HR-553

ELGARD™ CATHODIC PROTECTION SYSTEM

Iowa Department of Transportation
Pennsylvania Ave. Bridge over I-235
Des Moines, Iowa

OPERATION AND MAINTENANCE MANUAL

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INTRODUCTION

I. INTRODUCTION

A. General

Following is the Operations Manual for the Pennsylvania Ave Bridge over I-235 located in Des Moines, Iowa, which was installed from July 1992 to October 1992. The project uses ELGARD™ 210 Anode Mesh and is divided into 3 zones.

Periodic data collection and/or inspection of the cathodic protection system is required to insure proper operation and a long life. This Operation Manual contains a schedule, operation procedures, operation log forms, a rectifier panel drawing, and pertinent reference material. Operation procedures and operating records are contained in the body of the manual, while blank operation forms, as built drawings, and pertinent reference material are contained in the appendices

NOTE: It is recommended by ELGARD Corporation that the Operation Manual be kept in the rectifier cabinet or other safe location at all times. In addition, the keys to the doors of the rectifier cabinet should be placed in a safe location

Caution: NEVER cut into the overlay on the structure without first contacting ELGARD Corporation and reviewing the approved "as-built" project drawings.

B. Scope

This Operation Manual covers all of the essential procedures necessary to monitor and maintain the cathodic protection system. If any problems develop, and cannot be solved from the information provided throughout this manual, then call, write, or facsimile ELGARD Corporation using the information shown on the cover sheet. In addition, if more information is required than is contained in the REFERENCE MATERIAL APPENDIX, then contact ELGARD Corporation for more cathodic protection information.

OPERATION LOG FORMS

II. NORMAL OPERATING PROCEDURES

A. OPERATION LOG FORMS

1. General

Following are the operation log forms required for recording all data which should be taken. The work forms follow and blank forms are located in Appendix A of the manual. These forms are used to document the operation of the system and provide necessary information for changes in the operating parameters or for troubleshooting system problems.

2. Log Forms

NOTE: Whenever a log form is filled in, all requested information should be included.

a. Operation Schedule

b Visual Inspection Log Form - I

c. Visual Inspection Log Form - II

d. Rectifier Operation Log Form

e. Depolarization Test Form

Iowa Department of Transportation
Pennsylvania Avenue Bridge over I-235

RECOMMENDED SCHEDULE FOR TAKING OPERATING DATA

	MONTH											
OPERATION	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
VISUAL INSPECTION												
RECTIFIER OUTPUT INSPECTION												
DEPOLARIZATION TESTING												

Iowa Department of Transportation
Pennsylvania Ave. Bridge over I-235

VISUAL INSPECTION LOG FORM - I

RECORDER	DATE	CONCRETE		JUNCTION BOXES		CONDUIT		RECTIFIER ENCLOSURE	
		YES	NO	YES	NO	YES	NO	YES	NO

Check "YES" if damage is present.

Iowa Department of Transportation
Pennsylvania Ave. Bridge over I-235

VISUAL INSPECTION LOG FORM - II

ITEM	DATE/ RECORDER	COMMENTS (DESCRIPTION OF DAMAGE INCLUDING NUMBER AND SIZE OF DAMAGED AREAS)
CONCRETE		
JUNCTION BOXES		
CONDUIT		
RECTIFIIER ENCLOSURE		

Iowa Department of Transportation
Pennsylvania Ave Bridge over I-235
Rectifier Operation Log Form

RECTIFIER SERIAL NUMBER 920944

DATE	RECORDER	TEMP (F/C)	RAIN/WATER ON THE DECK?		METER OUTPUT	ZONE 1		ZONE 2		ZONE 3		REMARKS
			YES	NO		VOLTS	AMPS	VOLTS	AMPS	VOLTS	AMPS	
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2.8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							
					DESIRED		2 8		2 8		3 2	
					ACTUAL							

Iowa Department of Transportation
Pennsylvania Avenue Bridge over I-235
Depolarization Test

Data taken by: ________ **Date:** ________

Rectifier Serial No.: 920944 **Weather:** ________

	Elapsed Time,min.	Actual Time of Reading	Rebar Static Potential RC mV = -mV vs. Reference Cell					
			Zone No. 1		Zone No. 2		Zone No. 3	
			RC-1 mV	RC-2 mV	RC-1 mV	RC-2 mV	RC-1 mV	RC-2 mV
On Potential	0							
Instant-Off Potential	<1 sec							
	10							
	20							
	30							
	40							
	50							
	60							
	90							
	120							
	150							
	180							
	210							
	240							
	DELTA							

Delta is the difference between readings at "Instant-Off" and "Time 240"

NOTES

Settings Before Testing
Zone 1
Zone 2
Zone 3

Settings After Testing
Zone 1
Zone 2
Zone 3

OPERATION REFERENCE
DRAWINGS

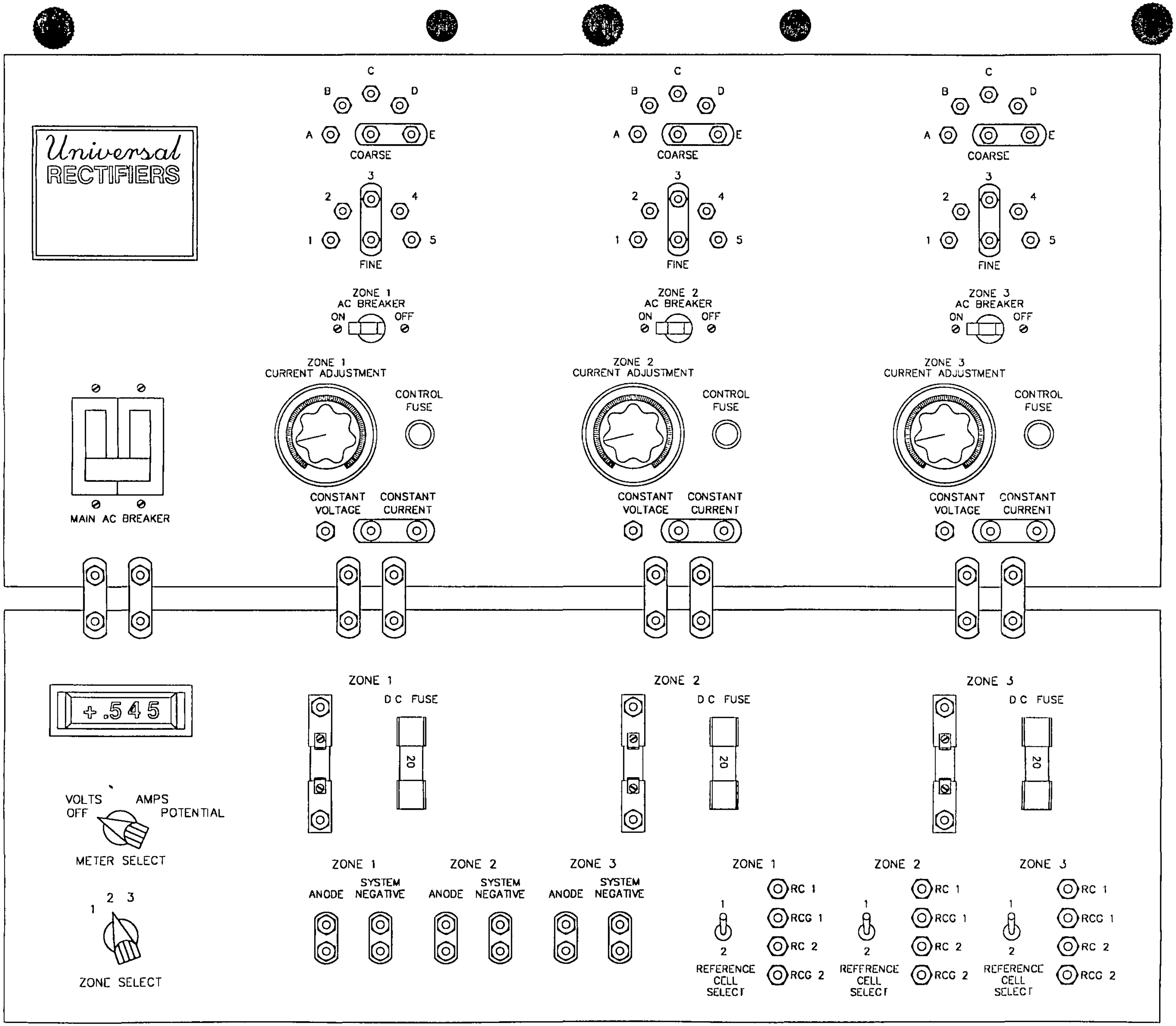
B. OPERATION REFERENCE DRAWINGS

1. General

Following is a drawing for reference when performing the scheduled operations This drawing is often referred to, so familiarize yourself with it now.

