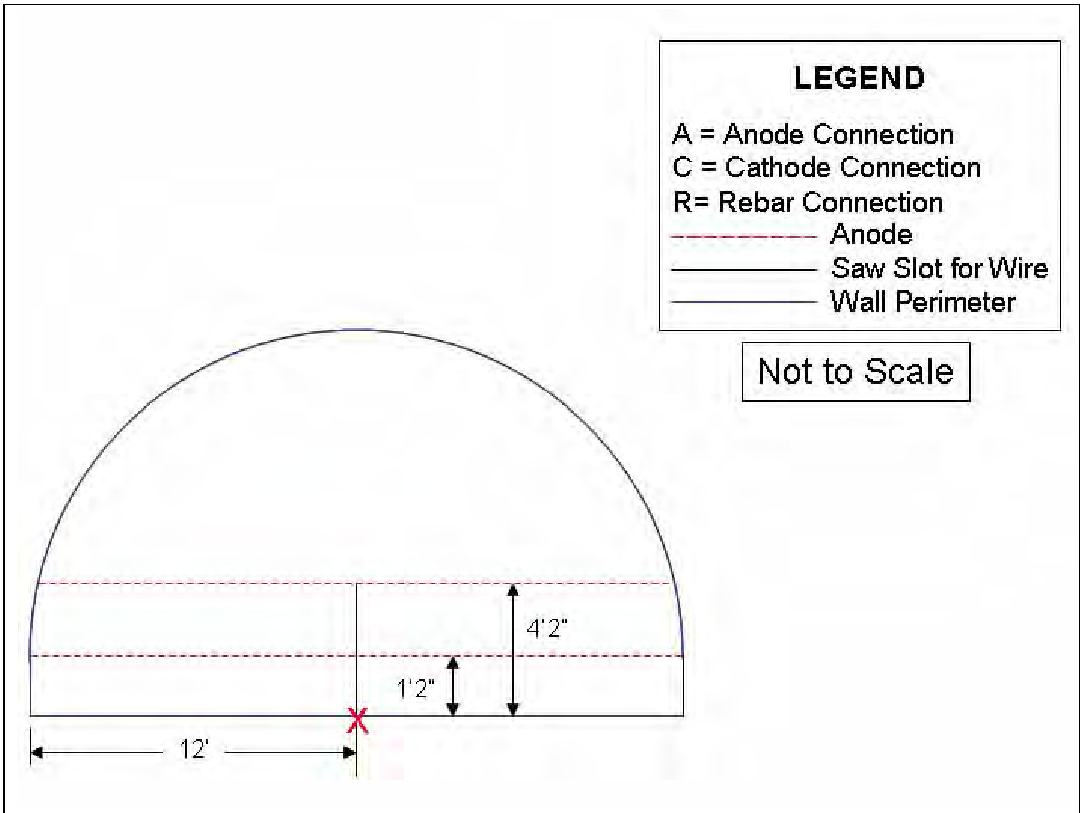

Figure G-20. As-Built Rear Wall Drawing for P02012

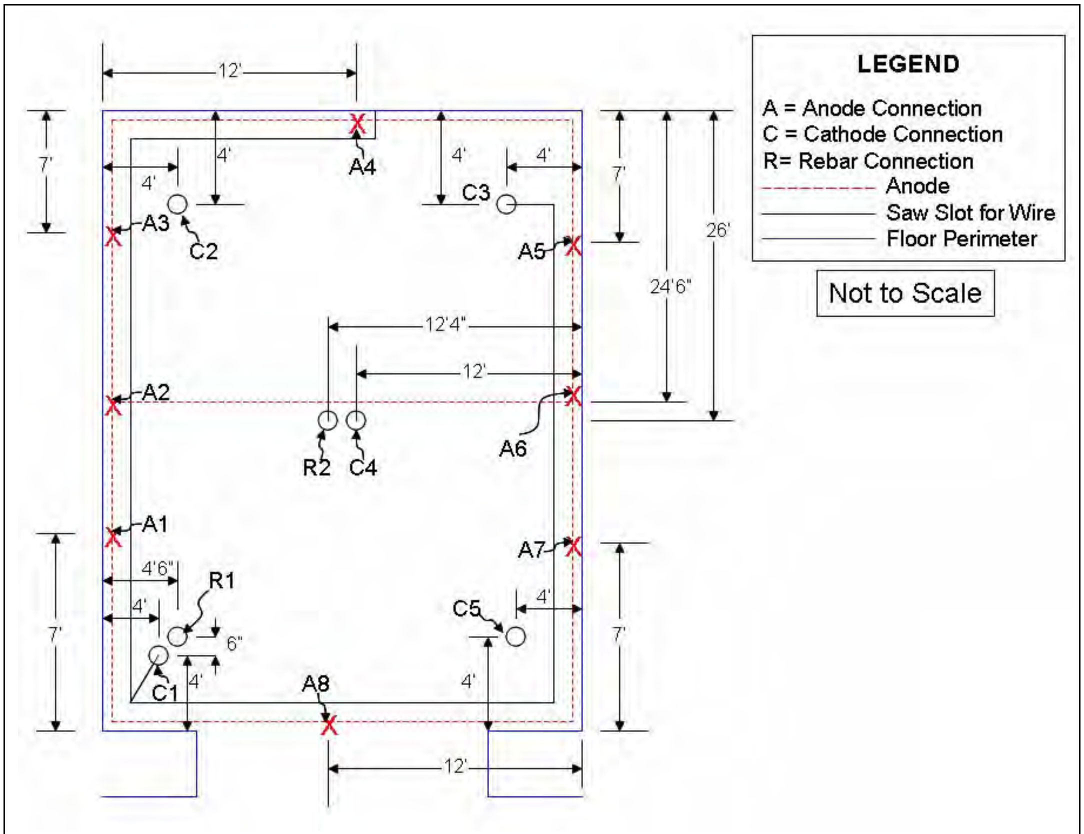

Figure G-21. As-Built Floor Plan Drawing for P02013

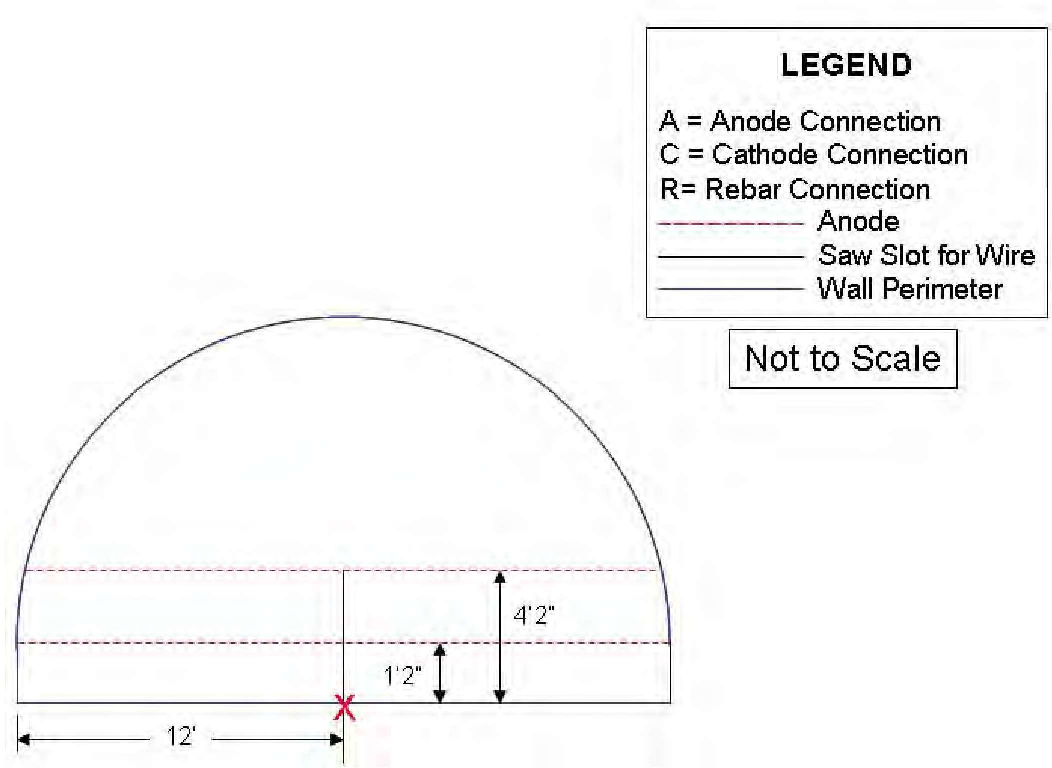

Figure G-22. As-Built Rear Wall Drawing for P02013

Appendix H: Draft Unified Facilities Guide Specifications for Electro-Osmotic Pulse Implementation in Earth-Covered Magazines

GUIDE SPECIFICATION FOR

ELECTRO OSMOTIC PULSE TECHNOLOGY TO CONTROL WATER SEEPAGE INTO CONCRETE STRUCTURES
(July 2004 Draft)

PART 1 GENERAL

1.1 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by basic designation only.

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)

NEMA TC 2	(1990) Electrical Polyvinyl Chloride (PVC) Tubing (EPT) and Conduit (EPC-40 and EPC-80)

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA 70	(1996) National Electrical Code

UNDERWRITERS LABORATORIES (UL)

UL 6	(1993) Rigid Metal Conduit

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 1248	(1984; 1989) Polyethylene Plastics Molding and Extrusion Materials

1.2 SUBMITTALS

Government approval is required for submittals with a "G" designation; submittals not having a "G" designation are for information only. When used, a designation following the "G" designation identifies the office that will review the submittal for the Government. The following shall be submitted in accordance with SECTION 01330 SUBMITTAL PROCEDURES:

SD-01 Preconstruction Submittals

QA/QC Plan: G, [____]

A quality assurance plan for installation of the EOP system to include personnel safety issues, installer certification, application and inspection of the EOP system, location and placement of splices, grout curing provisions, means to assure dry interior surfaces, quality assurance sampling and cleanup. Indicate the testing that will be performed and identify the party or parties responsible for this testing.

SD-02

Provide drawings that document the as-built installation of the system. Include system layout and wiring diagrams.

SD-03 Product Data

Materials

Manufacturer's product data sheets indicating physical, mechanical, and chemical characteristics of all materials used in the EOP system.

Delivery Inspections

Material Safety Data Sheets (MSDS) for all materials to be used at the job site in accordance with OSHA and 29 CFR 1910.1200.

SD-06 Test Reports

Field Test Data
Pre-installation photographs
Post-installation photographs

SD-07 Certificates

Contractor Qualifications; G, [____]

A list of a minimum of five (5) completed EOP projects performed by the contractor in the last 4 years for the U. S. Government. Include summaries for each of the related projects. Include for each project: project title, the U. S. Government agency for which the work was performed, a short description of the work and supporting documentation including names and telephone numbers of persons who have knowledge of the completed project.

Personnel: Submit a roster of technical and support personnel who would be available for assignment to the work. These rosters shall include the names, positions and qualifications of all potential participants.

SD-08 Manufacturer's Instructions

EOP System; G, [____]

Submit one copy of the user's guide and operating manual for the EOP control unit to be installed.

SD-10 Operation and Maintenance Data

EOP maintenance; G, [____]

Provide written procedures to properly maintain the installed EOP system as well as written manufacturer recommended repair procedures for damage to the in-place EOP system.

1.3 GENERAL REQUIREMENTS

A complete, operating electro-osmotic water seepage protection system in accordance with applicable federal, state and local regulations, NFPA 70 (National Electrical Code), and the requirements of this contract shall be provided. The project shall include pre-installation inspection of the site, development of site specific plans and specifications, installation of the EOP system, and adjustment and testing of the protection system. Buy American Act provisions must be followed as well as conforming to applicable standards (e.g. ASTM, NFPA, and UL) and regulations.

1.4 QUALIFICATIONS

Provide all professional staff, support staff, and specialists necessary to plan, supervise and perform the required work. Provide adequate professional supervision to assure the accuracy, quality and completeness of all work required. Additionally, provide a person who is qualified and competent as defined in Section 01 of Engineering Manual (EM) 385-1-1 for all job sites. The U.S. Army Corps of Engineers Safety and Health Requirements Manual, EM 385-1-1 may be accessed at: http://www.hq.usace.army.mil/soh/hqusace_soh.htm.

TECHNICIAN

This position requires a minimum of 3 years experience in control of water intrusion in below-grade structures. The technician is directly responsible for the installation of the system and will be instrumental in services such as cutting and drilling, cable assembly, electrode wiring, epoxy and grout placement, etc.

INSTALLER

This is an entry level position that requires a minimum of one (1) year experience in assisting technicians and engineers. Performs tasks which require mainly physical abilities and effort involving a limited amount of specialized skill or prior experience. Works directly with the technician and assists in the installation of the system.

1.5 WORK SITE SAFETY

Workers having access to the work area shall be informed of the contents of the applicable material safety data sheets (MSDS) and of potential health and safety hazards associated with it's application as well as protective controls associated with materials used on the project. Personnel having a need to use hearing protection, respirators and masks shall be instructed in the use and maintenance of such equipment.

