PB2001-102192

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICE CENTER
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EVALUATION OF A CHEMICAL HUMECTANT APPLIED TO AN EXISTING METALLIZED ZINC CATHODIC PROTECTION SYSTEM

SEPTEMBER 2000

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of a Chemical Humectant Applied to an Existing Metallized Zinc Cathodic Protection System		5. Report Date September 2000 6. Performing Organization Code
7. Authors Arron Rambach, P.E.		8. Performing Organization Report No. EA 65-680848 F2000 RM 999 (subjob 30003)
9. Performing Organization Name and Address California Department of Transportation (CALTRANS) Division of Materials Engineering and Testing Services 5900 Folsom Blvd. Sacramento, California 95819-4612		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address California Department of Transportation Sacramento, CA 95814		13. Type of Report and Period Covered Final 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report documents the application of a humectant chemical to an existing metallized zinc cathodic protection system at the Yuba Pass Separation and Overhead (03-NEV-80-KP R95.65). The cathodic protection system has been in operation since 1994, but has not achieved performance standards in accordance with criteria of the National Association of Corrosion Engineers (NACE). The metallized zinc cathodic protection system has not been able to shift the potential electronegatively 100 mV from the native potential. Since the system has not achieved NACE standards, corrosion of the reinforcing steel has not been halted. Caltrans has reached the conclusion that effective cathodic protection polarization has not been achieved because the electrical resistance at the zinc/concrete interface is sufficiently high, such that not enough current is conducted from the zinc anode to the reinforcing steel.

The purpose of this research project is to evaluate the effectiveness of a chemical humectant to improve the performance of the existing cathodic protection system. It is theorized that the humectant, which is hygroscopic, will attract moisture from the air to the zinc/concrete interface. As a result, the resistance of the zinc/concrete interface should be reduced, cathodic protection current should increase, and polarization of the reinforcing steel should improve.

Initial results, over a two-month period, of the humectant treatment indicate that polarization has increased at some reference cell locations but not at all reference cells. Initial results also show that the resistance of the zinc/concrete interface has been substantially reduced. However, the true effectiveness of the humectant treatment will be monitored over time.

17. Key Words		18. Distribution Statement
humectant, Enhance-3™, metallized zinc, cathodic protection, Yuba Pass		No Restriction
19. Security Clasif. (of this report) Unclassified	20. Security Clasif. (of this page) Unclassified	21. No. of Pages

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ACKNOWLEDGEMENTS

The author would like to acknowledge the following Division of Materials Engineering and Testing Services personnel for their assistance during various phases of the project: Doug Parks, Robert Reis, Mike Tolin, Ken Koebbe, and Arlena Gutierrez. In addition, the author would like to acknowledge the following individuals for their assistance: Tim Kennelly of the California Department of Water Resources. Lastly, the author would like to thank the contractors, subcontractors, and consultants involved with this project.

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INTRODUCTION

This report documents the application of a humectant chemical to an existing metallized zinc cathodic protection system at the Yuba Pass Separation and Overhead. The bridge number, district, county, route, kilometer post (post mile), and expense authorization are as follows: Bridge No. 17-0023R, 03-NEV-80-KP R95.65 (PM R59.44), and EA 65-680848. The existing cathodic protection system has been in operation since 1994, but has not achieved polarization shift standards established by the National Association of Corrosion Engineers (NACE) Recommended Practice RP0290-90, "Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures". The California Department of Transportation (Caltrans) theorizes that the existing cathodic protection system has not been able to achieve the 100 mV polarization shift in the electronegative direction from the native potential due to the high resistance at the zinc/concrete interface.

OBJECTIVE

The objective of this research project was to treat the surface of the metallized zinc concrete at Bent 4R with a humectant chemical in order to reduce the electrical resistance of the zinc/concrete interface. Caltrans has theorized that the resistance across this zinc/concrete interface is high (conversely, the conductance across this interface is low such that effective cathodic protection current cannot be delivered) for two primary reasons:

1. The concrete is dry, especially near the surface of the concrete. Excessively dry concrete lacks moisture that is necessary to facilitate ionic flow, transport reactants such as oxygen, and distribute oxidation products at the anode. Furthermore, moisture is able to evaporate through the porous metallized zinc, leaving the zinc/concrete interface especially dry.

