

TECHNICAL REPORT
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CPC PROGRAM FINAL REPORT
ELECTRICAL RESISTANCE PROBE CORROSION
SENSORS FOR IN-SITU ASSESSMENT FOR
WATERFRONT STRUCTURES
FY09 OSD PROJECT F09NV04



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This report of the electrical resistance (ER) probe corrosion sensor technology demonstration project has been prepared to present the findings of the ODUSD (AT&L), Director of Corrosion Policy and Oversight, FY09 project FNV04, Electrical Resistance (ER) Probe Corrosion Sensors for In-Situ Assessment for Waterfront Structures. Short-term test results indicate that the ER Probes generally function as intended, and several lessons have been learned in relation to installation and operation to prevent premature failure of the probes.					
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EXECUTIVE SUMMARY

This report of the electrical resistance (ER) probe corrosion sensor technology demonstration project has been prepared to present the findings of the Office of Secretary of Defense, Acquisition, Technology and Logistics (OSD AT&L), Director of Corrosion Policy and Oversight, FY09 project FNV04, Electrical Resistance (ER) Probe Corrosion Sensors for In-Situ Assessment for Waterfront Structures.

This report discusses the project phases of (1) planning and design, (2) installation, (3) system commissioning and testing, (4) analysis. Technical challenges discussed include (1) design and construction issues and (2) lessons learned.

Installation of the ER probes was completed in March 2010. Short-term test results indicate that the ER Probes generally function as intended, and several lessons have been learned in relation to installation and operation to prevent premature failure of the probes. Standard cathodic protection potential tests taken on the pier during the project period indicate that adequate corrosion protection has been generally achieved, and to date, correlate with significantly declining cumulative corrosion rates periodically measures on the probes. Long term monitoring of the probes will allow accurate evaluation of the long-term performance of these probes.

ACRONYMS AND ABBREVIATIONS

AgCl	Silver Chloride
CP	Cathodic Protection
DC	Direct Current
DLA-E	Defense Logistics Agency - Energy
DFSP	Defense Fuel Supply Point
ER (Probe)	Electrical Resistance (Probe)
FLC (formerly FISC)	Fleet Logistics Center (formerly Fleet Industrial Supply Center)
ICCP	Impressed Current Cathodic Protection
IR (drop)	Voltage (drop)
mil	0.001 inch
mpy	Mils per year
mV	Millivolts
NAVFAC	Naval Facilities Engineering Command
NAVFAC ESC	Naval Facilities Engineering Service Center
POL	Petroleum, Oil, and Lubricants
S/E	Structure-to-Electrolyte

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TABLE OF CONTENTS

1.0	INTRODUCTION	1
1.1	Background	1
1.2	Project Outcomes	2
2.0	TECHNICAL INVESTIGATION	3
2.1	ER Probe Technology	3
2.2	Acquisition Plan	4
3.0	RESULTS AND ANALYSIS	9
3.1	Post-Installation Tests	9
3.2	Economic Summary	12
3.3	Lessons Learned	14
4.0	CONCLUSIONS	15
	REFERENCES	16
	Appendix A. Approved Project Plan	A-1
	Appendix B. Installation Contract Statement of Work	B-1
	Appendix C. Test Data	C-1

LIST OF TABLES

Table 2-1. ER Probe Information	8
Table 3-1. Summary of Probe Test Data	10
Table 3-2. Initial ROI Calculation	13

LIST OF FIGURES

Figure 2-1. Typical ER probe used for this project.	3
Figure 2-2. Schematic of ER probe installation	5
Figure 2-3. Encapsulation of probe connectors. Not visible are the probe bodies extending through holes in the work surface	5
Figure 2-4. Probe with encapsulated connector	6
Figure 2-5. Probe with attached silver-silver chloride reference electrode (blue tube)	7
Figure 2-6. Pre-assembled conduit system	7
Figure 2-7. Typical test box (red arrow)	8
Figure 3-1. Damaged control probe. Note missing probe tip.	11
Figure 3-2. Corrosion of ER probe connector.	12

1.0 INTRODUCTION

This project demonstrated the effectiveness of electrical resistance (ER) probe corrosion sensors as an alternative means to monitor the cathodic protection (CP) system effectiveness on waterfront structures where voltage (IR) drop errors could not be eliminated from structure-to-electrolyte potential test measurements. This report was prepared to present the findings of the project.

The ER probes for this demonstration project were installed on two fuel piers on a Naval Base in Guam. Recent standards published by the National Association of Corrosion Engineers (NACE) have indicated acceptance of monitoring devices such as coupons, electrical resistance probes, and linear polarization resistance probes in lieu of the standard reference electrodes. Demonstration of this technology will serve to directly gauge the effectiveness of electrical resistance probes as a viable alternative to using standard silver-silver Chloride (SSC) reference electrodes in determining the adequacy of CP protection of waterfront structures.

Proper installation, operation, and maintenance of cathodic protection systems on buried submerged metallic waterfront structures are necessary to ensure adequate corrosion protection of the structure. Essential to the proper maintenance and operation of CP systems are periodic inspections of the CP rectifiers and equipment and potential tests of the structures to determine the CP system effectiveness. Although underwater inspections of submerged waterfront structures are conducted on a six or seven year cycle, improved corrosion monitoring systems are needed to detect any accelerated corrosion that may occur between inspections.

This technology demonstration project was funded by a grant from the Corrosion Policy and Oversight Office in the Office of the Secretary of Defense (OSD). Periodic testing of the ER probes was performed concurrently with periodic inspections of the CPS normally conducted as part of the Defense Logistics Agency - Energy (DLA-E) centrally managed CP Program. The Naval Facilities Engineering Service Center (NAVFAC ESC), now the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC), managed the project design, installation, and system testing.

1.1 Background

Proper maintenance and operation of CPS, monthly or bimonthly inspections, and preventive maintenance of the CPS rectifiers and equipment, are essential to ensure adequate protection of the structure to prevent corrosion caused failures. Current “state of the practice” in DOD and the private sector for submerged waterfront structures is to physically connect a portable multi-meter and reference electrode to the CP system and perform a dip cell survey to measure system potentials with the rectifiers “on” in accordance with NACE Standard SP0176 ^[1]. In a dip cell survey, potential measurements of submerged structures are taken with portable reference electrodes placed in the water adjacent to the structures being tested.

With the rectifiers “on” and the CP currents not interrupted, “on” potential readings often contain an error known as voltage (IR) drop error. IR drop error results from the interaction of the cathodic protection current with the electrolyte resistance. One way of accounting for this error is

to momentarily interrupt the cathodic protection current and measure the potential immediately after interruption. This “instant-off” potential is substantially free of IR drop error.

The piers used for this demonstration project are protected by two impressed current CP systems each with an average current output of over 400 amperes, but commercially available current interrupters are manufactured for a maximum of 100 amperes. Instead, interruption of the system requires three people in communication by cell phone or radio. One person to take the test measurements and one person at each rectifier to simultaneously turn them off and back on during the testing process at each test point. This procedure is not feasible for normal maintenance operations. Hence, potentials are normally taken with the rectifiers “on” and adequate protection is determined based upon the experience of the CP engineer.

Even in cases where current interruption is possible, there may be other sources of current at that location such as those from nearby cathodic protection systems, stray currents, or telluric currents that can introduce IR errors in the test measurements. Dip cell surveys provide average potential readings of nearby piles, but may not reflect the true potential in obscure or shielded parts of the pile geometry, e.g. inside of the H-pile flange. Resistance probes have been developed that will allow direct measurement of the corrosion rate of a structure, and can be used to indicate the effectiveness of CP in the obscure areas. A successful demonstration of resistance probes will allow the CP system to be monitored by just one person.

Recent standards published by NACE have indicated acceptance of monitoring devices such as coupons, electrical resistance probes, and linear polarization resistance probes in lieu of the standard reference electrodes. Much of the focus for such devices has been on their use in soil to monitor pipelines and tanks because of the hazards resulting from corrosion caused leaks. Little has been focused on its application for monitoring waterfront structures.