1.6 PREINSTALLATION CONFERENCE

Participate in a meeting between the Contracting Officer, Contractor, the Contracting Officer's Representative and other interestedc parties to discuss the project requirements. Review and discuss all aspects of the project including Specifications, environmental control, surface preparation, EOP system application, quality assurance, schedule requirements, and safety. Request clarification of any ambiguities, and advise the Contracting Officer and the Contracting Officer's Representative of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

1.7 PROJECT/SITE CONDITIONS

Conduct site assessment and structure testing to determine the feasibility of EOP installation. This assessment shall include the following:

(1) The conductivity of the structural material and the backfill material including soil and/or water conductivity. This testing shall be done by using either a standard 4-probe conductivity/resitivity tester; a 2-probe method that utilizes the EOP Control Unit as the power source; or a 2-probe method that uses a "Protimeter", or similar instrument, to measure the relative moisture content. When the EOP Power Supply is used as the power source, one (1) anode and cathode are temporarily installed and connected to the unit. The power supply voltage and current are then used to determine the conductivity.

(2) Document the site using a variety of methods, including but not limited to, photographs, physical measurements, drawings, and verbal descriptions of the site and relevant features and information.

1.10 WARRANTY

Provide a standard warranty that may be used at the option of the Government. Under the terms and conditions of the warranty, the EOP Water Control System and its components shall be warranted against defects for a period of a minimum of two years after the installation is complete. Any problems with the EOP System shall be corrected at no expense to the government or building occupants during this period.

PART 2 PRODUCTS

2.1 ANODES

2.1.1 Ceramic Anodes

The anode (positive electrode) consists of electro-catalytic coatings applied by thermal decomposition to specially prepared titanium substrates. The electro-catalytic coatings are formulated primarily of platinum group metals and appropriate binders. The coatings are applied by spraying or dip coating aqueous salts of the metals onto an acid etch-cleaned titanium substrate and heating to several hundred degrees Celsius. Multiple layers of coating may be applied by this process to provide the desired final coating thickness. The resulting mixed metal oxide coating shall be:

Highly conductive (10-3 Ω-cm to 10-6 Ω-cm resistivity).
Crystalline (anhydrous).
Corrosion and acid resistant.
Very hard (hardness of 60).
Highly abrasion resistant.

The nickel metal oxide (ceramic) coated titanium or niobium wire anode material is available in a variety of configurations for optimization of specific current density and current distribution requirements. It is a ceramic-metal multi-layer composite that is ductile, rugged, and easy to use. It consists of an ultra thin layer of an iridium-tantalum-titanium, mixed metal oxide ceramic deposited onto either a solid titanium core (STI version), a copper cored titanium interface (CTC) or a copper cored niobium-titanium interface (CNC version). The latter has a niobium interface for other applications requiring the added high voltage capacity of niobium with respect to breakdown voltage characteristics that are not of concern in these applications.

The nickel metal oxide anode coating is exceptionally durable in combination with the ductile commercially pure titanium substrate. It has been tested at current densities over 2000 amperes per square foot of anodic current discharge. It is fabricated primarily from precious metal and refractory metal oxides in sufficient quantities and ratios to provide a defined life expectancy.

2.2 CATHODES

Cathodes (negative electrodes) are copper clad steel rods which meet the minimum requirements for grounding of electrical systems per NFPA 70. The cathode normally receives electric current from positive ceramic coated titanium wire electrodes. This action normally provides corrosion mitigation for the negative electrode and therefore common metal materials can be used for this purpose. A commonly used electrode is the common copper clad steel electrical ground rod, typically 5/8-in. diameter by 6-ft long (minimum), which can be driven through a purposely made hole in either the structure wall or slab into the surrounding earth.

2.3 EOP CONTROL UNIT

2.3.1 Control Unit

The EOP control unit supplies a dc voltage with alternating polarity to the anodes and the cathodes. Control units shall have a programmable output pulse pattern. The dc power delivered by the unit shall be within manufacturers specifications and shall meet the system designer's specifications.

The unit uses a standard 120 Volt ac power source. An external ac power switch must be provided and appropriately labeled. The labeling for this switch must clearly identify which position is off. The control unit can be either hard-wired or plugged into a 120 Volt outlet. If metal, the outlet box is required to be grounded.

All electrical connections must be enclosed, either within the control unit itself or within a separate enclosure.

2.1.3.2 Circuit Protection

Overcurrent protection of the ac input shall be fully contained within the unit itself. The output of each unit shall have short circuit protection.

2.3.3 Wiring

AC supply wiring shall be installed in accordance with NFPA 70.

2.3.4 Wiring Diagram

A complete electrical connection diagram showing both the ac and the dc connections to the power supply shall be posted on the inside cover of the unit or its enclosure.

2.3.5 Control Unit Panel Cover

The control panel of the EOP control unit shall have a lockable cover which will also allow viewing of the panel display. If a cover is not available on the unit itself then a separate enclosure to house the entire unit shall be provided. The enclosure shall have a lockable hinged door which will permit viewing of the control panel display when closed. The enclosure shall not interfere with the cooling requirements of the unit. Holes, conduit knockouts, or threaded hubs of sufficient size and number shall be conveniently located in the enclosure.

2.4 ELECTRODE WIRING

All interior and exterior wiring shall be enclosed in either conduit, raceways or tubing and shall be installed in accordance with NFPA 70. Conduit shall be securely fastened at 2.4 m (8 foot) intervals or less. Splices shall be made inside outlet fittings only. Conductors shall be color coded and labeled for easy identification.

Anode supply wires shall have insulation UL rated for at least 600 Volts. Wires from the power supply to the anode junction boxes shall be at least 12 AWG and have red insulation. No more than 20 amps should be handled by the 12 AWG wire. The wire from the junction box to the anode string shall be at least 14 AWG and have blue insulation. Wire enclosures, including raceways, conduits, and junction boxes, within the anode system shall be nonmetallic. The wire from the junction box to the anode shall be connected to the anode with an in-line crimp type splice connector. The connector shall be protected with thermal heat shrink insulated tubing containing a sealant to provide an air tight seal for the connection. The wires in the junction boxes shall have markers designating the circuit letter and anode number permanently attached to facilitate testing and repair.

Wires from the power supply to the cathodes shall be at least 10 AWG with type RHH or RHW insulation. Wires shall be connected to the cathodes using exothermic welds: brazing, "Cadweld", or Burndy "Thermo-Weld" or approved equal. Use of these materials shall be in accordance with the manufacturer's recommendations. The welded area shall be suitably protected so that only the ground rod and insulated wire is exposed. Buried cathode wires shall be encased in rigid nonmetallic conduit suitable for burial. Wiring used for the cathodes shall have black colored insulation.

All exposed wiring and conduits shall be clearly marked as an EOP System. Label spacing is up to the judgment of the installer, but at least one label per room. All labeling shall be in English.

2.5 CONDUIT

Rigid galvanized steel conduit and accessories shall conform to UL 6. Nonmetallic conduit shall conform to NEMA TC 2.

PART 3 EXECUTION

3.1 SYSTEM INSTALLATION

3.1.1 Repair of Cracks or Voids

Any cracks or voids where obvious water penetration is occurring shall be repaired. This is done with either mortar, foams or epoxies depending upon conditions. All materials will be compatible with the EOP system.

3.1.2 Concrete and Soil Conductivity

A test of the concrete and soil conductivity is done to verify both the amount and location of the anodes and cathodes. This testing is done by using a temporary power source to an EOP Control Unit. One anode and cathode are hooked up to the unit and used for testing conductivity.

3.1.3 Anodes

Anodes shall be located no closer than 5 cm (2 inches) to any rebar embedded in the structure. The electrical connection between the anode lead wire and the anode feed wire shall be sealed and shall extend to the insulated portion of the feed wire

3.1.3.2 Ceramic anodes

Grooves are chipped or cut into the floor at the floor-wall juncture using a pattern which is determined from conductivity testing. The groove depth shall allow for sufficient filler material to protect the wire from external damage. After all wiring is placed in the grooves, a mortar compatible with the EOP system is used to fill the grooves. The grooves are filled with mortar and finished.

3.1.4 Cathodes

Cathodes are installed adjacent to the structure. They may be installed through the structure walls or through the floor. Installation is accomplished by drilling a hole through the structure, inserting the cathode into the hole, and then driving it into the exterior soil. For optimum system operation, electrical isolation must be maintained between the structure material and the cathode. The lead and supply wires will be protected by enclosing them in a plastic raceway or flexible nonmetallic conduit.

3.1.5 EOP Control Unit

The EOP Control Unit is mounted in an area that is suitable to both the user and the installer. Wiring is run from the unit to both the anodes and cathodes. This wire may he mounted using any of the following methods: surface mount with plastic wire mold; conduit and junction boxes; or by embedding within the wall and encasing with mortar, which results in a flush to surface condition. After the unit is turned on, it is adjusted and calibrated. The system is now operational.

3.2 OPERATION

The following tasks shall be evaluated and reported:

3.2.1 EOP Control Unit Output Voltage

The EOP Control Unit output voltage shall be monitored. The normal operating output voltage is ± 30 VDC. The output voltage shall never exceed ± 50 VDC. Due to the fact that every installation will be different, and load current is dependent on the number of anodes, or the total length of wire, and the moisture content of the structural material, only qualitative performance criteria can be given. When the moisture level reaches its nominal EOP operating level, the load current will become nearly constant.

3.2.2 EOP Control Unit Output Current

The EOP Control Unit output current shall be monitored. Due to the fact that every installation will be different, and load current is dependent on the number of anodes, or the total length of wire, and the moisture content of the structural material, only qualitative performance criteria can be given. At start up, current shall be greater for high moisture conditions than for low moisture conditions. A properly operating system shall show a significant drop in current during the first few months of operation as the moisture is slowly driven out of the structure material. When the moisture level reaches its nominal EOP operating level, the load current will become nearly constant.

3.2.3 EOP Current Density

The EOP Current density shall be evaluated and reported as milliamps per linear foot of anode installed in the loop. At start-up this value should not exceed 6.5 mA/LF. If the current is greater, selected cathodes should be taken off line.

3.2.4 EOP Current Waveform

The EOP dc current wave form pattern shall correspond to Figure [___].

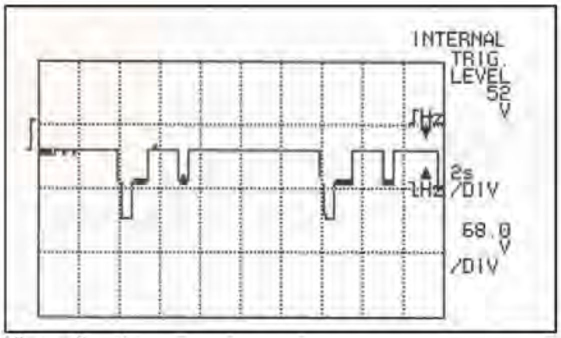

Figure [___]

3.2.5 Relative Humidity Monitoring

Record substrate moisture readings at several locations along the structure perimeter before, during, and after EOP installation. These readings should be taken at the same locations at various time intervals to check for trends.

3.3 FINISH

Where installation of the EOP system has damaged wall or floor finishes, restore the damaged surfaces to the same appearance that was before the commencement of work.

3.4 DOCUMENTATION

3.4.1 Moisture

Document the amount of water seepage existing in the affected areas, prior to installation of EOP systems. The visual documentation shall consist of still photographs or video. The surface moisture content of the structure material and the relative humidity of the interior space shall be documented prior to installation of the EOP system.

3.4.2 Mold and Other Biological Growth

Document the presence and location of mold or other biological growth in the work area. The visual documentation shall consist of still photographs or video. Obtain samples of mold for analysis.

3.4.3 Operating Parameters

Document operating parameters of EOP system at time of EOP system commissioning. This documentation shall include ac voltage and current (power input), dc voltage and current, and waveform analysis.

3.4.5 User's Guide

Provide a user's guide and operating manual for the EOP control unit shall be provided. Drawings of the design and drawings that document the as-built installation of the system shall be included.

3.5 CLEAN UP

Store all materials in a place and manner which protects them from damage or contamination. Regularly inspect all materials to identify damage or deteriorating items. The Government will not be liable for the security of any equipment or materials left on site.

Provide protection to all Government and occupant's property. The Contractor shall be responsible and liable for all damages to the Government or other property due to any negligence on the part of himself or his workers in the orderly prosecution and sequence of his work. Take appropriate steps to safeguard the contents of the facilities while the Contractor and/or any of the employees are working. Contractor personnel are not permitted to use any Government supplies or equipment unless specific authorization is obtained from the Contracting Officer or his/her representative.

After each work day and upon completion of all work, clean the area of all dirt and debris generated as a result of this operation and dispose of in accordance with installation policy and Federal, State and Local regulations.

Appendix I: Draft Unified Facilities Criteria for Electro-Osmotic Pulse

DRAFT UFC X-XXX-XX
13 February 2008

UNIFIED FACILITIES CRITERIA (UFC)

DRAFT

ELECTRO-OSMOTIC PULSE SYSTEM TO CONTROL WATER SEEPAGE IN BELOW GRADE CONCRETE STRUCTURES

UFC x-xxx-xx
13 February 2008

UNIFIED FACILITIES CRITERIA (UFC)

DRAFT ELECTRO-OSMOTIC PULSE SYSTEM TO CONTROL WATER SEEPAGE IN BELOW GRADE CONCRETE STRUCTURES

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes MIL-HDBK-XXXX, dated Month YYYY.