2. Reference Drawing

a. Figure 1 - Rectifier Control Panel


Universal
RECTIFIERS
C
B
D
A
E
COARSE
3
2
4
1
5
FINE
ZONE 1
AC BREAKER
ON
OFF
ZONE 2
AC BREAKER
ZONE 3
AC BREAKER
ZONE 1
CURRENT ADJUSTMENT
ZONE 2
CURRENT ADJUSTMENT
ZONE 3
CURRENT ADJUSTMENT
CONTROL
FUSE
MAIN AC BREAKER
CONSTANT
VOLTAGE
CONSTANT
CURRENT
+.545
ZONE 1
ZONE 2
ZONE 3
D C FUSE
20
VOLTS
AMPS
OFF
POTENTIAL
METER SELECT
1 2 3
ZONE SELECT
ANODE
SYSTEM
NEGATIVE
RC 1
RCG 1
RC 2
RCG 2
REFERENCE
CELL
SELECT
REFFRENCE
CELL
SELECT

OPERATION PROCEDURES

C. OPERATION PROCEDURES

1. General

The guidelines that follow give the individual who is performing the regular inspection an easy procedure to follow in order to maintain the cathodic protection system. Each of these subsections is organized according to the procedures required to fill out each of the four log sheets provided in Section II. A. 2.

2. Operations Schedule

The Operations Schedule is provided to give the inspector a guide to follow when performing the operation procedures. As it reads, the visual, rectifier output, and lightning protection device inspections should be performed monthly, while the depolarization test should be performed three times per year.

3. Visual Inspection

a. General

This inspection should be performed a minimum of once per month. The following list of areas should be viewed while performing this inspection.

1. Damaged rectifier cabinet.

2. Blocked or plugged external rectifier cabinet ventilation shafts located on the bottom of the rectifier.

3. External rectifier AC disconnect switch should be placed in the "ON" position. This switch is located in a separate electrical box mounted on the same pole as the rectifier.

4 Cracked, splintered, vandalized, or otherwise unacceptable conduit and junction box conditions.

5 Concrete damage such as saw cut slots or core holes.

b. Documentation

When the visual inspection is being performed it is very important to fill out the log forms in a legible manner. The following steps illustrate the proper manner to complete forms:

1. Record your name and the date.

2. Visually inspect the specified areas and place a check in the "YES" column if damage is found or "NO" if no damage is found.

3. If "YES" is checked, then go to the "COMMENTS" section and record a description of the damage. In addition, ELGARD should be contacted.

RECTIFIER OUTPUT
INSPECTION

4. Rectifier Output Inspection

a. General

This inspection should be performed a minimum of once per month, and it is recommended that it be done in conjunction with the Visual Inspection. The following steps and diagrams serve as a guide to perform the inspection.

b. Documentation

1. Go to the Rectifier Operation Log Form and fill in the following information.

    a. Date

    b. Recorder

    c. Temperature

    d. Check "YES" or "NO" if there is rain or standing water on the bridge deck.

    e. The "Desired Meter Output" has already been placed by ELGARD Corporation.

    f. The "Actual Meter Output" is what will be recorded here along with any remarks.

c. Procedure

1. Unlock the cabinet and remove the lock.

2. View the Rectifier Panel Layout in Figure 1. Familiarize yourself with the drawing and the panel. You will be referring to it often.

3. Look at the MAIN AC BREAKER Switch and note if it is in the "ON" or "OFF" position. It should be in the "ON" position. If it is not, switch it to the "ON" position

4. Look at the individual AC BREAKER switches for each zone and note if they are in the "ON" or "OFF" position. They should be in the "ON" position. If they are not, switch them to the "ON" position.

5. Now, go to the METER SELECT switch and note the various headings around the dial. Turn the METER SELECT switch to the "AMPS" heading.

6. Now, go to the ZONE SELECT switch and note the numbers 1, 2, and 3 around this dial. Each number represents a zone of the cathodic protection system. In order to see the actual zone layout, go to Appendix C, which contains the as built drawings

7. Move the dial on the ZONE SELECT switch to the number "1" and record the actual values of AMPS in the "ACTUAL" row of the RECTIFIER OPERATION LOG FORM. Switch the METER SELECT switch to the "VOLTS" heading and record the actual value of VOLTS in the "ACTUAL" row of the RECTIFIER OPERATION LOG FORM. Please take care to note that the Number "1" on the ZONE SELECT switch is Zone 1 on the RECTIFIER OPERATION LOG FORM and so on for the rest of the numbers.

8. Record the actual values of VOLTS and AMPS for the rest of the zones as described in Step 7. Please take care to note that the METER SELECT switch is in the proper position to read the value you are recording, "VOLTS" or "AMPS".

9. Compare the values recorded above in the "ACTUAL" column to those in the "DESIRED" column for "AMPS".

10. If the values recorded for "AMPS" in the "ACTUAL" row are not within one to two tenths (i.e., 0.1 to 0.2) of the "AMPS" in the "DESIRED" row, then the CURRENT ADJUST DIALS should be rotated until the meter reads the desired Amps.

11. Please note that the number the ZONE SELECT switch is facing should match the number of the ZONE OUTPUT DIAL that is being rotated. For instance, if the ZONE SELECT switch is facing number "2" , then the CURRENT ADJUST DIAL that is being rotated should be for zone 2. Clockwise rotation increases current to a zone, while counter-clockwise rotation decreases current to a zone.

12. Please be sure to record anything which had to be changed in the "Remarks" column of the RECTIFIER OPERATION LOG FORM.

DEPOLARIZATION TESTING

5. Depolarization Testing

a. General

The guidelines that follow are intended to give the individual who is performing the regular inspection a clear cut procedure to follow in order to perform a Depolarization Test.

NOTE: If the guidelines are not followed, the cathodic protection system will not function properly and corrosion of the reinforcing steel may result.

b. Documentation

1. The Rectifier Operation Log Form should be filled in at the beginning and end of the test. The procedure for that is described above in Section 4.

2. Go to the Depolarization Test Form and fill in the following information:

    a. Date

    b. Recorder

    c Temperature

    d. Record weather conditions, such as, rain or standing water on the bridge deck

    e. Actual time of the test.

3. The example in Appendix D serves as a guide for documentation purposes.

c. Procedure

Following are the steps required to perform a Depolarization Test. The Depolarization Test should be performed every April, July, and October, as shown on the Operations Schedule It should not be performed when it is raining or if there is standing water on the deck.

1 Locate the RECTIFIER CONTROL PANEL drawing from page 9

2. Unlock the rectifier cabinet.

3 Familiarize yourself with the drawing and the actual Rectifier Panel.

4. Locate the DEPOLARIZATION TEST FORM in Section II A from above. Fill in all pertinent information and remember that this is important information and must be recorded.

5. Repeat Steps 7 through 12 of the Rectifier Output Inspection from above and record the "AMPS" and "VOLTS" values for each zone in the Notes Section of the Depolarization Test Form

6. Rotate the METER SELECT switch to the "POTENTIAL" heading

7. Rotate the ZONE SELECT switch to the number "1" and flip the REFERENCE CELL SELECT switch for zone 1 to the number "1". Record the On Potential value shown on the meter for Zone No. 1 Reference Cell No. 1 in the row designated "On Potential".

8. Flip the REFERENCE CELL SELECT switch for zone 1 to the number "2" and record the On Potential value shown for Zone No. 1 Reference Cell No. 2.

