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R.A. Carello and D.M. Parks

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16. ABSTRACT

This report describes the application and testing of two separately installed metallized zinc cathodic protection (CP) systems: one applied to the deck and the other to the soffit of a reinforced concrete bridge that had been contaminated from deicing salt use on the top surface. Both installations are impressed current systems. The deck system was installed by state forces and the soffit system was installed by contract.

Documentation includes the CP designs, application parameters, and 3.6 years of field monitoring to determine the effectiveness of each system. The systems have been operating since November 1985.

Impressed current delivered through a metallized zinc, deck applied distribution anode has shown to be an effective bridge deck CP system.

Impressed current delivered through a metallized zinc, soffit applied distribution anode did not provide complete protection for the reinforcing steel due to the high electrical resistance of the soffit concrete.

Several successive years of below average precipitation during the study period, and the application of a slurry seal and a chipseal coat to the bridge deck CP system, affected the operation and ability to monitor both the deck and soffit CP system.

17. KEYWORDS

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DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY,
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CATHODIC PROTECTION OF A REINFORCED CONCRETE BRIDGE DECK AND SOFFIT USING METALLIZED ZINC

FINAL REPORT # FHWA/CA/TL-91/05
CALTRANS STUDY # F84TL04

Performed by .... Office of Environmental and Engineering Services, Corrosion Technology Branch

Supervised by .... Mas Hatano, P.E.

Principal Investigator .... Douglas M. Parks, P.E.

Co-investigator .... Richard A. Carello

Report Prepared by .... Richard A. Carello
Douglas M. Parks, P.E.

Douglas M. Parks, Chief
Corrosion Technology Branch

REGISTERED PROFESSIONAL ENGINEER
DOUGLAS M. PARKS
No.25696
Exp. 12/31/93
CIVIL
STATE OF CALIFORNIA

JOHN WEST, Chief
Division of New Technology,
Materials and Research

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in ^{2})	6.432 x 10 $^{-4}$	square metres (m ^{2})
	square feet (ft ^{2})	.09290	square metres m ^{2})
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (l)
	cubic feet (ft ^{3})	.02832	cubic metres (m ^{3})
	cubic yards (yd ^{3})	.7646	cubic metres (m ^{3})
Volume/Time (Flow)	cubic feet per second (ft ^{3}/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s ^{2})	.3048	metres per second squared (m/s ^{2})
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s ^{2})
Density	(lb/ft ^{3})	16.02	kilograms per cubic metre (kg/m ^{3})
Force	pounds (lb)	4.448	newtons (N)
	kips (1000 lb)	4448	newtons (N)
Thermal Energy	British thermal unit (Btu)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-lb)	.1130	newton metres (Nm)
	foot-pounds (ft-lb)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (° C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

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1.0 INTRODUCTION

Concrete normally provides excellent corrosion protection for embedded reinforcing steel. At some threshold of chloride concentration and given an adequate supply of oxygen and moisture, the embedded steel begins to corrode and damage to the concrete soon follows.

The Federal Highway Administration (FHWA) has been a strong advocate for cathodic protection (CP) as a reliable means of controlling corrosion in reinforced concrete bridge decks contaminated by salt. In an April 23, 1982 memorandum (1) providing FHWA's position on cathodic protection, the Federal Highway Administrator said "the only rehabilitation technique proven to stop corrosion in salt-contaminated bridge decks, regardless of the chloride content of the concrete, is cathodic protection". The administrator's memorandum stated that "the use of cathodic protection on sound, but salt-contaminated bridge decks can save billions of dollars".

Consistent with this position, the State of California, in the early 1980's, experimented with alternative cathodic protection coatings in an effort to develop conductive coatings for application to vertical concrete surfaces. Laboratory test results showed that metallized zinc applied to the concrete surface had excellent conductivity, bonded well to the concrete, and was capable of delivering sufficient CP current to provide effective cathodic protection to the reinforcing steel.

In 1983, the first metallized zinc cathodic protection system was installed on a pier of the Richmond-San Rafael Bridge in the San Francisco Bay Area (2). The system consisted of zinc metal sprayed, with oxy-acetylene metallizing equipment, over the surface of the concrete and over the top of copper and stainless steel primary anode pads which had been epoxied to the concrete surface. As designed, DC current supplied to the primary anode pads was distributed uniformly over the surface of the concrete by the zinc metal, which in turn delivered the current to the reinforcing steel via the moisture in the concrete.

This report discusses the application of the metallized zinc cathodic protection technology to a bridge deck monitored for 3.6 years. Two impressed current metallized zinc cathodic protection systems were evaluated. One system was installed on two lanes of a reinforced concrete bridge deck, and a second system was applied to the bottom surface (soffit) of the same bridge under the opposing two traffic lanes.

The effectiveness and efficiency of both metallized zinc CP systems were evaluated for this research project.

2.0 CONCLUSIONS

The following conclusions are based on a 3.6-year field evaluation (beginning in 1985 and a supplementary field check in 1992) of independent metallized zinc cathodic protection systems applied to the top surface of a reinforced concrete bridge deck and to the bottom surface (soffit) of the same deck.

<u>Deck CP System</u>

1. A system composed of metallized zinc stripes arc sprayed over embedded primary anode pads and protected from traffic damage with an asphalt concrete overlay, was successfully installed on a reinforced concrete bridge deck.

2. Some zinc coating disbondment occurred during the metallizing process due to the slow speed of the metallizing gun traversing the surface of the concrete deck. This can be corrected for future installations by optimizing the spray rate for metallizing concrete.

3. The deck CP system delivered cathodic protection current to the reinforcing steel, however, due to the combination of below average precipitation, the application of the slurry seal and the inadvertent application of a deck chipseal, the system did not provide complete cathodic protection during the initial study period. However, as was shown by the supplemental 1992 test data, when the concrete received adequate moisture, the current density and polarization decay increased dramatically. These results verify that this system has potential for being an effective bridge deck cathodic protection system.

<u>Soffit CP System</u>

1. A metallized zinc CP system consisting of a continuous flame-sprayed coating over primary anode pads was successfully applied to the bottom surface (soffit) of the reinforced concrete bridge deck.

2. A higher gun traversing speed used to metallize the soffit produced a zinc coating with a higher concrete bond strength compared to the metallized stripes of the deck system which partially disbonded.

3. Since the bridge deck was contaminated with salt from the top surface, the soffit concrete surface was less conductive requiring a higher driving voltage to deliver CP current from the soffit (bottom side) of the deck.

4. Due to the higher driving voltage requirement, the soffit CP system, while delivering some protective current, did not provide complete protection for the reinforcing steel.

3.0 RECOMMENDATIONS

1. Based on this short-term evaluation, metallized zinc CP systems should be tried on other bridge decks provided slurry seals are not used in the installations. The metallized zinc CP system, however, should not be used on the bottom surfaces of bridge decks that have been contaminated with salt from their top surface due to the inability of the system to overcome the increased resistance to current flow from this type of application.

2. Due to the reduction in moisture, which affects the operation of a deck-applied metallized zinc CP system, slurry seals should not be used to temporarily protect the zinc stripes from traffic wear before the AC overlay is installed.

3. Long-term monitoring of the CP systems installed at the East Camino Undercrossing should be conducted under a separate research project to better define these limitations caused by the moisture barriers applied to this deck CP system.

4. More research is needed to determine what effects the consumption and bond strength of the zinc coating at the concrete interface have on the long-term effectiveness of this type of CP system.

5. Other bond strength testing devices should be tried to more accurately measure the bond strength of metallized coatings on concrete surfaces.

4.0 IMPLEMENTATION

Copies of this report will be sent to Caltrans district and headquarters offices and to the Federal Highway Administration.

As a result of preliminary data developed from this study, a federally funded research project was begun in 1987 to apply the metallized zinc cathodic protection system to a bridge deck near Redding, California. Four other types of CP systems were also applied to two adjacent bridges in order to compare the five individual CP systems.

The State of Oregon DOT is presently applying a metallized zinc cathodic protection system to one of Oregon's historical bridges located in the coastal area. The contract, which will be completed in the fall of 1991, calls for the metallizing of approximately 100,000 square feet of concrete surface and will provide CP to the substructure of the bridge.

The California DOT, Division of New Technology, Materials and Research will be available to assist district and headquarters personnel who are interested in using this type of cathodic protection system.

5.0 BRIDGE SITE & CP INSTALLATION DESCRIPTIONS

The East Camino Undercrossing was the first reinforced concrete bridge deck to be cathodically protected with a metallized zinc CP system. This structure is located on State Route 50, approximately 6 miles east of Placerville, California, at an elevation of 3300 feet (Figure 5-1).

The structure is an 89-foot long, 3-span, reinforced concrete T-Beam bridge built in 1964, and has a total deck surface area of approximately 7200 square feet.

Deicing salts are applied to the bridge deck during the winter season to control ice formation. As a consequence, the structure has a history of corrosion damage with numerous patches used to repair spalled and delaminated concrete. A total percentage of deck area of 55% had been patched prior to installing the CP systems.

The average annual precipitation at the East Camino UC (as reported by the California Division of Forestry, Institute of Forestry Genetics, located approximately 2 miles west of the structure) is approximately 40 inches.The average annual temperature ranges from 38 to 91 degrees Fahrenheit.

Two different methods of metallizing were used to install the zinc distribution anodes. Both installations were impressed current CP systems. 1) The first delivered current to the two eastbound lanes, shoulder, and median from the metallized top surface of the bridge deck (approximately 3000 sq ft of deck surface). 2) A separate system delivered current to one-half of the westbound lanes (approximately 1400 sq ft of concrete surface) from the metallized bottom (soffit) surface (Figure 5-2). Separate rectifiers were used to supply the CP current to each system. All half-cell potential measurements were made on the top surface of the deck.

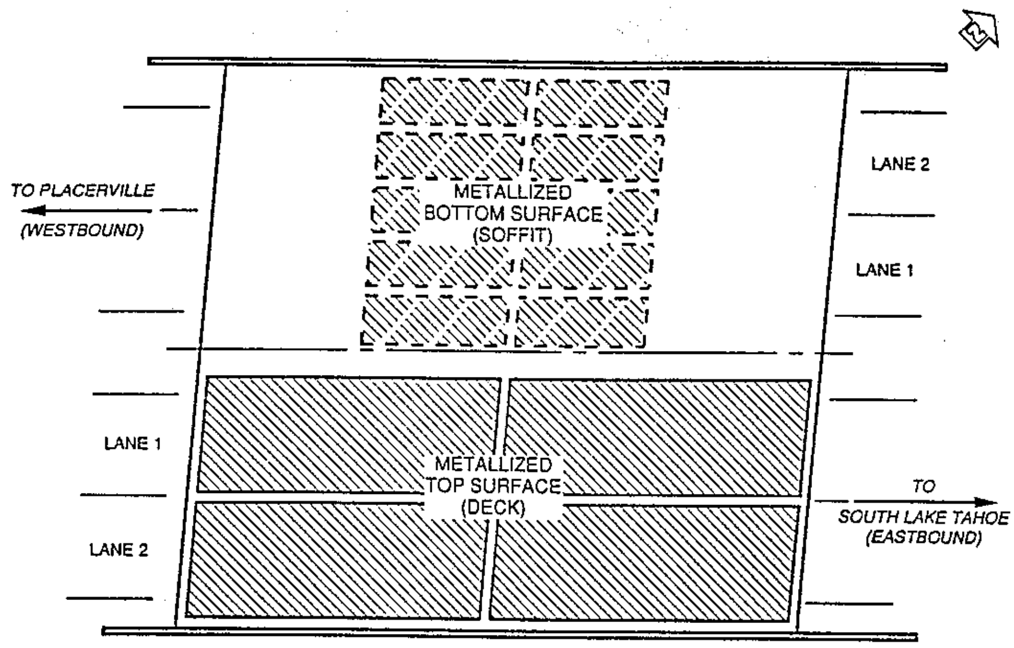


Figure 5-2, METALLIZED BRIDGE SURFACES, EAST CAMINO UNDERCROSSING

The delivery of CP current to the bridge deck reinforcing steel is influenced by the electrical resistance of the concrete and the continuity of the reinforcing steel in the deck. Consequently, for this study, the surface area of reinforcing steel used for current density calculations is the steel mat closest to the current delivery anodes (e.g., the top mat of the deck CP system and the bottom mat of the soffit CP system) directly beneath the zinc- coated surface of the concrete.

Also, the ratio of the surface area of the reinforcing steel in the top rebar mat to the deck concrete surface is approximately 0.5 to 1 and that for the bottom rebar mat to the soffit concrete surface area is approximately 0.56 to 1.

Part of the design of a CP system is the selection of an appropriate current density required for adequate protection. Through many years of experience by experts in corrosion control, typical values have been developed for bare steel in soil and seawater which serve as guidelines for designing systems. For seawater, this value is between 5 and 15 milliamperes per square foot (mA/sq ft) of steel surface area depending on the geographic location. For soil it is between 1 and 3 mA/sq ft (3).

A design maximum current density of 2 mA/sq ft was selected for this study in order to approximate the current density that was used for the Sly Park Bridge CP installation (4), California's first CP system.

5.1 Deck CP System Design (Eastbound Lanes)

In order to more accurately measure current density, the eastbound half of the bridge was divided into four independently wired conductive quadrants separated by 1 foot wide clear areas as shown in Table 5-1 and Figure 5-3.

The basic components of the deck CP system are given in Table 5-2.

The deck CP system was designed for a 10-year life based on the consumption rate of the metallized zinc and the expected operational current density of the system. The design life was also chosen to coincide with that expected of the AC overlay.

The consumption rate of metallized zinc used as a CP distribution anode had been previously studied (2). An applied volume of 0.5 lb of zinc per square foot of concrete surface area was needed for a 10-year design life (using a current density of 2 mA/sq ft of steel surface area). This volume of metal was equivalent to a uniform thickness of approximately 0.015 inches.

TABLE 5-1
DECK CP SYSTEM
CONDUCTIVE QUADRANT SURFACE AREAS

CP QUADRANT	AREA PROTECTED (SQ FT)
NW	685
NE	685
SW	785
SE	785
TOTAL	2940

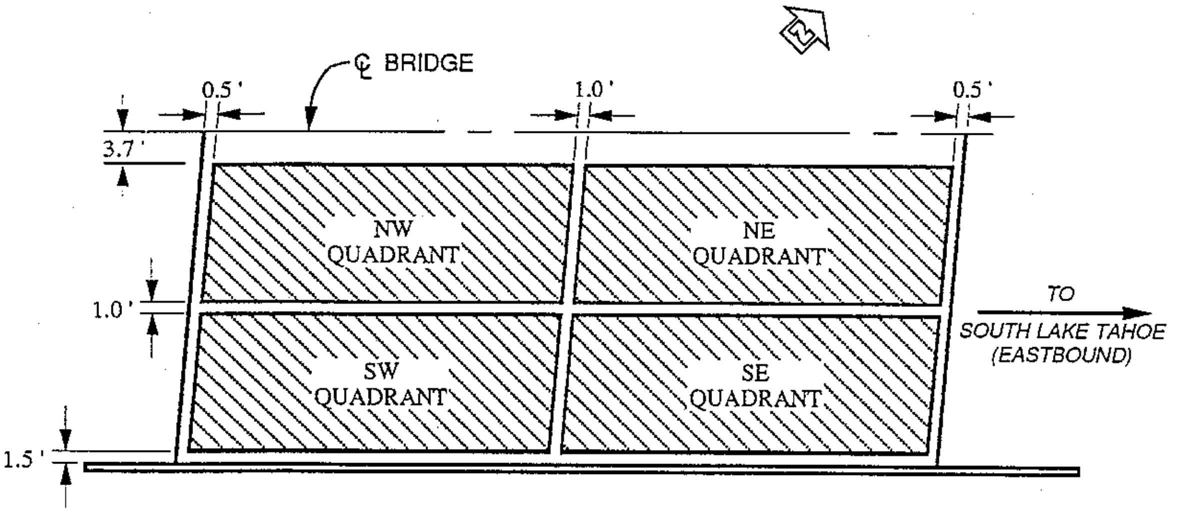


Figure 5-3, DECK CP SYSTEM, CONDUCTIVE QUADRANTS

TABLE 5-2
DECK CP SYSTEM, BASIC COMPONENTS

COMPONENT	DESCRIPTION	INSTALLATION
Primary Anodes	Six 2" square brass or zinc pads per quadrant	Epoxied flush with deck with wires extending through deck
Distribution Anode	5" wide metallized zinc stripes, spaced transversely on 10" centers with four longitudinal stripes to form grid pattern: stripe design thickness 0.024"	Truck mounted. Remotely controlled arc-spray metallizing equipment.
Overlay (1)	Slurry seal	Installed for temporary anode protection.
Overlay (2)	1" Asphalt concrete layer	Long-term anode protection from traffic wear.
Rectifier	Constant voltage max. 24 volts DC, 16 amperes	Supplies CP current to deck system only; installed below deck in control box.
Rebar Ground Connections	Eight independent ground leads	Four evenly spaced redundant connections along each rail, cadwelded to rebar.

The metallized zinc was applied in stripes on the deck, with alternating spaces of bare concrete to allow the asphalt concrete (AC) overlay to bond directly to the concrete deck. The designed thickness of each stripe was increased (to approximately 0.024") to compensate for the deck area not being coated between each metallized stripe. The 5-inch-stripe width was dictated by the effective spray pattern width of the metallizing gun tip set at its optimum spraying height.

Multiple primary anodes were used for the deck system since there was limited experience with this method of electrically connecting the metallized zinc distribution anode. Both brass and zinc anodes were used to evaluate the ability of these different materials to deliver CP current over an extended time period.

In order to monitor the current density at the top and bottom reinforcing steel mat levels of each quadrant, five-inch-long rebar segments were isolated in both mats and wired independently to the control box. These rebar segments are identified as isolated bars and are discussed later.

All electrical leads from each component within the deck system, including the isolated bars, were made up of two wires. One wire carried the current flow (a 12-gage solid copper wire) and the other was dedicated as a test lead (an 18-gage stranded copper wire) for monitoring the system.

Detailed descriptions of the primary anodes, isolated bars, rebar grounds and electrical system are contained in Appendices 12.1, 12.3, 12.4 and 12.5.

5.2 Metallizing the Deck

The deck was metallized with zinc wire using a commercial electric arc gun mounted on a truck. The metallizing gun was attached to a Caltrans-designed-and-built movable carriage and traversing frame mounted at the rear of a 1.5-ton flatbed truck. This design allowed the metallizing gun to traverse the width of a 12-foot traffic lane during the spraying process. The deck was metallized by an operator using remote controls tied to the truck by an umbilical cord. Descriptions and photos of the metallizing process and equipment are contained in Appendix 12.6.

Since the metallized coating adheres to the concrete by mechanical bond, the deck was shotblasted before the coating was applied. Sandblasting was not used on the deck to minimize disrupting adjacent traffic with overspraying and dust. As the concrete deck surface was roughened to provide a good mechanical bond surface, the shotblast was recycled and the dust and concrete laitance were collected by a filtering system within the equipment.

Table 5-3 presents the metallizing parameters selected for the design of the deck CP system and those achieved during the metallizing operation.

TABLE 5-3
ARC-SPRAY METALLIZING PARAMETERS, DECK CP SYSTEM

SUBJECT	ORIGINAL DESIGN	AS PERFORMED
Type of Wire/Purity	Zinc/99.9%	Zinc/99.9%
Metallized Zinc Output, lb/hr	110 (1)	90
Zinc Wire Size, Inches/Gage	0.090/11	0.090/11
Number of Metallizing Guns Used	1	1
Gun Tip to Surface Distance, Inches	8 to 9 (1)	8 to 9
Arc Metallizing Gun Power Output:		
D.C. Volts	26 (1)	25
Amperes	450 (1)	450
Zinc Deposit Efficiency, %	70 (2)	40
Stripe Width, Inches	5	5
Stripe Spacing, Inches O.C.	8	10
Average Stripe Thickness, Inches	0.024	0.014
Number of Passes With Gun per stripe	3	3
Deposited Zinc Volume, lb/sq ft, Concrete	0.5	0.23
Gun Traversing Speed, Inches/Second	2.5	2.5
Ambient Air Temperature During Metallizing, Degrees F	- - -	100+

(1) Mogul Arc-spray Systems Instruction Manual, Model A-6
(2) Results Of Caltrans Laboratory Testing.