DRAFT UFC X-XXX-XX
13 February 2008

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

AUTHORIZED BY:

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FIGURES

TABLES

CHAPTER 1

INTRODUCTION

1-1 **PURPOSE AND SCOPE**. These instructions provide guidance for the design of electro-osmotic pulse systems to control water seepage in at and/or below grade concrete structures. The guidance in these instructions is primarily to provide sufficient information for general purposes. Most projects, however, include some aspects that are very site-specific or some conditions that are not common. Designers are encouraged to obtain assistance when unusual or unfamiliar situations are encountered. Additionally, the design and application of EOP systems is principally for existing construction. Designing an EOP system requires measuring and establishing values that can only be made on existing construction and can not be predetermined. The Appendix E to these instructions contains the electrical design for Electro-Osmotic Pulse systems.

1-2 **APPLICABILITY**. These instructions apply to all HQUSACE/OCE elements and all Major Subordinate Commands (MSC) and District Commands (DC) having Army military design and construction responsibility.

1-3 **REFERENCES**. Appendix A contains a list of references used in this UFC.

1-4 **OVERVIEW OF ELECTOR OSMOTIC PULSE DESIGN.** Below-ground concrete structures such as basements, tunnels, and elevator shafts are prone to sustain structural damage from chronic water seepage through walls and floors. The application of EOP technology provides a very sustainable, reliable, low cost method for preventing or correcting water seepage over the application of traditional sealants, membranes or costly excavation to place drainage tiles around the facility exterior. Electro-Osmotic Pulse (EOP) technology represents the preferred alternative for eliminating or preventing water seepage. The system consists of a positive (+) side electrode (Anode) and a negative (-) side electrode (Cathode) (Figure 1-1). The positive electrode is grouted/mortared directly into the concrete walls, floors or slabs. The negative side electrode is placed in the surrounding soil or water. A pulsing DC voltage is applied between the electrodes to produce an electric field in the walls, which moves water from the dry side of the walls toward the wet side, against the hydraulic gradient.

When properly installed, this technology:

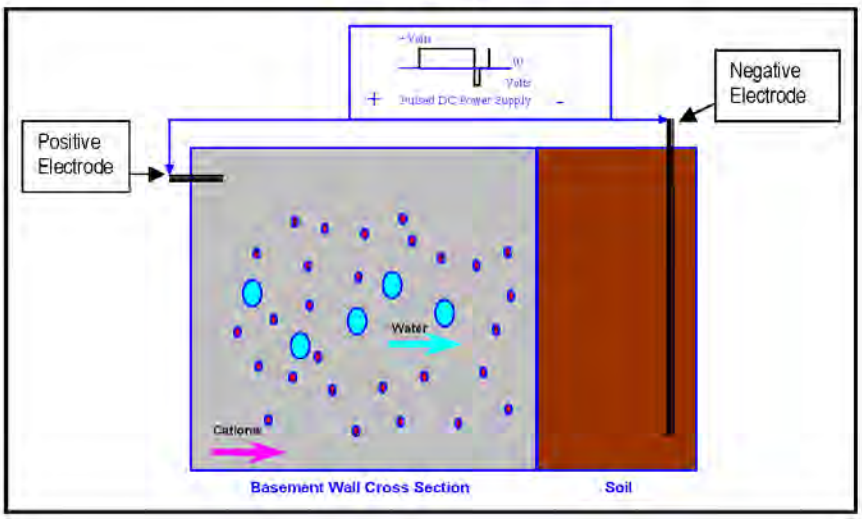
- Dries up existing concrete structures at and/or below grade.
- Prevents water seepage into structures at and/or below grade.
- Prevents efflorescence, mineral deposits and chalking.
- Lowers interior relative humidity.

- Reduces corrosion of the concrete reinforcing bar and on interior mechanical systems located in the facility.

- Eliminates harmful bacteria.

This method of water proofing below grade construction and at grade concrete slabs and floors offers a significant advantage over conventional methods in renovation applications to stop water intrusion in that all the work is done from inside the structure. Procedures for installing the EOP system are contained in TM 5-620, Facilities Engineering Maintenance and Repair of Architectural and Structural Elements of Buildings and Structures.

Figure 1-1. Electro-Osmotic Pulse Waveform and Movement of Water through Concrete.



CHAPTER 2

ELECTRO-OSMOTIC PULSE SYSTEM DESIGN

2-1 DESIGN REQUIREMENTS

The Electro-Osmotic Pulse System designer must satisfy the following for each project:

a. Fully indicate or follow the Scope of Work in the contract documents.
b. Comply with applicable codes, regulations and laws.
c. Provide a design within funding limits.
d. Provide a design within Scope of Work limits.
e. Provide a design that satisfies the functional requirements of the project.
f. Provide complete, accurate, and coordinated construction/procurement documentation for the Project.
g. Provide a design that is in accordance with sustainable design principles.

2-1.1 Designer Qualifications.

Design and review must be accomplished by, or in consultation with, professional electrical designers with significant design experience in Electro Osmotic Pulse. Qualification of designers is based on education, experience and examination. Electrical designers will have completed a recognized program of academic training in design; and/or will have attained registration or licensure as required by the locality or district where the project work occurs. The Government reserves the right to approve or disapprove the qualifications of the designer selected by an A/E or a Contractor.

2-1.2 Design Considerations

The design of an EOP system requires a number of factors and conditions to be determined or assumed for consideration when determining the system layout and performance for the structure which the system is being designed. The collection of data through surveys and engineering drawings is necessary at the beginning of the project to establish all considerations that must be taken into the development of the design on an EOP system.

2-1.2.1 **Development of Design Criteria and Considerations for Electro-Osmotic Pulse Systems.** Electro-Osmotic Pulse Systems are for existing construction and the development of the design requires accomplishing all of the falling actions to establish the criteria and data that must be considered in the design.

2-1.2.1.1 **Data Collection.** To establish design parameters, it is necessary to make certain assumptions that may affect data collection, how that data is used, or the weight of the data's impact on the design. It should be assumed the exterior waterproofing system has failed. However, it will be necessary to determine what the failure mechanism was during the data collection. When developing the design it should be assumed that steel reinforcement (rebar) is continuous and that structural drawings are fairly accurate.

2-1.2.1.1.1 Collect Historical Information from Occupants in the Area. This data can indicate the severity of water intrusion problems. Data on failures and failure rates of nearby structures can be valuable and should also be considered.

2-1.2.1.1.2 Collect Drawings and Other Information. Drawings of the structure to be treated and the area where the system will be installed are needed to provide the physical dimensions of the structure for determining surface area to be treated, and the amount and location of any reinforcing steel and/or any other embedment(s) in the concrete. Structural design and construction characteristics such as the presence of expansion joints and control joints, honeycombing, membranes, coatings (both architectural and moisture barrier types), and sealers are also important in designing the EOP system. The design mix of the concrete, including the use of accelerators, must also be included.

2-1.2.1.2 **Site Survey and Tests.** It is necessary to accomplish an initial survey of the wall and floor areas where EOP is to be installed. This is necessary to identify sources of moisture and to identify location of steel reinforcing. Where ever mold or mildew growth is identified, the source of moisture should be determined. In the event the source is from spills, ceiling leaks, plumbing leaks, etc. these must be corrected prior to installation of EOP. EOP will not resolve those sources of moisture intrusion. The checklist located at Appendix B is to be used for survey data collection and moisture level recording.

Moisture levels in the existing concrete must be measured (Appendix D, "Moisture Level Measurement"). Table 2-1 is used for making this estimate after moisture level measurements are complete. The moisture content of the concrete is used to determine current density requirement estimates to achieve effective dewatering.

2-1.2.1.3 **Life Span.** Generally, the design of the EOP System will be based on a 25-year life span.

2-1.2.1.4 **Impact of Coatings.** Any previously applied coatings installed on the exterior surface of the concrete such as waterproofing must also be evaluated. These coatings, if non-permeable, will prevent or reduce effectiveness of an EOP system. It must be determined that any coating that exits is breathable.

2-1.3 Design of Electro-Osmotic Plus System.

The design of the Electro-Osmotic Pulse System for the intended structure will use the following calculations and system elements combined with the previous considerations to develop the final design.

2-1.3.1 **Calculate Current.** The current required for treatment of surface(s) to be treated by Electro-Osmotic Pulse must be calculated.

2-1.3.1.1 The overall current requirement of an electro-osmotic pulse system is determined by multiplying the surface area to be treated by the required current density. The current density is obtained by measuring the moisture content in representative surfaces of the treatment area and multiplying these areas by the current density requirements provided in Table 2-1.

Table 2-1. Concrete Current Density Required for Effective Treatment

Moisture Content (per Proti-Meter) at 1- & 3-in. depths*	2 Weeks	6 mo	20 yr +
Greater than 30%	2.20 mA/sq ft concrete	0.22 mA/sq ft	0.11 mA/sq ft
Less than 30%	1.10 mA/sq ft	0.11 mA/sq ft	0.06 mA/sq ft
*These values are generated by dividing the current density capacity of the anode current density limit per lineal foot of wire, ribbon or mesh from the anode material's manufacturer's specification by the maximum area of 3 sq ft of concrete that 1 lineal ft of anode can treat (high moisture content) or 6 sq ft (moderately moist concrete).			

2-1.3.2 **Determine Positive Electrode Spacing Requirement.** Positive electrodes must be placed in all cold joints, construction joints, and concrete cracks showing evidence of water intrusion during the site survey. As a rule, this generally is adequate for most construction. However, when water permeates through the concrete at other locations, the following steps need to be included in the design to determine positive electrode spacing.

2-1.3.2.1 Positive Electrode spacing is dependent on the moisture content levels in the concrete. The moisture level is measured as referenced in Appendix D using the Proti-Meter (or its equivalent) and should be measured when the concrete is at its most moist condition. This moisture level is measured at the surface, and at depths of 1 and 3 inches.

2-1.3.2.2 If the readings taken at all 1 and 3 inch depths are equal to or greater than 30 percent, then electrode runs must be spaced 3 ft apart for these areas.

2-1.3.2.3 If the moisture content is of concern and treatment is desired but the readings at the 1- and 3-in. depths are less than 30 percent, then the spacing may be increased to 6 ft.

2-1.3.2.4 If the surface readings are substantially higher than the readings at the 1- and 3-inch depths, this is generally due to condensation from the interior air on to the concrete surface, the surface temperature of which is below the dew point temperature and thus is not considered in the design.

2-1.3.3 **Positive Electrode Operating Current Maximum Limits.** These maximum current limits must be established and not exceeded due to the detrimental effect it can have of causing corrosion to rebar and deteriorating the concrete.

2-1.3.3.1 The limits on operating currents for the positive electrode are expressed in terms of milliamperes of current per square foot (current density) of electrode in contact with the cement mortar. (See Table 2-2.) Given the use of MMO ceramic coated titanium electrode material, the minimum coating system has a projected life substantially in excess of all other system components. The durability of the coating is therefore not a concern.

Table 2-2. Positive Electrode Operating Limits

Operating Time	Current Density on Positive Electrode	Current Limit for 1/16-in. Diameter Wire Positive Electrode	Current Limit for ¼-in. Ribbon Positive Electrode	Current Limit for 1/2-in Ribbon Mesh Positive Electrode	Current Limit for 3/4-in Ribbon Mesh Positive Electrode
2 wk	400 mA/sq ft	6.5 mA/LF	18.3 mA/LF	42 mA/LF	62.8 mA/LF
6 mo	40 mA/sq ft	0.65 mA/LF	1.83 mA/LF	4.2 mA/LF	6.28 mA/LF
Life of system	20 mA/sq ft	0.33 mA/LF	0.92 mA/LF	2.1 mA/LF	3.09 mA/LF

2-1.3.3.2 Conversely, the positive electrode current density can have a dramatic impact on the cement mortar grout placed around the electrode if certain limits with respect to time are exceeded.

2-1.3.4 **Current Density Requirement on Concrete for Effective Moisture Removal**. The maximum current density required is a function of the moisture content in the concrete Table 2-1 lists the maximum current density of concrete required per square foot of concrete surface, given the above electrode spacing limit and field experience.

2-1.3.5 **Positive Electrode (Anode)**: Mixed Metal Oxide (Ceramic) Coated Titanium Positive Electrodes

2-1.3.5.1 The Positive Electrode (anode) shall consist of a precious mixed metal oxide (MMO) catalyst sintered to a Grade 1 titanium substrate (per ASTM B265). The anode shall be in the form of a ribbon mesh, louvered ribbon, or wire provided in rolls approximately 250 feet (76 meters) in length. The anode MMO coating is electro-catalytic coatings applied by thermal decomposition to the specially prepared titanium substrates. The electro-catalytic coatings are formulated primarily of platinum group metals and appropriate binders. The coatings are applied by spraying or dip coating aqueous salts of the metals onto an acid etch-cleaned titanium substrate and heating to several hundred degrees Celsius. Multiple layers of coating may be applied by this process to provide the desired final coating thickness. The resulting mixed metal oxide coating is:

- Highly conductive (10^{-3} Ω-cm to 10^{-6} Ω-cm resistivity).
- Crystalline (anhydrous).
- Corrosion and acid resistant.
- Very hard (hardness of 60).
- Highly abrasion resistant.

2-1.3.5.2 Nickel metal oxide (ceramic) coated titanium or niobium wire, ribbon and mesh anode material are available in a variety of configurations for optimization of specific current density and current distribution requirements. It is a ceramic-metal multi-layer composite that is ductile, rugged, and easy to use. It consists of an ultra thin layer of an iridium-tantalum-titanium, mixed metal oxide ceramic deposited on to either a solid titanium core (STI version), a copper cored titanium interface (CTC) or a copper cored niobium-titanium interface (CNC version). The latter has a niobium interface for other applications requiring the added high voltage capacity of niobium with respect to breakdown voltage characteristics that are not of concern in these applications.