9 Record the On Potential values for all the reference cells making sure that the ZONE SELECT switch and REFERENCE CELL SELECT switch are in the proper locations corresponding to the reading you are recording. Record the time when the On Potential readings are recorded.

10. Now it is time to record the Instant-Off Potential value for each reference cell. This is accomplished by setting the switches to read the reference cell you are recording and switching the AC BREAKER switch for the zone of the reference cell you are recording to the "OFF" position. The second value shown on the meter after the AC BREAKER switch is switched "OFF" is the Instant Off Potential. Record this value.

11. Repeat this procedure for all the reference cells and record each reference cell's Instant Off Potential. Record the time the Instant Off Potential values were recorded.

12. Turn each AC BREAKER switch for all three zones to the "OFF" position and continue to observe and record IR Free Potential readings at ten minute intervals for the first hour and at thirty minute intervals for the last three hours.

13. After the four hour test, it is time to calculate and record "Delta". This is done by subtracting the value "Time 240" minutes from the "Instant Off" value. Be sure to double check the calculation as this is critical to the operation of the system.

14. The AC BREAKER switch for each zone should be returned to the "ON" position.

15. Recheck the "AMPS" and "VOLTS" per Step 5 and record the values in the Notes Section.

16. Mail or facsimile the Depolarization Test Sheet and the Rectifier Operation Log Form to ELGARD Corporation for evaluation.

17. The "Depolarization Test" is now complete.

18. If an adjustment is necessary, ELGARD will notify you with the new settings.

APPENDIX A

APPENDIX A

1. Visual Inspection Log Form - I
2. Visual Inspection Log Form - II
3. Rectifier Operation Log Form
4. Depolarization Test Form

Iowa Department of Transportation
Pennsylvania Ave. Bridge over I-235

VISUAL INSPECTION LOG FORM - I

RECORDER	DATE	CONCRETE		JUNCTION BOXES		CONDUIT		RECTIFIER ENCLOSURE	
		YES	NO	YES	NO	YES	NO	YES	NO

Check "YES" if damage is present.

Iowa Department of Transportation
Pennsylvania Ave. Bridge over I-235

VISUAL INSPECTION LOG FORM - II

ITEM	DATE/ RECORDER	COMMENTS (DESCRIPTION OF DAMAGE INCLUDING NUMBER AND SIZE OF DAMAGED AREAS)
CONCRETE		
JUNCTION BOXES		
CONDUIT		
RECTIFIIER ENCLOSURE		

Iowa Department of Transportation
Pennsylvania Ave Bridge over I-235
Rectifier Operation Log Form

RECTIFIER SERIAL NUMBER 920944

DATE	RECORDER	TEMP (F/C)	RAIN/WATER ON THE DECK? YES	NO	METER OUTPUT	ZONE 1 VOLTS	ZONE 1 AMPS	ZONE 2 VOLTS	ZONE 2 AMPS	ZONE 3 VOLTS	ZONE 3 AMPS	REMARKS
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							
					DESIRED		28		28		32	
					ACTUAL							

Iowa Department of Transportation
Pennsylvania Avenue Bridge over I-235
Depolarization Test

Data taken by: ________ **Date:** ________

Rectifier Serial No.: 920944 **Weather:** ________

	Elapsed Time,min.	Actual Time of Reading	Rebar Static Potential RC mV = -mV vs. Reference Cell Zone No. 1 RC-1 mV	Zone No. 1 RC-2 mV	Zone No. 2 RC-1 mV	Zone No. 2 RC-2 mV	Zone No. 3 RC-1 mV	Zone No. 3 RC-2 mV
On Potential	0							
Instant-Off Potential	<1 sec							
	10							
	20							
	30							
	40							
	50							
	60							
	90							
	120							
	150							
	180							
	210							
	240							
	DELTA							

Delta is the difference between readings at "Instant-Off" and "Time 240"

NOTES

Settings Before Testing
Zone 1
Zone 2
Zone 3

Settings After Testing
Zone 1
Zone 2
Zone 3

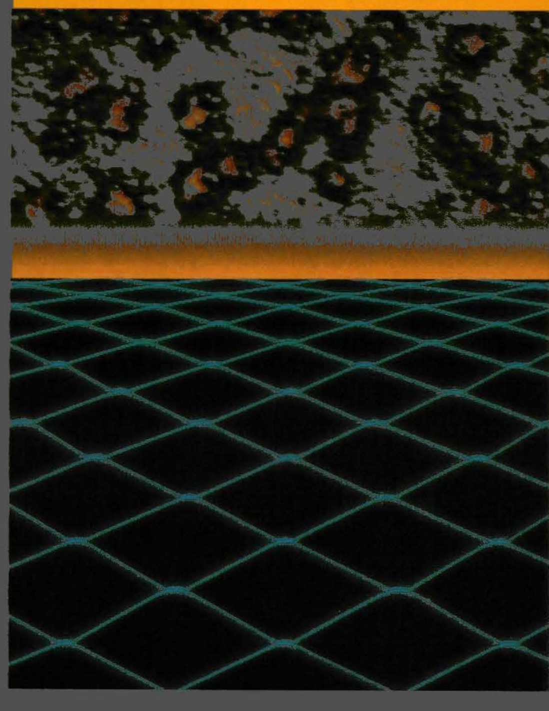
APPENDIX B

APPENDIX B

Pertinent Reference Material

ELGARD

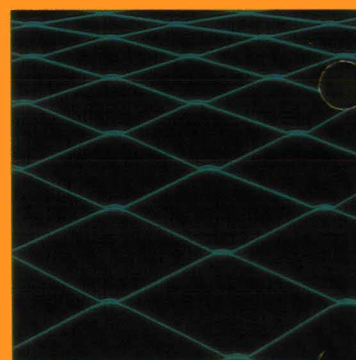
THE LEADER IN CORROSION PREVENTION



ELTECH

ELGARD Corporation's unique products and innovative systems halt corrosion in steel-reinforced concrete and conventional offshore and in-ground structures. ELGARD develops, manufactures, and distributes advanced cathodic protection (CP) materials and systems. These proprietary systems are easy to install, permanent, and cost effective.

The most visible victims of corrosion's ravages are the bridges that make up our transportation network. In northern areas and locations adjacent to the ocean, corrosion eats away at structural members causing great expense and inconvenience. Cathodic protection is the best solution to these problems.



Proprietary technology, in tandem with advanced products and engineering, position ELGARD as the leader and pacesetter in the growing CP industry. ELGARD benefits from the substantial resources of its parent, ELTECH Systems Corporation, which is the world's leading developer and producer of non-consumable anodes for the chlor-alkali and other electrochemical industries. The Company is committed to advancing new technologies and products, allocating a significant part of its revenues to research and development activities.

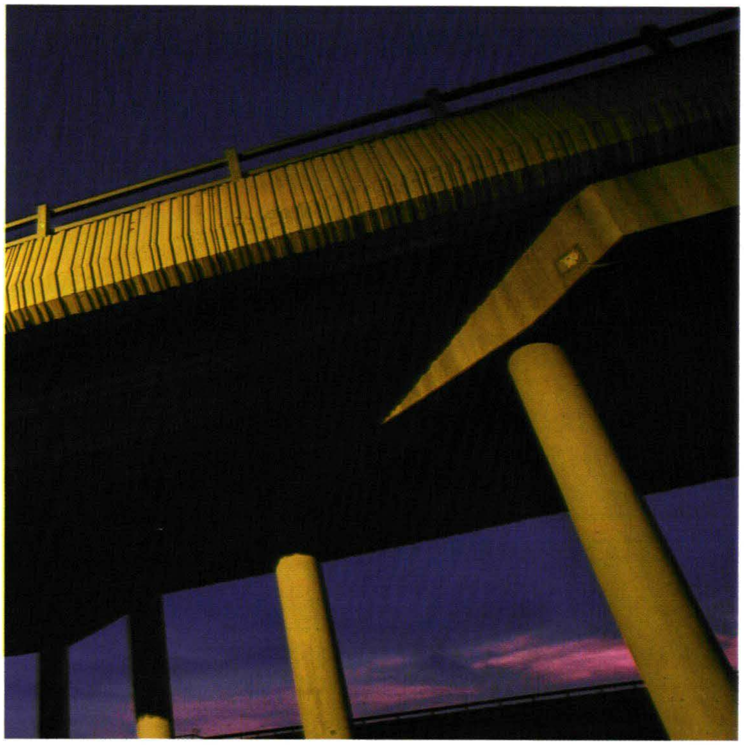
ELGARD Corporation, an ELTECH Systems Company, is located at 100 Seventh Avenue, Suite 300, in Chardon, Ohio 44024-1095. Telephone: (216) 285-0380.