2. Zinc oxides collecting at the zinc/concrete interface due to the cathodic protection corrosion process buildup and further increase the resistance of the concrete.

The Albany Research Center of the U.S. Department of Energy and the Oregon Department of Transportation have researched various humectant chemicals[1]. Their laboratory and field-testing have shown that application of humectant chemicals can combat the two primary causes of high resistant concrete mentioned above. Humectant chemicals, substances that promote the retention of moisture, will penetrate the porous zinc anode, remain at the zinc/concrete interface, and promote ionic conductance of the concrete electrolyte. The result is improved cathodic protection, recognized by reduction in circuit resistance as well as achieving the NACE criteria of 100-mV polarization shift.

The objective of this research project was to determine whether application of a humectant chemical improves the performance of an existing metallized zinc cathodic protection system. Short-term performance and initial results are discussed in this report. However, the true effectiveness of the humectant, as determined by long-term performance, will be monitored over time. If long-term performance proves that the humectant enhances the moisture retaining ability of the reinforced concrete for a sufficient service life, then Caltrans may incorporate humectant treatment as a standard application for metallized zinc cathodic protection systems.

SITE DESCRIPTION AND BACKGROUND

The Bridge site is located in Northern California on Interstate 80 in Nevada County at the Yuba Pass Separation and Overhead, kilometer post R95.65 (post mile R59.44). The site elevation is approximately 1600 meters (5,250 feet). Seasonal rainfall and snowfall occur during the fall and winter months. The average annual precipitation measured at a nearby observation site is 1815 mm/year (71.5 inches/year). Summers are typically dry with low relative humidity (in comparison to a coastal region), while winters are cold and wet.

The Yuba Pass Separation and Overhead is comprised of a separate left and right bridge originally constructed in 1963. The bridges separate Interstate 80 from Route 20, which runs underneath Route 80 (see Photograph 1). The left (westbound) bridge is a four span 157-meter structure. The right (eastbound) bridge is a four span 137-meter structure. Each bridge consists of a reinforced concrete deck on steel I-beams that are supported by two reinforced concrete columns at three bents. (Humectant was applied to both columns at Bent 4 of the right structure.)

Both the left and right bridges are subject to deicing salt application during the winter months. Drainage of salt-contaminated deck runoff through deck drains adjacent to each bent, leakage of salt-contaminated water through the deck joints, and direct contact of the columns to salt-contaminated snow (from snow removal equipment) contribute to the high chloride exposure of the bridge columns and I-beam bearing pedestals of both bridges. Consequently, both bridges have a history of corrosion and corrosion-related repair.

In 1994, installation of a metallized zinc cathodic protection system was completed. The system was installed on Bent 4 of the right bridge (See Photograph 2). The metallized zinc system was part of a larger bridge substructure rehabilitation project. In addition to the metallized zinc system, the substructure rehabilitation project also included the installation of another type of cathodic protection system (Eltech "Elgard 210") at Bent 4L as well as application of a silane penetrant sealer to the other bents[2].

Both the metallized zinc (Bent 4R) and the Elgard (Bent 4L) cathodic protection systems have been in operation since 1994. Caltrans monitors their performance by conducting periodic (typically on a semi-annual or annual basis) polarization decay testing to determine whether 100 mV polarization shift criteria as established by NACE is achieved. Since 1994, the Elgard system has been performing well with polarization shifts in excess of 100 mV. However, the metallized zinc system has not performed as well as the Elgard system. Polarization shifts were consistently below 100 mV, indicating the inability to halt corrosion. Polarization decay testing has been conducted in various months over the last five years, indicating that seasonal variations do not influence polarization much. In other words, the zinc system has been unable to polarize 100 mV regardless of the month or season.