2-1.3.5.3 The nickel metal oxide anode coating is exceptionally durable in combination with the ductile commercially pure titanium substrate. It has been tested at current densities over 2000 amperes per square foot of anodic current discharge. It is fabricated primarily from precious metal and refractory metal oxides in sufficient quantities and ratios to provide a defined life expectancy. Because the coating is already oxidized, it is not consumed when operating as the positive electrode in EOP applications and is dimensionally stable. This dimensional stability is a major advantage in that the resistance to earth does not increase with time as it does with other more consumable anodes such as HSCI or Graphite.

2-1.3.5.4 EOP systems should use a titanium substrate mixed metal oxide coated ribbon, titanium substrate mixed metal oxide coated wire mesh positive electrode or copper-cored titanium wire with a minimum diameter of 1/16 in. The ribbon anodes are normally used in .25 and .5 inch widths. The wire mesh anode is made from perforated titanium and is normally used in .5 and .75 widths. These anodes should have a current density of 5.0 mA/ft at a minimum. The wire mesh is preferred as it is not susceptible to voids forming during grouting. The voids collect water and cause corrosion of the electrode.

2-1.3.5 **Negative Electrode (Cathode).**

2-1.3.5.1 **Type**. The negative electrode receives electric current from positive ceramic coated titanium wire, ribbon, and mesh electrodes. This action normally provides corrosion mitigation for the negative electrode and therefore common metal materials can be used for this purpose. A commonly used cathode is the common copper clad steel electrical ground rod, typically 5/8-in. (15.9 mm) diameter by 6-ft long (minimum). The rods shall be made of nickel-plated steel that is heavily plated in copper for high levels of conductivity and good corrosion resistance. The rods shall meet or exceed UL standard 467 and ANSI C33.8. These will be driven through a purposely made hole in either the structure wall or slab into the surrounding earth.

2-1.3.5.2 **Installation**. A hole is formed in the concrete through which the electrode is driven and the lead wire is exothermically welded or brazed to the rod prior to insertion. This connection is then waterproofed with epoxy before insertion through the wall or slab. After driving, the entire connection receives additional waterproofing by filling the cavity with epoxy. The lead wire is then routed in slots that are later filled with cement mortar back to the appropriate junction box.

2-1.3.5.3 **Number of Negative Electrodes**.

2-1.3.5.3.1 The number of electrodes is defined both by the need for uniform distribution of treatment current and maximum allowable circuit resistance. There must be at least one negative electrode for each 50 lineal feet of positive electrode. Additional negative electrodes may be required if the soil resistivity into which the negative electrode is inserted is unusually high.

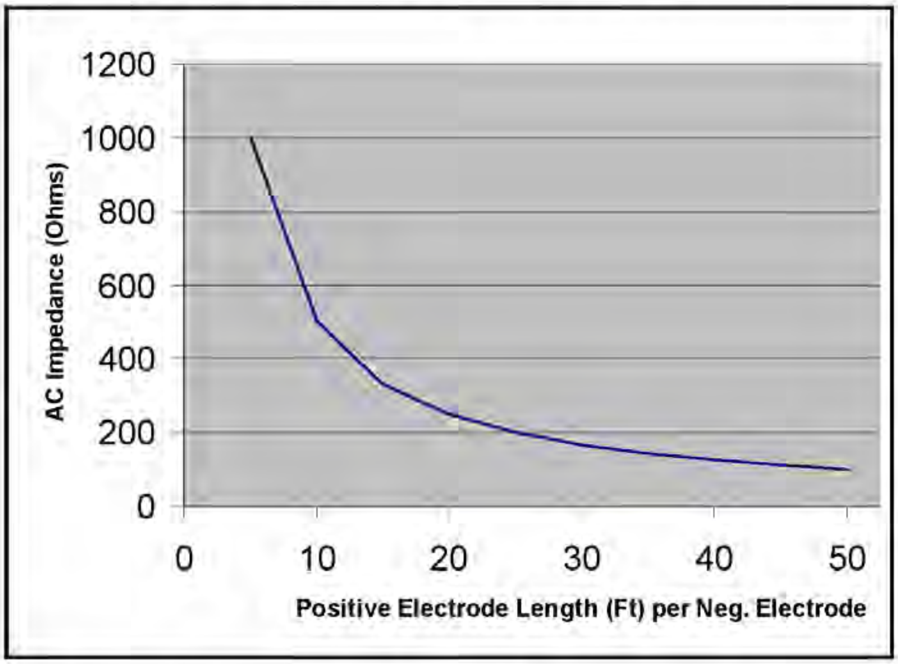
2-1.3.5.3.2 Given that the resistivity of the concrete does not vary greatly, the EOP circuit resistance will be primarily controlled by the presence of moisture in the concrete and the resistance to current flow through the soil to the negative electrode. Since (1) the soil characteristics are controlled by nature, and (2) the positive electrode configuration is controlled by other design factors, the only design variable for modifying the system circuit resistance is to change either the number or length of negative electrodes in contact with the earth.

2-1.3.5.3.3 Normally, the number of electrodes is determined by installing one electrode at a time for each 50-ft segment of positive electrode wire and then by measuring the AC impedance (resistance as measured by a Nilsson Model 400 meter or its equivalent) between the two installed electrodes. If this measured resistance is 100 ohms or less, then 1 electrode is sufficient for this 50-ft segment. If the positive electrode segment is only 25 ft long, then a resistance of 200 ohms is acceptable. If the total positive electrode length is 40 ft, the resistance can be up to 125 ohms, and so on (Figure 2-2).

2-1.3.5.4 If the resistance measured between the corresponding positive and negative electrodes is higher than the allowable resistance, either additional negative electrodes must be installed or a greater length negative electrode must be used.

2-1.3.5.5 If the resistance measured between the positive and negative electrode is substantially lower than the desired resistance and therefore the current limit on the positive electrode is exceeded, some negative electrodes may be disconnected from the system, or a shorter negative electrode is installed.

Figure 2-1. Maximum Positive to Negative Electrode Resistance.



2-1.3.6 **Electrode Lead Wires and Connections**

2-1.3.6.1 **Available Wire Types**. All electrodes should be provided with stranded (seven strands minimum) annealed copper lead wires. High Molecular Weight, Low Density Polyethylene (HMWPE) is the most popular anode lead wire insulation; however both Kynar/HMWPE and Halar/HMWPE dual extrusion insulations are available for more demanding situations where chlorides, oil, or other harsh environments are involved. Other cable insulations have been used including EPR/CSPE (ethylene propylene rubber/chloro-sulphonated polyethylene commonly called Hypalon), and are available when suitable for the application. It is important that the appropriate cable insulation be selected for the environment.

2-1.3.6.2 **Positive Electrode Lead Wire Connections**. All positive electrodes to lead wire connections shall be made in junction box/test stations only. No splices of the positive electrode to wire connections shall be permitted within the concrete or grouted/mortared slots.

2-1.3.6.3 **Rebar Connection**. Rebar cages are also to be connected with lead wires to the control box. In the initial survey the steel reinforcing bar should have been identified. If the structure is reinforced with a double mat of rebar or more, then continuity of the rebar must be checked. This is necessary for connection to the control unit that will prevent stray current corrosion. This is not a requirement for single mat reinforcing. The rebar cage must be exposed at two points so that lead wires can be attached. The lead wire is attached by using an eye bolt threaded into the rebar. This requires drilling and tapping the rebar with matching threads for the eye bolt selected for use. These connection points will receive positive electrode backfill.

2-1.3.6.4 **Negative Electrode Lead Wire Connections**. Negative electrode to lead wire splices must be moisture proofed using epoxy encapsulation.

2-1.3.6.5 **Junction Box Electrode Connections**. Connections within the junction box must be made in a manner to assure their long term durability. This is most commonly accomplished by the use of wire nuts or compression connectors. All splices should be made to assure their electrical isolation from any other metallic components within the junction box and also the box itself.

2-1.3.6.6 **Junction Box**. This box shall be of nonmetallic construction with stainless steel fittings. The box cover must be fitted with a waterproof gasket.

2-1.3.6.7 **Conduits**. Rigid galvanized steel conduit and accessories shall conform to UL 6. Nonmetallic conduit shall conform to NEMA TC 2. Conduit shall be securely fastened at 2.4 m (8-ft) intervals or less.

2-1.3.7 Electrode Backfill.

2-1.3.7.1 The positive electrode backfill provides a compatible, ionically conductive environment that can be easily grouted into place around the electrode assuring intimate contact to the surrounding cementitious structure. Specialty grouts designed for compatibility with electrical devices in concrete such as MasterFlow 928 and SikaRepair 223 are the preferred materials. However, in extreme circumstances common backfill Portland Cement Mortar grout may be used. When using cement mortar grout, it may have additives that make the mortar expansive upon cure to ensure mechanical holding within the slot. Caution must be used in the selection of these expansive agents to make sure they do NOT raise the electrical resistivity of the cement mortar. Similarly, only cement mortar slurries should be brushed into the slots to serve as bonding agents. Most synthetic bonding agents are nonconductive or at least highly resistant to the passage of electric current and should never be used.

2-1.3.7.1.1 The MMO Titanium wire, ribbon or mesh anode is placed into the active electrode slot cut into the concrete and then the backfill is troweled or caulked into place around the wire, ribbon or mesh. Special care must be taken when backing around the electrodes, especially when using a cement mortar grout. If there are any air pockets created adjacent to the wire, ribbon or mesh, these will collect water which will then become acidic over time that in turn can produce hydrogen gas. This will result in corroding or deterioration of the anode,

2-1.3.7.2 Where the positive electrode wire is routed to the junction box in slots not intended as current discharge slots, the wire shall be covered with heat shrink tubing.

2-1.3.8 **Determining the number and length of positive electrode slots.** This calculation is to be used in the design when the concrete surface is wet and the interior is also wet, indicating that water is entering through the concrete.

2-1.3.8.1 **Slab Positive Electrodes**. For slab on or below grade applications, the positive electrode is placed in slots no more than 3 ft apart over the entire surface of the slab surfaces to be treated with the first and last slots within 3 in. of the perimeter of the slab to be treated.

2-1.3.8.2 **Wall Positive Electrodes**. For systems where the wall is the primary treatment surface, the first electrode slot is always placed within 3 in. of the floor slab along the entire wall length to be treated. If high moisture levels exist to a height greater than 3 ft above the floor slab, than additional slots will be needed at 3-ft intervals in horizontal slots. If only moderate moisture levels exist from the 3-ft level up, then additional horizontal slots are needed only if this condition exists above a 5-ft height in which case the second slot is provided at the 6-ft level.

2-1.3.8.3 **Floor to Wall Junctures only**. If the treatment area only involves an area defined as being within 2 ft into the slab and up the wall from the floor-to-wall juncture, only one positive electrode slot is required, which is placed within 3 in. of this juncture either on the wall or slab surface.

2-2 PREPARE LIFE CYCLE COST ANALYSIS.

The life cycle cost analysis should be prepared according to the guidelines given in TM 5-802-1 (reference). Another source of information on performing life cycle cost analyses is NACE Publication 3C194 (Technical Committee Report) (reference). The choice of a particular electrode type and configuration for design calculation is somewhat arbitrary. The economics may dictate switching to a different design configuration and repeating the applicable design steps.

2-3 PREPARE PLANS AND SPECIFICATIONS.

Prepare plans that show the treated structure, locations of the power source, the EOP control unit, the electrodes, the negative side components, wire routing, junction boxes, wire color coding, and other pertinent information. Prepare a one-line diagram to show the entire system, including wire sizes, electrode type(s), power circuit, power circuit protection, and source of power. Prepare specifications to describe required features of the system components.

CHAPTER 3

CRACK REPAIR

3-1 CRACK REPAIR IN CONJUNCTION WITH EOP

3-1.1 **Conditions Suitable to EOP**. The need for crack repairs and injection procedures required to be accomplished in conjunction with EOP is best explained by understanding the most suitable conditions for an EOP system. The perfect environment for the installation of EOP is saturated concrete; i.e., concrete that:

- Paints and sealers will not stick to.
- Is cool and damp to the touch.
- Has calcification and/or mold buildup on its surface.
- Sweats or has beads of moisture on the surface.

These concrete structures are solid with no voids or cracks. Any voids or cracks will act as insulators and inhibitors of both current flow and the movement of water from the dry side to the wet side.

3-1.2 **Create the Proper Environment**. Most waterproofing needs exits in areas that have flowing water and for EOP to be effective requires the proper environment be created for the system to perform properly. To accomplish this, access must be available to perform all required repairs and create conditions that are compatible with the EOP system, and that will create the correct operating environment for EOP.

3-1.3 **Crack Repair**.

3-1.3.1 **Settling Cracks**. There are many different types of cracks that need to be addressed. "Settling cracks" are caused by movement after the concrete has cured. In most cases, these are narrower cracks that will not experience a lot of movement. In this case, the crack is usually injected with a hydrophilic grout because the lower viscosity will penetrate the crack better. When the cracks are larger and there is a need to fill a significantly greater volume, a hydrophobic grout is generally used, but either of these grouts may be used. All cracks 1/32 inch wide or greater are to be sealed.

3-1.3.2 **Cosmetic Cracks**. Repairing cracks (or damage) not caused by movement should be accomplished. These cracks do not always leak, but they will occasionally allow moisture penetration. In most cases, some surface area is chiseled away immediately around the crack, and the crack or damaged area is repaired with hydraulic cement. All cracks 1/32 inch wide or greater are to be sealed.