Initially, the zinc was applied in 5-inch-wide stripes with a 3-inch-wide clear area between each stripe. During the metallizing process, however, the stripe spacing was changed because the zinc overspray was covering a larger portion of the 3-inch-wide clear area between each stripe than anticipated. There was concern that the zinc overspray would interfere with the bond of the subsequent AC overlay. To prevent this interference, the spacing was increased to 12 inches O.C. and the number of spraying passes were increased to five (to maintain the same volume of zinc applied per square foot of concrete surface).

Since the resulting additional thickness of zinc on each stripe, due to the increased spacing, caused the metallized zinc to disbond from the concrete surface, the spacing was reduced to 10" O.C. and three spraying passes per stripe were used. These corrections reduced the amount of disbondment but did not eliminate it altogether. Partial disbondment was due in part to the slow traversing speed of the truck mounted equipment supporting the metallizing gun.

All transverse stripes within each quadrant were electrically connected by spraying four longitudinal stripes, the length of the structure, across the transverse stripes. These longitudinal stripes were contained within each quadrant and did not bridge any of the one-foot-wide clear areas between quadrants. The result was a grid pattern of zinc stripes (Figure 5-4). The zinc stripes also traversed each exposed brass primary anode pad previously placed in the deck surface in order to make the necessary electrical connection to the CP rectifier.

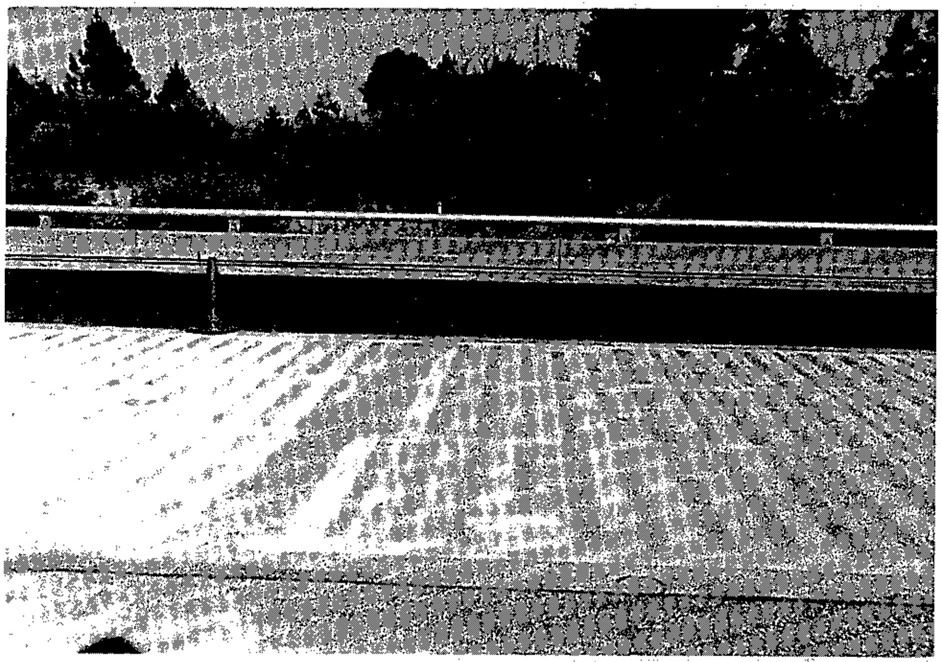


Figure 5-4, DECK METALLIZING GRID PATTERN, EAST CAMINO UNDERCROSSING

A 1 sq ft area around each primary anode pad was sprayed with zinc to insure direct contact between the pad and several of the nearest zinc stripes (Figure 5-5).

As with spray painting, some of the sprayed material did not become part of the metallized coating due to volatilization, bounce back, and overspray. Table 5-3 presents the application rate and deposit efficiency achieved.

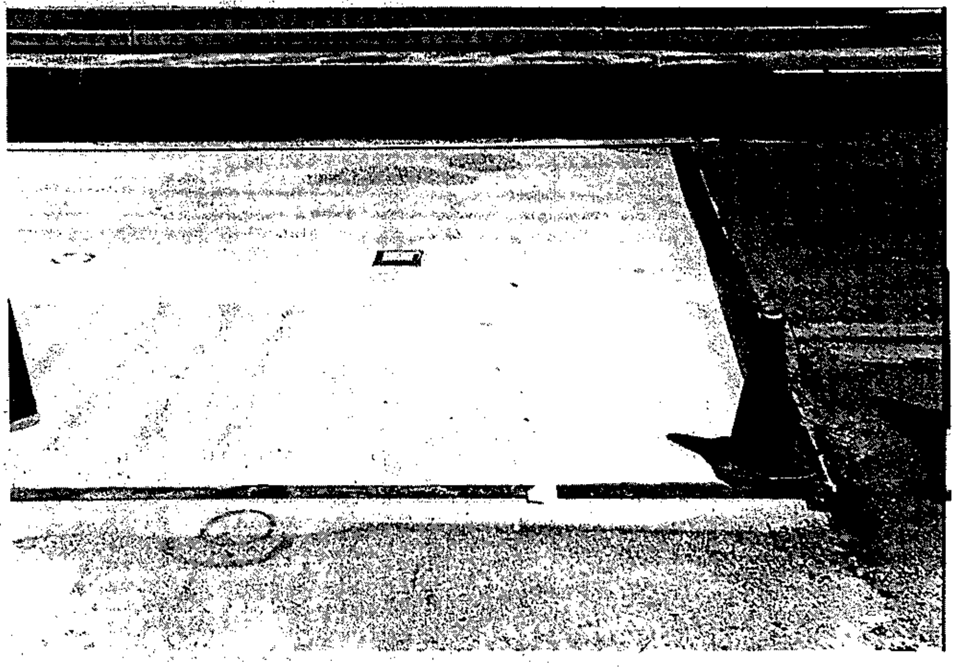


Figure 5-5, METALLIZED GRID PATTERN OVER PRIMARY ANODE PAD

Precautions were also taken to protect workers and the environment from exposure to zinc fumes and dust. A vacuum system was attached to the nozzle of the arc metallizing gun to continuously recover the zinc dust overspray and fumes during the metallizing process. The vacuum exhaust system recovered the zinc fumes and light particles at the source of ignition (gun tip) and fed them through a water wash scrubber. Since the metallizing process was remotely controlled away from the zinc fumes, the metallizing operator did not wear an air-fed respirator mask. As a precaution though, the operator wore a particulate filter mask during the metallizing operation.

The recovered zinc dust (taken from the vacuum wash scrubber) was placed in hazardous waste barrels which were taken to an authorized hazardous waste site for disposal.

Safety information presented in the Materials Safety Data Sheet for controlling the zinc metal dust and fumes (5) was used during the metallizing operation.

5.3 Applying the AC Overlay

Since the metallized deck coating would be exposed to traffic and snow chain wear if left uncovered, an asphalt concrete (AC) overlay was applied to protect the zinc from damage. However, since there was an extended time delay between metallizing and the application of this 1 inch AC wearing course, an asphaltic emulsion slurry seal was applied over the metallized area. The slurry seal protected the zinc coating from traffic wear for three months until the AC overlay was applied.

The slurry seal will not be required under a normal contract installation if the AC overlay is applied before the structure is reopened to vehicular traffic.

5.4 Soffit CP System Design (Westbound Lanes)

A metallized zinc CP system was also applied to the deck bottom surface (soffit) of the East Camino Undercrossing under a separate contract to determine the ability of this type of installation to provide CP to the top mat of reinforcing steel. The metallized zinc soffit CP system was composed of the horizontal surfaces of the ten bays under the second span of the westbound lanes (Figure 5-6). The bent caps and diaphragms were not metallized. The other two spans (one and three) under the bridge were reserved for future systems as well as serving as control areas for this study.

The basic components of the soffit CP system are given in Table 5-4.

The soffit CP system was designed with a life of 10 years to match that of the adjacent deck CP system. The same current density (2 mA/sq ft of steel surface) and applied volume of 0.5 lb of metallized zinc per square foot of concrete surface were used (uniform thickness of approximately 0.015 inches).

The anode pads were recessed and epoxied so that their top surface was flush with the surface of the concrete. Since the metallized zinc did not have to be protected, the CP wiring was surface mounted.

Five-inch-long isolated bars, as described for the deck system, were installed in both the top and bottom rebar mats of each bay to monitor the current density.

The electrical wiring was installed in a fashion similar to that used with the deck CP system (e.g., 2 wire leads to each component).

Detailed descriptions of the primary anodes, isolated bars, rebar grounds and electrical system are contained in Appendices 12.2, 12.3, 12.4 and 12.5.

Figure 5-6, EAST CAMINO UNDERCROSSING SOFFIT

TABLE 5-4
SOFFIT CP SYSTEM, BASIC COMPONENTS

COMPONENT	DESCRIPTION	INSTALLATION
Primary Anodes	One 2" square brass pad per bay (10 bays)	Epoxied flush with surface of soffit
Distribution Anodes	Uniform coating of metallized zinc applied to 10 bays in span 2: 10 bays in spans 1 & 3 were not metallized; uniform design thickness 0.015"	Hand held oxygen-acetylene metallizing equipment.
Rectifier	Constant voltage max. 50 volts DC, 5 amperes	Supplies CP current to soffit system only; installed below deck in control box.
Rebar Ground Connections	Uses the same 8 ground leads as the deck CP system	Four evenly spaced redundant connections along each rail, cadwelded to rebar.

5.5 Metallizing the Soffit

The soffit was metallized under a separate contract. Metallizing was accomplished simultaneously with two hand-held guns (by a commercial metallizing contractor) using the flame-spray (oxygen/acetylene) method of melting the zinc wire. Zinc was sprayed evenly, (rather than in stripes, as was done on the deck) over the entire horizontal surface within each bay (Figure 5-7) using a sweeping motion of the gun at a rate of about two feet per second. During the metallizing process, the zinc coating was also sprayed across the brass electrical contact pads (which had been epoxied to the concrete surface prior to metallizing). The metallizing process and equipment are described in Appendix 12.6.

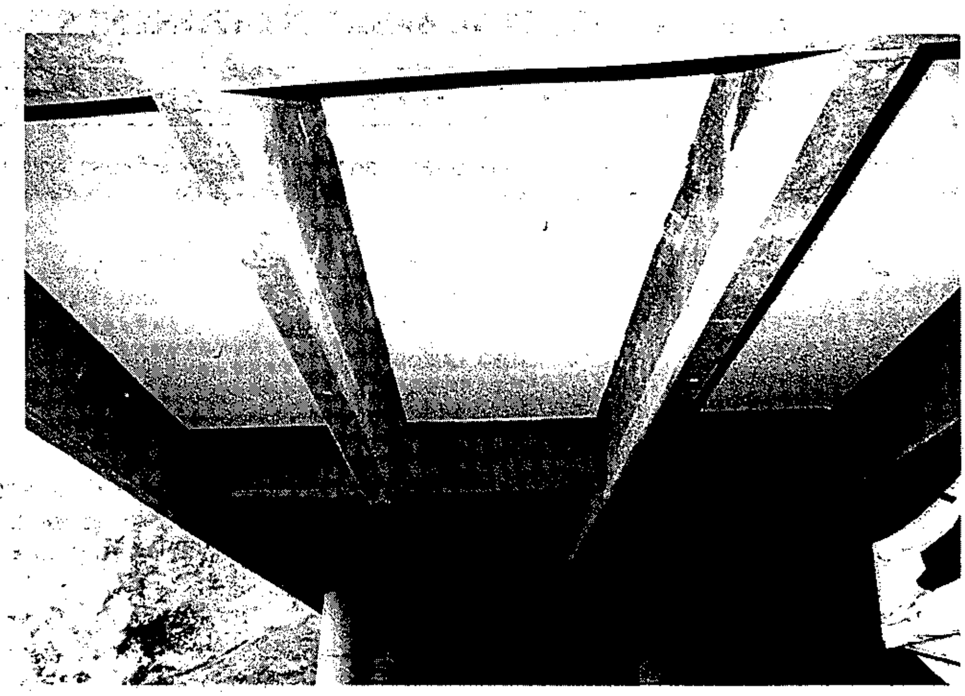


Figure 5-7, SOFFIT METALLIZED AREAS,
EAST CAMINO UNDERCROSSING

Prior to metallizing, the concrete surfaces were sandblasted, using a 20 grit copper slag blasting media, to remove the cement paste sheen and surface laitance and to produce a uniform rough texture. The nozzle pressure was 80 to 100 psi at a blast distance of approximately 12 inches.

The metallizing parameters selected for the design of the soffit CP system and those values measured during the metallizing operation are shown in Table 5-5.

TABLE 5-5
FLAME-SPRAY METALLIZING PARAMETERS, SOFFIT CP SYSTEM

SUBJECT	ORIGINAL DESIGN	AS PERFORMED
Type of Wire/Purity	Zinc/ 99.9%	Zinc/99.9%
Metallized Zinc Output, lb/hr/gun	65 (1)	57
Zinc Wire Diameter, Inches	0.186	0.186
Number of Guns Used	2	2
Gun Tip to Surface Distance, Inches	5 to 8 (1)	8 to 12
Combustion Material Used, Total Cu Ft		
Oxygen	2760 (1)	3000
Acetylene	1140 (1)	1200
Zinc Deposit Efficiency, %	50 (2)	70
Zinc Application Format	Continuous Coating	Continuous Coating
Average Uniform Thickness, Inches	0.015	0.023
Deposited Volume, lb/sq ft, Concrete	0.5	0.75
Gun Traversing Speed, Inches/Second	- - -	24
Ambient Air Temperature During Metallizing, Degrees F	- - -	70+

(1) Metco 10E Flame Spray Gun Instruction Manual, Catalog #10E-777
(2) Results of Caltrans Laboratory Testing.

Precautions were also taken to protect workers and the environment while the soffit was metallized. During the sandblasting and metallizing operations, each bay was surrounded by a canvas enclosure, hung from a portable scaffolding system (Figure 5-8). Workers within the enclosure wore air-fed respirator masks during both operations. A vacuum system attached to the enclosure drew off the light particles and fumes while the sandblast and zinc residues were funneled into hazardous waste barrels which were taken to an authorized hazardous waste site for disposal.

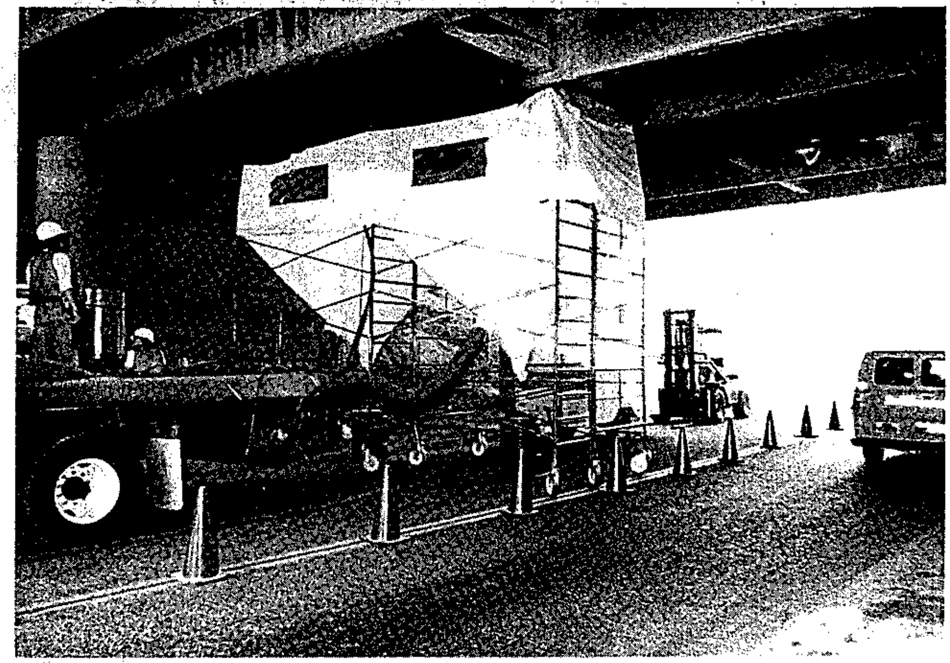


Figure 5-8, SOFFIT METALLIZING OVERSPRAY COLLECTION SYSTEM

6.0 PRELIMINARY SITE TESTING

Prior to applying the CP systems to the East Camino Undercrossing, the following preliminary surveys were conducted: Half-cell potential survey, concrete cover survey, chloride concentration tests, and deck delamination and patching surveys.

6.1 Half-cell Corrosion Potential Survey

A half-cell corrosion potential survey was conducted in April 1985 in accordance with ASTM Designation C-876 (6). Figure 6-1 shows the placement of saturated sponges at each intersecting point of the 4 foot grid pattern and the measuring technique used during the survey.

The results of the potential survey as well as an equipotential contour map of the corrosion potentials of the deck are presented in Section 9.1.

Figure 6-1, CORROSION POTENTIAL SURVEY, EAST CAMINO UNDERCROSSING

6.2 Bridge Deck Concrete Cover Survey

At the same time the deck half-cell corrosion potential survey was being conducted, a survey was also conducted to determine the thickness of concrete cover over the deck reinforcing steel mat. The concrete cover was determined using a "James", Model C-4952 "R" Meter at 63 points evenly spaced across the bridge deck.

Results of the concrete cover survey are presented in Section 9.2.

6.3 Chloride Concentration Tests

The concrete deck was cored and the recovered cores were analyzed to determine chloride concentration of the deck concrete. Twenty-nine 1-inch diameter full depth cores taken from primary anode or isolated bar locations were used. Each core was cut into 1-inch segments relative to depth of the concrete deck. The segments were individually crushed and total chloride content determined in accordance with California Test 404 (7).

The results of these tests are presented in Section 9.3.

6.4 Deck Delamination and Patching Surveys

The deck was surveyed in June 1984 to determine the existence of previously patched areas as well as existing delaminated areas. The deck was also resurveyed in April 1985 (prior to metallizing) to determine the extent of newly developed delaminations that had occurred since the June 1984 survey.

Table 6-1 lists the dates of the delamination and patch surveys.

In order to have a permanent record of all detected delaminations or patched areas, the deck surface was videotaped. A video camera mounted on the back of a vehicle recorded the marked outlines of the delaminated areas (discovered by the chain dragging technique) along with an index tape as the vehicle was driven along the deck (Figure 6-2). These data were later transcribed to produce a plan view drawing of the deck with the delaminated areas.

The exposed reinforcing steel in the eastbound lanes was sandblasted and coated (with an epoxy conforming to California Standard Specification formulation 8040-013-08A) prior to being patched. Repairs to the westbound lanes did not include coating the rebar with epoxy. This specification was inadvertently omitted from these repairs.

The patch material used to repair the eastbound lanes was "IC210" Rapid Set Concrete and that used for the westbound lane repairs was "Burke 928" High Alumina Patch Mix.

The new concrete was not epoxy-bonded to the old concrete because the epoxy would electrically shield the delivery of CP current to the reinforcing steel beneath the epoxied area.

There is no record of the type of repair procedures for patches applied prior to the 1984 survey.