Caltrans has attempted to improve polarization of the zinc system by increasing the driving voltage of the constant-voltage rectifier, but increased output has not improved polarization significantly. It is believed that increasing the driving voltage has little effect on polarization and current delivered due to the high circuit resistance (particularly at the zinc anode/concrete interface). The driving voltage has been increased to as high as 17 volts, but was reduced to 10 volts for safety precautions and fear of accelerated anode consumption. On the other hand, the Elgard cathodic protection system operates at approximately 2 volts while achieving 100 mV polarization shifts. Caltrans has concluded that dry concrete and zinc oxide corrosion products at the anode/concrete interface have impeded the ability of the concrete electrolyte to conduct current from the zinc anode to the reinforcing steel.

FIELD WORK FOR HUMECTANT APPLICATION

On May 24, 2000, humectant was applied by an airless sprayer to the entire metallized zinc surface of Bent 4R. The corrosion engineering consultant, Corrosion Restoration Technologies Inc., recommended use of the Enhance-3™ humectant. Enhance-3™ is a lithium bromide aqueous solution that is clear, colorless, odorless, and generally non-hazardous. The product was packaged in 19-L (5-gallon) plastic containers.

The corrosion engineering consultant hired a licensed painting contractor, Jeffco Painting & Coating Inc., to apply the humectant. A subcontractor was hired to manage the lane closure and traffic control. A lane closure for Route 20 underneath the bridge was required during the humectant application.

On the day of the treatment, the weather was cool, dry, and sunny. The entire application, including set-up and take down, took about four hours (8:00 a.m. to 12 p.m.). However, actual spraying time was only about 30 minutes. The entire metallized zinc surface (including two columns and bent cap) were sprayed. Total surface area sprayed was approximately 130 m^2 (1400 ft^2). At an application rate of 9.8 m^2/L (400 ft^2/gal), approximately 14 L (3.8 gal) of Enhance-3™ was applied. The painter estimated that approximately 10% of material was lost due to overspray (see Photograph 3). As recommended by the corrosion engineering consultant and humectant supplier, only one coat was necessary to saturate the concrete surface with humectant. Photographs 3 through 5 show the application of the humectant.

The paint subcontractor used the following equipment to apply the humectant chemical:

Table 1: Equipment Used by Subcontractor to Apply Humectant

Paint Spay Equipment	Graco EP 1000 Electric Airless Sprayer, 0 to 21 mPa (0 to 3,000 psi) Graco Silver Spray Gun Graco 4/25 Reversible Spray Tip 6.25 mm (0.25 in) supply hose
Generator	Makita Portable, 6 kilowatts
Boom Man-Lift	JLG, 600S, 225 kg (500 lb.), 18 m (60 ft) length
Personal Protection Equipment	Tyvex, 14120, Dupont body suit and spray hood Generic splash eyeguards Latex rubber gloves 3M, 6000 Series respirator with organic vapor cartridges

In general, the field work for the humectant application occurred without any major problems or delays. Initially, the supply hose malfunctioned at a fitting, but the painting subcontractor readily rectified that situation. The weather was favorable (dry, sunny, and minimal wind). The painter reported that he did not smell the humectant chemical as he was spraying, but he could feel a "slick, soapy substance" on his fingertips and hands.

The colorless chemical did not change the color of the metallized zinc surface other than to give the appearance that the surface was wet. The surface looked wet until the humectant penetrated the porous zinc. The site was visited one month after treatment, and the metallized zinc surface no longer appeared wet. Instead, the concrete surface looked dry with some scattered wet spots. The appearance changed from wet to dry because the humectant migrated from the surface to the zinc/concrete interface. However, even though the concrete looked dry two months after application, according to the corrosion engineering consultant and humectant supplier, the humectant would remain at the zinc/concrete interface. It is expected that over time, as the useful life of the humectant is reached, the humectant chemical will slowly diffuse into the bulk concrete.

EVALUATION OF EFFECTIVENESS OF HUMECTANT TREATMENT

The effectiveness of the humectant treatment can be evaluated by comparing the performance of the metallized zinc cathodic protection system prior to application with the performance of the system after the concrete has been treated. Performance of the cathodic protection system can be observed in terms of potential shift of the reinforcing steel and circuit resistance.