3-1.3.3 **Cracks Caused by Design**. Cracks caused by design; i.e., control joints and expansion joints, must be treated in a way that will allow for continued movement even after the repair is completed. In most cases, a flexible epoxy, such as Micor Joint filler or equivalent, is used in these areas. Epoxy can only be applied in dry areas, however, once it has cured, it has great adhesion capabilities and will allow for continued movement in the cracks. When surfaces are wet and prohibit use of epoxy, use of a moisture cured urethane is required such as Strata-Tech 524 or equivalent. When conductivity is required, such as when the anode is in the joint, conductive materials may be added to the epoxy repairs.

3-1.3.4 **Voids.** Voids in walls are usually the result of poor placement procedures when the concrete was poured initially. If these voids are not too large and in confined areas, the bad sections of concrete are chipped out and replaced with hydraulic cement. If the voids are just porous concrete and extend along or through the wall, these areas are injected with a hydrophilic grout. Another type of void is created by design such as with concrete block walls. When installing EOP in a concrete block structure, all voids and cavities in the blocks must first be filled. This is accomplished by filling the blocks with a pumpable concrete grout.

3-1.3.5 **Wall Openings Created by Design**. Openings in walls are almost always created by design, e.g., chases or conduits. When repairing an abandoned chase, the opening is filled with a concrete material – either brick or cement – and then the crack where the patch abuts the existing cement is injected with thin hydrophilic grout. There are two kinds of conduits, active and inactive. An inactive or abandoned conduit is filled with activated Oakum and sealed over with hydraulic cement. Oakum works well for smaller diameter conduits by itself. Larger diameter conduits may require use of an insert with the Oakum. An active conduit, or one with wires running through it, is a more difficult repair. The pipe is usually sealed with activated Oakum. The life expectancy of this repair is somewhat short-term compared to the other repairs. However, it is the only way to allow for future use of the conduit such as adding or repairing wires.

APPENDIX A

REFERENCES

GOVERNMENT PUBLICATIONS:

1. Department of the Army

   Defense*Link* Publications
   Internet site http://www.defenselink.mil/pubs/

   TM 5-620, Facilities Engineering Maintenance and Repair of Architectural and Structural Elements of Buildings and Structures.

2. Department of the Army

   Defense*Link* Publications
   Internet site http://www.defenselink.mil/pubs/

   TM 5-802-1, Economic Studies for Military Construction Design Applications

NON-GOVERNMENT PUBLICATIONS:

NACE International

NACE Publication 3C194 (Technical Committee Report)

APPENDIX B

MOISTURE PROBLEMS CHECKLIST

Place & Date	
Customer	
Address	
Point of contact	
Phone	
Fax	
Address of object	
Project No.	
Construction Data	
Age of structure	
Size of structure	
Foundation	
External walls	
Internal walls	
Floors	
Cracks/holes?	
Reason?	
Salt appearance?	
Fungus?	
Odor?	

Rotten Materials?	
Ventilation?	

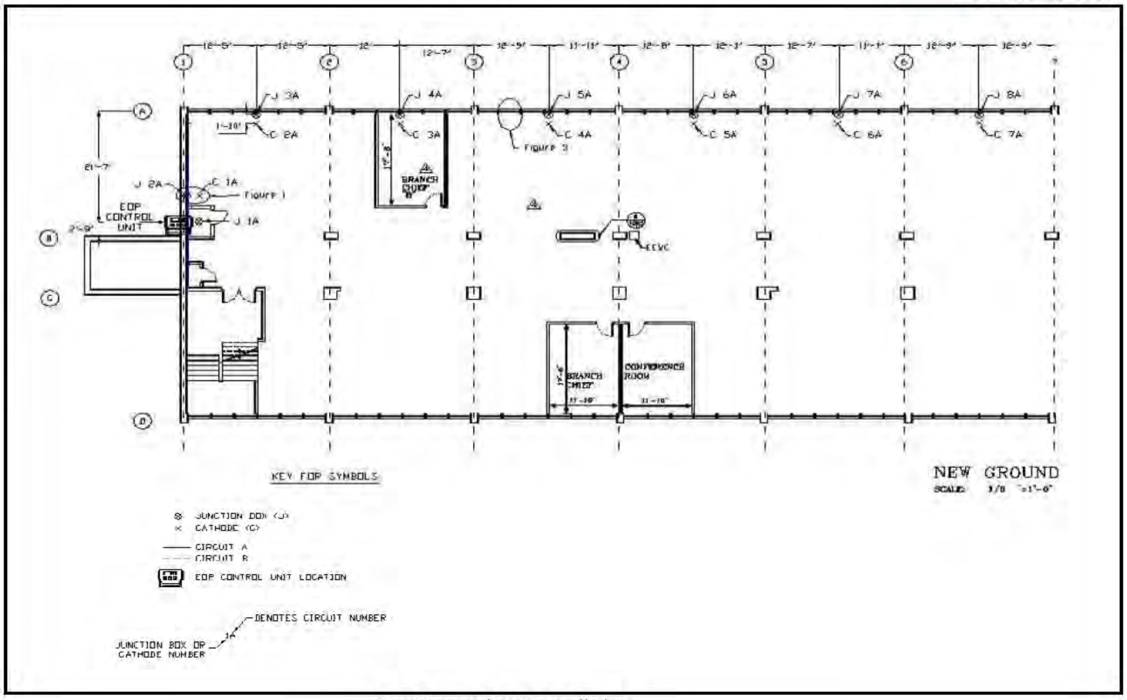
CONDITION OF SOIL & TOPOGRAPHY		
Soil		
Excavation?		
Back filling?		
Water table?		
pH-level		
Topography		
Drain pipes		
MOISTURE		
When discovered		
Greater during Spring?		
Greater when heavy rain?		
Location of moisture		
Standing water on floors?		
MOISTURE READINGS		
Moisture level (in RH)		
Moisture level (Protimeter)		
1 ft on the wall	1 in.	3 in.
3 ft on the wall	1 in.	3 in.
In the floor	1 in.	3 in.
RH in room		
Temperature in room		
Temperature, construction		

Dew point	
Temperature, outside	
RH outside	
Condensation?	
Moisture level in wood	
Located where?	
GENERAL INFORMATION	
Other buildings with same problems?	
Present use of area	
Future use of area	
Inside drain?	
Location of EOP unit	
110V available?	
Building ground	
Drawings of construction?	
Pictures of object?	
Other information:	
SOLUTIONS	
Source of problems	
More info. Necessary?	
The best possible solution	
PERSONS REPRESENTED AT INSPECTION	
For surveyor	

Name	
Title	
Phone	
FAX	
PERSONS REPRESENTED AT INSPECTION	
For customer	
Name	
Title	
Phone	
FAX	

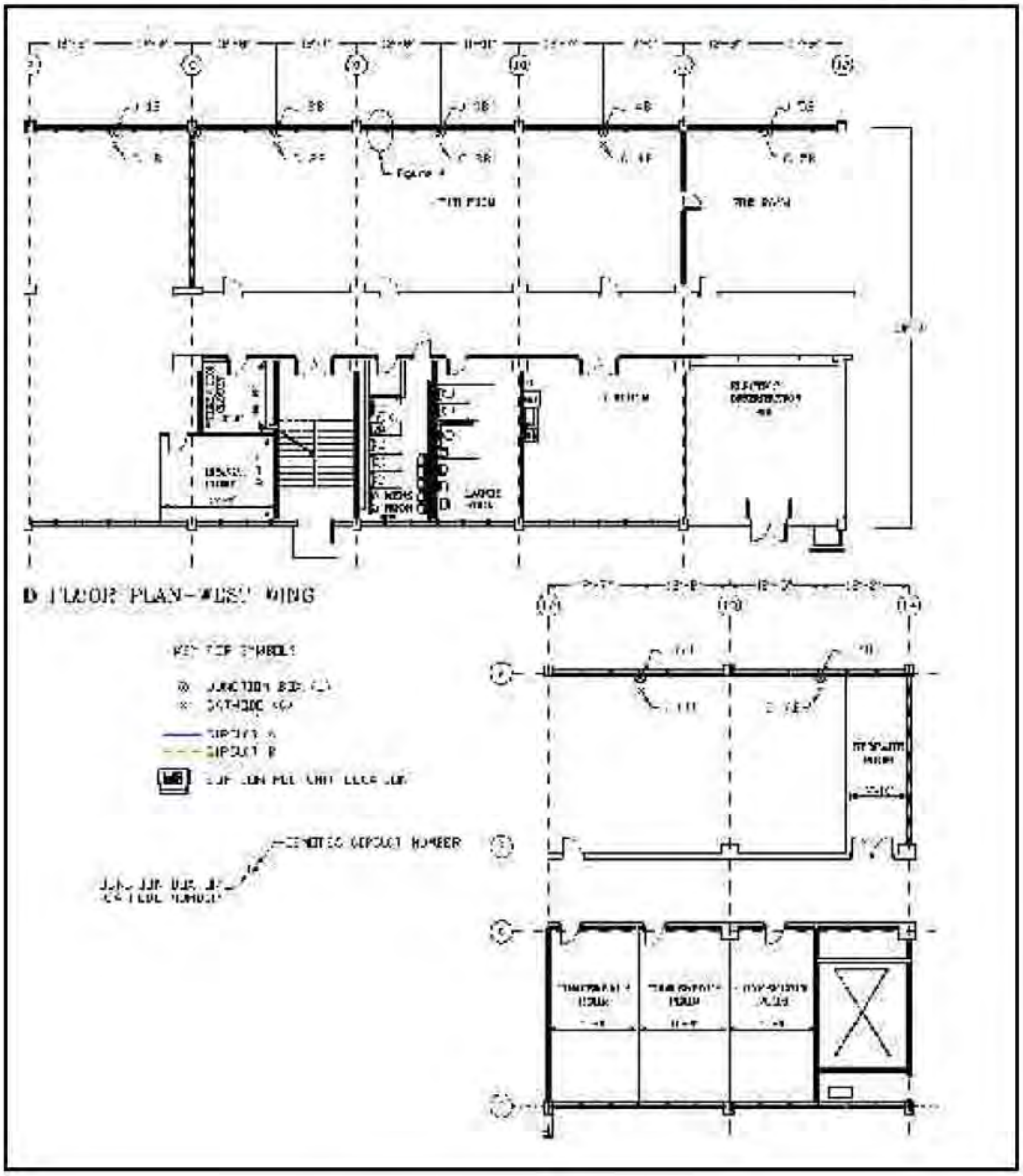
APPENDIX C

EXAMPLES OF ELECTRO-OSMOTIC SYSTEM DESIGN



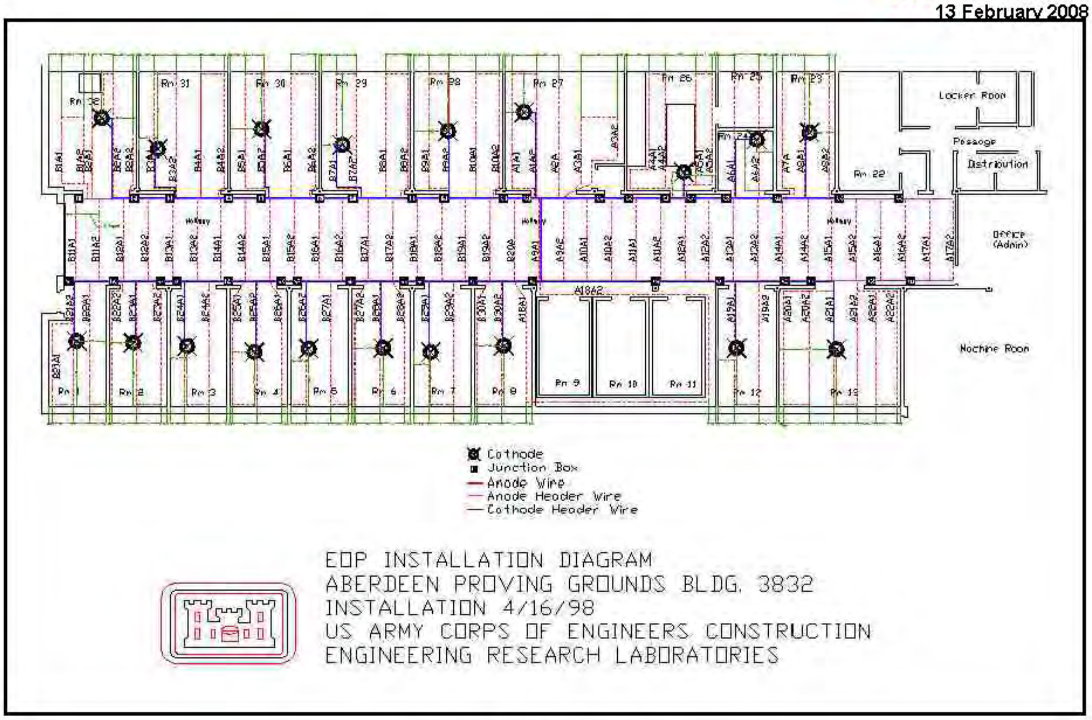
Fort Monmouth EOP Installation

DRAFT UFC X-XXX-XX
13 February 2008



Fort Monmouth EOP Installation (cont.).