1.2 Project Outcomes

The anticipated outcomes of the project were to:

1. Demonstrate the technical and economic feasibility of the ER probe as a monitoring/testing tool for evaluating CPS effectiveness.
2. Provide an analysis of the cost effectiveness, benefits, and lessons learned regarding the applicability of ER probes on waterfront structures.
3. Transition the technology for use on other Navy and DOD installations with waterfront structures that utilize cathodic protection systems if successfully implemented during this project in Guam.
4. Develop or revise as appropriate, Navy Design Policies, Unified Facilities Criteria Documents and Guide Specifications related to cathodic protection, and post this report on the DOD CorrDefense website.

2.0 TECHNICAL INVESTIGATION

2.1 Electrical Resistance (ER) Probe Technology

An ER probe monitoring system consists of an electrical resistance meter, usually with data logging functions, connected to a probe. The meter may be permanently installed to provide continuous information, or may be portable to gather periodic data from a number of locations. This technique operates by measuring the change in electrical resistance of a metallic element immersed in a product media relative to a reference element sealed within the probe body. If the corrosion occurring in the vessel under study is roughly uniform, a change in resistance is proportional to an increment of corrosion. Although universally applicable, the ER method is uniquely suited to corrosive environments having either poor or non-continuous electrolytes such as vapors, gases, soils, hydrocarbons, and non-aqueous liquids.

Figure 2-1 illustrates the fixed process probe that was selected for this study. This ER probe has a thin walled cylindrical sensing element which is welded onto a body of the same material. No other materials are in contact with the corrosive medium. Welds are vacuum annealed during assembly to minimize corrosion effects. The probe may be used in aggressive organic or inorganic fluids over the entire pH range.



Figure 2-1. Typical ER probe used for this project.

2.2 Acquisition Plan

This technology demonstration project was funded by a grant from the Corrosion Policy and Oversight Office in the Office of the Secretary of Defense (OSD). **Appendix A** contains the original OSD approved Project Plan. The Naval Facilities Engineering Service Center (NAVFAC ESC) managed the project design and installation, and also continues to monitor the long-term performance of the system.

The ER probes were installed at the Delta/Echo Pier complex located in Guam, Marianas Islands. The existing CPS consists of two impressed current rectifiers and ten deep well anode beds located along the shoreline of the Delta/Echo Pier complex installed to protect the submerged steel pier support piling and mooring dolphin steel sheet piling. The probes were installed in five different locations along the Delta/Echo Pier complex in order to gauge the CPS effectiveness of the submerged steel pier components at different parts of the complex. Periodic ER probe measurements were compared with standard silver-silver chloride (SSC) electrodes permanently mounted adjacent to the ER probes as well as with measurements taken during routine periodic dip cell tests using portable SSC electrodes. Successful operation of the ER probes will validate their use as an alternative method for monitoring submerged steel waterfront structures.

2.2.1 Project Planning/Design

Some important considerations for the pier ER probe installations included:

- Geometrical sizing and shaping the sensor to be suitable for the pier salt water environment.
- Placement of the sensors in various sections of the pier pilings where they may be shielded from the CP system and the SSC electrode during dip surveys.
- Properly mounting the probes to the pier structure to prevent mechanical damage.
- Effects of stray current interference on the probe.
- Installation of a control probe to measure corrosion rates outside the influence of the pier CP system.
- Installation of test boxes to facilitate testing.

ER probes with a ten (10) year instead of the two (2) year life indicated in the project plan (Appendix A) were selected to account for exposure to the highly corrosive seawater environment and effects of stray current from the high output current CP system before the probes were connected to the CP system. The ER probes and structure terminal connections were installed, at five prescribed locations three feet below mean low tide level on selected H-piles and sheet piles at the Delta/Echo Piers. **Figure 2-2** illustrates a typical installation.

Protection of the probe connectors from exposure to moisture was paramount as failure of the connector would render the probe useless. The electrical connector between the probe and the test wires was encapsulated with epoxy in a plastic conduit on-shore prior to installation to prevent exposure of the connector to the saltwater and protect the connection from corrosion (**Figures 2-3 and 2-4**).

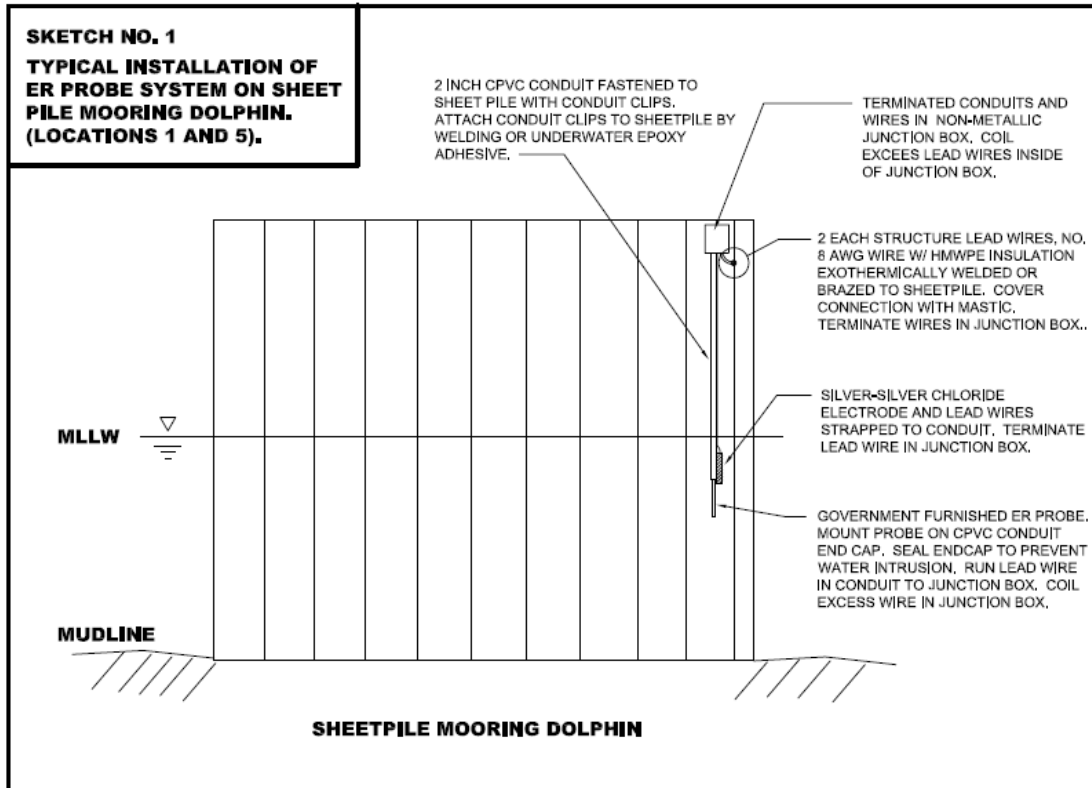


Figure 2-2. Schematic of ER probe installation



Figure 2-3. Encapsulation of probe connectors. Not visible are the probe bodies extending through holes in the work surface



Figure 2-4. Probe with encapsulated connector

A secondary monitoring system was provided for the ER probe installation on the pier to serve as a comparison. The secondary monitoring system included the installation of a standard SSC reference electrode in close proximity to each ER probe as shown in **Figure 2-5**.

The completed probe/silver chloride reference electrode assembly was mounted to the planned submerged sections of electrical conduit on shore prior to installation, again, to prevent water intrusion into the conduit system (**Figure 2-6**). The intent of this process was to ensure that this assembly would be installed such that an open end of the conduit system would not be submerged below water during installation, thereby minimizing water intrusion into the conduit system.

The test wires for the SSC electrodes were run together in the conduit system with the ER probe test wires and two structure test lead connections to a conveniently located terminal box (**Figure 2-7**). This overall monitoring system would allow the ability to test/correlate the test results from the ER probe and a standard SSC electrode. The test box would also serve as a connection point between the probe and the protected structure after the effects of stray current interference were evaluated. A control probe was installed nearby the pier, but outside the influence of the pier CP system.