Potential Shift of Reinforcing Steel

Reinforcing steel potential was measured using a Fluke 87 multi-meter in comparison with reference cells. Two graphite reference cells were permanently embedded in the concrete when the metallized zinc cathodic protection system was constructed in 1994. In addition, three half cell ports were constructed for use of portable copper/copper sulfate (CSE) reference cells. In other words, the potential of the reinforcing steel could be measured at five locations (two graphite reference cells plus three CSE reference cells).

As indicated earlier in this report, prior to the application of the humectant, the metallized zinc cathodic protection system was not performing effectively. Since original installation in 1994, the system has been unable to polarize the reinforcing steel 100 mV in the electronegative direction in accordance with NACE standards, even when operated at a driving voltage as high as 17 volts. Four-hour polarization decay tests consistently showed the potential shift in the 30-mV to 80-mV range, which is less than the 100-mV NACE criteria.

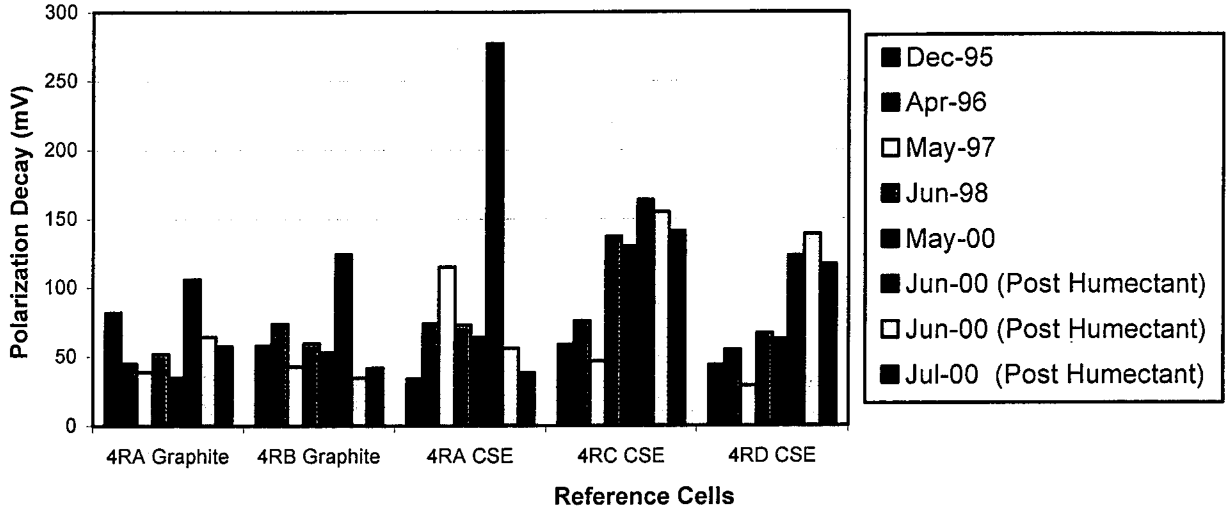
As measured by four-hour polarization decay testing, potential shifts have increased since the metallized zinc anode was treated with humectant on May 24, 2000. In the two-month period since treatment, 100-mV polarization has occurred for some of the reference cell locations, but not for all five reference cells. (Historically, 100-mV polarization had not been achieved at any of the five reference cell locations prior to application of humectant.) Table 2 shows the potential readings and polarization for the most recent four-hour test. Graph 1 illustrates that the humectant has improved polarization at reference cells 4RC and 4RD (CSE), but not at 4RA (graphite and CSE) or 4RB.

Table 2: Potential and Polarization Measurements after Humectant Application*

Half Cell Port Location	Half Cell Type	On Potential (mV)	Instant-Off Potential (mV)	IR Drop (mV)	4-Hour Potential (mV)	Polarization (mV)
4RA	Graphite	-168.5	-155.6	12.9	-98	57.6
4RB	Graphite	-113.2	-96.8	16.4	-55	41.8
4RA	CSE	-440	-380	60	-341.5	38.5
4RC	CSE	-448	-416	32	-274.7	141.3
4RD	CSE	-374	-352	22	-235.4	116.6

*Four-hour polarization decay testing on 7/13/00. Measurements taken with Fluke 87 multimeter with negative lead connected to reference cell and positive lead connected to reinforcing steel. Graphite reference cells permanently embedded in concrete. Portable copper/copper sulfate (CSE) reference cells inserted in half cell ports.