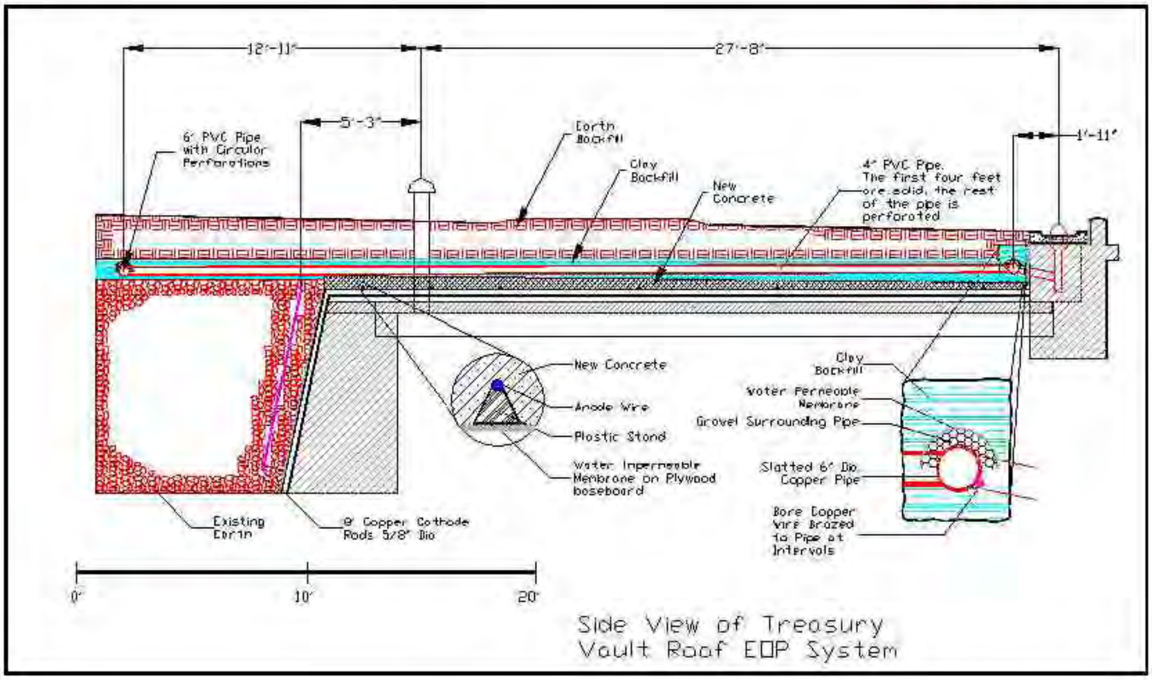
DRAFT UFC X-XXX-XX
13 February 2008



Aberdeen EOP Installation

22

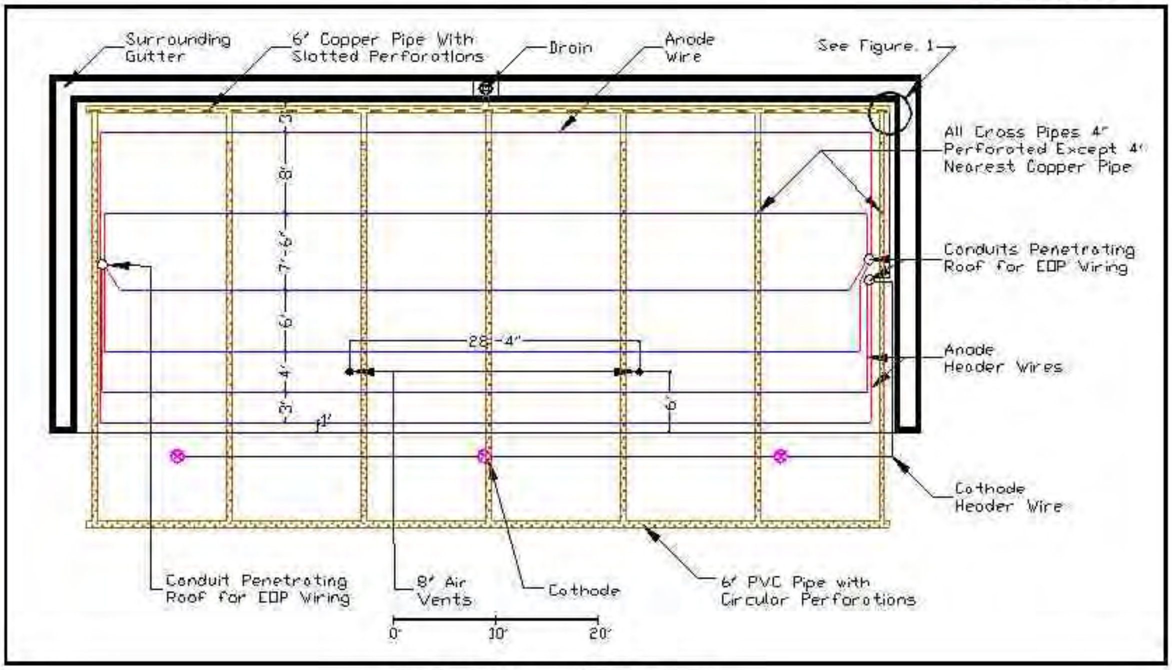
DRAFT UFC X-XXX-XX
13 February 2008



U.S. Dept of Treasury EOP Installation

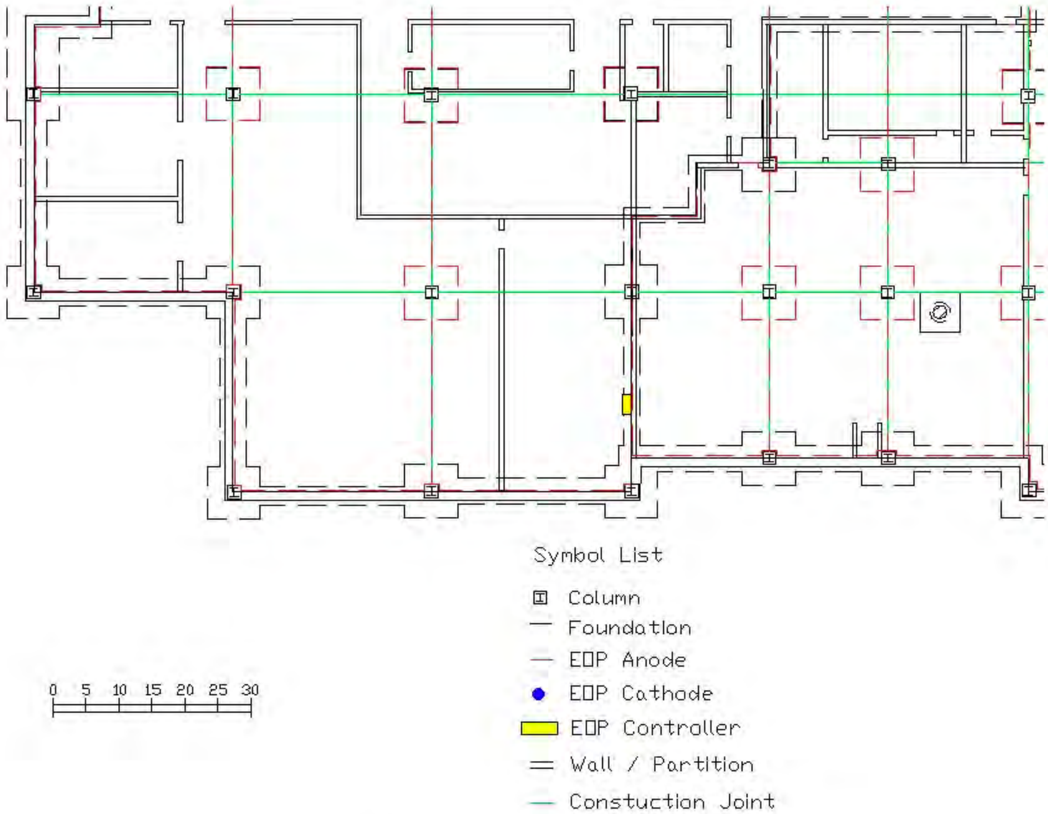
23

DRAFT UFC X-XXX-XX
13 February 2008



U.S. Dept of Treasury EOP Installation

DRAFT UFC X-XXX-XX
13 February 2008



HQ Basement Section EOP Installation

APPENDIX D

MOISTURE LEVEL MEASURMENT

This procedure provides a standardized method for the measurement of moisture in concrete using the Protimeter Surveymaster SM® moisture meter.

The Surveymaster meter provides a method for easy and accurate surveys for relative moisture levels in various building materials. The meter is used to identify and determine the extent of water intrusion or dampness, which may provide a basis for microbial growth, material decay or EOP design.

The instrument readings are based on percent moisture for wood. In any material other than wood the meter will give readings of %wood-moisture-equivalent (%WME). Levels above 20% for wood generally indicate a potential for rot. Therefore, a reading above 20% in any building material indicates a condition, which must be investigated further.

The unit has two modes.

- **Measure Mode** uses direct contact with material between two electrodes to determine the level of moisture present.

- **Search Mode** uses Radio Frequency (RF) signals as a rapid non-invasive method to detect wetness beneath the surface of materials.

For this procedure only the "Measure Mode" will be considered and recommended for use.

Definitions:

- **% WME**: the moisture level in any building material other than wood expressed as a moisture content of wood.

- **Measure Mode**: Using the pins, LED and digital display of moisture content in percent.

- **Search Mode**: Using RF detection, LED display of relative moisture content beneath the surface of building materials.

- **Light Emitting Diode Codes**

  Green LED's: Air-dry conditions.
  Yellow LED's: Slightly in excess of normal. Investigate further.
  - **Red LED's:** Excess moisture.

Deep Wall Probes: two long probes insulated but for their tips for the measurement of moisture deep inside a wall regardless of surface moisture or salts contamination.

Salt Contamination: salts deposited in the building material by previous water intrusion are hygroscopic and may enhance the ability of the material to draw moisture from the room air in humid settings maintaining high moisture conditions. Under dry conditions, this potential is not measurable by the Surveymaster.

Unusual readings: seemingly absurd readings may be attributable to electrically conductive materials such as aluminum foil vapor barrier or carbon containing materials.

Calibration of the Surveymaster

- Turning Power On: press the Pin button on the front of the meter. The unit will remain on for 30 seconds and then turn itself off.
- Warm-up: A warm-up is not required for this meter.
- Remove the protective cover over the pins.
- Press the two needle electrodes against the two exposed wires of the calibrator.
- The reading will be 17-19. If not, return the instrument for repair.

Measure Mode:

- Temporarily suspend operation of EOP system if it is operating. (The meter operates on the principle of electrical resistance and electrical current in the concrete or masonry building material can affect the moisture readings.)
- Remove the cover over the pins.
- Push the pins firmly into building materials.
- Press the Pin button.
- Obtain the surface reading on both the digital display and the LED's.
- For readings in recessed or difficult areas recover the pins and connect the external probes to the socket on the right-hand side of the meter body.
- Repeat readings

Deep Wall Probes: two long probes insulated but for their tips for the measurement of moisture deep inside a wall regardless of surface moisture or salts contamination.

Salt Contamination: salts deposited in the building material by previous water intrusion are hygroscopic and may enhance the ability of the material to draw moisture from the room air in humid settings maintaining high moisture conditions. Under dry conditions, this potential is not measurable by the Surveymaster.

Unusual readings: seemingly absurd readings may be attributable to electrically conductive materials such as aluminum foil vapor barrier or carbon containing materials.

Calibration of the Surveymaster

- Turning Power On: press the Pin button on the front of the meter. The unit will remain on for 30 seconds and then turn itself off.
- Warm-up: A warm-up is not required for this meter.
- Remove the protective cover over the pins.
- Press the two needle electrodes against the two exposed wires of the calibrator.
- The reading will be 17-19. If not, return the instrument for repair.

Measure Mode:

- Temporarily suspend operation of EOP system if it is operating. (The meter operates on the principle of electrical resistance and electrical current in the concrete or masonry building material can affect the moisture readings.)
- Remove the cover over the pins.
- Push the pins firmly into building materials.
- Press the Pin button.
- Obtain the surface reading on both the digital display and the LED's.
- For readings in recessed or difficult areas recover the pins and connect the external probes to the socket on the right-hand side of the meter body.
- Repeat readings

- To obtain readings below the surface of the concrete or masonry building material, drill two ¼ inch diameter holes in the building material to the desired depth, typically 3 inches, centered ½ inch apart. Clean the drill dust out.
- For measuring moisture in the holes, attach the Deep Wall Probes to the socket on the right-hand side of the meter body and press the probes firmly against the bottom of the holes.
- Read levels for each desired depth up to the maximum penetration distance.

Documenting readings:

- There is no data logging capability in this instrument. By holding the "on" button while performing the test the unit will hold the maximum reading until the button is released.

Conversion to real percent moisture:

To convert %WME readings to percent moisture in concrete use the following equation:

%RHC = %WME X 0.92375

Where %RMC is the percent relative moisture in concrete.