Figure 2-5. Probe with attached silver-silver chloride reference electrode (blue tube)



Figure 2-6. Pre-assembled conduit system

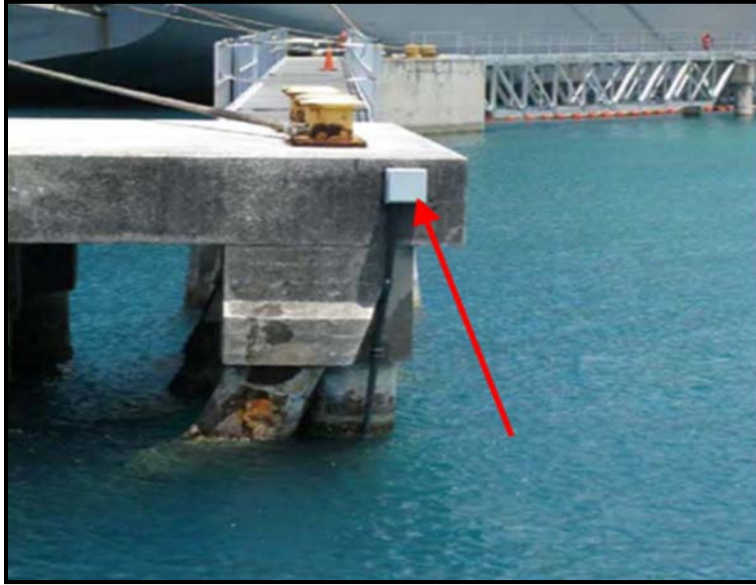


Figure 2-7. Typical test box (red arrow)

2.2.2 Procurement and Installation

Installation was planned for accomplishment by contract change order with a contractor, Shaw Environmental, already on-site executing a pier fender system repair project. For the purposes of this demonstration project, the ER probes were purchased by NAVFAC ESC and furnished to the contractor as Government Furnished Equipment. **Table 2-1** summarizes the details of the ER probes used in this project. All other materials such as test wires, electrical conduits, and test boxes were provided by the contractor. **Appendix B** includes the contractor statement of work including the installation drawings and sketches. Installation was completed in March 2010.

Table 2-1. ER Probe Information

PROBE SER #	METER PROBE ID #	PART #	DATE	ELEMENT TYPE	ALLOY TYPE	MULTI- PLIER	CHECK	INITIAL
10627	627	ER00207001237503	5/7/2009	CT50	C1010	X25	794	138
10630	630	ER00207001237503	5/7/2009	CT50	C1010	X25	795	115
10631	631	ER00207001237503	5/7/2009	CT50	C1010	X25	791	105
10633	633	ER00207001237503	5/7/2009	CT50	C1010	X25	796	120
10634	634	ER00207001237503	5/7/2009	CT50	C1010	X25	794	121
10635	635	ER00207001237503	5/7/2009	CT50	C1010	X25	794	110

2.2.3 Commissioning and Monitoring

About one month after completion of all of the probe installations, NAVFAC ESC conducted the first commissioning tests. Prior to taking periodic measurements, the planned procedure was to leave the probes disconnected from the CP system to allow the probes to freely corrode and to measure the effects of cathodic protection interference from the Pier CP systems. Subsequently, on-site inspections and checks were conducted in conjunction with periodic on-site inspections of the CP systems.

3.0 RESULTS AND ANALYSIS

3.1 Post-Installation Tests

3.1.1 System Testing and Evaluation

Baseline test data for the ER probes were taken to be used as a basis for monitoring corrosion. Probe corrosion rates were measured just after installation, but prior to the CPS being re-energized. We intended to not connect the probes to the CP system for the first six months to allow the probes to freely corrode in the saltwater and evaluate the effects of CP stray currents on the probes. They would then be connected to the CP system and receive cathodic protection.

Periodic measurements of the probes with a proprietary electrical resistance meter and SSC electrode potentials taken in accordance with NACE SP0176 after the pier CP systems were energized are tabulated in **Appendix C**. ER Probe corrosion rate measurements are summarized in **Table 3-1**. After only five months of operation, significant CP system stray current effects on the probes were noted. Corrosion rates were so high that two of the probes, Nos. 630 and 631, had corroded past the limits of their useful lives (ten years) in only five months. The remaining three probes were also rapidly approaching the limits of their useful lives, requiring their immediate connection to the pier CP system ahead of the planned six month schedule (See **Table 3-1**). To accomplish this, one of the pier structure test leads in each test box was temporarily connected to the measurement terminals in the probe test lead connector, thus, connecting the probe to the CP system. This connection had to be temporarily removed in order to connect the ER meter to take a measurement as quickly as possible in order to minimize stray current effects. Typical measurement times were two to three minutes, and the probes were then immediately reconnected back to the CP system. Theoretically, connection of the probes to the CP system should result in mitigation of corrosion of the probe.

A control probe, No. 635, was installed in the vicinity, but outside the influence of the pier CP system. The intent of the control probe installation was to measure the free corrosion rate of the probe outside the influence of cathodic protection and its stray current effects. A few months after installation, the control probe tip was found physically damaged for causes unknown (**Figure 3-1**). A second control probe was installed, but without the epoxy encapsulation of the electrical connector between the probe and the test wires. This probe subsequently failed due to corrosion of the electrical connector (**Figure 3-2**). Corrosion products on the connectors introduce additional resistance into the probe measuring circuit. Since the resistance of an ER

Table 3-1. Summary of Probe Test Data

Probe ID Number	Corrosion Rate (mpy) [1]							
	27 April 2010	23 June 2010	20 September 2010	9 November 2010	17 April 2011	1 September 2011	8 November 2011	13 April 2012
627	14.07	19.5	19.2	15.43	9.41	7.66	7.06	5.07
630	16.93	23.7	[4]					
631	16.71	27.2	[4]					
633	24.84	23.1	17.2	14.58	9.66	7.96	6.92	5.05
634	27.04	27.5	20.4	17.33	0.84	[5]		
635	n/a [2]	[3]						

Table Notes:

[1] Probes installed March 2010 by Shaw Environmental.

[2] Control probe installed in April 2010.

[3] Meter probe check failed. Removed September 2010 and found physically damaged.

[4] Probe corroded past useful life. All remaining functional probes connected to the CP System.

[5] Meter probe check failed. Cause unknown.

probe is very low from the onset, any additional small amounts of resistance from corrosion product or poor connection can result in inaccurate measurements or failure. A third control probe may be installed in the future as part of the long term monitoring plan beyond the two year duration of this demonstration project.

Metal loss from the probes is cumulative over time. The electrical resistance meter measures the resistance and an algorithm calculates the cumulative corrosion rate over the period of time since the first measurement. Corrosion rates increased significantly shortly after the CP systems were energized due to the anticipated stray current effects. After the probes were connected to the CP system, the corrosion rates of the functioning probes have significantly declined and were still declining to date. The declining corrosion rates suggest that the CP system has mitigated corrosion of the probes, and the cumulative corrosion rates are anticipated to continue to decrease to negligible rates with time. The corrosion rate for probe No. 634 indicated a very low corrosion rate as compared to probe Nos. 627 and 633 after 12 months. This probe subsequently failed for causes unknown, although it is suspected that the electrical connector between the probe and test wire has failed similarly to the second control probe.

SSC electrode test results indicate that the piles are receiving adequate cathodic protection. Adequate cathodic protection is achieved when measured potentials are -800 mV or more negative when measured between the protected structure and the SSC reference electrodes immersed in the adjacent sea water as specified in NACE SP0176 section 4.3.1^[1]. Subsequent to connection to the pier CP system, declining ER probe corrosion rates to this point in time appear to correlate with the adequate SSC electrode cathodic protection potentials on the piles, and are therefore a viable alternative to monitoring CP system effectiveness.



Figure 3-1. Damaged control probe. Note missing probe tip.



Figure 3-2. Corrosion of ER Probe Connector.