Graph 1: Polarization Decay



At this point in the short-term evaluation of the effectiveness of the humectant treatment, it is unclear why the humectant treatment has improved the potential shift of the reinforcing steel to greater than 100 mV for only some of the reference cells. It is possible that the metallized zinc anode has disbonded (i.e., delaminated) from the surface of the concrete at those locations (locations A and B) where 100-mV polarization was not achieved. In fact, in one area (immediately below location A) the metallized zinc anode has been removed entirely by abrasion form snow blower spray. At locations where the zinc anode has delaminated from the concrete due to improper bonding, cathodic protection polarization will be minimized due to a large circuit resistance at the delamination, even if humectant collects at the delaminated zinc/concrete interface.

Caltrans will adjust the voltage output of the zinc cathodic protection system in an effort to achieve 100-mV polarization at all reference cell locations. Voltage levels may need to be adjusted periodically or seasonally, as environment influences the resistance of the concrete.

Circuit Resistance

In addition to potential shift of the reinforcing steel, the effectiveness of the humectant application can also be evaluated in terms of circuit resistance. The circuit resistance of the metallized zinc cathodic protection system is calculated by dividing the driving voltage by the current delivered from the rectifier. The driving voltage is measured by using the Fluke 87 multimeter to determine the potential difference between the positive and negative sides of the rectifier. The current delivered is measured by using the Fluke 87 multimeter to determine the voltage loss across a 0.005-ohm shunt that was installed in series with the cathodic protection circuit.

Prior to application of the humectant, circuit resistance measurements for the metallized zinc system varied substantially from 10 ohms to over 100 ohms. On the other hand, circuit resistance of the Elgard cathodic protection system was much more stable and was in the 1-ohm to 3-ohm range. The higher circuit resistance for the zinc system is consistent with the fact that the zinc system had not been able to achieve 100-mV polarization prior to humectant treatment, whereas the Elgard has consistently achieved 100-mV polarization.

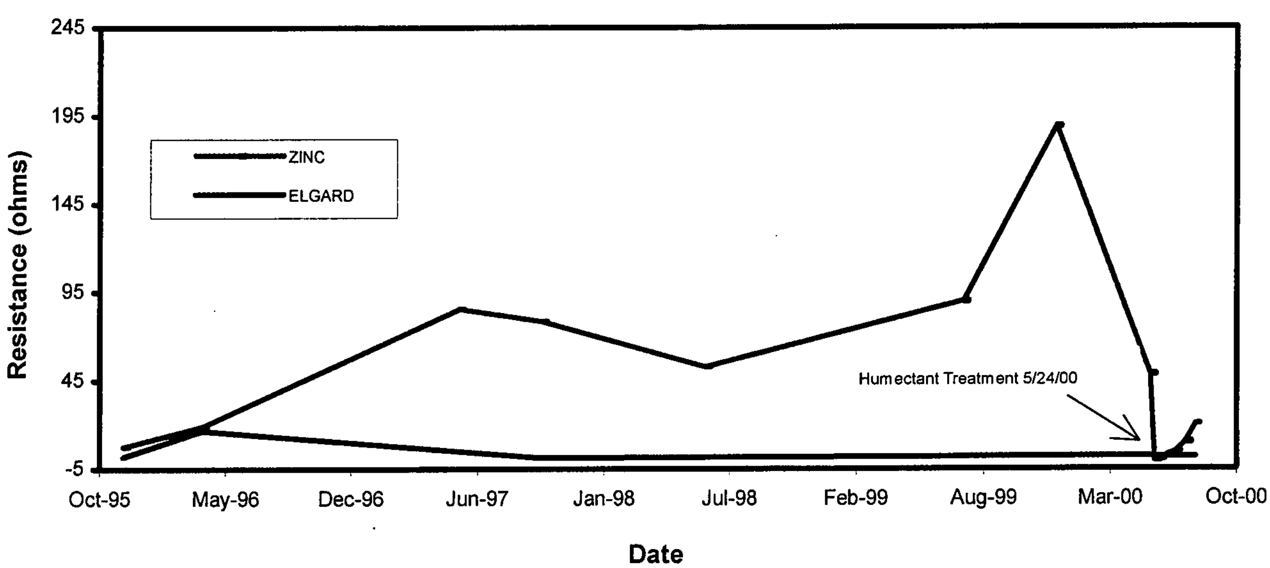
After the humectant was applied to the zinc system on May 24, 2000, the circuit resistance dropped from the 10 ohm to 100-ohm range to less than 20 ohms. However, as shown below in Table 3 and Graph 2, the circuit resistance has started to increase in the two months following treatment. For the most part, the weather has been dry and sunny since the humectant treatment was applied. The low relative humidity (compared to a coastal region) may also play a role in the increase in circuit resistance since treatment.