APPENDIX E

EXAMPLES OF ELECTRICAL DESIGN FEATURES FOR ELECTRO-OSMOTIC SYSTEM

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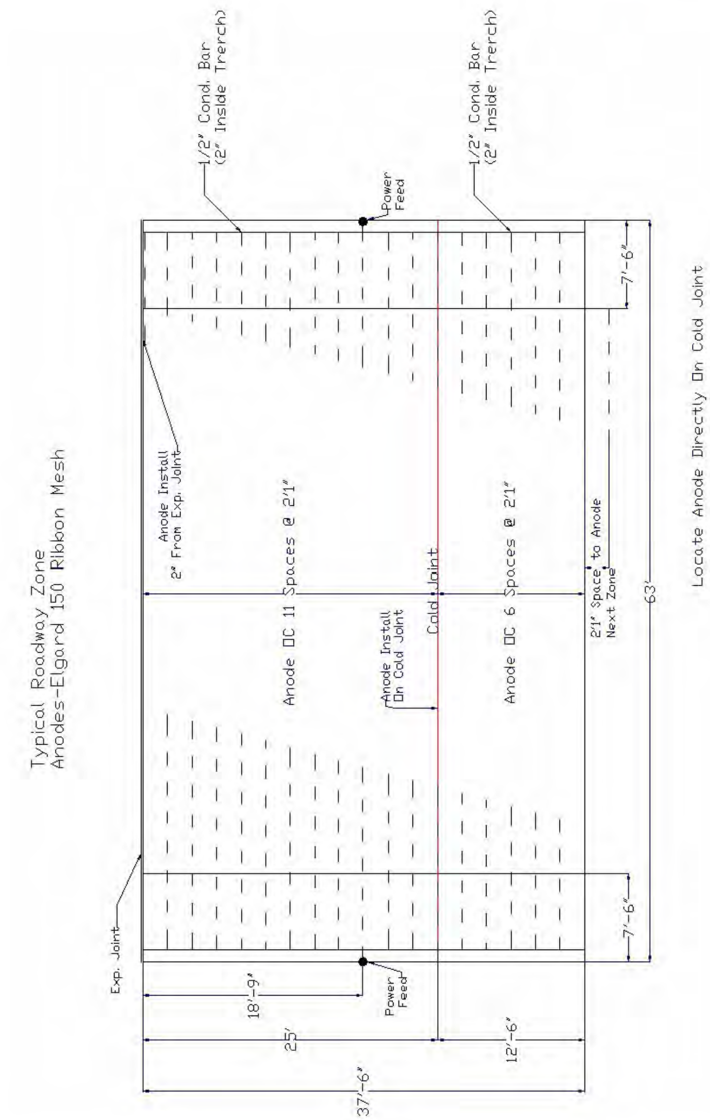

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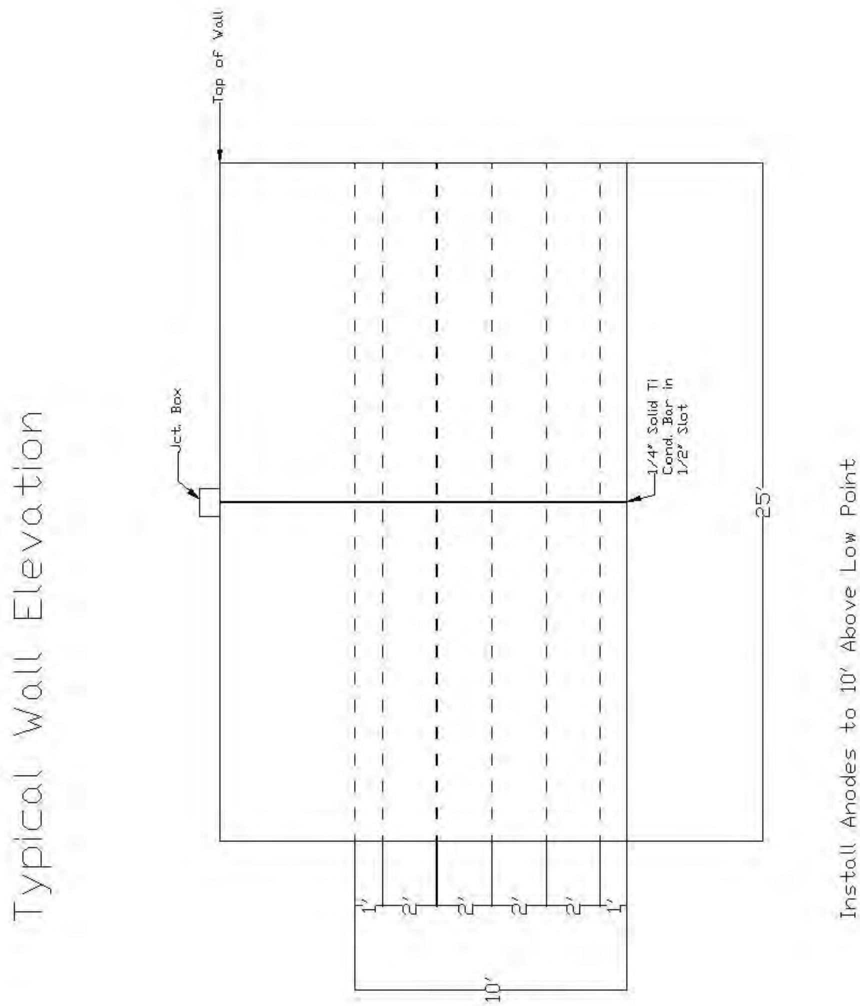
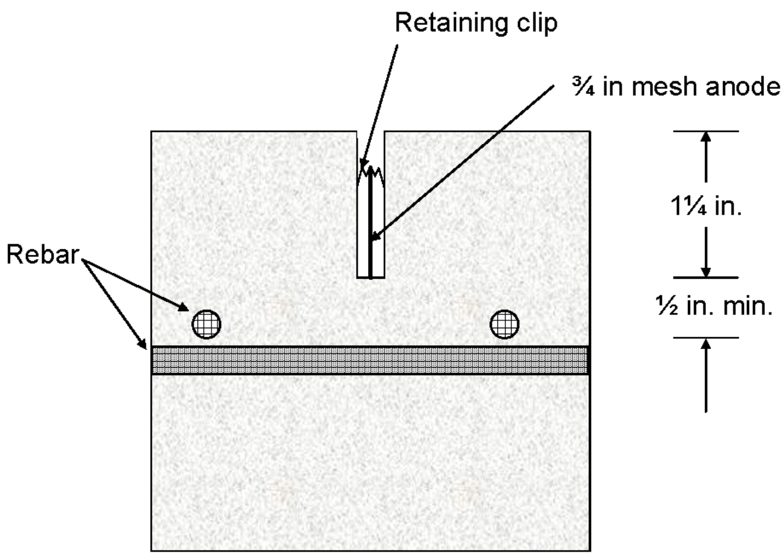
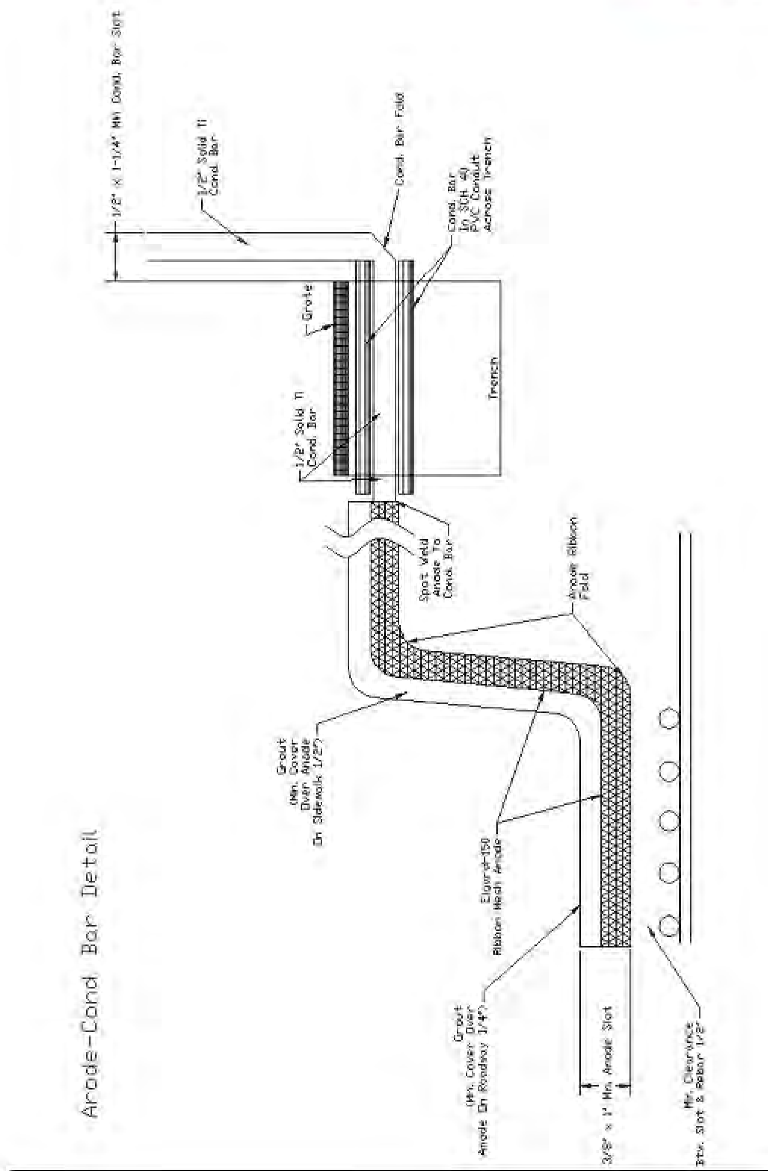
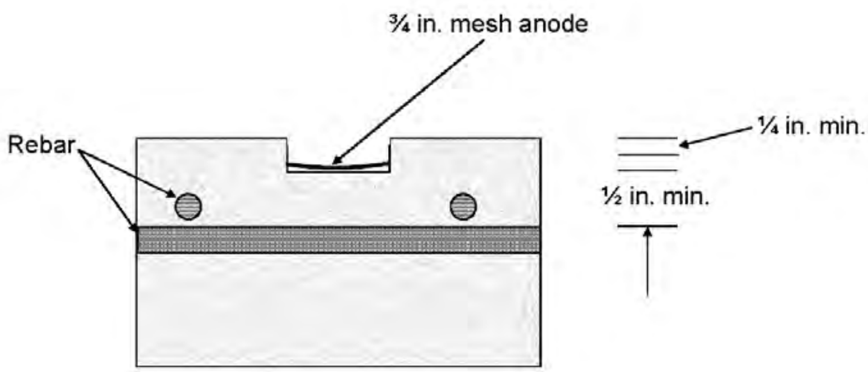


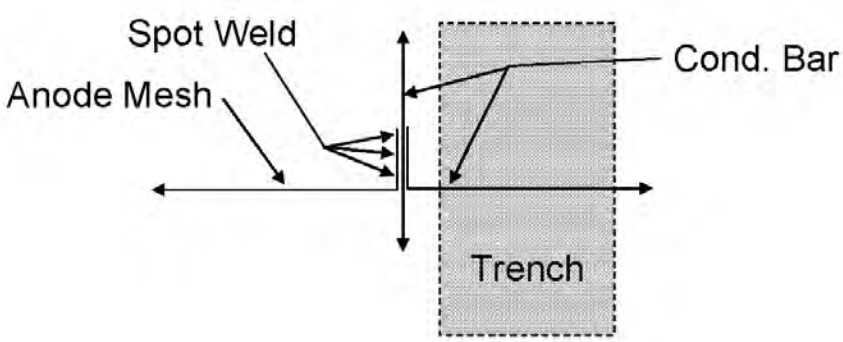


NOTES: Mesh ¾ in. wide and .05 in. thick expanded metal Titanium with mixed metal oxide coating

½ in. min. spacing between all rebar and mesh anode


Anode-Cond Bar Detail
1/2" x 1-1/4" Min Cond. Bar Slot
1/2" Solid Ti Cond Bar
Cond. Bar Fold
Cond. Bar In SCH 40 PVC Conduit Across Trench
Grate
1/2" Solid Ti Cond. Bar
Trench
Spot Weld Anode To Cond. Bar
Anode Ribbon Fold
Grout (Min. Cover Over Anode On Sidewalk 1/2")
Elgard-150 Ribbon Mesh Anode
Grout (Min. Cover Over Anode On Roadway 1/4")
3/8" x 1" Min. Anode Slot
Min. Clearance Btw. Slot & Rebar 1/2"


¾ in. mesh anode
Rebar
¼ in. min.
½ in. min.