TABLE 6-1
DECK DELAMINATION SURVEYS AND REPAIRS*

DATE	PROCEDURE CONDUCTED	LOCATION	REASON
June 1984	Detect and record deck delaminated areas	EB & WB Lanes	Locate existing delaminated and prior patched areas
Sept 1984	Repair delaminated concrete deck surfaces (Deck CP System)	EB Lanes	- - -
April 1985	Detect and record deck delaminated areas	EB & WB Lanes	Record new delaminated areas occurring since June 1984 survey
June through Nov 1985	Metallize deck and soffit CP surfaces and start CP current application	EB & WB Lanes	- - -
June 1986	Repair delaminated concrete deck surfaces (Soffit CP System)	WB Lanes	- - -

* There are no Records of the Repair Procedures Prior to 1984

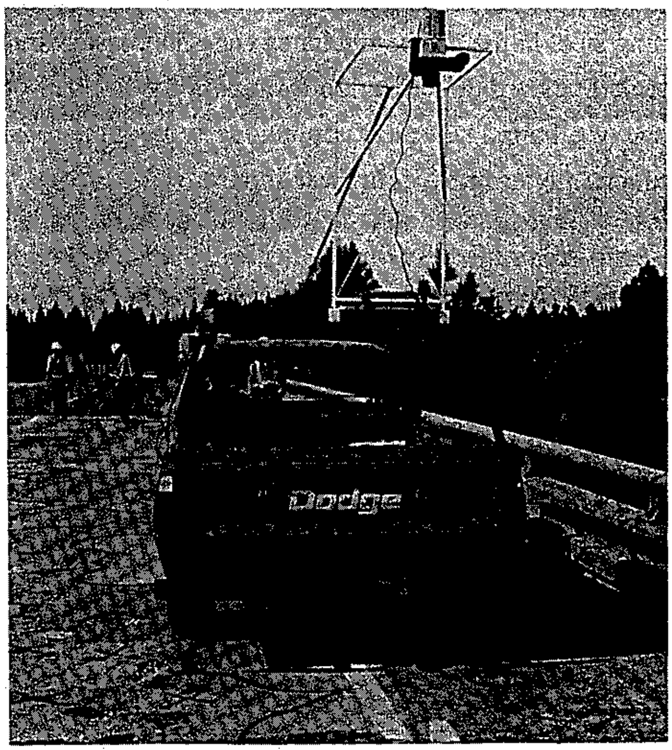


Figure 6-2, DECK DELAMINATION SURVEY, RECORDING METHOD

The results of these surveys and views of the deck after each survey are presented in Section 9.4, Table 9-4 and Figure 9-2.

7.0 FIELD INSTALLATION TESTING

In addition to the many routine tests required to determine proper installation and workmanship, several specific tests were conducted: short circuit and concrete resistance tests, zinc thickness tests, and zinc bond strength tests.

7.1 Short Circuit and Concrete Electrical Resistance Tests

As with any CP system, there should not be any unintended metallic contact paths between the distribution anode and the reinforcing steel to be protected (e.g., exposed tie wires, form nails touching the reinforcing steel, etc.). Otherwise, a short circuit will occur.

An electrical short circuit detector, developed by Caltrans, was used to find short circuits in the deck. The apparatus was rolled across the deck, similar to a lawn roller, to detect short circuits, (Figures 7-1 and 7-2).

A modification of this method was used to detect the presence of exposed metal objects on the soffit surface for that CP system. In this alternate method, while the same wiring schematic was used, a hand-held pad was substituted for the roller and pressed against the soffit surface of the deck (Figures 7-3 and 7-4).

A second type of short circuit monitoring was used during the metallizing operation. Continuity between the reinforcing steel and the metallized coating was continuously monitored. A high impedence voltmeter (set on a low voltage DC scale) was kept continually connected between the reinforcing steel and the metallized coating. If no short circuit existed, the voltmeter displayed an open circuit potential. If a metallic path were encountered, the display would read zero, indicating electrical continuity.

The electrical resistance of the concrete between the metallized zinc coatings of the quadrants or bays and the nearest reinforcing steel mat was measured. After the surfaces had been metallized, each quadrant and bay was connected independently to a DC power source and energized to a current delivery of 0.5 amps at 30 volts. The voltage drop across the concrete was measured directly between the zinc coating and the underlying reinforcing steel mat and the resistance calculated.

Results of both these tests are presented in Section 9.5.

Figure 7-1, DECK SHORT CIRCUIT TEST

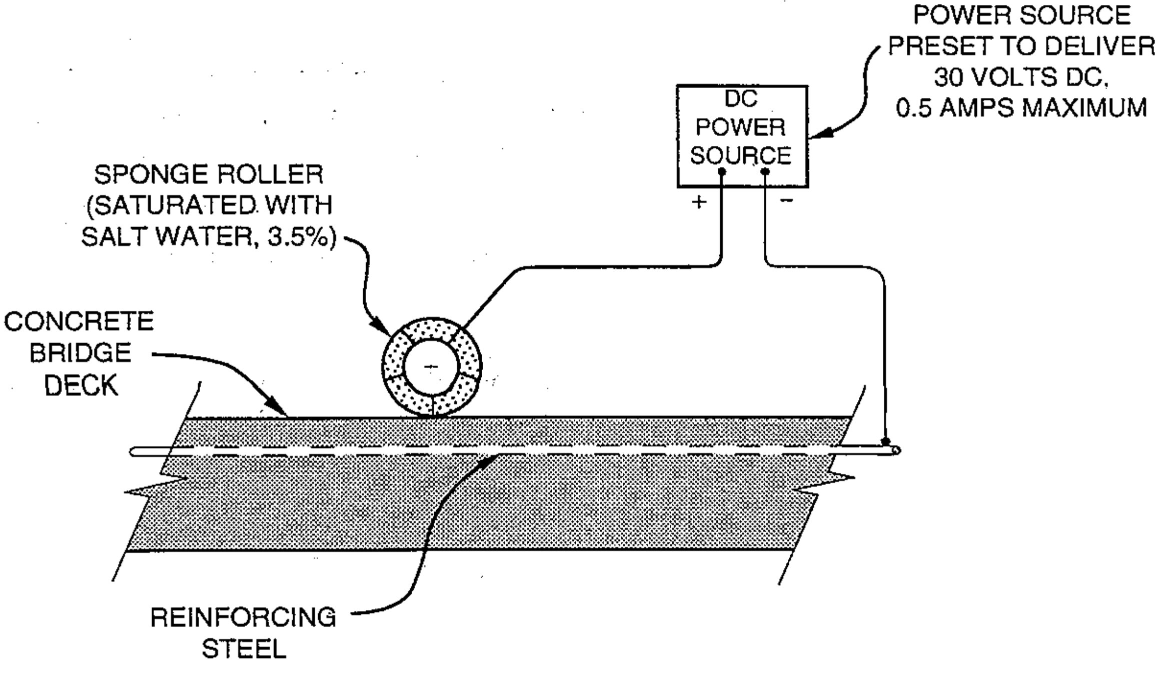


Figure 7-2, DECK SHORT CIRCUIT TEST, SCHEMATIC

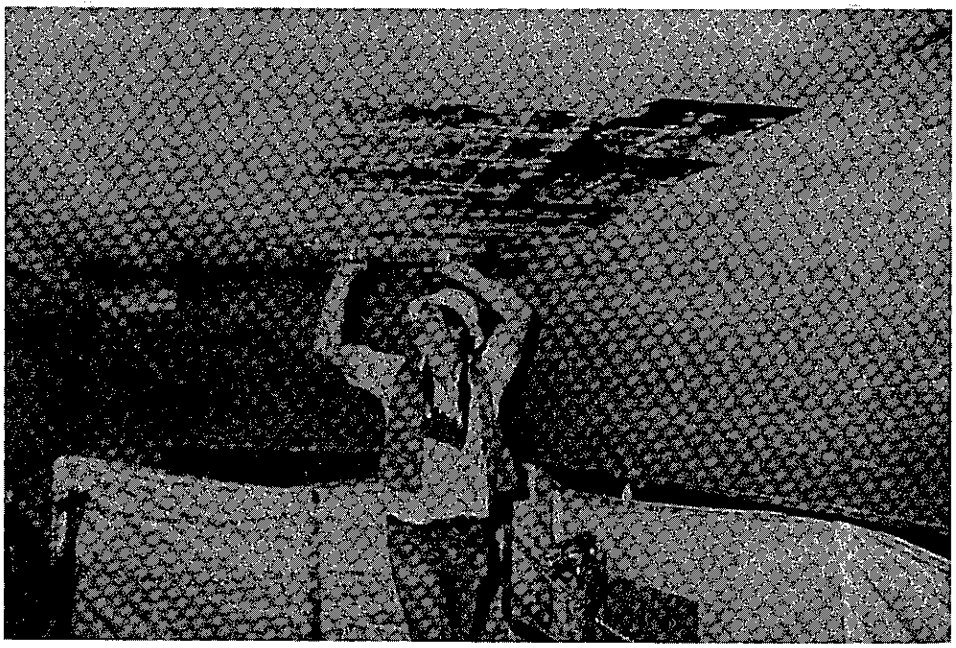


Figure 7-3, SOFFIT SHORT CIRCUIT TEST

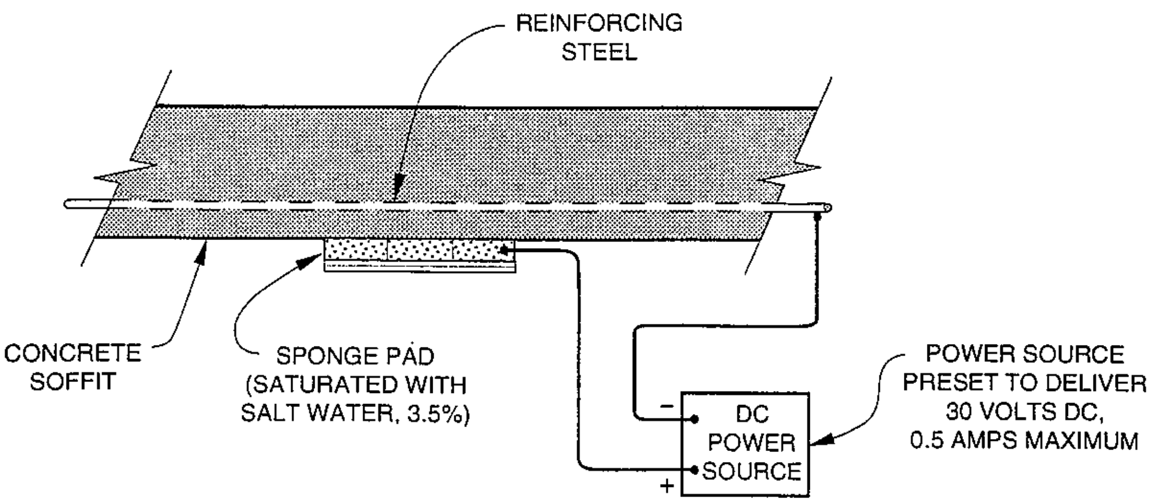


Figure 7-4, SOFFIT SHORT CIRCUIT TEST, SCHEMATIC

7.2 Zinc Thickness Tests

The metallized zinc stripes for the deck CP system were applied by repeated passes of the metallizing gun. Since the spray pattern of the gun had a conical shape, the stripes did not have a uniform thickness across their width. In cross section, the stripes were shaped like mounds, having a maximum thickness at the middle, tapering to "nothing" at each outter edge.

A commercial bond strength tester was initially going to be used to recover the metal sample to determine the zinc thickness and measure the zinc bond strength. This method of recovery was not successful and was abandoned. The problems with this procedure are described in the following section on bond strength.

In lieu of the planned method of sample recovery, the thickness of the zinc stripes was determined by removing multiple samples across the width of a representative number of stripes. A cold chisel and hammer were used. Because the thickness of the zinc was not uniform across the stripes, multiple samples, each approximately 1 x 1 inch, were taken at each location. Figure 7-5 presents the typical layout and identification of the stripe thickness samples removed from the deck.

Since the metallized zinc was applied to the soffit surface (of the westbound lanes) as a continuous coating sprayed uniformly within the ten bays, only one sample was removed from each bay. The same cold chisel and hammer method was used as described above.

The deck and soffit samples were measured in the laboratory to determine the applied thickness of the zinc. The recovered samples were first enlarged to ten times their original size with an optical comparator to accurately measure the total surface area of each sample. The samples were then weighed using a Mettler HK160 precision electronic scale. From this data and the density of the metallized zinc, the unit area weight and applied thickness of the samples were calculated.

Also included in the calculations was the "as applied" density of the metallized zinc which is 89% of the original wire density (8).

The zinc thickness test results are presented in Section 9.6.

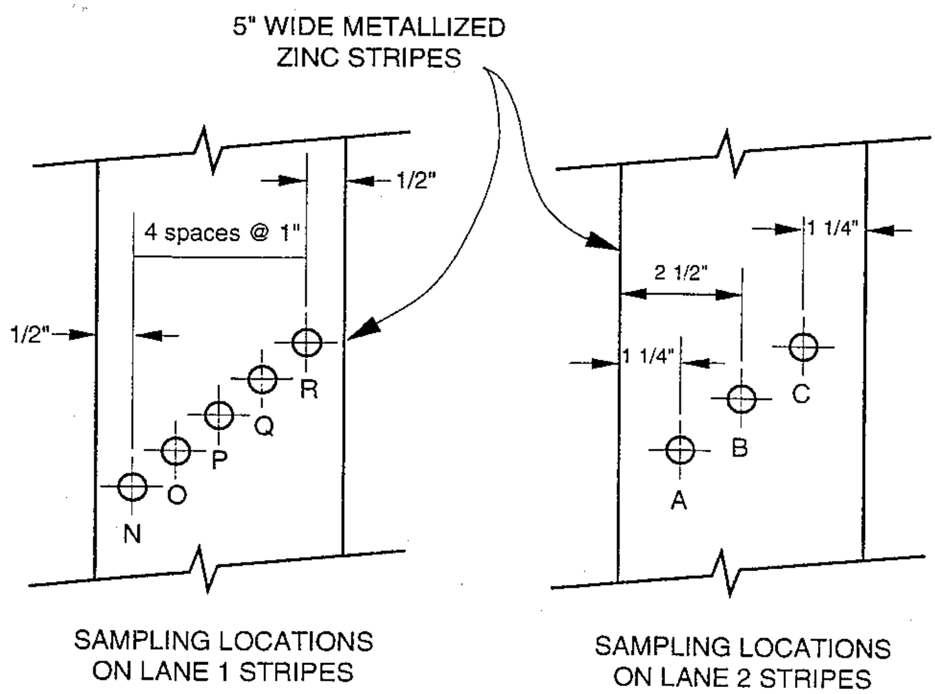


Figure 7-5, TYPICAL LOCATION AND IDENTIFICATION OF TEST SAMPLES REMOVED FROM DECK ZINC STRIPES

7.3 Zinc Bond Strength Tests

A modification of an existing paint adhesion test procedure was originally going to be used to determine the bond strength and to recover the metal sample for the applied metal thickness evaluation (as reported in Section 7.2). The Elcometer Adhesion Testor, Model 106, Range No. 2, was used to determine the zinc bond strength, however, the procedure was modified as explained below. This test method (ASTM D-4541-85) is normally used to measure the adhesion of paint to metal.

The method consists of using 0.80-inch-diameter aluminum "dollies" that are glued to the surface of the coating to be tested. According to the standard procedure, an epoxy is used as the adhesive to permanently bind the coating to the dolly. This procedure was modified. A commercially available hot glue adhesive was substituted as the bond material between the dolly and the zinc coating. It was intended that after the sample was recovered, the glue would be disolved and the clean metal sample would be further tested. This modified procedure was used successfully in the laboratory, but was not successful in the field.

The extreme range of thicknesses of the deck stripes along with the incidence of disbonding along the centerline of the stripes (due to the high application rate and resulting thickness) precluded accurate measurement of zinc bond strength in the field.

The bond tests performed on the soffit metallized surface tended to separate between either the hot glue and the pulling dolly or the metallized zinc surface before the zinc separated from the concrete surface. Based on these problems, further testing with this procedure was terminated for the deck and soffit metallized surfaces.

Subsequently, additional laboratory tests were performed using the hot glue method on prepared metallized concrete specimens to determine the bond strength between the hot glue and the zinc surface. These results might indicate an approximate lower limit for the bond strength between the zinc coating and the surface of the concrete.

The results of these supplementary laboratory bond strength tests are reported in Section 9.7.

8.0 EVALUATING THE CP SYSTEMS

Records documenting the driving voltages, current density, weather, and polarization shifts were maintained in order to evaluate the operation and effectiveness of the individual CP systems.

8.1 Cathodic Protection Criteria

A key indicator of the effectiveness of CP is the measurement of the electrical potential of the reinforcing steel in the structure. Typical values measured on steel in concrete range from -0.1 to -0.6 volts versus $Cu/CuSO_4$ reference electrodes. Values more negative than -0.350 volts (vs $Cu/CuSO_4$) generally indicate that active corrosion is occurring (ASTM Designation C-876). When CP is applied, this potential shifts in a negative direction and, in general, as more CP current is applied, the shift becomes more negative. The amount of this potential shift is an indication of the degree of corrosion protection being achieved.

The "working" criterion used in this study for reinforced concrete was the achievement of a 0.100 volt polarization shift over a 4-hour period in a more negative direction due to the application of CP current (9).

Section 9.8 presents the operational parameters of the cathodic protection systems along with recorded weather history of the area.

8.2 Polarization Decay Surveys

Since it is difficult to measure potential while the CP current is actually flowing, the rectifier is turned off and measurements are taken immediately thereafter. This technique is commonly known as taking "instant-off" potential measurements.

If the CP current remains off, the reinforcing steel will return to its "natural" or "native" potential by shifting in a positive direction. This return, or "decay" as it is called, may take a few hours or several days depending on many factors. In this study the polarization shift was determined from the polarization decay established during the four-hour instant-off procedure.

A total of 10 instant-off and polarization decay deck surveys were conducted during the operational period of the CP systems for this structure. While not all the surveys were for a four-hour "off" period, most surveys were conducted for a minimum of 2 hours. Access to the structure for periods exceeding 2 hours was not always possible.

The number of surveys and length of time of each survey is presented in Table 8-1.

TABLE 8-1
INSTANT-OFF SURVEYS AND "OFF" DURATION

Total number of surveys	10
Surveys of 1 hour duration	10
Surveys of 2 hour duration	6
Surveys of 4 hour duration	2

The surveys were conducted in such a way that multiple locations across the deck were monitored simultaneously during the instant-off period and these same locations were monitored continuously throughout the polarization decay period.

The polarization decay data presented in this report were recorded using a video camera to capture the transient voltages measured. The video camera recorded the images displayed by a total of 13 voltmeters (with LCD digital displays) and an LCD time clock with a seconds display.

By advancing the VCR tape frame by frame, the exact value and time of the instant-off potential was determined as well as the values of the polarization decay curves relative to time.

Section 9.9 presents the polarization decay results of the instant-off surveys conducted on the bridge deck as well as the average current density of each CP system.

9.0 RESULTS

The results of all testing conducted as described in Sections 6.0 (Preliminary Site Testing), 7.0 (Field Installation Testing), and 8.0 (Evaluating the CP Systems) are presented as follows.

9.1 Half-cell Corrosion Potential Survey

The results of the data gathered from the April 1985 half-cell potential survey have been plotted on a topographic map of equipotential lines and are presented in Figure 9-1.

Table 9-1 presents the range of corrosion potentials in percent of total area for both the eastbound and the westbound sides of the structure.

These results showed that over 54 percent of the total deck area was above the -0.350 volt range (vs Cu-$CuSO_4$) indicating that active corrosion is probably occurring (6).