CORROSION PREVENTION: A 21ST CENTURY NECESSITY

The projected cost to repair ·d replace corrosion-damaged structures is staggering. The cost not to repair them is far greater and much more threatening.

Today much of our infrastructure built upon steel components is seriously threatened by a destructive and persistent enemy: corrosion. Corrosion attacks reinforced concrete structures including bridges, substructures, elevated expressways, tunnels, parking garages, and industrial plants, as well as such conventional steel frameworks as buried tanks, pipelines, and offshore platforms.

Reinforced concrete structures deteriorate as corrosion weakens their basic integrity. The most obvious symptom is the ever present "pothole." But beneath the surface, corrosion-contaminated piers, support columns, and decks pose far greater hazards.



The scale of the corrosion problem in the U.S. alone is indicated by sobering statistics reported by the Federal Highway Administration (FHWA). More than half of the 500,000 U.S. bridges are structurally deficient and will require an estimated $50 billion to repair or replace them. The FHWA further projects that another 3,500 bridges will deteriorate annually. Corrosion substantially contributes to these deficiencies.

Less conspicuous are the wide variations of corrosion-endangered steel structures that do not capture the public's attention as vividly. Many steel frameworks that support our industrial base are less noticed. For example, gasoline station storage tanks, offshore platforms, ship hulls, pipelines, piers and docks, and locks/dams are subject to corrosion. In these structures, corrosion causes expensive repairs and may lead to severe environmental hazards.

The preferred technique to stop corrosion, based on historical performance and results, is cathodic protection. The reason for heightened acceptance: the CP method attacks corrosion at its root causes, insuring no recurrence which may lead to added expense and inconvenience.

CORROSION, AN ELECTROCHEMICAL PROCESS

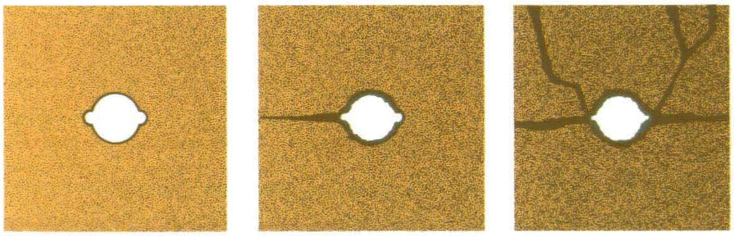
The principal cause of corrosion in reinforced concrete is salt, from winter de-icing chemicals and seawater, that penetrates the concrete thereby accelerating the rusting of the embedded steel. Although concrete appears impenetrable, it functions like a rigid sponge. The chloride ions, which form when salt breaks down, then move through the pores of the concrete initiating the corrosion process when contacting the steel.

As steel corrodes, the rust expands to several times the volume of the original steel and stresses the surrounding concrete. When this stress exceeds the tensile strength of the concrete, cracks spread radially. Some reach the surface, where more salt and water enter rapidly, and the corrosion process accelerates.

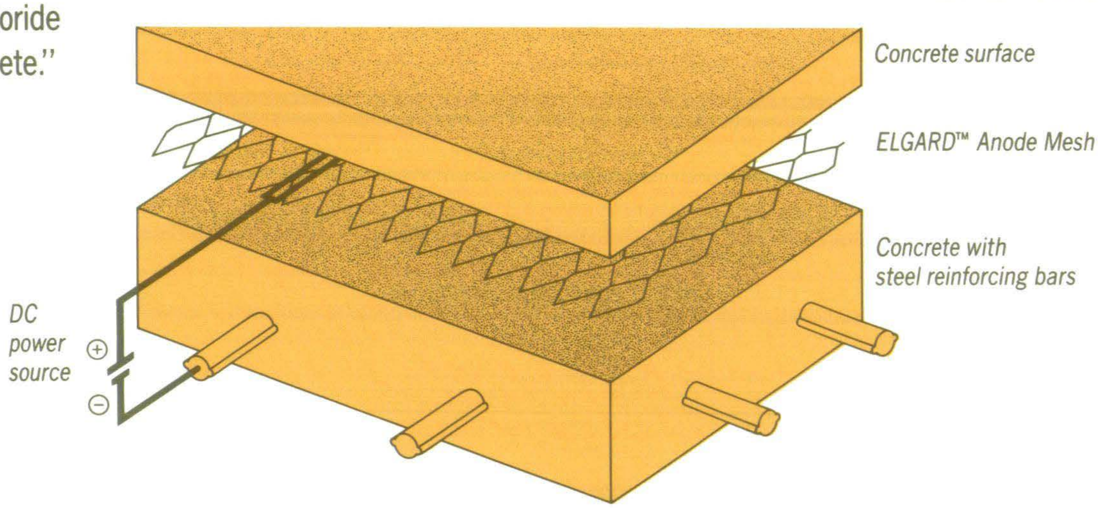
Once the salt has permeated the concrete, corrosion cannot be stopped by conventional repair methods. Patching, sealers, and membranes do not halt the electrochemical corrosion process and, therefore, do not eliminate the need for periodic repair.

CP technology is being chosen more frequently to halt premature deterioration of reinforced concrete structures. ELGARD offers the user the best combination of benefits balancing performance and cost.

The FHWA, after extensive testing, reports that the cathodic protection approach is "the only rehabilitation technique that has proven to stop corrosion in salt-contaminated bridge decks regardless of the chloride content of the concrete."



Cracks form around steel reinforcing bar



ELGARD's *proprietary CP technology* includes a range of anode and system capabilities. This strong position draws upon patents granted and pending, supported by extensive system application experience. At the core of ELGARD's CP technology is the patented dimensionally stable anode (DSA)®.* These titanium-based anodes come in many forms, including mesh, ribbon, rod, wire, and sheet. ELGARD anodes remain intact and unchanged over their lifetime, completely compatible with the working environment.

Electrochemically, the ELGARD CP systems prevent chloride ions from reacting with the steel bars by driving a low voltage DC current to the steel. The process stops corrosion in existing concrete already contaminated with chlorides and can also protect steel in any new construction.

ELGARD CP systems when applied to conventional steel structures prevent corrosion for the same reasons. They protect the integrity of the steel from rust by the same electrochemical process described.

*DSA is a registered trademark.

BENEFITS OF ELGARD CP SYSTEMS IN REINFORCED CONCRETE STRUCTURES

PERFORMANCE

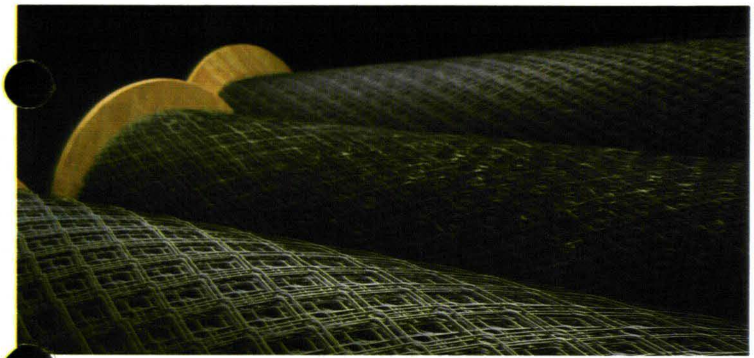
The ELGARD anodes do not affect the surrounding concrete and remain unchanged in shape, geometry, and dimension during their lifetime. In addition, the ELGARD anodes provide low electrical resistance, chemical stability, and much redundancy in the number of electrical paths.