3.2 Economic Summary

3.2.1 Original Estimated Return on Investment (ROI)

The original project plan proposal (Appendix A) estimated the project return on investment as follows:

1. Total Project Cost was estimated at \$180,000.
2. Useful Life Savings (ULS) is shown in **Table 3-2**. The paragraph following the table describes the savings:
3. Initial estimated discounted ROI computation (discounted at 7%) from the original project plan proposal is shown in **Table 3-2**.

Table 3-2. Initial ROI Calculation

Return on Investment Calculation							
Investment Required							180
Return on Investment Ratio						Percent	249%
Net Present Value of Costs and Benefits/Savings						62	510
							448
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	15		5		5	14	9
2	15		5		4	13	9
3	15		8		7	12	6
4	15		5		4	11	8
5	15		5		4	11	7
6	265		8		5	177	171
7	15		5		3	9	6
8	15		5		3	9	6
9	15		8		4	8	4
10	15		5		3	8	5
11	15		5		2	7	5
12	265		8		4	118	114
13	15		5		2	6	4
14	15		5		2	6	4
15	15		8		3	5	3
16	15		5		2	5	3
17	15		5		2	5	3
18	265		8		2	78	76
19	15		5		1	4	3
20	15		5		1	4	3

The background information and assumptions for the above ROI calculation are as follows:

1. Estimated costs for the ER Probe installation/testing for this project = \$180,000 (OSD funding = \$90,000).
2. Baseline annual maintenance cost estimated at \$15K based on periodic testing (“on” readings) twice per year (two-person crew plus pro-rated travel costs) and IR Free testing once per year (3-person crew plus pro-rated travel costs)
3. New system annual maintenance cost estimated at \$5K based on periodic testing (ER probes) twice per year (one-person plus pro-rated travel costs) and annual testing once per year (2-person crew plus pro-rated travel costs). Also included is a cost of \$3K to replace the probes every third year as the probes have a reported two year life.
4. Baseline includes cost for corrosion caused repairs identified during periodic underwater inspection surveys conducted about every six years. Repairs identified for waterfront facilities historically have ranged from \$250K to over \$1,000K. Although dip surveys indicate CP is generally adequate, it is uncertain if full protection is being achieved at obscure areas of the piles (e.g. inside the web of an H-pile). Therefore, if actual corrosion rates are not known, the lower repair estimate is used.

3.2.2 End of Project ROI Evaluation

The estimated end of project ROI is similar to the originally estimated ROI of 2.5 as shown in Table 3-2. Longer term monitoring beyond the two-year duration of this demonstration project will be necessary in order to accurately validate some of the assumptions made in the initial ROI calculation.

3.3 Lessons Learned

Several important lessons were learned during the course of the project:

- Select and install probes in locations to preclude physical damage. Avoid locations where floating debris and day to day operations can result in damage to the probes or test wiring system.
- Encapsulate the probe connection to the lead wire. It is imperative to do this for submerged applications to prevent water intrusion and corrosion of the connection.
- Pre-assemble sections of conduits to be submerged before installation. This is also necessary to prevent water infiltration into probe-lead wire connection.
- Connect the probe to the CP system as soon as practical after the CP system is energized in order to help ensure long-term operation. For probes to be installed in the vicinity of CP systems, particularly those operating at high CP system current levels, the potential for stray current effects is high.
- Design a good connection means between the probe and the CP system that will easily enable temporary disconnection to take measurements with the ER meter.
- If monitoring location is critical, it may be a good idea to provide a backup permanent reference electrode adjacent to the probe in the event the probe fails and cannot be immediately replaced.

3.4 Implementation

Based upon the successful two-year demonstration, recommended revisions will be submitted to subject matter experts and committees responsible for updating Navy Cathodic Protection Unified Facilities Criteria Documents and Guide Specifications. Documents that will be targeted include but are not limited to:

- Draft UFC 3-570-02 currently under revision. This manual will consolidate UFC 3-570-02N Electrical Engineering Cathodic Protection and UFC 3-570-02A Cathodic Protection
- UFGS 26 42 13.00 20 Cathodic Protection by Galvanic Anodes
- UFGS 26 42 19.00 20 Cathodic Protection by Impressed Current

This report will be posted on the NAVFAC Corrosion Control web page, the DOD CorrDefense website, and the Defense Technical Information Center.

4.0 CONCLUSIONS

This project investigated the effectiveness of the electrical resistance probes as a viable alternative to using standard Silver-Silver Chloride (SSC) reference electrodes for corrosion monitoring of waterfront structures. The objective was to evaluate the effectiveness of an ER probe in determining the adequacy of CP protection of waterfront structures. Based upon test results to date, the following is a summary of conclusions and lessons learned:

- Declining cumulative corrosion rates of the pier ER probes since their connection to pier CP system imply that corrosion of the probes is being mitigated by the CP system. The probes should be monitored beyond the original two-year project period to evaluate their long term effectiveness.
- The continued decline of pier ER probe cumulative corrosion rates to negligible levels over time validates the concept that the probes are a viable alternative to monitoring CP system effectiveness.
- ER probes installed to monitor pier CP systems are subject to stray current interference, and should only be allowed to freely corrode for a short period of time, and then immediately connected to the CP system to ensure long-term operation.
- For applications where the ER probe will be submerged, it is imperative that every effort be taken to prevent water intrusion into, and the subsequent corrosion of the connector between the probe and its lead wire.
- The ER probes should be mounted in a location and manner to minimize physical mechanical damage.
- Based on the results of this project, the ROI for use of ER Probes to monitor the effectiveness of CP on waterfront structures is about 2.5. Longer term monitoring will be necessary to accurately validate some of the assumptions made in the ROI calculation.

REFERENCES

- [1]** NACE SP0176-2007 Corrosion Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated with Petroleum Production. Houston, Texas: 2007

APPENDIX A

APPROVED PROJECT PLAN

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DOD Corrosion Prevention & Control (CPC) Program FY2009

PROJECT PLAN

ER Probe Corrosion Sensors for In-Situ Assessment for Waterfront Structures

Revised July 29, 2008

Submitted By:

Naval Facilities Engineering Service Center

PROJECT F09 NV04

1. STATEMENT OF NEED

PROBLEM STATEMENT: Current CP criteria for adequate protection established by industry and DOD require potential measurements to be free of voltage (IR) drop errors. Many waterfront CP system installations do not include a means for eliminating the IR drop errors, and adequacy of protection cannot be accurately assessed. Underwater inspections have noted failures on structures thought to be adequately protected based on periodic dip cell potential surveys.

Dip cell survey, potential measurements of submerged structures taken with portable reference electrodes placed in the water adjacent to the structures being tested often contain an error known as IR Drop error. IR Drop error results from the interaction of the cathodic protection current with the electrolyte resistance. One way of accounting for this error is to momentarily interrupt the cathodic protection current and measure the potential immediately after interruption. This “instant-off” potential is substantially free of IR Drop error. A limitation of the dip cell survey is that the test measurements indicate average potentials of all structure elements in the vicinity and may not accurately indicate potentials in obscure or shielded areas (e.g. inside the flange of an H-pile).

It is not possible to feasibly interrupt cathodic protection current on waterfront structures on which sacrificial anodes are directly connected to the structure. Also, many waterfront structures are protected by impressed current CP systems with current outputs far exceeding the ratings of commercially available current interrupters, again inhibiting the ability to interrupt the CP current. It is difficult to ascertain with confidence the adequacy of protection on such facilities.

IMPACT STATEMENT: Without a means for eliminating the IR drop errors adequacy of protection cannot be accurately assessed. Inability to accurately assess the waterfront structure CP levels increases risk of corrosion failures of these structures. In addition to repairs to the structure, a corrosion failure will also result in adverse impacts due to:

- Downtime and loss of service of the structure (unavailability during repairs) hampering the ability to perform the mission in support of war fighting efforts, adversely impacting operational readiness. Delaying of repairs can result in significant increase in scope.
- Increased probability of damage to the waterfront structure or ship due to improper functioning of a steel pile fender system because of corrosion failure of a submerged section.
- Potential safety hazards from catastrophic failure caused by unseen corrosion of submerged structure elements.
- Decreased system capacities. Significant corrosion of structural members can result in reduction of load handling capability and hamper the ability to service ships berthed at the structure.