TABLE 9-1
HALF-CELL CORROSION POTENTIAL SURVEY

LOCATION	Percent of Total Area of Deck vs Potential (Cu-$CuSO_4$)		
	< 200 mV (%)	200 to 350 mV (%)	> 350 mV (%)
EB Side	1.7	44.8	53.5
WB Side	0.1	44.7	55.2
Total Deck	0.9	44.7	54.4

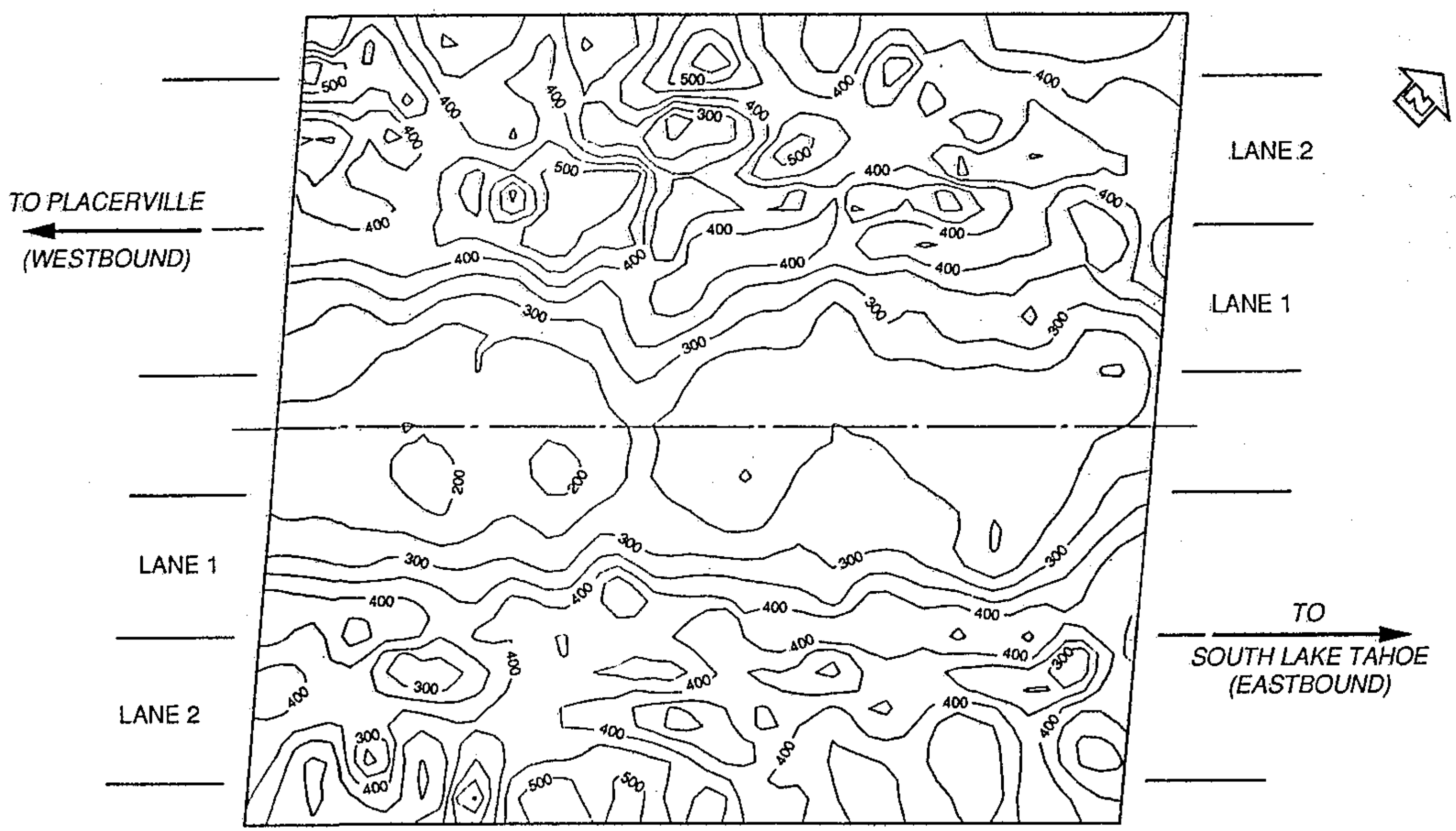


Figure 9-1, EAST CAMINO UNDERCROSSING DECK CORROSION POTENTIALS (NEGATIVE VALUES vs Cu-$CuSO_4$), APRIL 1985

9.2 Bridge Deck Concrete Cover Survey

Table 9-2 presents the results of the survey to determine the thickness of concrete cover over the top mat of reinforcing steel.

TABLE 9-2
MEASURED CONCRETE COVER OVER THE TOP MAT OF DECK REINFORCING STEEL, EAST CAMINO U.C.

Deck Area	Concrete Cover In Inches*		
	Average	Median	Range
EB Lanes Deck CP System	2.31	2.25	1.5 — 3.0
WB Lanes Soffit CP System	2.27	2.25	2.0 — 2.75

* Results are based on 63 measured locations evenly spaced across the bridge deck.

9.3 Chloride Concentration Tests

Table 9-3 presents the results of chloride concentration testing of the concrete cores removed from the bridge deck. The results are recorded versus the depth of bridge deck from the top surface.

TABLE 9-3
CHLORIDE CONCENTRATION OF BRIDGE DECK CONCRETE
lb Cl^-/ cu yd

DEPTH	Eastbound Lanes *			Westbound Lanes **		
	AVERAGE	MEDIAN	RANGE	AVERAGE	MEDIAN	RANGE
0-2	5.7	7.1	1.4 - 9.3	5.7	5.8	0.4 - 11.0
2-4	2.4	2.2	0.8 - 4.8	1.8	1.3	0.4 - 4.8
4-6+	1.3	1.2	0.8 - 2.1	0.7	0.3	0.1 - 2.6

* Results of 13 samples
** Results of 16 samples

9.4 Deck Delaminations

Figure 9-2 is a plan view of the bridge deck showing the surface area of the deck patched during previous repairs and the delaminated area detected during this study. In both cases, the number 2 lanes (of the eastbound and westbound directions) have the largest amount of previously patched and newly delaminated areas.

The percentages of the delaminated areas for the bridge deck are presented in Table 9-4.

9.5 Short Circuit and Concrete Electrical Resistance Tests

Based on the test described in Section 7.1, no short circuits were found on either the deck or the soffit surfaces.

Table 9-5 presents the results of electrical resistance testing of the concrete matrix between the metallized surfaces of the quadrant or bay and the nearest reinforcing steel mat.

9.6 Zinc Thickness Tests

Table 9-6 presents the average thicknesses of sixty four metal samples representing the metallized coating on the deck and ten samples from the soffit coating.

TABLE 9-6
APPLIED METALLIZED ZINC THICKNESS
Inches x 0.001

CP SYSTEM	METALLIZED AREA	LOCATION ON STRIPE *	APPLIED THICKNESS		
			AVERAGE	MEDIAN	RANGE
DECK	** Lane 2 and Shoulder	A	14.2	13.5	8.5 — 25.6
		B	31.3	27.9	24.3 — 43.6
		C	13.7	12.2	7.8 — 26.4
	*** Lane 1 and Median	N	6.5	6.6	4.6 — 8.9
		O	15.6	16.2	5.6 — 22.7
		P	28.3	28.4	25.7 — 30.3
		Q	18.3	18.8	15.8 — 19.6
		R	5.7	5.6	4.1 — 7.9
SOFFIT	**** Results of 10 Bays		23.2	23.3	14.7 — 37.2

* See Figure 7-5, Section 7.2 for sample identification
** Result of 13 groups of samples
*** Results of 5 groups of samples
**** Results of 1 sample per bay

9.7 Zinc Bond Strength Tests

Table 9-7 presents the results of seventy two tests conducted to determine the bond strength between the hot glue adhesive and the metallized zinc surface on concrete lab specimens.

TABLE 9-7
BOND STRENGTH OF HOT GLUE ADHESIVE TO METALLIZED ZINC LABORATORY SPECIMENS
PSI

AVERAGE	MEDIAN	RANGE
67	50	0 — 250

9.8 Cathodic Protection Operational Parameters

In November 1985, the CP systems were activated and CP current was applied to the deck and soffit systems of the bridge.

Driving Voltage: The driving voltage of the deck system was initially set at 3.0 volts (nominal) while the driving voltage of the soffit system was set at 26 volts. A graph showing the variation in the driving voltages during their CP operation is given in Figure 9-3.

The driving voltage was increased in January 1986 to 5 volts on the deck system and to 40 volts on the soffit system in order to maintain the design current density criteria of 2 milliamps per square foot of steel surface area. This was achieved on the deck CP system, but the current density of the soffit CP system increased only to 1.2 mA/sq ft.

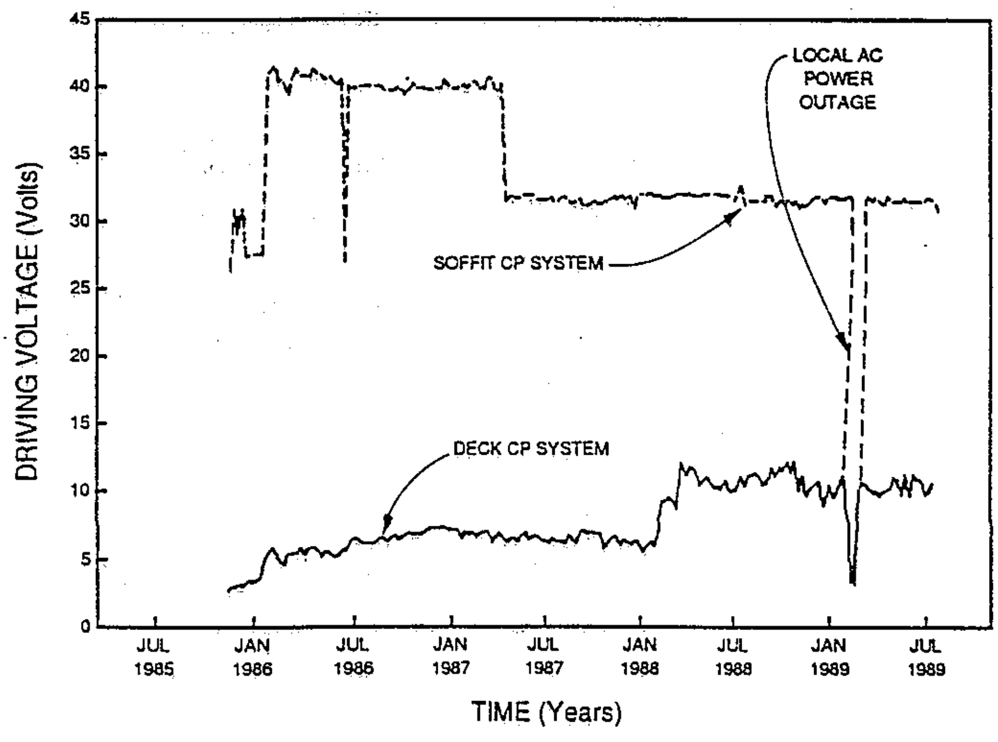


Figure 9-3, VARIATION OF DRIVING VOLTAGE VS TIME, DECK AND SOFFIT CP SYSTEMS

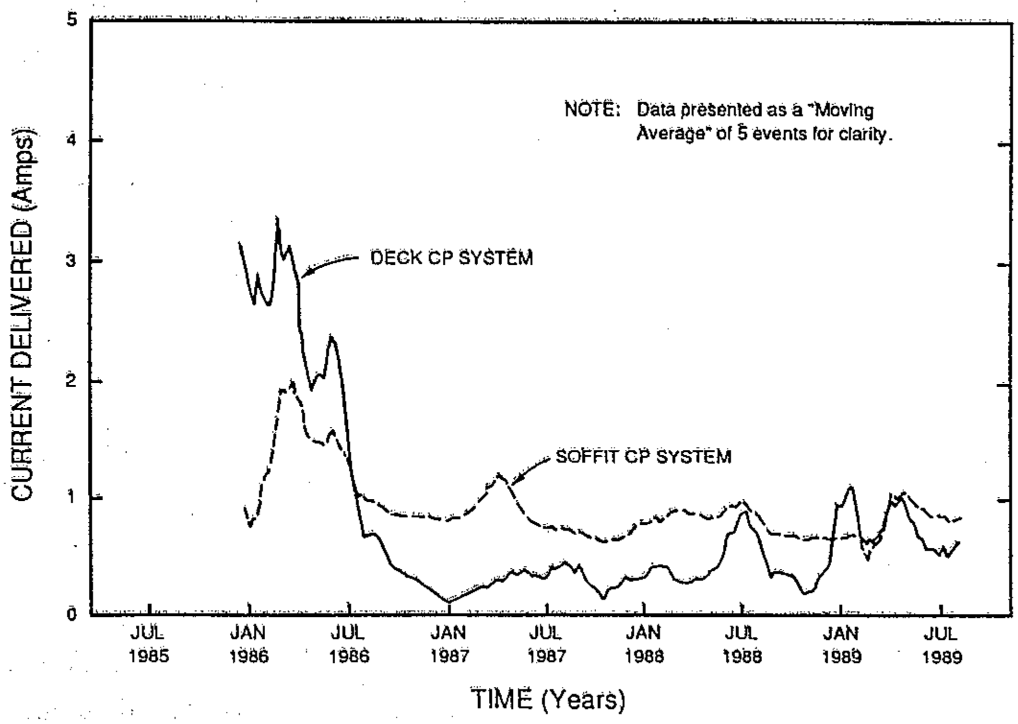
In June 1986, for safety reasons, the driving voltage of the soffit CP system was reduced to a nominal voltage of 30 volts to lower the effect of contacting the exposed metal coating. The deck CP system was not altered at this time and remained set at the nominal 5 volts.

Moisture Affects: As shown in Figure 9-4, seasonal climatological changes affect the current flow in the CP systems by changing the electrical resistance of the concrete. As expected, the CP current flow was higher during the wet periods and dropped off during the warm, dry summer as the concrete dried. The higher driving voltage was necessary on the soffit system to overcome the high electrical resistance of the concrete on that surface.

One of the requirements for the continued delivery of CP current is adequate moisture in the concrete. Two extremely dry weather years occurred immediately following the start-up of the CP systems. Table 9-8 presents the annual precipitation occurring during the test period of this project in percent of normal precipitation.

Another incident which reduced the amount of moisture in the concrete was the inadvertent application of an asphalt chipseal across the bridge deck in the summer of 1986. The chipseal on the westbound lanes, over the soffit CP system was removed shortly after being applied by roto-grinding the deck. The chipseal, however, was not removed from the eastbound lanes (the deck CP system) because the AC overlay protecting the metallized zinc coating was only about 3/4 inch thick. It was felt that the chipseal removal procedure would probably damage the coating and render the deck CP system inoperable.

In January 1988, to compensate for the recorded reduction in the delivered CP current, the driving voltage of the deck CP system was increased to a nominal 9 volts. This increase in driving voltage increased the average current density of the deck CP system from 0.09 to 0.22 mA/sq ft of steel. Since we were still experiencing below normal precipitation, we felt that was the primary cause of the low current density readings. No further voltage adjustments were made to the system at this time. It was felt that when the expected rainfall increased, and the circuit resistance dropped, the current density could be excessive.



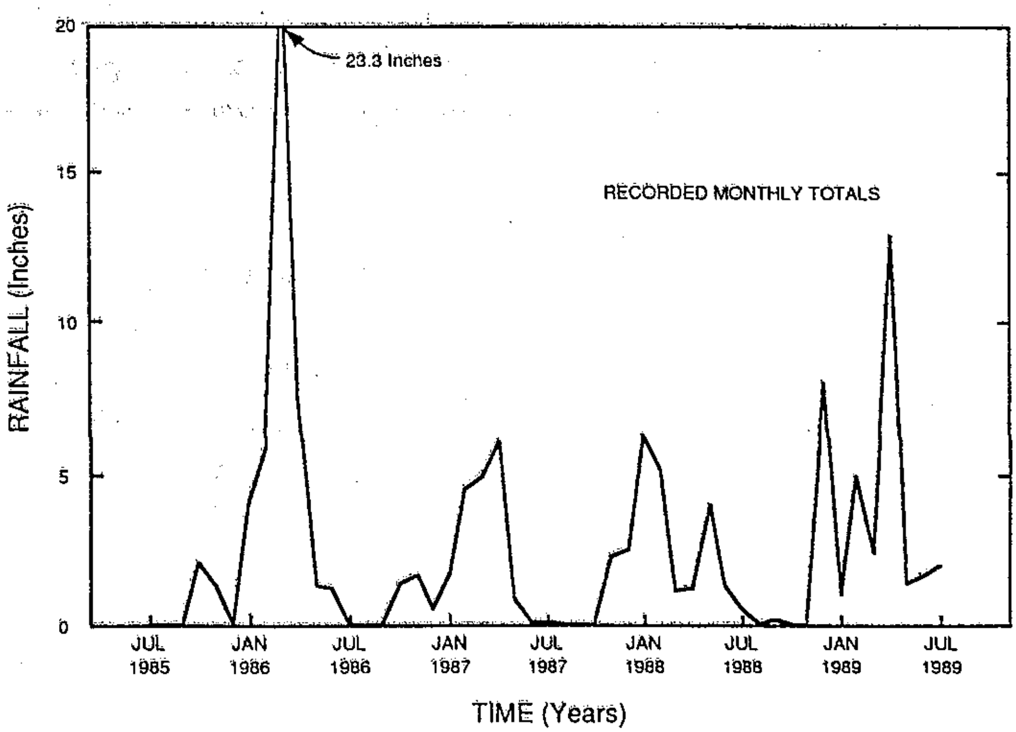


Figure 9-4, CP CURRENT AND PRECIPITATION VS TIME, DECK AND SOFFIT CP SYSTEMS

TABLE 9-8
ANNUAL PRECIPITATION

YEAR*	PRECIPITATION (Inches)	PERCENT OF NORMAL
85/86	46.5	115
86/87	21.9	54
87/88	24.4	60
88/89	34.1	84

* Weather Year Calculated as July to June

9.9 Cathodic Protection Effectiveness

Current Delivered: The capacity of the metallized zinc coating to discharge CP current is directly related to the amount of zinc metal applied and the consumption rate of the zinc. A theoretical maximum amount of CP current that could be delivered by each system was calculated using the consumption rate of zinc of 366 Ah/lb, the amount of zinc applied, and an estimated 50% current delivery efficiency of the coating (2). These values are shown, along with the cumulative current delivered for both systems, in Figure 9-5. Additionally, as presented in this report, consumption of the metallized zinc at the bonded surface of the zinc will result in a gradual buildup of oxides which will result in an increase in the circuit resistance. This buildup will have to be compensated for by increasing the driving voltage of the CP system.

The total CP current delivered during the 3.6 years of CP operation reported by this study was approximately 21,000 Ah for the deck system and 24,400 Ah for the soffit system.

Current Density: The CP systems on the East Camino UC were initialized to deliver a maximum current density of 2 mA/sq ft (of reinforcing steel surface area) during the wet periods and lesser current densities when the concrete was drier. In practice, the current densities measured weekly varied seasonally from 0.05 to 2.79 mA/sq ft for the deck system and between 0.08 to 2.71 mA/sq ft for the soffit system.

Each CP system was divided into quadrants or bays as described earlier. Figure 9-6 identifies the individual quadrants and bays (those areas provided CP current) relative to the deck area of the structure.