Spot Weld
Anode Mesh
Cond. Bar
Trench

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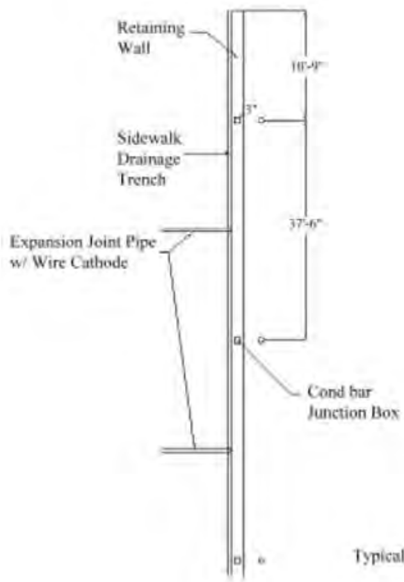
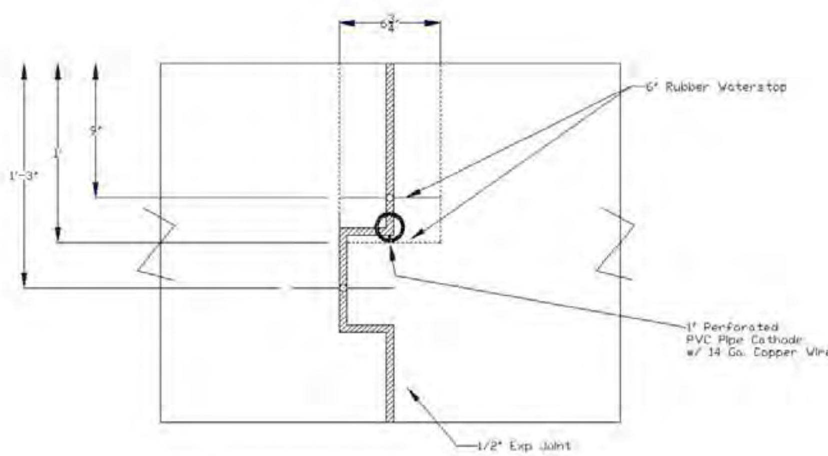
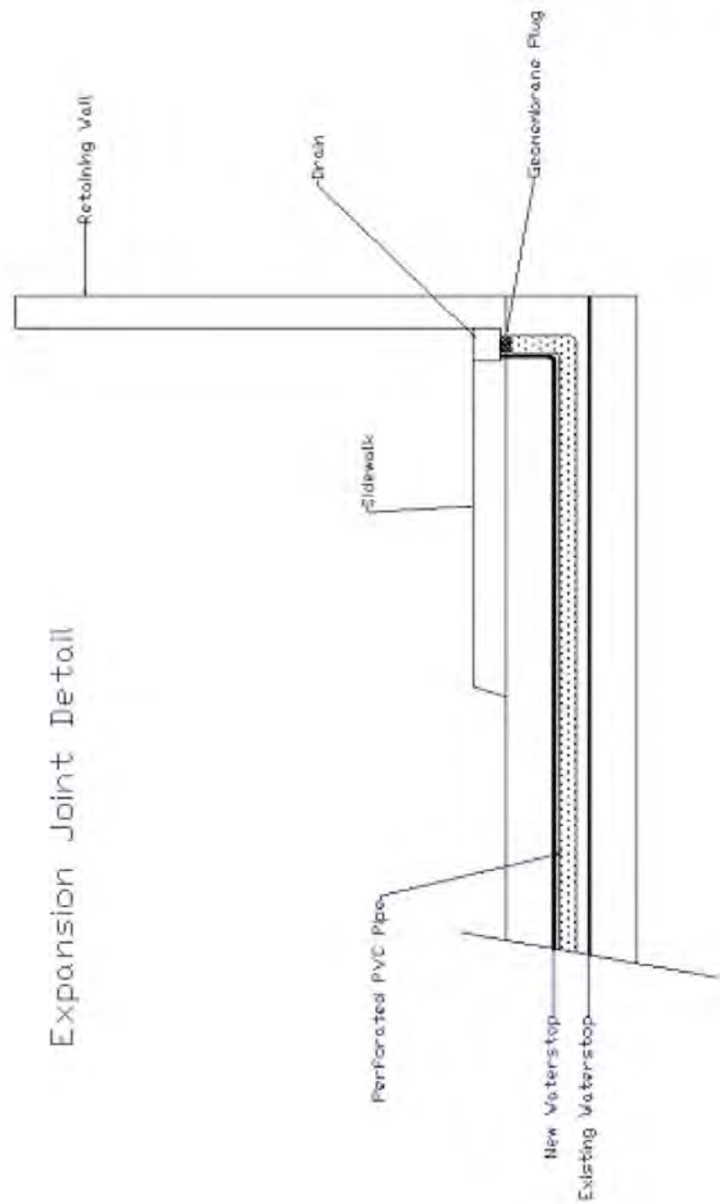


Typical Cathode Layout



Expansion Joint
With EOP


Retaining Wall
Drain
Geomembrane Plug
Sidewalk
Expansion Joint Detail
Perforated PVC Pipe
New Waterstop
Existing Waterstop

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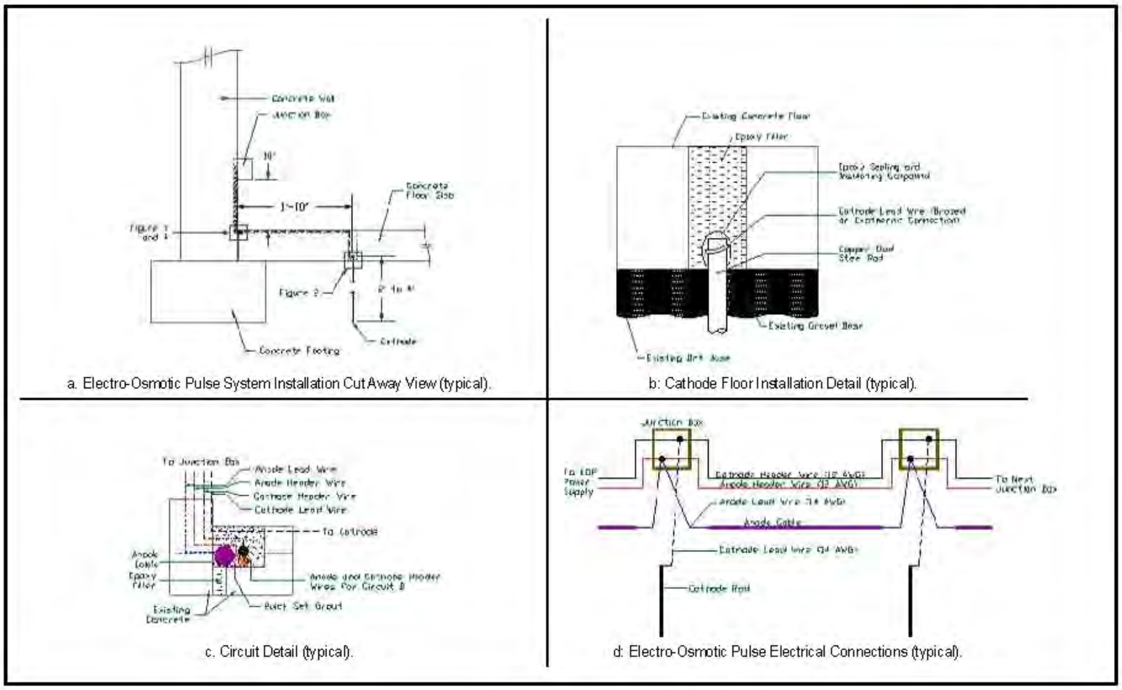
13 February 2008



a. Electro-Osmotic Pulse System Installation Cut Away View (typical).

b: Cathode Floor Installation Detail (typical).

c. Circuit Detail (typical).

d: Electro-Osmotic Pulse Electrical Connections (typical).

Typical Installation Design

APPENDIX F

Examples of Design Calculations

Example 1
Design Assumptions

1.1 Current density

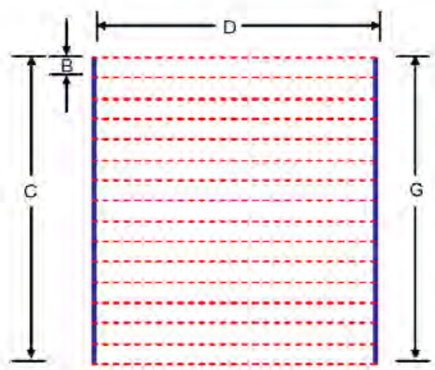
The design current density shall be 1.5 mA/ft^2 (16 mA/m^2) of concrete surface area.

1.2 Anode current density

Maximum allowable anode current density shall be 21 mA/ft^2 (226 mA/m^2) of active anode surface area for the first month of operation and 10 mA/ft^2 (108 mA/m^2) thereafter.

1.3 Anode voltage drop

In order to assure uniform current distribution to the roadway deck and retaining walls, the anode voltage drop shall not exceed 300 mV from the power feed point to the furthest point from the power feed.



Free Body Diagram: Feed Anodes from Both Ends

A Maximum Design Current Density	1.5	mA/ft^2
B Anode Spacing	2.083	ft
C Zone length	37.5	ft
D Anode length/Cond. Bar	63	ft
E Anode width	0.75	in.
F Anode resistance	0.08	Ω/ft
G Conductor bar length	37.5	ft
H Conductor bar width	0.5	in.
I Conductor Bar Resistance	0.0175	Ω/ft

2E=IR

$IR_{tot} \leq 300$ mV

Anode

$R_A = R_S L$

$R_S = 0.08\ \Omega/ft$

$L = 31.5$ ft

$= 2.52\ \Omega$

$I_A = \rho_I S_A L$

$\rho_I = 1.5\ mA/ft^2$

$S_A = 2.083$ ft

$L = 31.5$ ft

$= 98.4375$ mA

$E_A = I_A R_A / 2$

$= 124.0313$ mV

Conductor Bar

$R_C = R_C L$

$R_C = 0.0175\ \Omega/ft$

$L = 18.75$ ft

$= 0.328125\ \Omega$

$I_C = \rho_I S_C L$

$\rho_I = 1.5\ mA/ft^2$

$S_C = 18.75$ ft

$L_A = 31.5$ ft

$= 885.9375$ mA

$E_A = I_C R_C / 2$

$= 145.3491$ mV

Total IR

$IR_{tot} = E_A + E_C$

$= 269.4$ mV ≤ 300 mV? **OK**

Zone Current Draw $= \rho_I L_z W / 1000$

$\rho_I = 1.5\ mA/ft^2$

$L_z = 37.5$ ft

$W = 63$ ft

$= 3.54375$ A

Example 2

Center Feed Design Calculations

A	Maximum Design Current Density	2	mA/ft^2
B	Anode Spacing	1.000	ft
C	Anode length/Cond. Bar	38.5	ft
D	Anode width	0.75	in.
E	Anode resistance	0.8	Ω/ft

2E=IR

$IR_{tot} \leq 300$ mV

Anode

$R_A = R_S L$

$R_S =$ 0.8 Ω/ft

L= 19.25 ft

= 15.4 Ω

$I_A = \rho_I S_A L$

$\rho_I =$ 2 mA/ft^2

$S_A =$ 1.000 ft

L= 19.25 ft

= 38.5 mA

$E_A = I_A R_A / 2$

= 296.45 mV ≤300 mV? OK

Component Resistances		
Mesh Anode		
1/4"		Ω/ft
1/2"	0.12	Ω/ft
3/4"	0.08	Ω/ft
1"		Ω/ft
Conductor Bar		
1/4"	0.049	Ω/ft
1/2"	0.0175	Ω/ft
3/4"		Ω/ft
1"		Ω/ft

Example 3

End Feed Design Calculations

C

A	Maximum Design Current Density	2	mA/ft^2
B	Anode Spacing	1,000	ft
C	Anode length/Cond. Bar	19	ft
D	Anode width	0.75	in.
E	Anode resistance	0.8	Ω/ft

Component Resistances		
Mesh Anode		
1/4"		Ω/ft
1/2"	0.12	Ω/ft
3/4"	0.08	Ω/ft
1"		Ω/ft
Conductor Bar		
1/4"	0.049	Ω/ft
1/2"	0.0175	Ω/ft
3/4"		Ω/ft
1"		Ω/ft

$2E = IR$

$IR_{tot} \leq 300$ mV

Anode

$R_A = R_S L$

$R_S = 0.8 \Omega/ft$

$L = 19$ ft

$= 15.2\ \Omega$

$I_A = \rho_I S_A L$

$\rho_I = 2\ mA/ft^2$

$S_A = 1{,}000$ ft

$L = 19$ ft

$= 38$ mA

$E_A = I_A R_A / 2$

$= 288.8$ mV ≤300 mV? OK

Example 4

Double Feed Design Calculations

A	Maximum Design Current Density	2	mA/ft^2
B	Anode Spacing	2.083	ft
C	Anode length/Cond. Bar	43	ft
D	Anode width	0.75	in.
E	Anode resistance	0.08	Ω/ft

Component Resistances		
Mesh Anode		
1/4"		Ω/ft
1/2"	0.12	Ω/ft
3/4"	0.08	Ω/ft
1"		Ω/ft
Conductor Bar		
1/4"	0.049	Ω/ft
1/2"	0.0175	Ω/ft
3/4"		Ω/ft
1"		Ω/ft

$2E=IR$

$IR_{tot} \leq 300$ mV

Anode

$R_A = R_S L$

$R_S = 0.08$ Ω/ft

$L = 43$ ft

$= 6.88$ Ω

$I_A = \rho_I S_A L$

$\rho_I = 2$ mA/ft^2

$S_A = 1.000$ ft

$L = 43$ ft

$= 86$ mA

$E_A = I_A R_A / 2$

$= 295.84$ mV ≤300 mV? OK

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14. ABSTRACT
In below-grade buildings and buried structures, such as hardened secure facilities used for munitions storage on U.S. Army installations, water intrusion can cause serious structural damage and destroy stored materiel. Standing water and high humidity inside the structures can interfere with operation of mission-critical equipment, corrode structural steel, and promote the growth of noxious molds. Electro-Osmotic Pulse (EOP) technology can reverse below-grade water intrusion through concrete pores. It has been successfully installed in military infrastructure ranging from family housing to steel-reinforced deep structures and tunnels. EOP has been shown to prevent below-grade moisture seepage through concrete and keep interior concrete spaces at or below 50 percent relative humidity. This project demonstrated the use of EOP technology to stop water intrusion into earth-covered ammunition magazines at Fort A.P. Hill, VA. This report describes the project objectives, equipment acquisition, setup, and system initialization. Preliminary observations of operation and lessons learned are presented.

15. SUBJECT TERMS
Fort A.P. Hill, VA, electro-osmotic pulse (EOP), earth-covered magazines, concrete, anodes, cathodes, moisture control, waterproofing

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