Periodic maintenance and testing costs will continue to grow unless more efficient time saving technology can be utilized and accurately assess corrosion protection adequacy.

2. PROPOSED SOLUTION

TECHNICAL DESCRIPTION: Improved corrosion (cathodic) protection (CP) monitoring systems are needed for numerous Navy waterfront structures. Current state of the practice in DOD and the private sector is to physically connect a portable multi-meter and reference electrode to the CP system to and perform a dip cell survey to measure system potentials and current flow. With no ability to interrupt the CP currents, “on” readings with significant IR error must be taken, with adequate protection being assumed based upon the experiences of the CP engineer. In addition dip cell surveys provide average potential readings of nearby piles, but may not reflect the true potential in obscure or shielded parts of the pile geometry, e.g. inside of the H-pile flange.

Even in cases where current interruption is possible, there may be other sources of current at that location such as those from nearby cathodic protection systems, stray currents or telluric currents that can introduce IR errors in the test measurements. Resistance probes have been recently developed that will allow direct measurement of the corrosion rate of a structure, and can be used to indicate the effectiveness of CP in the obscure areas.

Recent standards published by the National Association of Corrosion Engineers have indicated acceptance of monitoring devices such as coupons, electrical resistance probes, and linear polarization resistance probes in lieu of the standard reference electrodes. Much of the focus for such devices has been on their use in soil to monitor pipelines and tanks because of the hazards resulting from corrosion caused leaks. Little has been focused on its application for monitoring waterfront structures.

This project proposes to demonstrate the use of recently developed electrical resistance probes to improve the corrosion monitoring system for the Delta-Echo POL pier on the Naval Base Guam. The piers are protected by two impressed current CP systems each with an average current output of over 400 amperes. Commercially available current interrupters are manufactured for a maximum of 100 amperes. Interruption of the system requires three people in communication by cell phone or radio. One person to take the test readings, and one person at each rectifier to simultaneously turn them off and back on during the testing process at each test point. Installation of resistance probes will allow the CP system to be monitored by just one person if shown to be successful. Probes will be installed in obscure locations, e.g. inside of an H-pile flange. Wiring will terminate in a “smart test station” to allow measurement of the probe data. Resistance probes may be installed on other waterfront structures in Guam that are protected by galvanic CP systems for comparison as necessary. The performance of the electrical resistance probes will be compared to a standard silver-silver chloride electrode and, if feasible, an IR free probe consisting of an integrated coupon and reference electrode. The product to be demonstrated will be the Rohrback Cosasco Corrosometer Probe (**Figure 1**).

(Proprietary picture has been removed)

Figure 1. Electrical Resistance Probe

RISK ANALYSIS: The risk in completing this technical effort is low. The technology is mature and commercially available. However, these probes, designed primarily for use in soil applications will be used in saltwater. Our proposed effort will assess this impact.

PROPOSED PHASES:

The project can be accomplished in a single phase. As part of the COMNAVMAR Fuel system CP system management program, a routine dip cell potential survey will be conducted at the piers as a baseline prior to installation of the ER probes. The ER probe system will be designed by NAVFAC ESC engineers and then installed as part of the COMNAVMAR Fuel system CP system management program. Test measurements will be taken periodically during routine CP system testing. After sufficient exposure selected probes will be removed and will be analyzed in the laboratory for overall condition and correlation with previous test measurements. This will enable an inference of the corrosion rate of pier piles and will provide a validation of the functioning cathodic protection system.

EXPECTED DELIVERABLES AND RESULTS/OUTCOMES: The primary deliverable, if successful, will be the Rohrbach Cosasco Corrosometer Probe as an inspection/ testing tool for assessing and maintaining adequate cathodic protection to control corrosion on waterfront structures. The secondary deliverable is an accurate assessment of the Delta-Echo Pier CP system effectiveness along with reduced time required for testing. An inference of the corrosion rate of pier piles from the probes can be made and this will validate the performance of the cathodic protection system. Successful implementation of this technology system on the Delta-Echo Pier in Guam will validate its transition for use on other Navy and DOD waterfront structures that utilize cathodic protection systems. Where appropriate, Navy Design Policies, Unified Facilities Criteria Documents and Guide Specifications, and Lessons Learned Reports will be developed and posted on the NAVFAC portal corrosion control and the DOD CorrDefense websites. A final report describing the details and results of the project will be submitted to OSD and distributed to Navy as well as tri-service design agencies.

PROGRAM MANAGEMENT: We propose the following project management team:

Co-Project Managers: NFESC

Stakeholders include NAVFAC (Naval Facilities Engineering Command) and the Commander Naval Infrastructure Command (CNIC).

Customer (end-user): Defense Energy Support Center (DESC), Naval Base Guam, and various DOD waterfront structure owners.

PROPOSED PROJECT SCHEDULE

Phase	Agent	Months After Funding Receipt
Evaluate corrosion sensors	NAVFAC ESC	1
Procure corrosion sensors and conduct preliminary tests	NAVFAC ESC	2 - 4
Prepare design and specifications for installation of sensors and instrumentation on wharf in Guam	NAVFAC ESC	2 - 6
Install corrosion monitoring sensors system into bulk fuel storage tank	NAVFAC ESC / contractor	8 - 9
Periodically obtain test data to determine initial performance	NAVFAC ESC	9 - 22
Final Report & Closeout	NAVFAC ESC	23 - 24

3. COST/BENEFITS ANALYSIS

a. Funding Requested: \$90K

Phase: Task	OSD (FY 09 \$K) *	DESC/NFESC (FY09 \$K)**
1A: Research ER probe specs, design probe installation, conduct baseline survey	20	20
1B: Install Probes	15	15
1C: Inspect Probe Installation	15	
1D: Periodically obtain test data to determine probe stability		20
1E: Document periodic test results (reports), prepare final report	40	35
Total Project Cost (TPC)	90	90

- * Includes \$90K of organic efforts to be accomplished in-house in FY09.
- ** Portion of anticipated FY09 matching funding from DESC to NFESC to manage cathodic protection systems at COMNAVMAR Fuels. Conducting baseline survey, installation of probes, periodic testing, and report writing will be integrated with routine COMNAVMAR CP system management efforts.

b. Return-On-Investment Computation

- 1) Total Project Cost is estimated at \$180,000.
- 2) Useful life savings and discounted ROI computation (discounted at 7%) is shown in the following table:

Return on Investment Calculation

Investment Required	180
Return on Investment Ratio	2.49
Percent	249%
Net Present Value of Costs and Benefits/Savings	62 510 448

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	15		5		5	14	9
2	15		5		4	13	9
3	15		8		7	12	6
4	15		5		4	11	8
5	15		5		4	11	7
6	265		8		5	177	171
7	15		5		3	9	6
8	15		5		3	9	6
9	15		8		4	8	4
10	15		5		3	8	5
11	15		5		2	7	5
12	265		8		4	118	114
13	15		5		2	6	4
14	15		5		2	6	4
15	15		8		3	5	3
16	15		5		2	5	3
17	15		5		2	5	3
18	265		8		2	78	76
19	15		5		1	4	3
20	15		5		1	4	3

Notes to Table:

1. Baseline annual maintenance cost estimated at \$15K based on periodic testing (on readings) twice per year (two-person crew plus pro-rated travel costs) and IR Free testing once per year (3-person crew plus pro-rated travel costs)
2. New system annual maintenance cost estimated at \$5K based on periodic testing (ER probes) twice per year (one-person plus pro-rated travel costs) and annual testing once per year (2-person crew plus pro-rated travel costs). Also included is a cost of \$3K to replace the probes every third year as the probes have a reported two year life.
3. Baseline includes cost for corrosion caused repairs identified during periodic underwater inspection surveys conducted about every six years. Repairs identified for waterfront facilities historically have ranged from \$250K to over \$1,000K. Although dip surveys indicate CP is generally adequate, it is uncertain if full protection is being achieved at obscure areas of the piles (e.g. inside the web of an H-pile). Therefore, if actual corrosion rates are not known, the lower repair estimate is used.