Table 3 compares circuit resistance between the zinc and Elgard systems as well as before and after treatment with the humectant. The table also expresses circuit resistance in units of ohm-m^2, which is calculated by multiplying the circuit resistance in ohms by the surface area of the anode. Graph 2 provides a visual comparison of the circuit resistance of the two cathodic protection systems.

Table 3: Circuit Resistance

Date	Zinc		Elgard	
	(ohms)	(ohms-m^2)	(ohms)	(ohms-m^2)
12/6/95	7.3	1,518	2.06	358
4/10/96	19	3952	1.7	296
5/23/97	85.7	17,826	?	?
9/30/97	78.4	16,307	1.51	263
6/17/98	52.75	10,972	1.86	324
7/29/99	90	18,720	1.92	334
12/22/99	189	39,312	2.6	452
5/18/00	48.9	10,171	2.38	414
5/24/00	Enhance-3™ Humectant Treatment			
5/25/00	0.05	1	1.95	339
6/1/00	1.1	229	2.2	383
6/28/00	4.43	921	1.90	330
7/13/00	10.25	2,134	2.03	353
7/29/00	20.2	4,202	1.94	337

Graph 2: Circuit Resistance



In the two months after treatment with the humectant, the circuit resistance of the zinc system has decreased substantially to a level that is comparable to the circuit resistance of the Elgard system. Long-term monitoring is needed to determine whether the circuit resistance since treatment remains low, or continues to increase. Although not known for certain, a representative of Enhance-3™ suggested that it might take approximately 200 days for the humectant treated circuit to reach a stable resistance. Caltrans will continue to measure and monitor the circuit resistance to determine whether there is a correlation with season and climate.

CONCLUSIONS

1. Application of the Enhance-3™ humectant chemical occurred without any major problems or delays. The process was straightforward and safe. No hazards were encountered. It is expected that most trained licensed painting contractors could properly apply the chemical. Standard paint equipment may be used, and highly specialized equipment is not required.

2. In the two-month period since application of the humectant chemical to Bent 4R, potential shift of the reinforcing steel has improved compared to polarization prior to treatment. 100-mV polarization criteria established by NACE has been achieved at some of the reference cells locations, but not at all reference cells. It is possible that zinc delaminating from the concrete due to disbonding may be the cause of inadequate polarization at some locations.

3. In the two-month period since application of the humectant chemical to Bent 4R, circuit resistance of the metallized zinc cathodic protection system has decreased substantially compared to prior to treatment. However, initial results indicate that the circuit resistance has started to increase in the two-month period since treatment. Although not known for certain, a representative of Enhance-3™ suggested that it might take approximately 200 days for the humectant-treated circuit to reach a stable resistance.

RECOMMENDATIONS

1. Although initial results are promising, it is recommended that Caltrans continue to monitor the performance of the humectant for a longer period of time to determine its service life. Caltrans will continue to periodically measure the polarization, circuit resistance, and current delivered of the humectant-treated metallized zinc cathodic protection system.

2. It is recommended that Caltrans continues to monitor the system until the humectant-treated circuit reaches a stable resistance. It is also recommended that Caltrans continues to monitor the CP system to determine whether adjustment of the driving voltage improves polarization at all five reference cell locations.