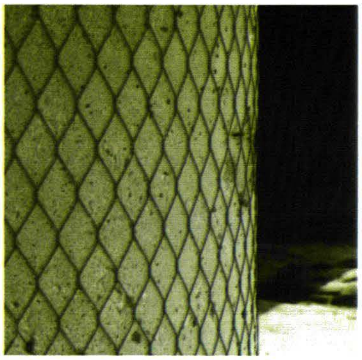
QUALITY AND LONG LIFE

The patented ELGARD anodes are rigorously pretested by ELTECH and independent sources. They can protect the construction from corrosion for 25 years or longer.

LIFE CYCLE SAVINGS

ELGARD's advanced anodes provide a less expensive alternative to periodic patching or complete deck replacement. Cost savings over the lifetime of a reinforced concrete structure are significant. ELGARD anodes insure full service life for the construction.





SIMPLE INSTALLATION

Regular construction crews install the systems. ELGARD's anode mesh and ribbon are transported to the construction site in large, factory-rolled spools ready for installation. The lightweight anode unrolls onto the scarified concrete surface and is cut easily with hand tools. Workmen then fit the material around drains, and can bend or wrap it around curbs, columns, and other irregular configurations.

Crews set the titanium conductor bars in place and weld them to the mesh or ribbon anodes with easy-to-use portable welders. Fasteners hold the anodes securely and the conductor bars are connected to a low maintenance, simple design, DC power source. A concrete overlay is then applied. A DC power source is activated as the final step.

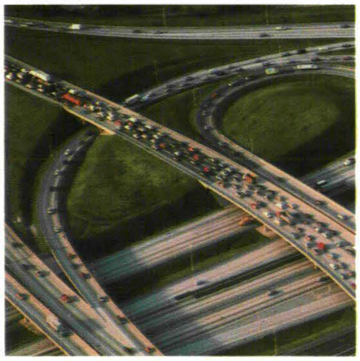
A FULL SYSTEMS APPROACH TO CATHODIC PROTECTION

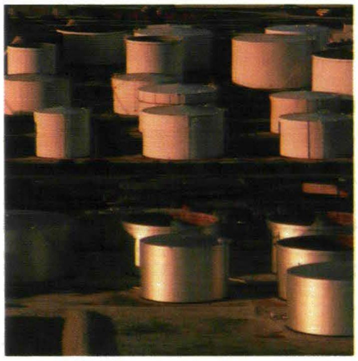
ELGARD's CP system installations for reinforced concrete are installed worldwide. ELGARD Corporation provides both modular inputs and complete systems including design, engineering, and installation. Within the system, components range from up-front diagnostic engineering and delamination studies to installation, startup, and maintenance programs.

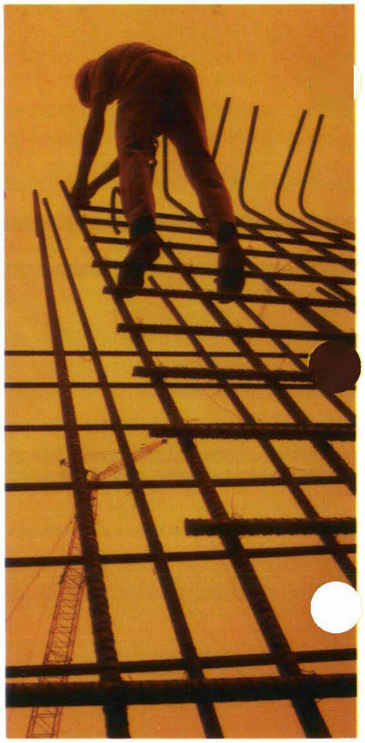
STEEL-REINFORCED CONCRETE STRUCTURES

ROADWAY RELATED STRUCTURES
Applications include bridge decks, substructures, sidewalks and abutments, elevated expressways, and tunnels. ELGARD's installation on Baltimore's Jones Falls Expressway is, to date, the largest CP bridge project in the world. The program is a joint effort of the Interstate Division of the Baltimore City Department of Transportation and the FHWA.

PARKING GARAGES
Cars carry de-icing chemicals into garages where concrete parking decks are exposed to surface runoff from melting ice. The lightweight ELGARD systems address special load requirements of most garages and can be used with thin concrete overlays. Most garages are designed for minimum load criteria and cannot withstand any additional dead weight on the decks.







INDUSTRIAL PLANTS AND FACILITIES
Industrial facilities, particularly those involved in chemical, petrochemical, and power generation, are vulnerable to corrosion in the form of corrosive atmospheres, spills, and gas leaks. The ELGARD CP approach insures their long-term reliability.

OTHER STEEL STRUCTURES

As a full service CP anode supply company, ELGARD produces non-consumable anodes for the conventional CP market. ELGARD's DSA® coated products include rod, sheet, plate, wire, tube, mesh and ribbon anodes. Its product lines for the North American market are also packaged under private labels.

Conventional CP applications include in-ground pipelines, tanks and miscellaneous structures; offshore platforms, ship hulls, pipelines, piers, docks, locks/dams; and industrial process equipment.

THE ELTECH SYSTEMS CORPORATION AND WHOLLY OWNED SUBSIDIARIES

ELTECH SYSTEMS CORPORATION

ELTECH Systems Corporation is a technology company dedicated to the development and commercialization of products and processes in the fields of electrochemistry, water and waste treatment, and specialty materials. ELTECH is headquartered in Boca Raton, Florida, with a European branch office in Geneva, Switzerland. World recognized as a developer of DSA® (dimensionally stable anodes) for the chlor-alkali industry, ELTECH holds over 1300 patents in the chemical, electrochemical, materials, and mechanical design areas. ELTECH supports a major effort in research and development of new products through ELTECH Research Corporation in Fairport Harbor, Ohio. ELTECH's wholly-owned subsidiaries include:

ELECTRODE CORPORATION

ELECTRODE Corporation develops and commercializes new types of metallic dimensionally stable anodes. DSA anode technology, introduced over 20 years ago, has revolutionized the chlor-alkali manufacturing economics. DSA anodes also find significant applications in hypochlorite and chlorate manufacturing, electrogalvanizing, electrowinning, electroplating, and cathodic protection. ELECTRODE's offices and manufacturing facilities in Chardon, Ohio supply DSA coatings for these broad ranges of commercial and research applications.

EES CORPORATION

EES Corporation (ELTECH Enviro Systems Corporation) develops and commercializes wastewater treatment systems for industrial and environmental applications. This technology is available internationally for marine and land-based systems. These systems find application in cooling water, wastewater, swimming and marine pools, drinking water, and heavy metal recovery. EES's office and manufacturing facilities are located near Houston, in Sugar Land, Texas.

ELGARD CORPORATION

ELGARD Corporation develops, manufactures, and distributes proprietary cathodic protection (CP) materials and systems for steel-reinforced concrete and conventional offshore and in-ground structures. ELGARD's products and innovative applications halt corrosion swiftly, permanently, and cost-effectively. This technology and advanced product engineering position ELGARD as a leader and pacesetter in the growing CP industry. ELGARD's office and manufacturing facilities are located in Chardon, Ohio.

INDUSTRIAL FURNACE SERVICES, INC.

Industrial Furnace Services, Inc. ("IFSI") provides innovative high-temperature technology solutions. Its high quality ceramic fiber and other fiber products for high temperature industrial environments are distributed internationally. Applications include the design, construction, and retrofitting of industrial furnaces, control systems, and combustion systems. IFSI's office and manufacturing facilities are located in Streetsboro, Ohio.

ELTECH RESEARCH CORPORATION

ELTECH Research Corporation (ERC), located in Fairport Harbor, Ohio, is the main research arm of ELTECH Systems Corporation. This company has been a pioneer in a wide range of electrochemical and materials-oriented projects over the past 20 years. These include the areas of chlor-alkali technology, battery systems, molten salt aluminum processes, chemical and electrochemical water treatment, aqueous metal winning and plating, ceramic materials for performance applications, and specialty electrodes and cells. ERC has a proven performance record of successful commercialization of technology.