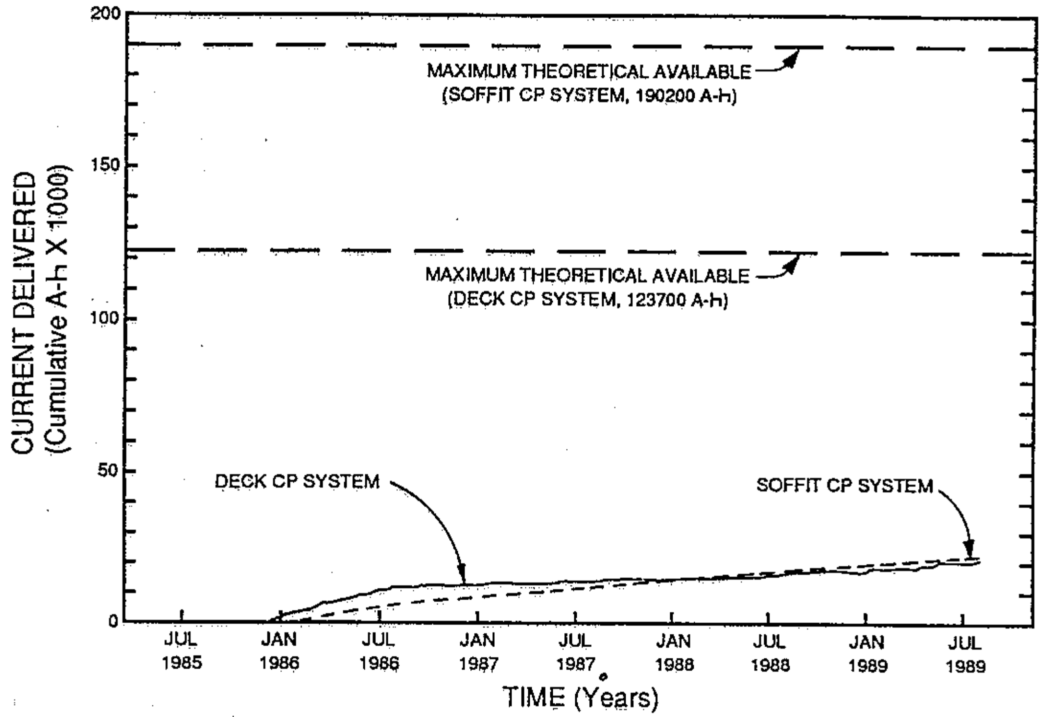


Figure 9-5, CUMULATIVE CURRENT DELIVERED VS TIME, DECK AND SOFFIT CP SYSTEMS

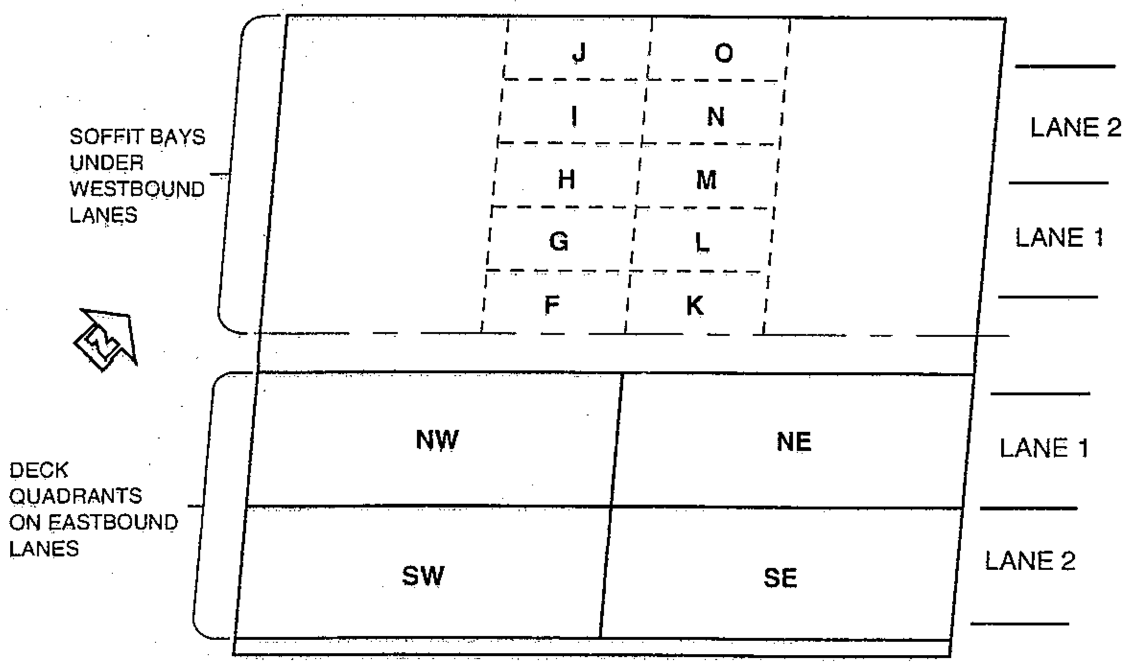


Figure 9-6, CP SYSTEM QUADRANT AND BAY IDENTIFICATION AND LOCATION

Figure 9-7 presents the current density delivered vs time for each of the four quadrants of the eastbound deck CP system, and Figures 9-8 and 9-9 shows this information for the bays of the westbound soffit CP system. These data are presented as a "moving average" of 10 events for clarity of the seasonal changes.

Bay M of the soffit system was excluded because the data were biased by extremely high current flows to that bay. There may be a near short circuit between the zinc coating and the reinforcing steel in Bay M. This short was not detected prior to energizing the soffit CP system.

To date (July 1989), the average current density supplied to the deck CP system has been 0.45 mA/sq ft and that for the soffit CP system has been 0.38 mA/sq ft (excluding bay M).

Since the quadrants and bays of these systems were independently wired, current flow to each could be monitored separately. Table 9-9 presents the average current density delivered to date (July 1989) to each area protected on the structure.

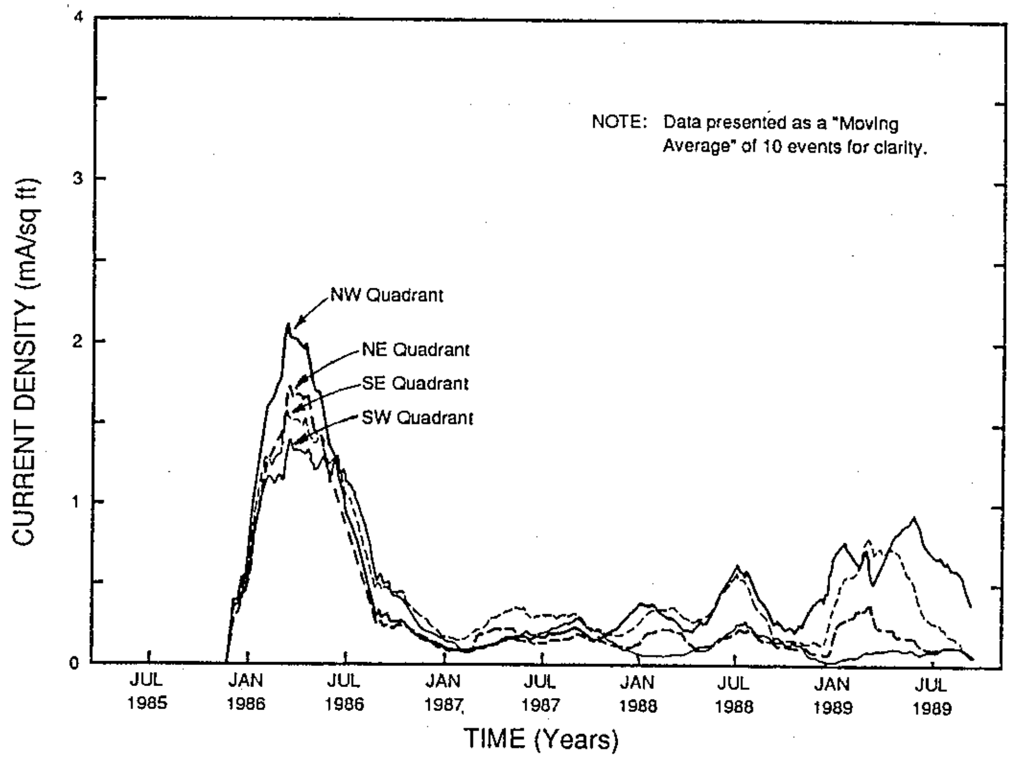


Figure 9-7, CURRENT DENSITY VS TIME, DECK CP SYSTEM

TABLE 9-9
COMPARISON OF CURRENT DENSITY VERSUS CP UNIT AREA PROTECTED, (NOV. 85 - JUL 89)
mA/sq ft steel

LOCATION	AVERAGE	RANGE
NW Quadrant	0.58	0.03 — 3.25
NE Quadrant	0.36	0.02 — 2.97
SW Quadrant	0.35	0.01 — 2.57
SE Quadrant	0.52	0.04 — 2.53
Combined Areas	0.45	0.05 — 2.79
Bay F	0.10	0.01 — 0.58
Bay G	0.26	0.02 — 1.56
Bay H	0.67	0.03 — 6.06
Bay I	0.43	0.03 — 2.99
Bay J	0.29	0.04 — 1.68
Bay K	0.13	0.01 — 1.25
Bay L	0.18	0.01 — 1.33
Bay M	6.42	0.57 — 7.94
Bay N	0.78	0.02 — 6.62
Bay O	0.55	0.08 — 2.64
Combined Areas	0.98 *	0.08 — 2.71

* Excluding Bay M Average Total for Bays = 0.38

The isolated bar installations described in Sections 5.1, 5.4, and Appendix 12.3 were used to measure current flow to each of the two reinforcing steel mats from each CP system (deck and soffit) during the first winter of CP application. Since the isolated bars were independently connected to each CP system, the current density could be monitored at each level of reinforcing steel.

The average current density results, based on the measurements of the isolated bars, are presented in Table 9-10.

<u>Polarization Decay</u>: The polarization decay results from ten instant-off surveys of 1 hour or more in duration are presented for each half-cell location (Table 9-11). The polarization decays are shifts in a positive direction with respect to the reinforcing steel for the test durations shown.

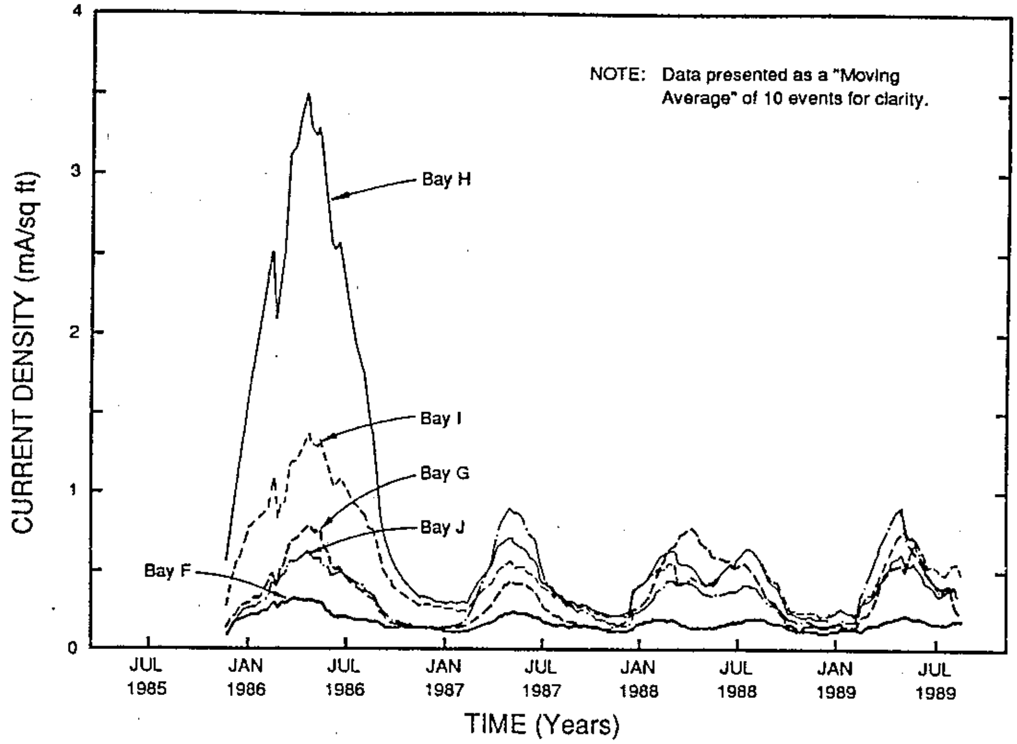


Figure 9-8, CURRENT DENSITY VS TIME, SOFFIT CP SYSTEM, BAYS F THROUGH J

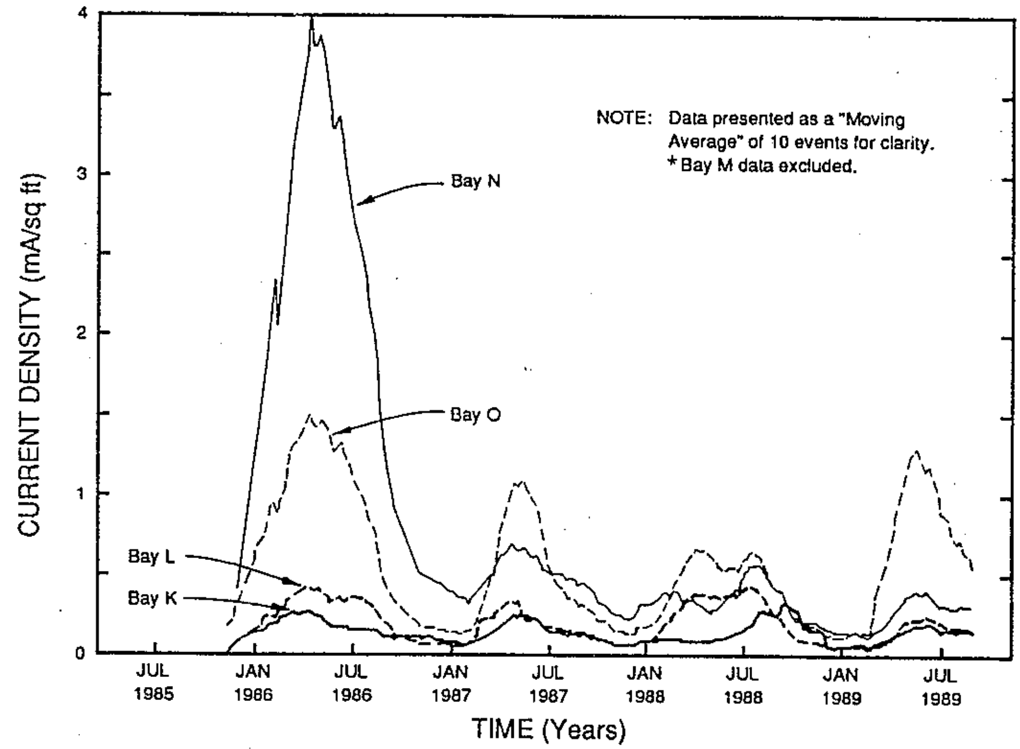


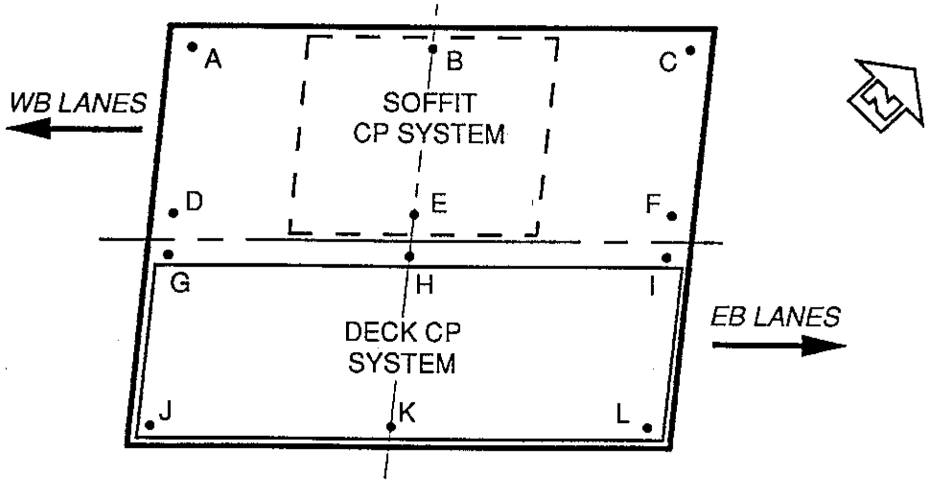
Figure 9-9, CURRENT DENSITY VS TIME, SOFFIT CP SYSTEM, BAYS K THROUGH O

TABLE 9-10
AVERAGE CURRENT DENSITY MEASURED AT THE LEVEL OF REINFORCING STEEL MATS
MEASUREMENTS TAKEN FROM ISOLATED BAR LOCATIONS
mA/sq ft steel

ISOLATED BAR LOCATION	SURFACE CP CURRENT WAS DELIVERED FROM	
	EB LANES DECK CP SYSTEM	WB LANES SOFFIT CP SYSTEM
* Top Rebar Mat	3.71	0.88
** Bottom Rebar Mat	0.08	0.18
Driving Voltage of CP System at Time of Testing, Volts	5.9	40.8

* Results from 11 Isolated Bars
** Results from 12 Isolated Bars

TABLE 9-11
POLARIZATION DECAY RESULTS



BRIDGE LOCATION MAP OF DATA COLLECTION
POINTS AND AREAS OF CP APPLICATION

NOMINAL VOLTAGE		INSTANT-OFF SURVEY DATES	CP OFF DURATION (Hrs)	POSITIVE POLARIZATION DECAY AT DATA COLLECTION POINTS (mV)											
SOFFIT CP	DECK CP			A*	B	C*	D*	E	F*	G	H	I	J	K	L
26	3	11-19-85	1	0	43	2	0	172	4	83	150	90	80	68	64
		11-22-85	1	0	42	0	0	180	0	79	81	82	64	43	45
		12-17-85	1	1	31	3	1	124	3	81	86	73	91	46	48
		1-22-86	1	0	33	0	0	136	0	70	91	69	57	29	30
40	5	2-26-86	1	8	45	11	0	144	5	62	84	57	67	48	50
			2	10	55	15	2	157	8	77	95	63	87	64	66
		8-2-86 Chipseal Applied to Bridge Deck; 10-2-86 Chipseal Removed From WB Lanes													
30		4-8-87	1	0	95	0	0	88	0	15	12	28	26	0	13
			2	0	102	5	4	102	4	24	18	35	32	3	19
		10-30-87	1	2	11	0	2	98	8	20	32	57	10	5	8
			2	0	14	1	1	109	15	27	42	67	16	12	16
		1-28-88	1	0	87	0	6	93	4	11	23	24	32	4	6
			2	0	96	5	8	106	8	7	31	27	37	11	13
	9	1-12-89	1	-	2	-	-	90	-	48	41	53	**	**	31
			2	-	0	-	-	110	-	52	47	54	**	**	35
			4	-	9	-	-	120	-	60	60	63	**	**	43
		4-18-89	1	-	37	-	-	86	-	30	19	32	34	11	1
			2	-	42	-	-	94	-	36	24	35	58	12	1
			4	-	50	-	-	107	-	46	31	41	100	19	6

* Areas of deck outside CP application area
\- Data not recovered
** Data invalid due to water leaks in halfcell ports

10.0 DISCUSSION OF RESULTS

This report has presented the results of two independent CP systems applied to the same bridge deck using metallized zinc as the distribution anodes. Both systems were applied to stop the corrosion of a salt-contaminated reinforced concrete bridge deck. The CP current of one system was supplied to the top surface of the deck, while the current of the other system was applied to the bottom surface (the soffit) of an adjacent area of the bridge deck.

10.1 Preliminary Site Tests

Extensive deck corrosion has resulted from successive years of applying deicing salts to the top surface of the deck.