IMPLEMENTATION

Transition Approach. Demonstration of this technology will serve to directly gauge the effectiveness of the Electrical Resistance probes manufactured by Rohrback Cosasco Systems. Successful implementation of this system on the Delta-Echo Piers in Guam will validate its use on other DOD cathodically protected waterfront facilities. Where appropriate, recommended criteria change requests to Navy Design Policies on cathodic protection will be submitted to the Tri-service Facilities Criteria panel who oversees all criteria revisions. Targeted criteria will include but not be limited to:

UFC 3-570-02N Electrical Engineering Cathodic Protection
UFC 3-570-06 Operation and Maintenance of Cathodic Protection Systems
UFGS 26 42 13.00 20 Cathodic Protection by Galvanic Anodes
UFGS 26 42 19.00 20 Cathodic Protection by Impressed Current

A final report describing the details, results of the project, and lessons learned will be prepared and submitted to OSD and distributed to Navy as well as tri-service cathodic protection technical representatives. Copies of the report will be posted on the NAVFAC ESC portal corrosion control and the DOD CorrDefense websites. It is intended that the results of this project will be beneficial for future use by all of NAVFAC, as well as tri-service installation management personnel when planning and designing cathodic protection projects for maintainability in order to realize long term facility life.

ROI Validation. We will validate return-on-investment by comparing current cathodic protection test methods with the more sophisticated and easier to conduct methodology proposed. Also laboratory analysis of test coupons will enable an inference on the corrosion rate of the pier structure in obscure areas of the structure to reduce the incidents of identification of corrosion required repairs resulting from inadequate protection.

APPENDIX B

INSTALLATION CONTRACT STATEMENT OF WORK

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ER Probe Corrosion Sensors for Assessment of Waterfront Structures

Background

Current cathodic protection (CP) criteria for adequate corrosion protection, established by industry and DOD, require potential measurements to be free of voltage (IR) drop errors. Many waterfront CP system installations do not include a means for eliminating the IR drop errors, and adequacy of protection cannot always be accurately assessed. Improved CP monitoring systems are needed for numerous Navy waterfront structures. Recent standards published by the National Association of Corrosion Engineers have indicated acceptance of monitoring devices such as coupons, electrical resistance probes, and linear polarization resistance probes in lieu of the standard reference electrodes. This project proposes to demonstrate the use of recently developed electrical resistance (ER) probes to improve the corrosion monitoring system of the Delta and Echo POL piers on Naval Base Guam. Demonstration of this technology will serve to directly gauge the effectiveness of the Electrical Resistance probes manufactured by Rohrback Cosasco Systems as a viable alternative to using standard Silver-Silver Chloride (SSC) reference electrodes in determining the adequacy of CP protection of waterfront structures.

Government Provided Materials

- Rohrback Cosasco electrical resistance probe. The shaft of the probe is about 18 inches long with a $\frac{3}{4}$ " connector to the cable. 50 feet of connecting cable will be provided.



Tasking

The contractor will install the ER Probes (government furnished), SSC reference electrodes, and structure terminal connections, at five prescribed locations three feet below mean low tide level on selected H-piles at the Delta and Echo piers at the Defense Fuel Supply Point in Guam, Marianas Islands as shown in the attached site plan and three sketches. Selection of the H-piles is not critical at Locations 2, 3, and 4, and the vendor can select any of the H-piles in the vicinity of the locations shown in the site plan. One of the limiting factors for pile selection is the maximum 50 ft. cable length. The probe and SSC electrodes shall be mounted in the inside of the H-pile flange. All leads from these points will be pulled through grey CPVC electrical conduit to a conveniently located terminal box. The submerged end and appropriate length of conduit should be prefabricated on-shore prior to installation to minimize water intrusion into the conduit.

Performance Period:

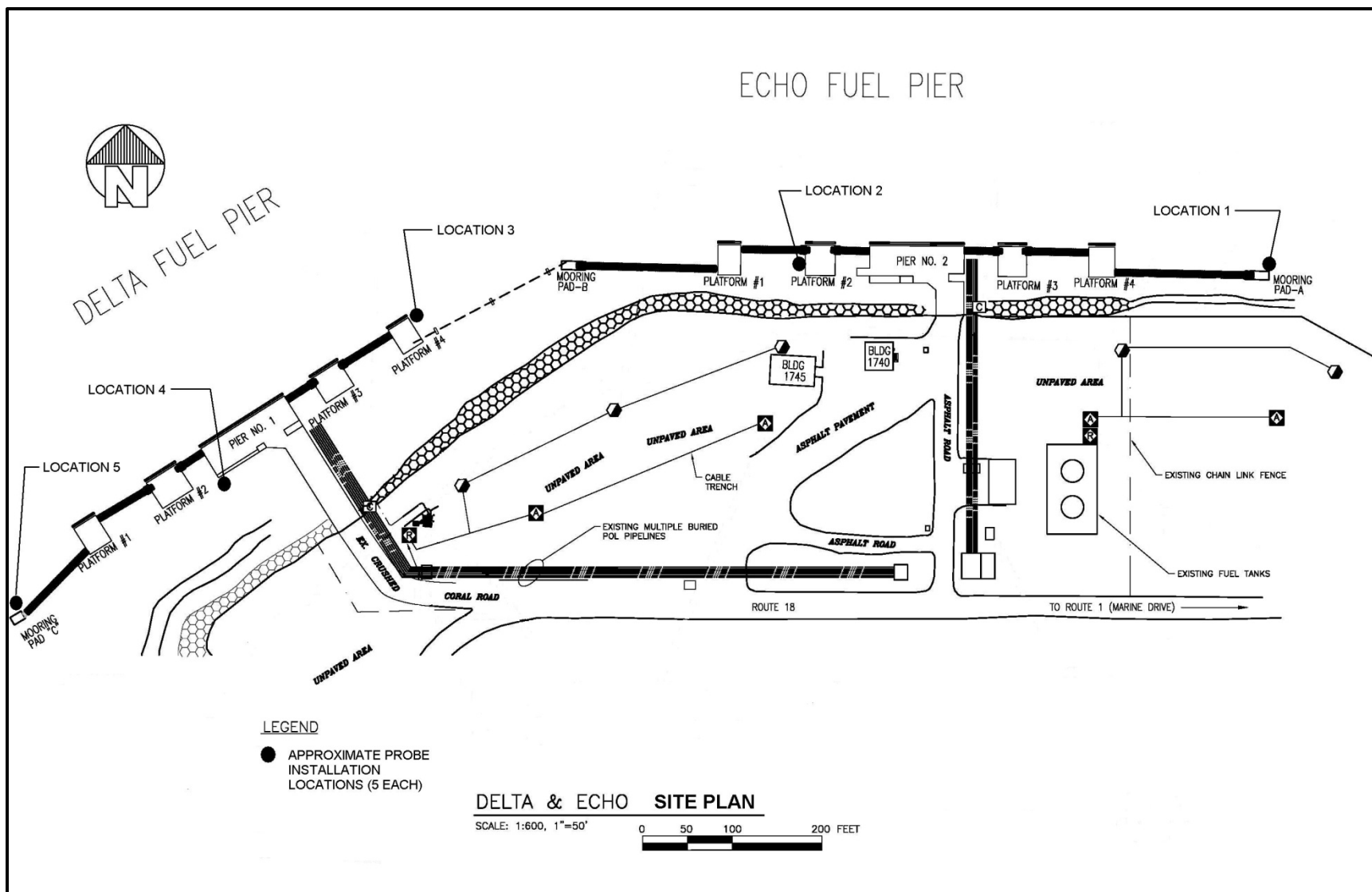
Estimated Start Date: February 2010

Completion Date: 90 days after contract award

Deliverables:

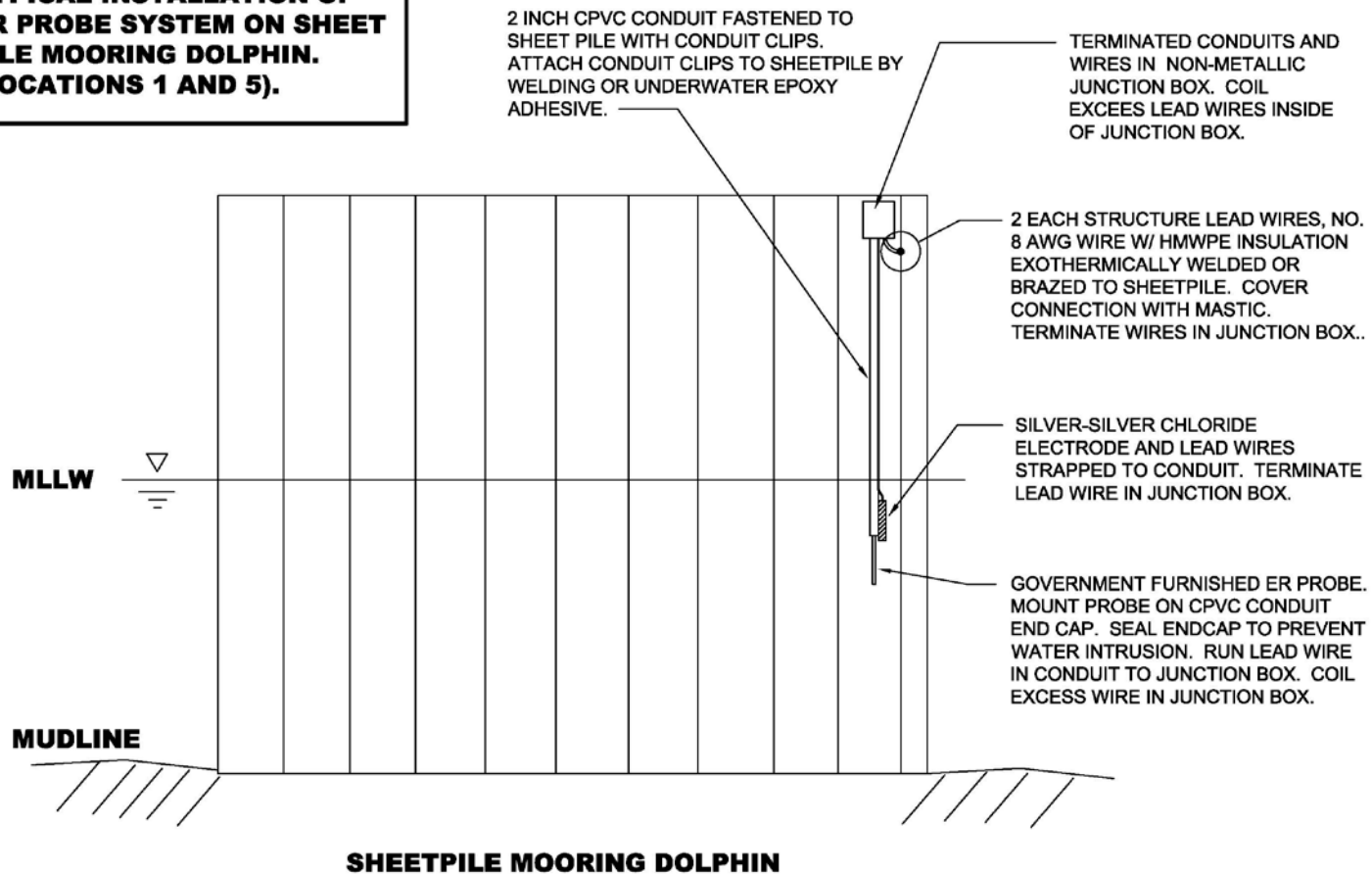
An installed ER Probe monitoring system at Delta and Echo piers

Point of Contact:



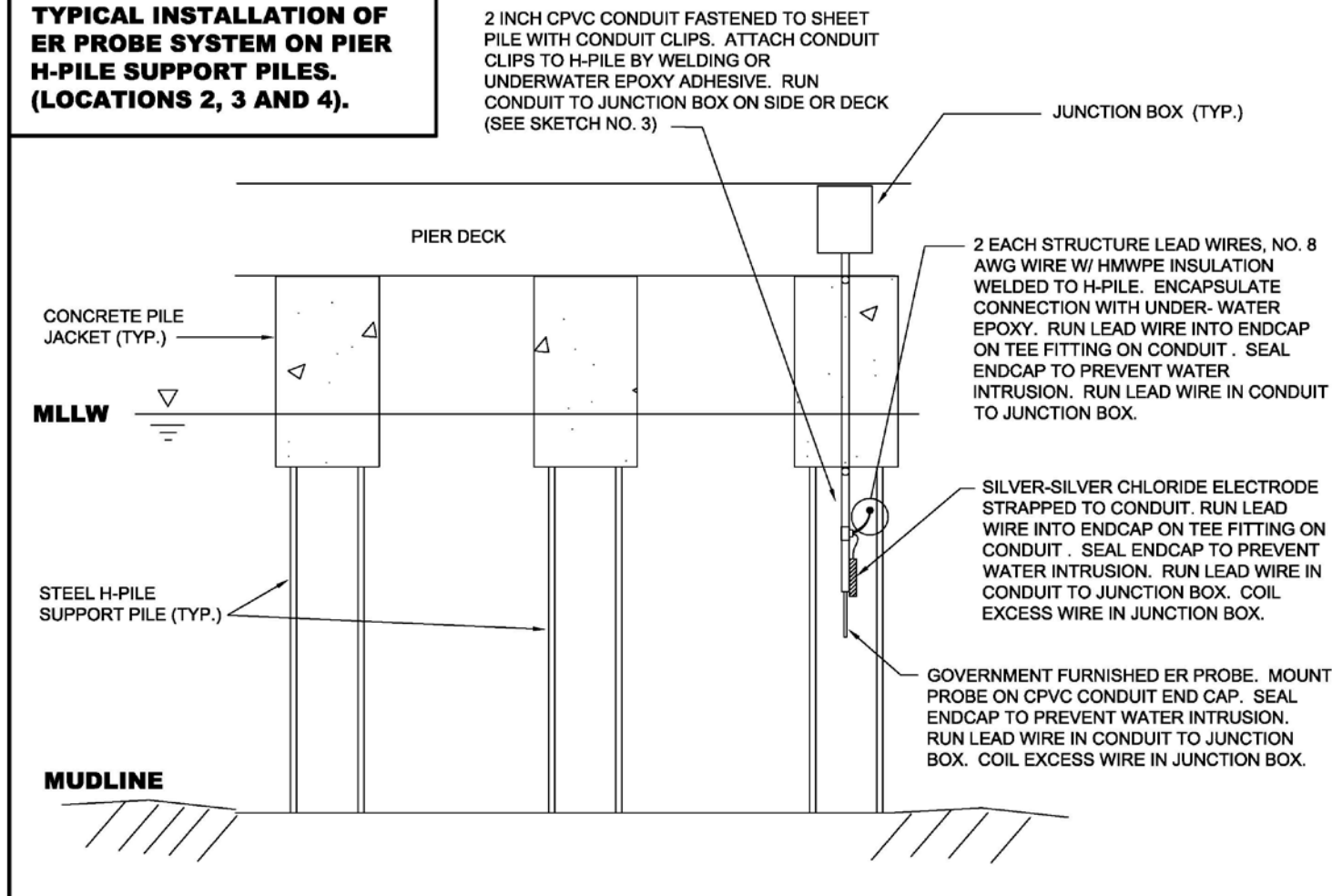
SKETCH NO. 1

**TYPICAL INSTALLATION OF
ER PROBE SYSTEM ON SHEET
PILE MOORING DOLPHIN.
(LOCATIONS 1 AND 5).**

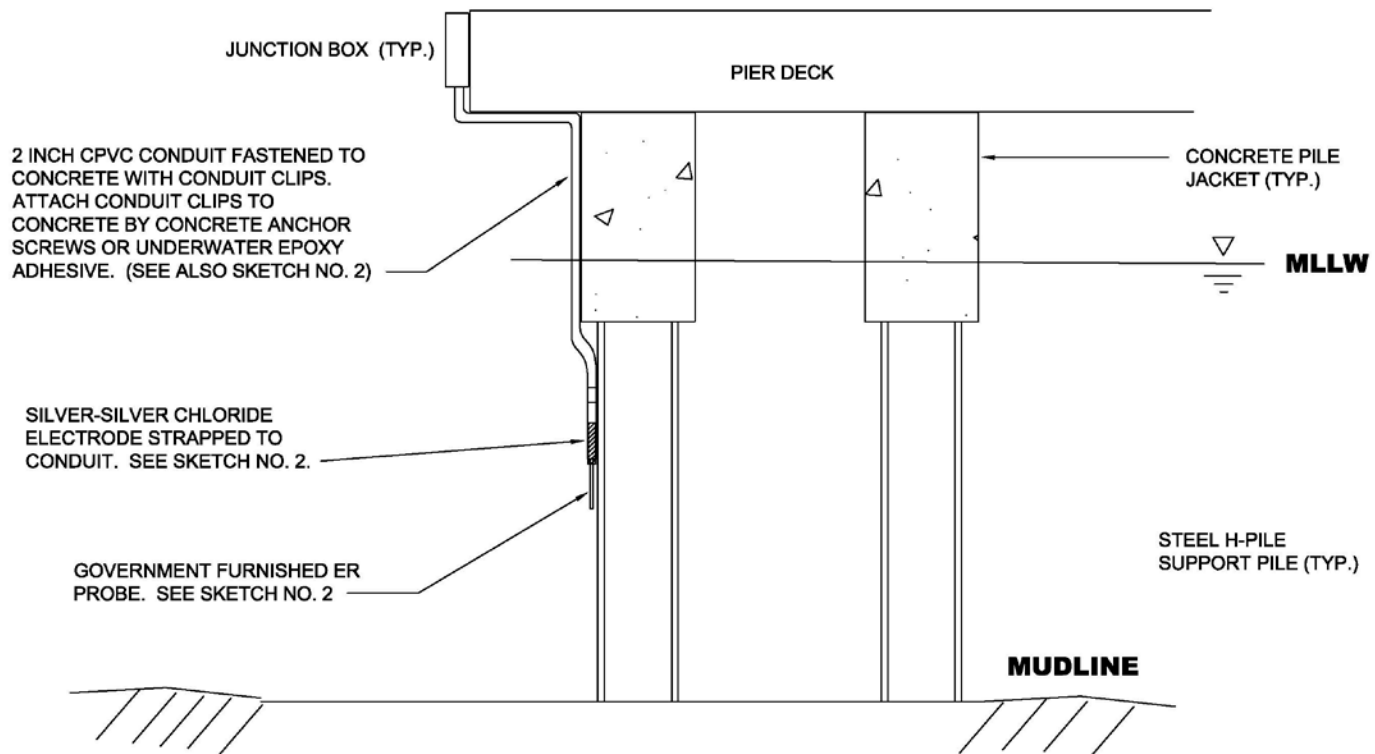


SKETCH NO. 2

**TYPICAL INSTALLATION OF
ER PROBE SYSTEM ON PIER
H-PILE SUPPORT PILES.
(LOCATIONS 2, 3 AND 4).**



SKETCH NO. 3
SIDE VIEW OF ER PROBE
SYSTEM ON PIER H-PILE
SUPPORT PILES.
(LOCATIONS 2, 3 AND 4).



APPENDIX C

TEST DATA

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TABLE C-1. ER PROBE/SILVER-SILVER CHLORIDE REFERENCE ELECTRODE TEST MEASUREMENTS

INITIAL INSP DATE	PROBE SER #	METER PROBE ID #	PART #	DATE	ELEMENT TYPE	ALLOY TYPE	MULTI- PLIER	CHECK	INITIAL	3 FEB 2010			27 APR 2010 (2)		
										METER READING	METAL LOSS (mil)	CORR RATE (mpy)	METER READING	METAL LOSS (mil)	CORR RATE (mpy)
2/3/2010	10627	627	ER00207001237503	5/7/2009	CT50	C1010	X25	794	138	383	9.57	n/a	511	12.77	14.07
2/3/2010	10630	630	ER00207001237503	5/7/2009	CT50	C1010	X25	795	115	351	8.77	n/a	505	12.62	16.93
2/3/2010	10631	631	ER00207001237503	5/7/2009	CT50	C1010	X25	791	105	346	8.65	n/a	498	12.45	16.71
2/3/2010	10633	633	ER00207001237503	5/7/2009	CT50	C1010	X25	796	120	361	9.02	n/a	361	14.67	24.84
2/3/2010	10634	634	ER00207001237503	5/7/2009	CT50	C1010	X25	794	121	313	7.82	n/a	559	13.97	27.04
2/3/2010	10635	635	ER00207001237503	5/7/2009	CT50	C1010	X25	794	110	356	8.9	n/a	587 (3)	7.95	n/a

METER PROBE ID #	23 JUN 2010			20 SEP 2010				9 NOV 2010				17 APR 2011			
	METER READING	METAL LOSS (mil)	CORR RATE (mpy)	METER READING	METAL LOSS (mil)	CORR RATE (mpy)	AgCl POT (mV)	METER READING	METAL LOSS (mil)	CORR RATE (mpy)	AgCl POT (mV)	METER READING	METAL LOSS (mil)	CORR RATE (mpy)	AgCl POT (mV)
627	693	17.3	19.5	863	21.57	19.2	-1009	855		15.43	-1044	835	20.87	9.41	-1049
630	727	18.2	23.7	>1000	(5)	(5)	-1042	>1000	(5)	(5)	-1058	>1000	(5)	(5)	-1065
631	778	19.5	27.2	>1000	(5)	(5)	-1081	881	22.02	17.49	-1114	>1000	(5)	(5)	-1135
633	728	18.2	23.1	790	19.8	17.2	-1091	807		14.58	-1096	825	20.62	9.66	-1091
634	750	18.8	27.5	824	20.6	20.4	-1063	843		17.33	-1066	354	8.85	0.84	-1075
635	(4)			(4)											

METER PROBE ID #	1 SEP 2011				8 NOV 2011				13 APR 2012			
	METER READING	METAL LOSS (mil)	CORR RATE (mpy)	AgCl POT (mV)	METER READING	METAL LOSS (mil)	CORR RATE (mpy)	AgCl POT (mV)	METER READING	METAL LOSS (mil)	CORR RATE (mpy)	AgCl POT (mV)
627	866	20.87	7.66		881	22.03	7.06		827	20.67	5.07	-1055
630												
631												-1134
633	863	21.57	7.96		849	21.23	6.92		803	20.07	5.05	-1098
634	(6)											
635												

TABLE C-2. SECOND CONTROL PROBE TEST DATA

INITIAL INSP DATE	PROBE SER #	METER PROBE ID #	PART #	DATE	ELEMENT TYPE	ALLOY TYPE	MULTI- PLIER	CHECK	INITIAL	8 MAR 2011			22 MAR 2011			26-Apr-11		
										METER READING	METAL LOSS (mil)	CORR RATE (mpy)	METER READING	METAL LOSS (mil)	CORR RATE (mpy)	METER READING	METAL LOSS (mil)	CORR RATE (mpy)
3/7/2011			ER00207001237503	5/7/2009	CT50	C1010	X25			294	n/a	n/a	367	9.17	47.45	(7)		

Notes to Tables C-1 and C-2:

- (1) Tested in office
- (2) Probes installed March 2010 by Shaw Environmental
- (3) Probe 635 (control probe on fence) tested 4/28/10
- (4) Control probe failed probe check. Sep 10 Inspection - probe damaged
- (5) Probe corroded past useful life
- (6) Probe failed. Cause unknown.
- (7) Probe failed. Inspection of probe revealed corroded connector.