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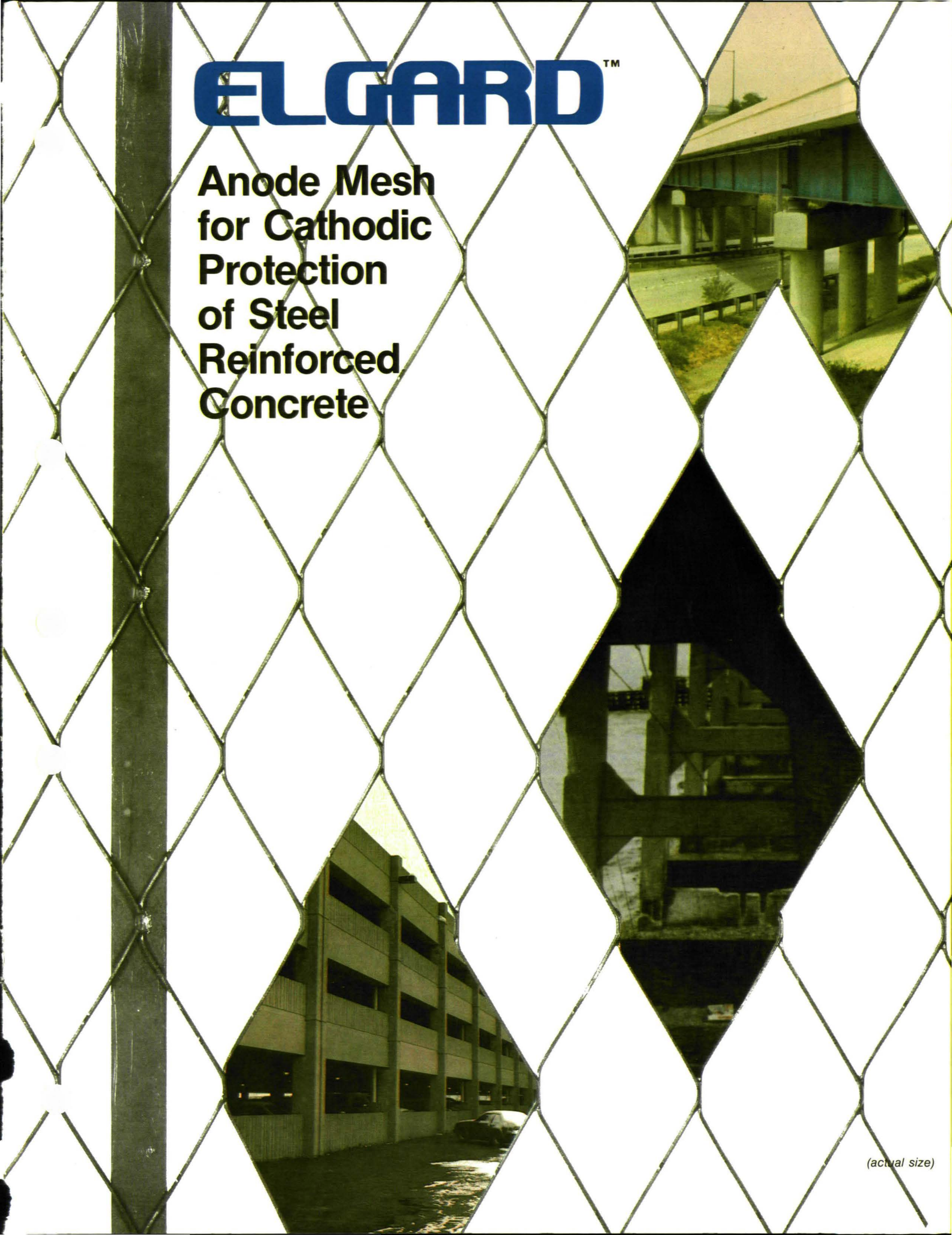
ELGARD™

Anode Mesh for Cathodic Protection of Steel Reinforced Concrete



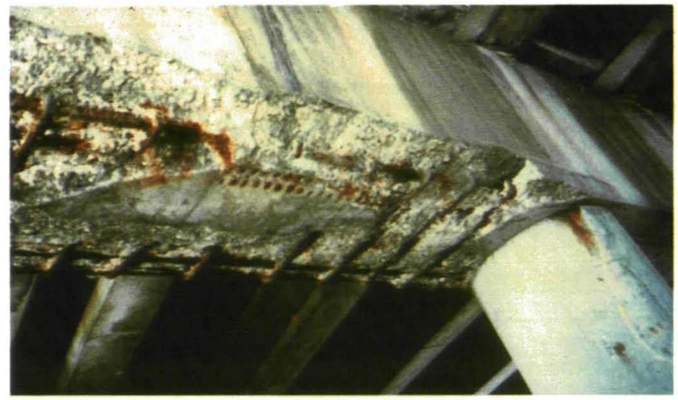
(actual size)

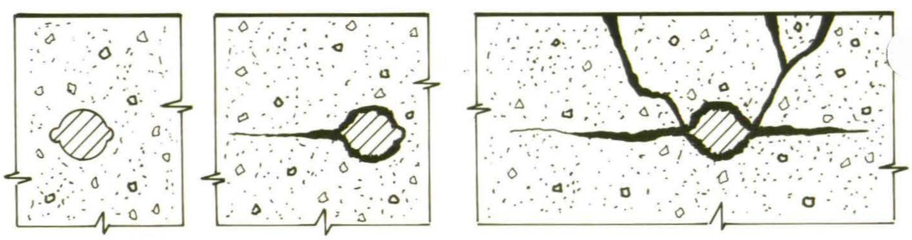
The Problem: Concrete Deterioration

Evidence of corrosion of reinforcing steel in concrete has become a familiar sight on our nation's highways and parking structures.

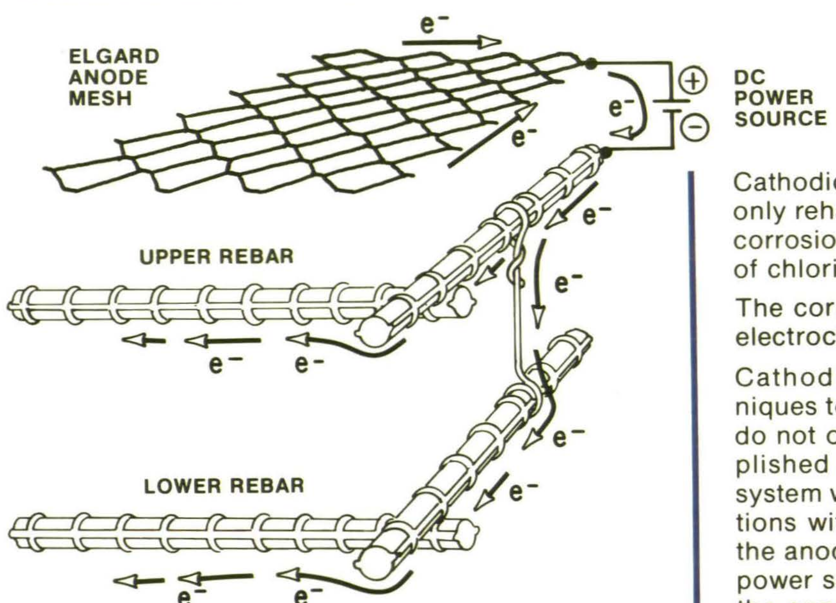
Since the corrosion products of the steel occupy several times the volume of the steel itself, tremendous tensile stresses are exerted on the surrounding concrete as the rebar corrodes. Cracks develop leading to subsurface fractures or delaminations.

Corrosion damage is not limited to highway bridge decks alone. Salt water running down bridge substructures from above, or splashed onto columns from below, often result in high chloride levels and extensive substructure damage. Salt is also carried into parking garages in the slush and ice which clings to vehicles. In this case, rain does not flush the salt away, and strong salt concentrations can develop. Reinforced concrete marine structures are subject to the same corrosion mechanism in the tidal and splash zones where salt concentration gradients are established. Even if seawater is not in direct contact with the structure, airborne ocean salts can contaminate the concrete and cause significant corrosion.





The Solution: Cathodic Protection with ELGARD™ Anode Mesh



Cathodic protection has been determined to be "the only rehabilitation technique that has proven to stop corrosion in salt-contaminated concrete regardless of chloride content of the concrete."