Corrosion activity was found in over half the area of the deck, indicated by the results of a deck potential survey where readings exceeded -0.350 volts (vs. $Cu/CuSO_4$). In addition, chloride concentrations, at the level of the deck steel based on the results of concrete core analyses, exceeded 1 to 2 lb chloride ion per yd^3 of concrete, which is generally considered to be the threshold limit for rebar corrosion to occur (10).

The history of spalling on the deck also supports the extensive corrosion activity. Bridge maintenance records indicated spalling began about 7 years after the bridge was constructed. Six years later, sizeable delaminated areas were found. Prior to applying cathodic protection, approximately half of the surface area of the deck had been patched due to corrosion-induced delaminations. This maintenance activity occurred over a 21-year period.

10.2 Field Installation

Two ways of applying cathodic protection to the bridge deck were chosen for this study so that installation and operational effectiveness could be compared.

There are obvious advantages to applying CP from the bottom surface or soffit of the deck. The soffit CP system was easier to install because holes in the deck weren't required for the placement of primary anodes, the use of a uniform coating eliminated most of the layout and masking for stripes as required for the deck system, and electrical wiring could be easily surface mounted and routed to the rectifier and control cabinet. In addition, minimal traffic control was required since the system was being installed over a secondary road. Lane closures weren't needed due to the limited traffic on the secondary road. Traffic was diverted around the work area by two flagpersons. The result was less worker exposure to freeway traffic.

The primary anode pads, surface mounted in each bay of the soffit CP system, were also more accessible if maintenance was necessary. For that reason only one primary anode pad was wired for current delivery to each bay. Continued electrical contact between the primary distribution anode pads and the zinc coating of the deck CP system was an initial concern because the pads were inaccessible under the AC overlay. As a precaution, six primary distribution anode pads were placed within each of the four quadrants on the deck.

For this project, the disadvantage of applying CP from the soffit was overcoming the high electrical resistance of this concrete surface to deliver an adequate amount of CP current. It was understood at the onset that only the top surface of the deck had been exposed to salt and for that reason, the soffit surface would be less conductive.

Metallized zinc stripes were used for the deck CP system to insure that there was some clear area between each stripe for the AC overlay to bond to the concrete deck. However, no work was done to determine how much clear concrete surface area was needed to prevent slippage of the overlay.

There were some differences associated with using arc versus oxy-acetylene metallizing equipment. As discussed in the sections of the report on metallizing, the mechanized arc system used for the deck could not be moved fast enough to avoid some disbondment of the stripes. To compensate for this problem, the distance between the stripes and the number of passes required for each stripe were reduced.

The applied thickness of the zinc also varied due to the equipment used. For the deck system, the arc gun had a fixed trajectory and spray pattern which produced a mounded stripe thickness profile. On the soffit, the consistency of the coating thickness was dependent on the skill of the two operators using the hand-held oxy-acetylene guns. With both types of application equipment, there was a great deal of variability in the thickness of the applied zinc coatings.

Determining the bond strength of the metallized coatings on the concrete surfaces was not very successful. The bond strength of the deck stripes could not be determined due to the variability of the stripe thickness and partial disbondment problems. The modified paint adhesion test procedure using the Elcometer Adhesion Tester was difficult to apply. Great care and skill were needed to administer this test. The tester had to be extremely careful to uniformly torque the equipment while maintaining an accurate alignment to avoid eccentric loading. For future work, another type of tester should be tried, one that is more stable and has a more uniform way of applying the load.

The asphalt slurry seal coat, used to protect the zinc stripes until the overlay was applied to the deck system, should not have been used. It appears that the slurry seal may have hampered the operation of the deck CP system as discussed in the next section. Better construction scheduling could have prevented this problem.

10.3 Cathodic Protection Operation and Effectiveness

During the 3.6 year study period, the operation of both CP systems varied due to below normal precipitation, the effects of the slurry seal and chipseal, and the nonhomogeneous state of the concrete due to differences in chloride contamination and multiple patches which influenced the uniform delivery of CP current to the deck.

To compensate for these effects, the driving voltages were increased on two occasions during this period to overcome the higher-than-expected circuit resistance of each CP system. The preset nominal driving voltage for the deck system varied from 3 to 9 volts and that for the soffit from 26 to 40 volts; however, the recorded average driving voltages for these systems were 8.0 and 34.0 volts during the period of this study.

The higher average driving voltage for the soffit CP system (about 4 times higher than the deck system) was needed to overcome the higher electrical resistance of the concrete at this surface which resulted from not being directly exposed to salt contamination.

The average current density in the quadrants of the deck CP system didn't vary significantly, ranging from 0.35 to 0.58 mA/ft^2 of steel. There was more variation in current density in the bays of the soffit CP system. Average values ranged from 0.10 to 0.78 mA/ft^2 of steel. Data from Bay M were excluded because of the high current delivery as explained in Section 9.9.

The range of average current density values for the quadrants and bays representing each CP system are fairly consistent with each other, excluding the data from Bay M and the high end values (single occurrences) of Bays H and N.

Since three of the four study years received below normal rainfall, the effect of precipitation on the operation of the CP systems is shown by the wide range of current densities. These ranges reflect the seasonal variation or moisture dependency of the systems. The lower current delivery values were recorded during the dry periods when the deck concrete was more resistant to current flow. As moisture increased, larger currents were measured and the resulting current densities of some test areas approached or exceeded the design value of 2 mA per ft^2 of steel surface area for the systems.

The slurry seal applied to the deck as temporary protection for the zinc distribution grid prior to installing the AC overlay and the inadvertent application of the chipseal about 9 months after the deck systems were energized also helped to reduce the amount of moisture reaching the eastbound lanes of the concrete deck. The chipseal did not influence the soffit CP system because it was removed during the summer, shortly after being applied.

Research has shown that a slurry seal reduces the water permeability of a pavement to very low values (11). The same report presents data showing that the permeability of the AC pavement can increase with the thickness of the applied overlay. The permeability increase is highly variable and much depends on field and design conditions such as asphalt content, aggregate grading, compaction method and temperature, and the void ratio of the finished AC overlay.

Local differences within the concrete such as density, cracks, the degree of salt contamination, previous deck patching materials along with varying moisture content create preferential paths for current flow. These differences prevented the CP current from being uniformly distributed to the reinforcing steel in the deck.

As of July 1989, there was no discernable difference in the delivery of CP current between either the zinc or brass electrical connectors (primary anodes) used in the deck CP system. The metallized zinc interface with these connections should be monitored as part of a long-term monitoring project for these systems.

Based on our evaluation criteria of 0.100 volt polarization decay, over a four hour period, neither CP system has been as effective as expected. Data from Table 9-11, Section 9.9 point this out.

Polarization decay values for the deck CP system prior to the chipseal incident were much higher and closer to the evaluation criteria than those recorded after this event. The above normal precipitation during the first year (85/86) of operation helped and the three below normal water years (measured from July to June) that followed, significantly affected the performance of this system. Another complicating factor mentioned above is the difficulty measuring accurate current flows to the quadrants due to the nonhomogeneous nature of the extensively patched and contaminated bridge deck.

Even with these concerns, it appears that the deck CP system is providing some cathodic protection to the deck reinforcing steel. The ability of the metallized zinc CP system to deliver cathodic protection current to the bridge deck steel is supported by tests conducted after the completion of the reporting period for this research project. During the spring of 1992, an instant-off survey was performed just after a period of high rainfall. The resulting polarization decay data indicated that the CP effectiveness was increased sufficiently when moisture was present in the concrete. The four hour polarization decay average during this test, as recorded at 9 individual reference cell locations across the deck CP system, was 99.9 millivolts with a range of 48.3 to 196.4 millivolts. The average current density delivered immediately prior to this test to the four quadrants ranged from 0.09 to 1.86 mA/sq. ft of steel.

Further long-term monitoring of this system is needed to determine whether the lack of moisture resulting from below normal precipitation and the sealing affects of the slurry seal and chipseal will impede the delivery of CP current and jeopardize the long-term effectiveness of this CP system. However, as evident from the Spring 1992 depolarization decay results, the effectiveness of the CP system will be restored with the return of normal rainfall.

The soffit CP system has been only marginally effective. The high average driving voltage required to overcome the circuit resistance does not leave room for future adjustment. The polarization decay data (Table 9-11) for the two deck locations (B and E) which were used to characterize the soffit CP system seem to be inconsistent. Given the likelihood that circuit resistance will increase with time and require an abnormally high voltage to drive this system, metallized zinc CP systems should not be applied to the bottoms (soffit) of bridge decks that are contaminated by salt from their top deck surface.

A cursory review of the isolated bar monitoring data indicate that about 98% of the CP current is reaching the top rebar mat when delivered from the top surface of the deck. Quite surprisingly, the top rebar mat received about 83% of the current when the CP current was delivered from the soffit or bottom surface of the deck (Table 9-10). These data, however, should be viewed with caution, because the results represent only one set of readings. Additional isolated bar current measurements should be taken during a long-term monitoring program of these CP systems.

10.4 Life Expectancy

Calculations based on the amount of CP current delivered by the two CP systems were used to determine the amount of zinc consumed up until the end of this study period (July 1989). The deck CP system has consumed 16.9% of the zinc that was theoretically available (as described in Section 9.9), while the soffit CP system consumed 12.4%.

Based on the volume of zinc applied to each CP system (deck system, 0.23 lb/sq ft of concrete; soffit system, 0.75 lb/sq ft of concrete) and the consumption rate of the zinc (as previously presented in Section 9.9), the estimated life expectancy of each CP system may exceed 20 years. These estimates assume that the current densities will be maintained at their present rates. The useful life of these CP systems will also depend on how efficiently the zinc coatings distribute current to the surfaces of the bridge deck.

The expected life and current densities are based on a uniform distribution of CP current. Experience has shown that the delivery of CP current through concrete is not uniform. It is evident that when current is being delivered from a large surface area conductor (such as the zinc coated surfaces) the zinc coating will be consumed in some areas long before other areas due to the nonuniformity of current delivery.

10.5 Installation Costs

The costs associated with installing the CP systems for this project reflect the uncertainties of a new technology. This was the first time the metallized zinc CP system was applied to a bridge deck. This study dealt with two independent systems: The CP system used on the top surface of the deck was installed by state forces; and the CP system applied to the bottom surface of the deck (soffit) was installed by contract.

The deck CP system was metallized with a Caltrans designed and built metallizing truck. An experienced commercial metallizer was employed to operate the metallizing equipment.

The arc-sprayed deck CP system cost approximately $9.62/sq ft. Costs include shotblasting the deck, placing the primary anodes, zinc application, a 1-inch-thick AC overlay, electrical wiring, traffic control, slurry seal, and waste disposal. This cost does not include the deck repair work, installing the isolated bars, or the rectifier. The cost for the deck CP system also does not include the development and fabrication costs for the truck-mounted metallizing equipment and control systems. If the cost of the slurry seal is deducted, the deck CP system cost would be reduced to $8.90/sq ft of concrete deck area.

The cost for installing the flame-sprayed soffit CP system by contract was $32.50/sq ft. This cost includes surface preparation, zinc application, anode placement, traffic control and waste disposal. The primary anodes were supplied and installed by Caltrans. The high metallizing cost of the soffit CP system reflect the first time bidding uncertainty by the contractor, and developmental costs associated with gearing up for this project, such as the overspray containment system. In addition, the contractor, even though having extensive commercial metallizing experience, had no prior experience metallizing a concrete surface with zinc.

Installation costs for other deck CP systems have been compared in a previous publication (12). While not all systems can be directly compared, (because some require an overlay) they all fall within the same approximate cost range of 3 to 9 dollars/sq ft. These costs obviously reflect to some degree the evolutionary development and installation learning curves for these systems.

In general, bridge deck cathodic protection costs will decrease as these systems gain wider acceptance and as competitive bids reflect the actual costs rather than the research and experimental nature of the earlier installed systems.

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12.0 APPENDICES

12.1 Primary Distribution Anodes (Deck)

Brass and zinc electrical contact pads (primary anodes) were used as a means to deliver the CP current to the zinc-coated bridge deck.

The primary anodes (Figure 12-1) consisted of 2" x 2" x 3/8" thick brass or zinc plates machined with an approximate 45 degree bevel on all 4 edges. The two wire leads (one current supply and 1 test lead) were silver soldered to the bottom surface of the pad and then epoxy coated to electrically insulate that surface.

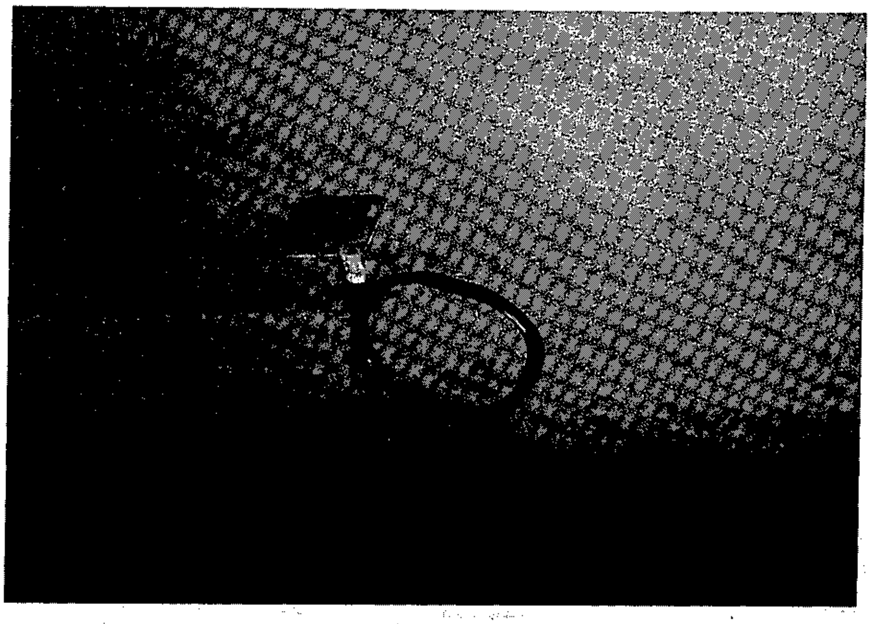


Figure 12-1, DECK PRIMARY ANODE, BRASS OR ZINC PAD

The primary anode pads were bonded into the concrete deck with epoxy with the top surface flush with the concrete surface of the deck (Figure 12-2). Since the anode pads on the deck CP system would be subjected to direct traffic loading the machined bevels were provided to mechanically lock the pads to the bridge deck with the epoxy.

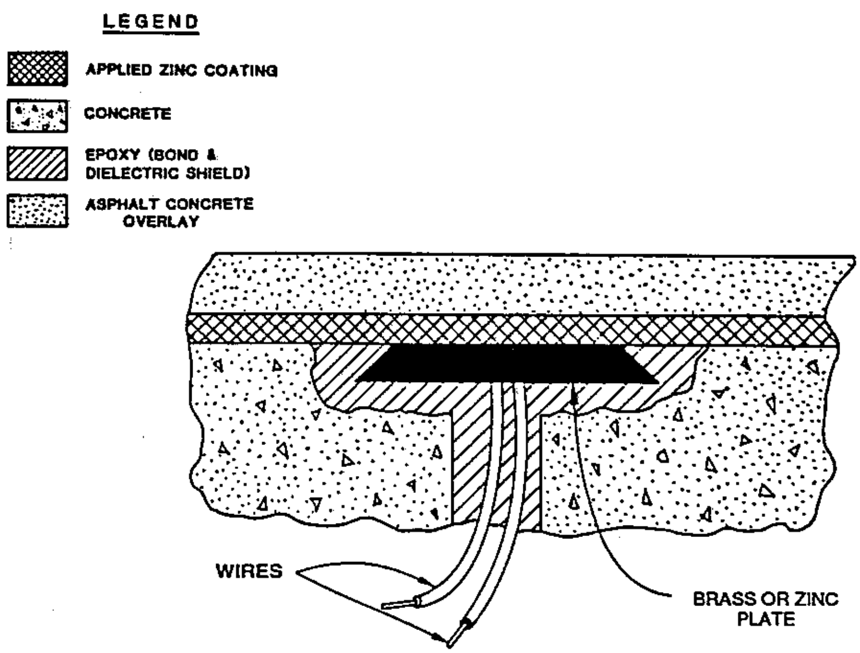


Figure 12-2, DECK PRIMARY ANODE PLACEMENT, CROSS SECTION

The location on the deck of each anode pad was ascertained and a 1 1/4-inch-diameter hole was cored through the deck at each location (Figure 12-3). The deck surface around the cored hole was chipped away to allow the recessed placement of the anode pad. Caution was used to insure that sufficient concrete was chipped away so that no portion of the brass pad was in direct contact with the concrete. The epoxy used to attach the anode pads to the concrete became the electrical insulator between the two.

The epoxy used (Concresive AEX 1419) was electrically nonconductive with sufficient viscosity to support the pads without flowing. The surface of each anode pad was sandblasted along with the remainder of the deck prior to metallizing (Figure 12-4).

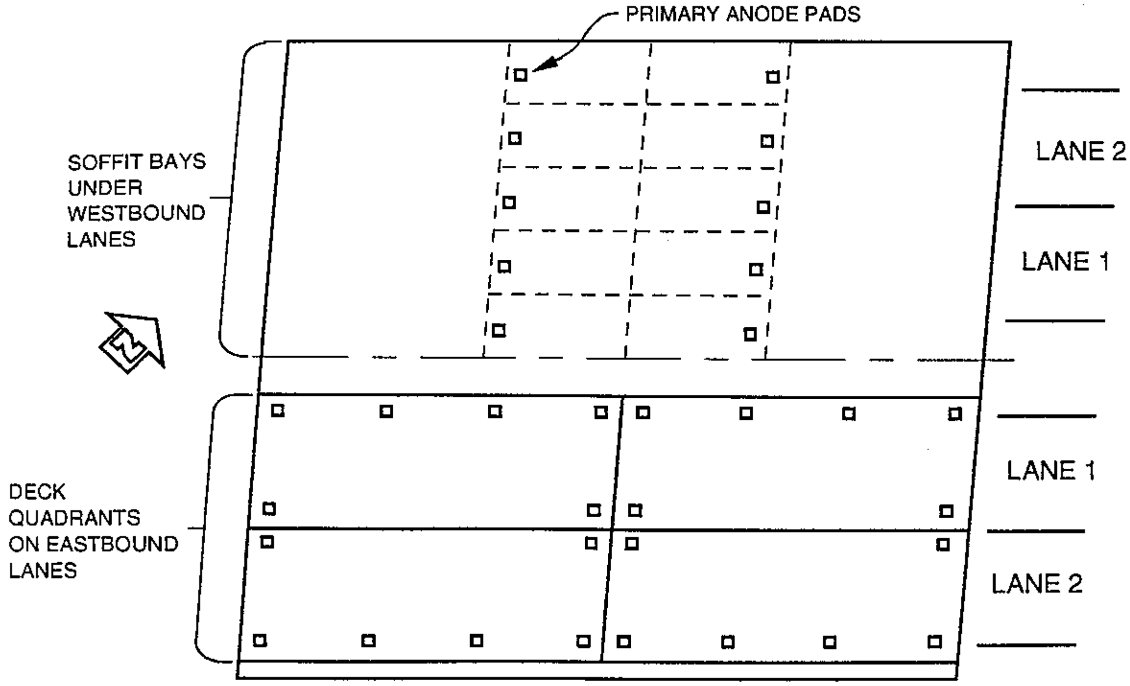


Figure 12-3, PRIMARY ANODE LOCATIONS, DECK AND SOFFIT CP SYSTEMS

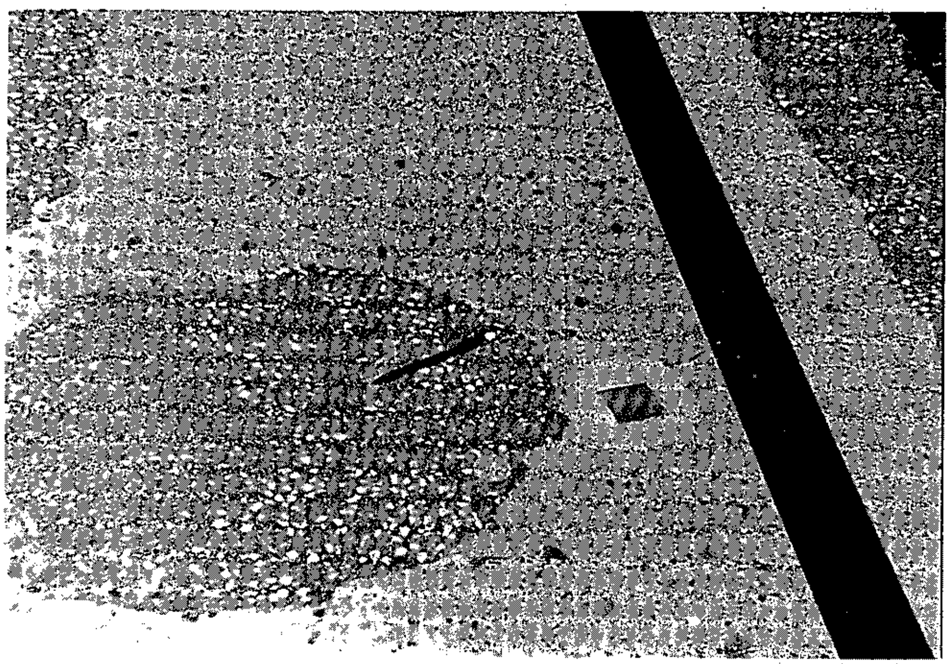


Figure 12-4, DECK PRIMARY ANODE IN PLACE

The two wire leads were extended through the cored holes in the deck to an electrical conduit (PVC) collector system attached to the underside of the deck. This conduit system leads to the control box.