3. If long-term performance proves that the humectant enhances the moisture retaining ability of the reinforced concrete for a sufficient service life, then it is recommended that Caltrans consider incorporating humectant treatment as a standard application of metallized zinc cathodic protection systems.

REFERENCES

1 B.S. Covino, Jr., G.R. Holcomb, S.J. Bullard, J.H. Russell, S.D. Cramer, U.S. Department of Energy, Albany Research Center, J.E. Bennett, JE Bennett Consulting, Inc., H.M. Laylor, Oregon Department of Transportation, "Electrochemical Aging of Humectant-Treated Thermal-Sprayed Zinc Anodes For Cathodic Protection", Paper No. 548, Corrosion 99.

2 Robert A. Reis, California Department of Transportation, "Construction Evaluated Report: Cathodic Protection Systems Installed on Substructure Surfaces", December 1995.

PHOTOGRAPHS

Photo 1: Yuba Pass Separation & Overhead (Bridges 17-0023 R/L). Left bridge in foreground, right bridge in back. Route 20 runs underneath the bridges and Route 80.

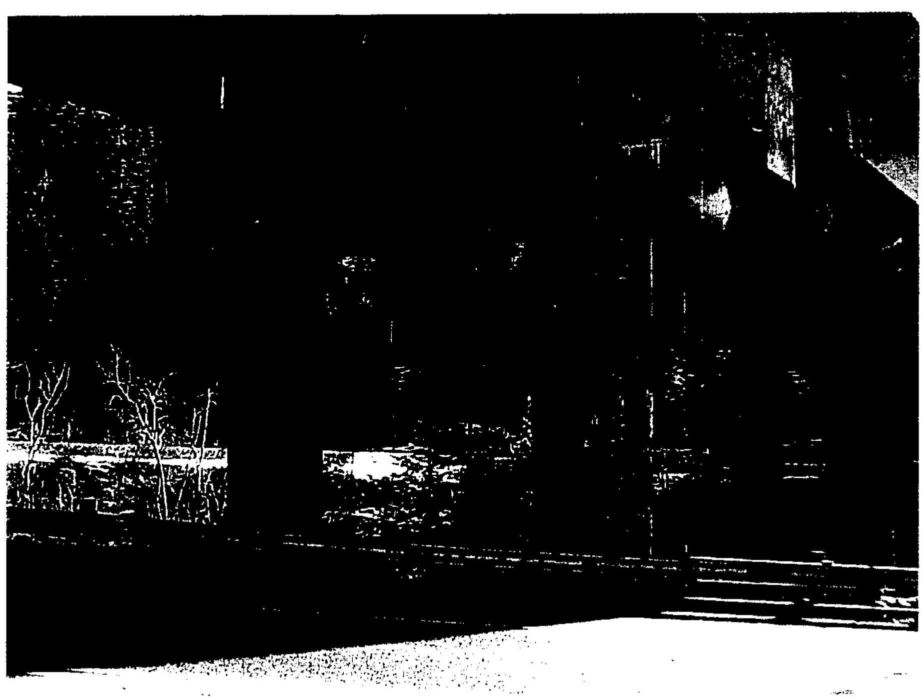


Photo 2: Bent 4 of Bridge 17-0023R showing metallized zinc coating. Photo taken 12/22/99.

Photo 3: Application of Enhance-3™ humectant by spray. The paint subcontractor estimated 10% overspray. Photo taken 5/24/00.

Photo 4: Application of Enhance-3™ humectant by spray. A 225 kg (500 lb.) JLG 600S man-lift with an 18-m (60-ft) extension was used to raise the painter. Photo taken 5/24/00.

Photo 5: Application of Enhance-3™ humectant by spray. A Graco EP 1000 electric airless sprayer was used. The spray gun was a Graco Silver spray gun with a 4/25 reversible tip. The humectant chemical was delivered with a 6.25 mm (0.25 in) supply line at 0 to 21 mPa (0 to 3,000 psi). Photo taken 5/24/00.