The corrosion of reinforcing steel in concrete is an electrochemical process.

Cathodic protection uses electrochemical techniques to insure that oxidation reactions (corrosion) do not occur at the reinforcing steel. This is accomplished by adding a supplemental anode to the system which is capable of sustaining oxidation reactions without suffering any physical damage. When the anode is connected to the positive terminal of a power supply, and when the reinforcing steel within the concrete is connected to the negative terminal, the entire reinforcing cage is forced to become cathodic as shown on the left.

Corrosion cannot occur while the steel is cathodic.

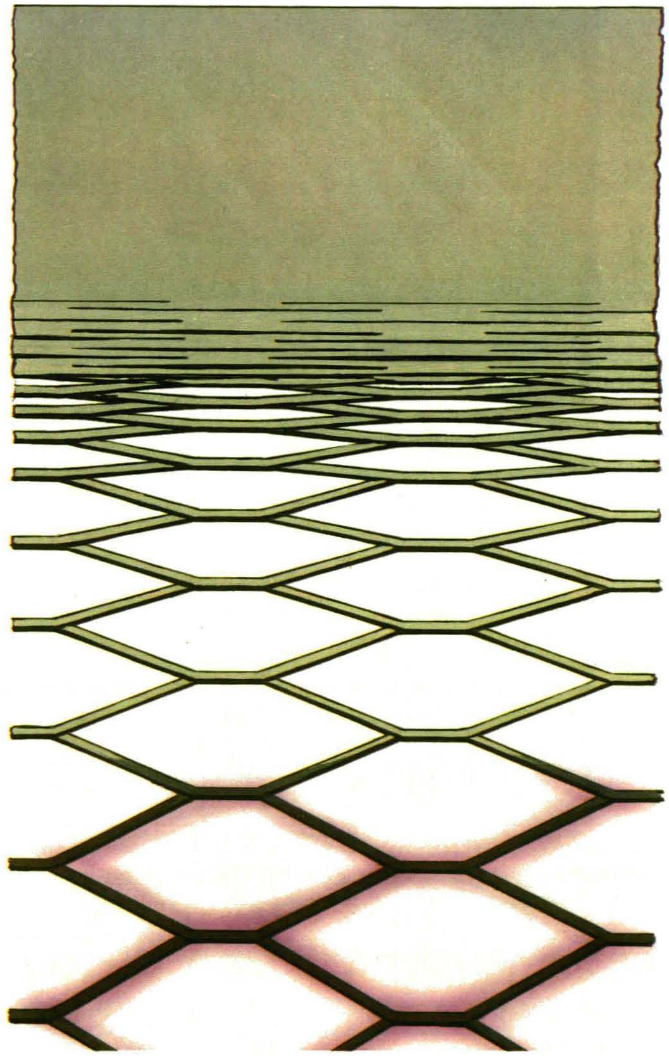
ELGARD Anode Mesh

Titanium

22 47.90
4.3
3562
1943
4.50
Ti
[Ar]$3d^2 4s^2$
Titanium

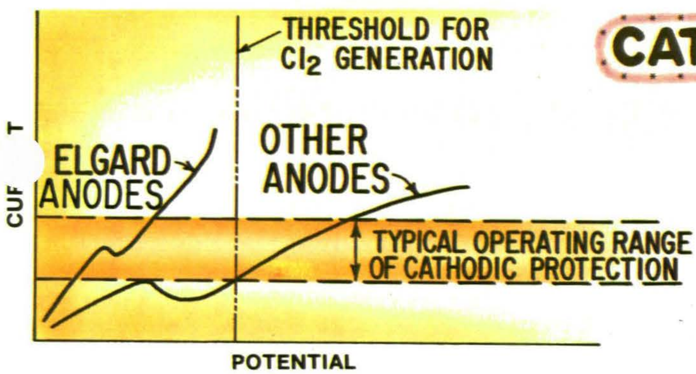
The ELGARD Anode substrate is high purity Titanium. Titanium is one of the most stable, corrosion resistant, high strength, lightweight materials found on earth. ELGARD mesh is highly expanded Titanium coated with a proprietary catalyst.

Titanium is not consumed during operation. This promotes a stronger concrete bond and a longer anode life.



Diamond Mesh

The Diamond Mesh pattern provides a low resistance and a uniform current density. Uniform current provides uniform protection. The Diamond Mesh pattern has thousands of current paths not available in other cathodic protection systems. Such redundancy makes the ELGARD Anode the only cathodic protection anode immune to system failures from cracks, core samples, or saw cuts. The redundant mesh pattern allows the anode to be cut to fit around columns, curbs, and drains without sacrificing even current distribution.



CATALYST

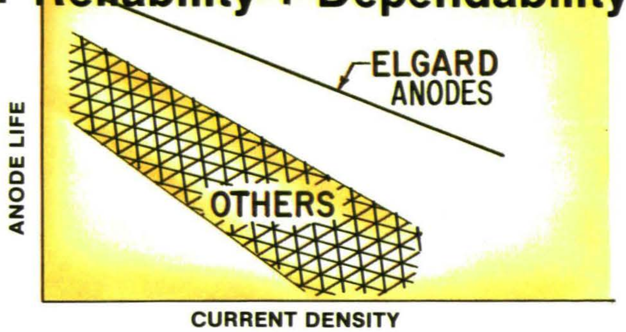
Uncatalyzed anodes will generate a mixture of carbon dioxide, chlorine, and oxygen. The proprietary catalytic coating on ELGARD Anodes forces the reaction to generate only oxygen, and is the only proven anode catalyst for cathodic protection.

Additionally, less acid is accumulated in the concrete with ELGARD Anodes than with other anodes. Acid and chlorine can harm both concrete and reinforcing steel. These properties of the catalyst allow operation of ELGARD Anodes at significantly higher current densities than other anodes.

Titanium + Catalyst = Long Life + Reliability + Dependability

The stability and resiliency of titanium coupled with the unique electrochemical characteristics of the catalytic coating result in ELGARD Anodes having the longest service life, by far, of any cathodic protection anode.

Tests by independent laboratories show that ELGARD Anodes have a design life up to ten times longer than other anode material, and can be operated at 40 MA/FT^2 which is 4 times higher than ordinary anodes.



The ELGARD System

Mesh Specifications

Composition	Titanium Grade 1
Roll Width ELGARD 210	48 Inches
ELGARD 150	45 Inches
Area Per Roll	1,000 Square Feet
Weight ELGARD 210	45 Lb./1,000 Ft^2
ELGARD 150	28 Lb./1,000 Ft^2
Diamond Dimension	3 Inch x 1-1/3 Inch
Resistance ELGARD 210	0.014 OHM/Ft.
ELGARD 150	0.026 OHM/Ft.
Bending Radius	3/32 Inch
Thermal Expansion	4.8×10^{-6} IN/IN/° F

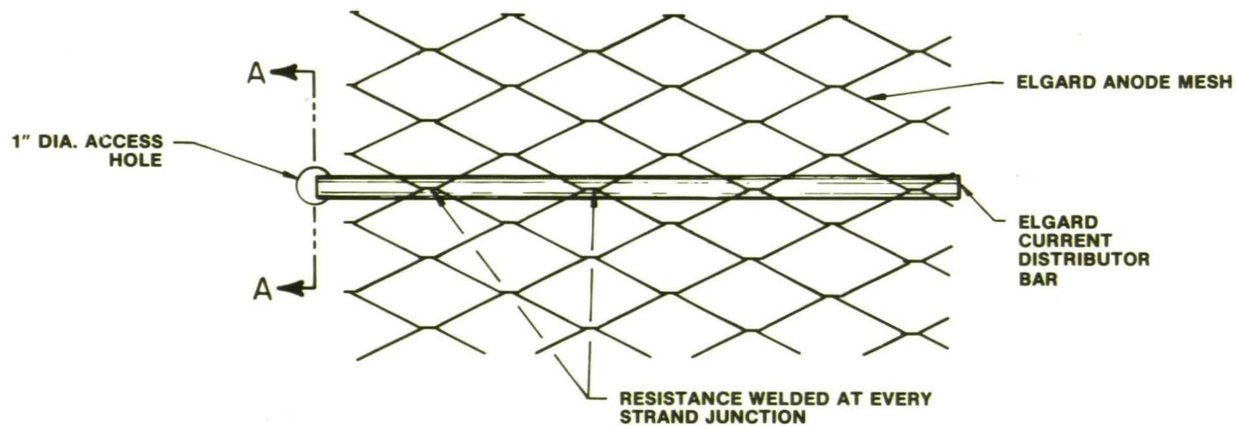
Mesh Characteristics

- THIN, LIGHTWEIGHT, EASY TO HANDLE AND CARRY. Thin overlays reduce material and installation costs, and minimize dead load on structure.
- FLEXIBLE; can be bent, twisted, or curved to fit any shape.
- STRONG; endures rough handling and supports normal construction activity. Does not weaken the overlay.
- SAFE; no toxic substance, no flammable materials, no chlorine generation, no safety hazards, unlimited shelf life.