12.2 Primary Distribution Anodes (Soffit)

Brass electrical contact pads (primary anodes) were used as a means to deliver the CP current to the zinc-coated soffit.

The primary anodes (Figure 12-5) consisted of 2" x 2" x 1/16" thick brass plates with binding posts (1/4"-20NC x 1 inch long brass bolts) silver soldered to the face surface of each pad. The binding posts would be used to attach the two wire leads (one current lead and one test lead) from the control box.

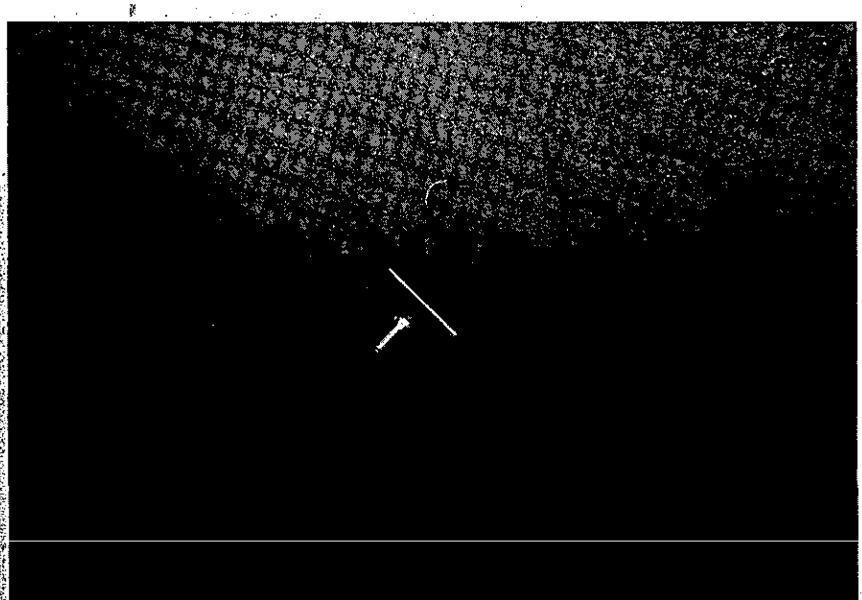


Figure 12-5, SOFFIT PRIMARY ANODE, BRASS PAD

At the location where the pads would be placed (see location drawing, Figure 12-3, Section 12.1), a recess was chipped into the concrete surface and the pad epoxied to it so that the face surface of the pad remained flush with the concrete soffit surface (Figure 12-6). Caution was used that sufficient concrete was chipped away so that no portion of the brass pad was in direct contact with the concrete. The epoxy used to attach the anode pad to the concrete became the electrical insulator between the two.

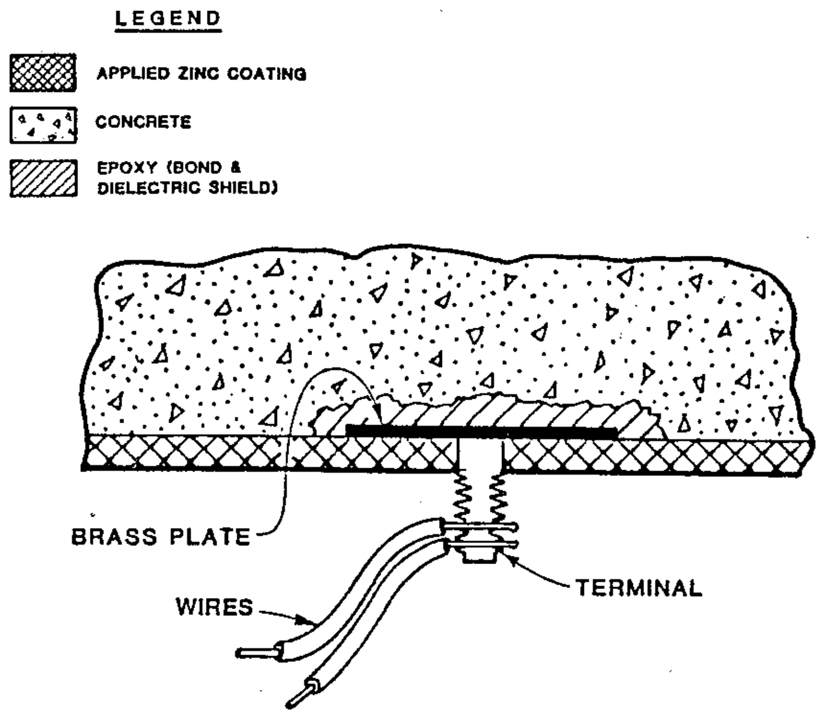


Figure 12-6, SOFFIT PRIMARY ANODE PLACEMENT, CROSS SECTION

The epoxy used (Concresive AEX 1419) was electrically nonconductive with sufficient viscosity to support the pads in place without flowing. The surface of each anode pad was sandblasted along with the remainder of the soffit surface prior to metallizing (Figure 12-7).

Prior to sandblasting and metallizing, the threaded surface of the binding posts was taped for protection from abrasive damage. The two wire leads from the brass anode pads (one current lead and one test lead) within the PVC conduit were surface-mounted (after metallizing) and continued to the control box.

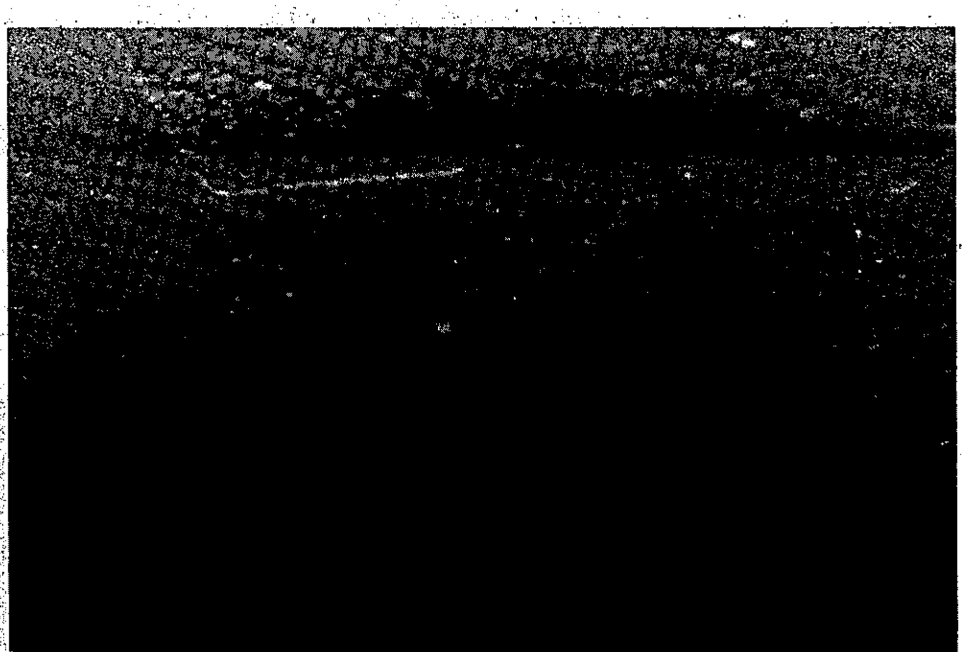


Figure 12-7, SOFFIT PRIMARY ANODE IN PLACE

12.3 Isolated Bars

Isolated bar measurement test stations were installed at ten locations on the upper reinforcing steel mat and at ten locations on the lower reinforcing steel mat of the bridge deck (Figure 12-8).

Each test station was comprised of two segments of reinforcing steel. Each segment (isolated bar) was approximately 5" long X 5/8" diameter (#5 rebar).

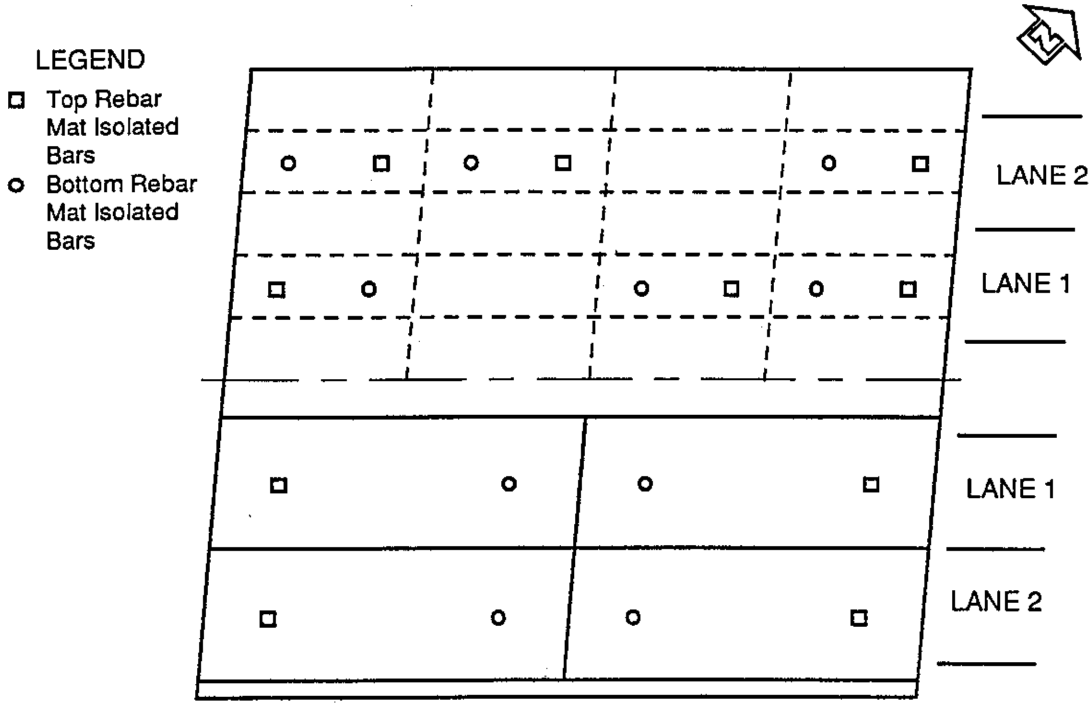
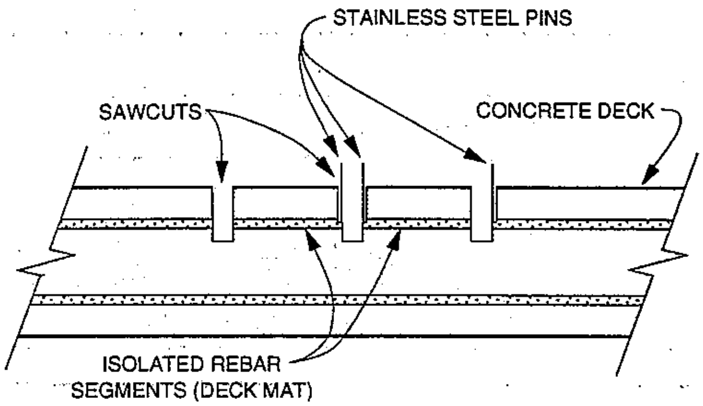


Figure 12-8, LOCATION OF ISOLATED BAR INSTALLATIONS

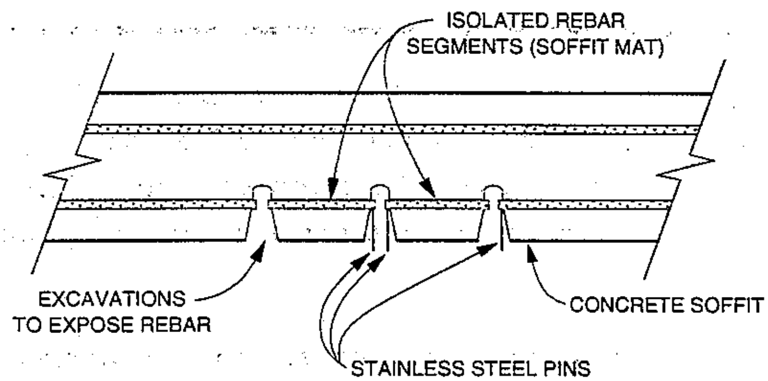
The isolated bars were portions of the existing reinforcing steel bar mat. The reinforcing steel segments at each location were carefully severed from the rest of the reinforcing steel mat within areas of sound concrete that had been neither patched nor cracked. The rebar segments were not removed from the concrete, but rather, remained undisturbed within their original environment (Figure 12-9).

The electrical connection to each isolated bar was made by mechanically swaging a 3-inch-long stainless steel pin into a predrilled hole in the rebar. The pin diameter was 0.125 inches while the drilled hole in the isolated bar was 0.120 inches. This was done (in lieu of soldering or welding the connection) in order not to alter the environment nor composition of the reinforcing steel bar segments.

The connecting wire leads (extending to the control box) were then soldered to the exposed ends of the pins (Figure 12-10). All pins, wire leads and connectors were then potted with non-conductive epoxy (Concresive AEX 1419) within the saw cuts in the concrete deck.



TOP REBAR MAT



BOTTOM REBAR MAT

Figure 12-9, TYPICAL ISOLATED BAR INSTALLATIONS

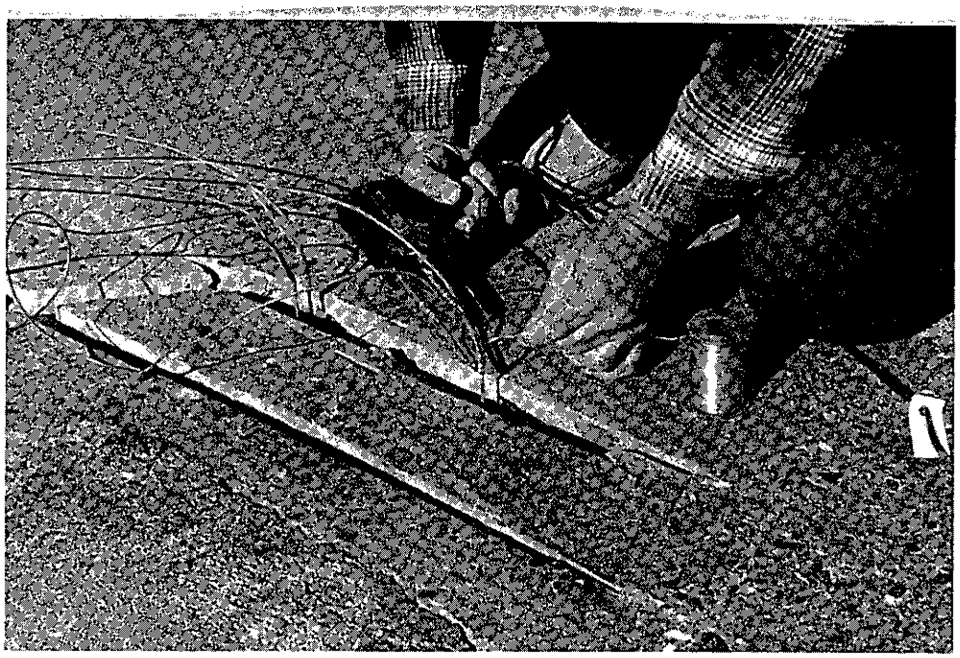


Figure 12-10, TOP REBAR MAT ISOLATED BAR WIRING

12.4 Rebar Electrical Ground Connections

The rebar ground leads (rectifier negative connectors) were exothermically welded by the CADWELD process to bridge deck top rebar mat bars at eight different locations (four evenly spaced along each shoulder of the deck). See Figure 12-11.

Saw cuts were made in the deck (approximately 1/2" wide x 1/2" deep) to provide recessed runners between the CADWELDED contact and a cored hole through the deck.

The two wire leads (one 12-gauge current return and one 18-gauge test lead) were placed within the sawcut grooves. The grooves along with the wires were potted with epoxy flush with the top surface of the deck.

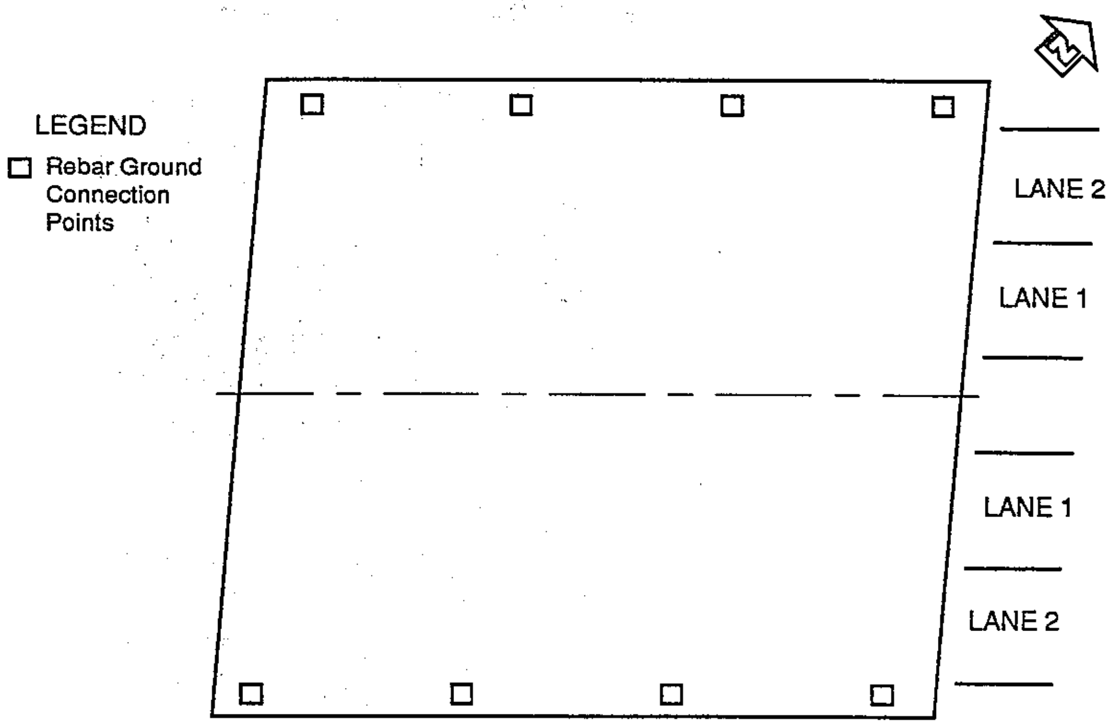


Figure 12-11, LOCATION OF REBAR GROUND CONNECTIONS

The two wire leads from each ground connection were extended through the cored holes in the deck to a electrical conduit (PVC) collector system attached to the underside of the deck.

The wires terminated at the Control Box where they were interconnected to form a single common ground circuit with each rectifier.

12.5 Control Box

All electrical circuitry, with the exception of that needed for the placement and wiring of temporary half-cells during instant-off surveys, was wired permanently to the Control Box located under the bridge structure (Figures 12-12, 12-13 & 12-14).

The Control Box, a standard California Model 200 Traffic Signal Cabinet (measuring approximately 2.0 ft X 2.5 ft X 6.2 ft high), housed all electrical circuitry and the soffit CP system rectifier. The deck CP system rectifier was housed separately within a cabinet attached to the control box.

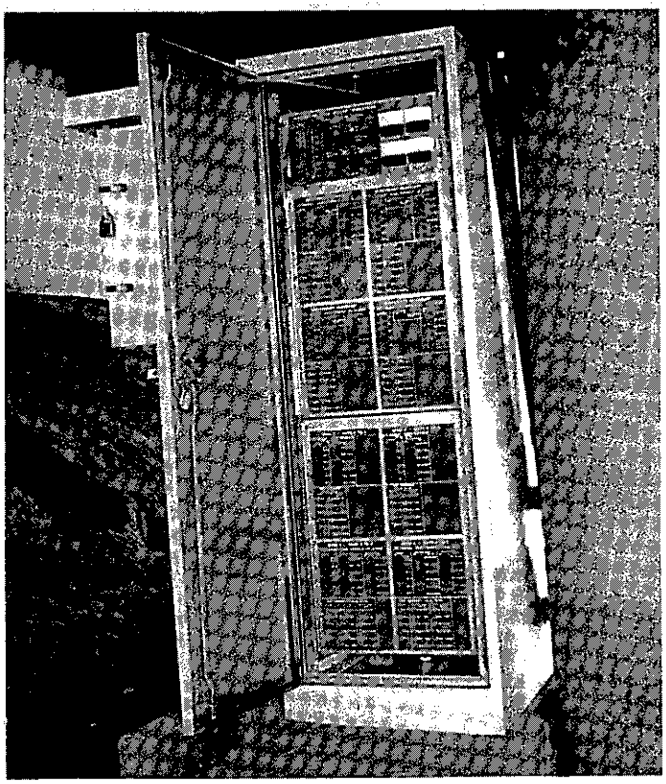


Figure 12-12, CONTROL BOX MONITOR TERMINALS

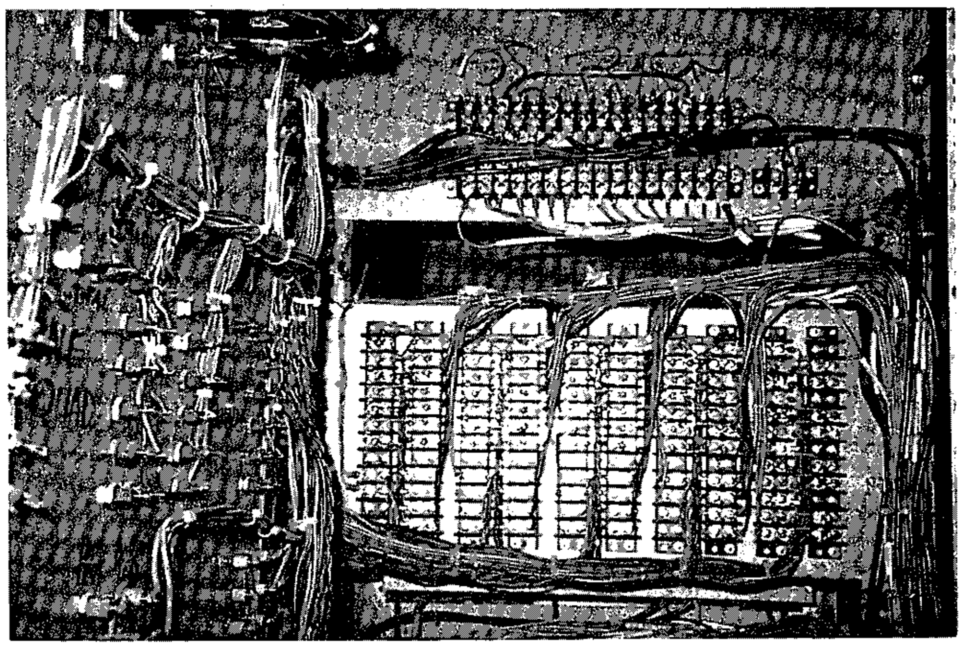
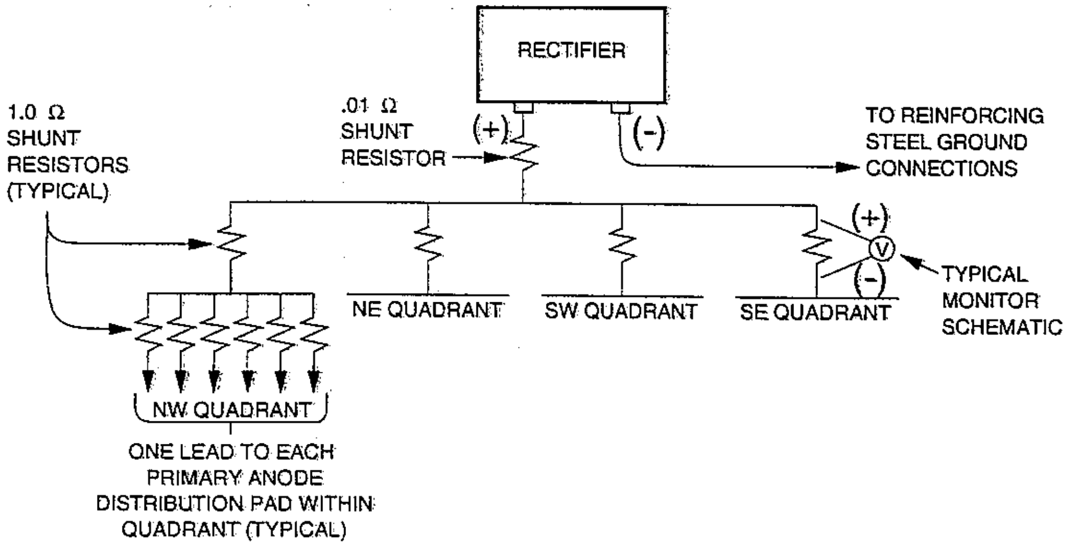
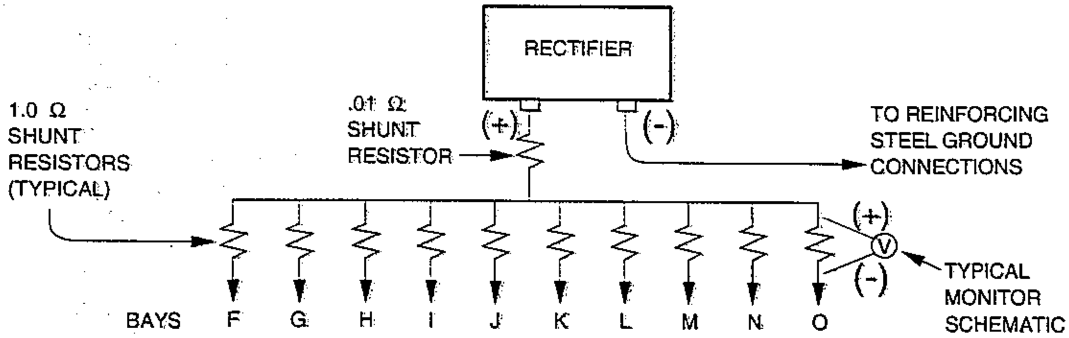


Figure 12-13, CONTROL BOX CIRCUITRY



DECK CP SYSTEM



SOFFIT CP SYSTEM

Figure 12-14, CP SYSTEM SCHEMATICS

The panel distribution allows for the independent monitoring of driving voltage and current flow to each quadrant and bay of the structure from the control box.

12.6 Metallizing Process and Equipment

Basically, metallizing is a technique which utilizes a metal or alloy in the form of wire or powder, melts it to liquid form by one of several methods, and sprays the molten metal as if it were paint, usually by means of compressed air. Typically, metallizing is used "metal-to-metal" to rebuild worn shafts and for similar applications (13,14,15,16,17,18,19,20).

Two methods were used on the structure in this study: "arc-spray" metallizing, and "flame-spray" metallizing.

The arc-spray process utilized a frame-mounted metallizing gun. Two wires are used with the arc system in lieu of one wire as with the flame-spray gun. The two metal wires are fed (in this case, zinc) through the back of the gun by an air driven motor and converge at a single point within the nozzle. As the wires pass through the gun, each wire is energized with opposite polarities of high DC electrical current. At the point of convergence, an arc is struck as the two wires contact each other and the resulting molten zinc is sprayed onto the surface with a jet of compressed air (Figure 12-15).

Metallizing of the deck surface was accomplished using truck-mounted equipment. All equipment necessary to metalize (i.e., zinc wire reels, DC rectifier and controller, vacuum recovery system, metallizing gun, and gun traversing mechanism) were mounted on a 1.5-ton flat-bed truck. A trailer-mounted AC generator was used to provide the required electrical service to the metallizing truck as was a trailer-mounted air compressor to supply the required compressed air.

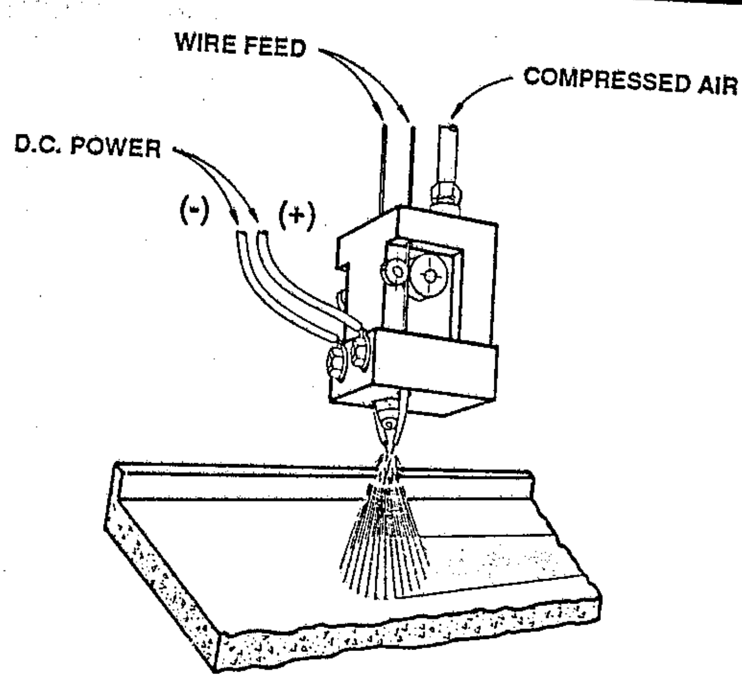


Figure 12-15, ARC-SPRAY METALLIZING GUN

The metallizing gun traversing system was hydraulically driven on a 12-foot-wide guide-frame mounted on the rear of the truck, at ground level, transverse to the axis of the truck.

A second hydraulic drive was coupled to the rear wheels of the truck to provide forward/backward movement of the metallizing equipment.

A shield around the metallizing gun head captured the zinc fumes and particle overspray which was ducted to the filter.

An operator with a remote control console controlled all movements and actions of the metallizing system (Figure 12-16).

Table 12-1 presents the specifications for the equipment used to arc spray the deck CP system.

The flame-spray process utilized a hand-held "gun". A single wire (in this case, zinc) is automatically fed through the back of the gun (powered by an air driven motor), and melted by the oxygen/acetylene gas flame. The resultant molten zinc is propelled out the nozzle by compressed air (Figure 12-17).

Metallizing of the soffit surface of the bridge deck was accomplished from within a zinc overspray tent enclosure. The tent was raised into position to enclose each bay to be sprayed. The operators wore air-fed respirators to protect them from the zinc dust and fumes during the spraying operation (Figure 12-18).

Table 12-2 presents the specifications for the equipment used to arc spray the deck CP system.

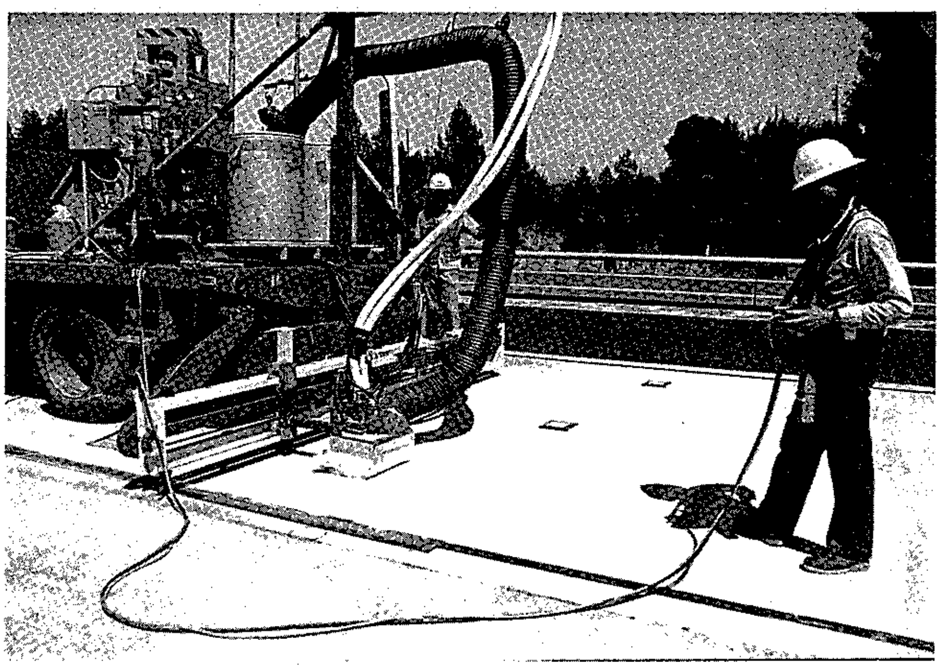


Figure 12-16, DECK METALLIZING SYSTEM

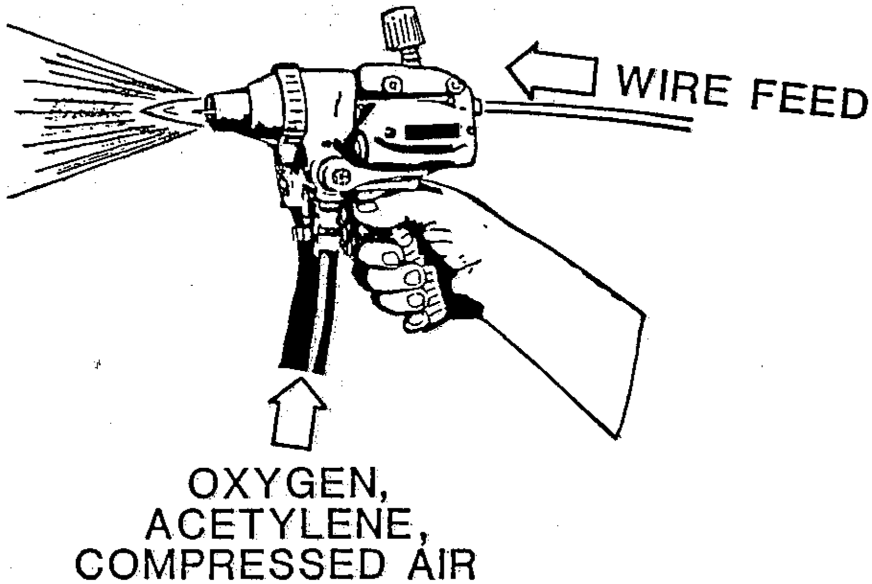


Figure 12-17, FLAME SPRAY METALLIZING GUN

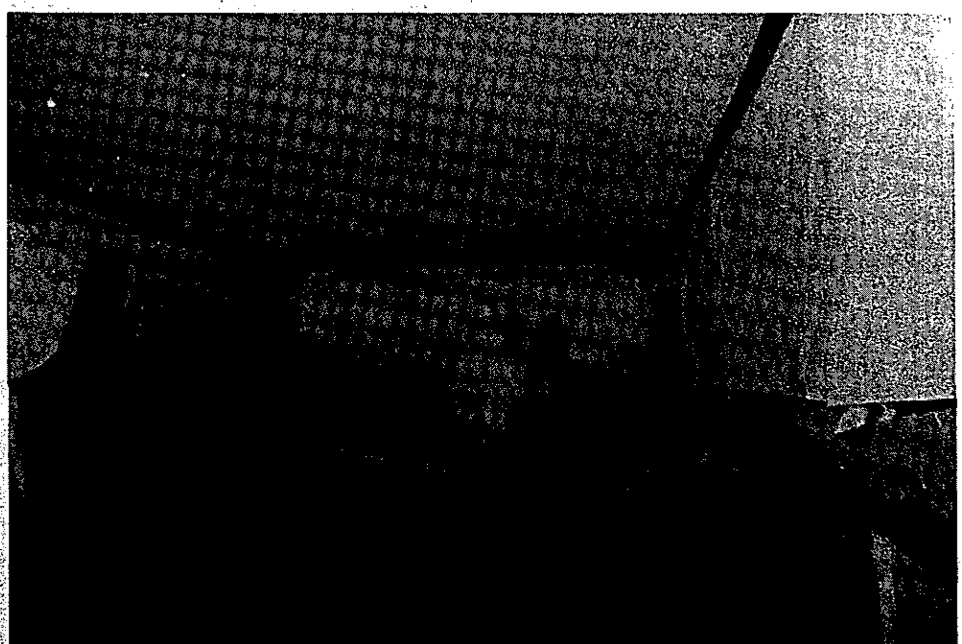


Figure 12-18, METALLIZING SOFFIT FROM WITHIN TENT ENCLOSURE

TABLE 12-1
METALLIZING AND AUXILIARY EQUIPMENT POWER AND UTILITY REQUIREMENTS

ARC-SPRAY METALLIZING

METALLIZING EQUIPMENT	
Type of Gun	Arc spray
Model	Mogul A-6-CPX-TR
Power Requirement	220/440 VAC, 120/60 Amp, 3 ph, 60 Hz
Output	480 Amp/39 Volt DC (100% duty cycle)
Compressed Air	40 CFM at 85 psi

VACUUM EXHAUST FILTER SYSTEM	
Filter	Turbulent action water wash scrubber
Power Requirement	7.5 HP, 200/440 VAC, 3 ph, 60 Hz
Air Flow Capacity	2700 CFM at 8" SP
Air Duct Size	8 inch diameter
Water Capacity	35 gallons

TABLE 12-2
METALLIZING AND AUXILIARY EQUIPMENT POWER AND UTILITY REQUIREMENTS

FLAME-SPRAY METALLIZING

METALLIZING EQUIPMENT	
Type of Guns	Flame spray (combustion)
Model	Metco 10E
Combustion Material	Oxygen / Acetylene
Combustion Rate: Oxygen	1.8 cu ft/lb zinc
Acetylene	0.7 cu ft/lb zinc
Compressed Air	30 CFM at 65 psi

VACUUM EXHAUST FILTER SYSTEM	
Filter	Baghouse type, dry filter
Air Flow Capacity	2000 CFM
Air Duct Size	12" diameter (2 used)