System Features

• Titanium Current Distributors

The mesh is welded directly to the distributor bars providing metallurgical bonds. Welds are made at every cross in the diamond pattern to provide additional electrical redundancy.

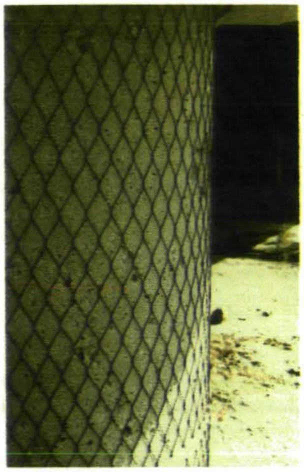


CURRENT DISTRIBUTOR WELDING DETAIL - PLAN VIEW

• Versatility

CUT TO FIT

BEND TO FIT



• Factory Quality

ELGARD mesh is fabricated and inspected at the factory rather than in the field. Factory quality assures fewer construction delays due to off-spec material.

• Supply Flexibility

ELGARD Corporation can provide the complete Cathodic Protection System, work through a general contractor, or just supply the anode mesh.

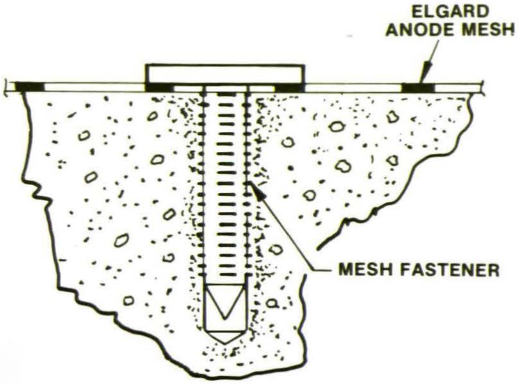
ELGARD System Installation Procedures

The most technologically advanced anode is also the easiest to use.

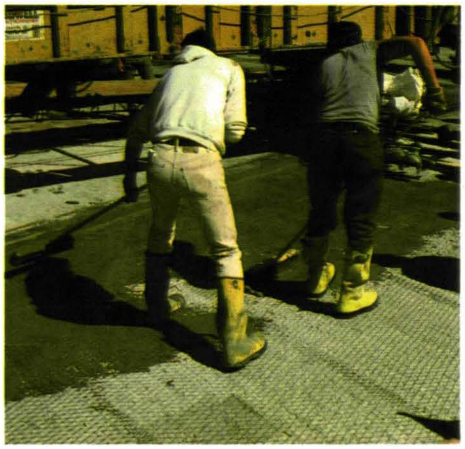
1 Preliminary activities include installation of reference cells and system negative connections to rebar. Delamination repair, sandblasting, and other standard pre-overlay activities are done.

2 ELGARD Mesh is unrolled from shipping spools onto surface to be cathodically protected. Normal tin snips are used to cut the mesh to fit around drains, curbs, columns, or other irregular configurations.

3 Titanium conductor bars are set in place and welded to mesh with easy to use portable welders provided. The ¼ inch diameter holes are drilled into the deck to accommodate "christmas tree" fasteners which hold the mesh securely in place. The anode conductor bars are connected to a low maintenance, simple design DC power source.



4 Concrete overlay is applied using normal pouring, pumping, or spraying procedures.



5 The DC power source is activated. Verification tests are conducted to ensure proper operation of the Cathodic Protection System.

The ELGARD System Concept

Performance

- UNIFORM CURRENT; Well distributed anode, low anode structural drop, 300 mV maximum.
- ADEQUATE CURRENT; 1 MA/FT^2 of steel, 2 MA/FT^2 of concrete.
- MINIMAL EFFECT ON CONCRETE; No chlorine generation, maintains high PH in concrete, similar thermal expansion to concrete.

Economy

- LONGEST ANODE LIFE; saves maintenance costs.
- LESS INSTALLATION TIME; saves costs.
- THINNER OVERLAYS; saves costs.
- SIMPLE RECTIFIER; saves costs.

Quality

- FACTORY QUALITY CONTROL assures fewer construction delays.
- SIMPLE INSTALLATION; Cut to fit, bend to fit, weld together. Avoids scrapping material in the field. Cracks in concrete not a problem, weather not a problem, no safety hazards.

Reliability

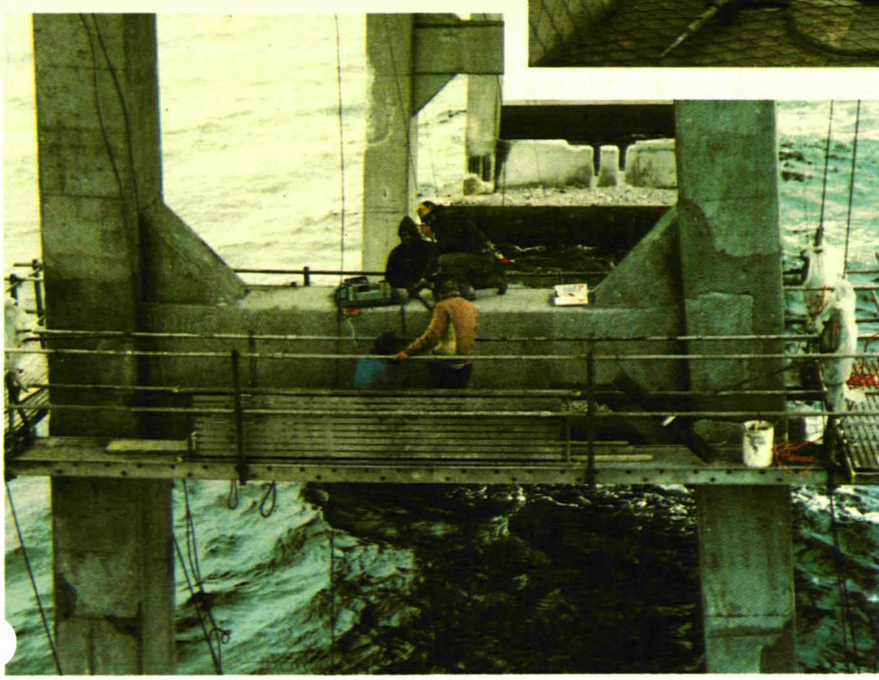
- LONGEST ANODE LIFE; Titanium cannot break down. No chlorine generation to harm concrete or rebar. Maintains alkaline pH in concrete.
- ELECTRICAL CIRCUIT; Metallurgical bonds are physically stronger and electrically superior.
- ELECTRICAL REDUNDANCY; Multiple welds multiple current paths.

Typical ELGARD System Installation and Applications

Bridge deck

Bridge substructure

Sidewalk and barrier wall



Marine structure

Parking garage

ELTECH Systems Corporation, with world headquarters in Boca Raton, Florida is a technology intensive corporation dedicated to the research, development and marketing of electrochemical technology. ELTECH's major worldwide activities are based on proprietary electrochemical technologies including the development and marketing of Dimensionally Stable Anodes (DSA®), new technology development, engineering services and consultation services. ELTECH has manufacturing facilities in the United States, Germany, and Sweden and research and development laboratories in the United States and Switzerland.

RESEARCH CENTER, *Fairport Harbor, Ohio*

MANUFACTURING FACILITY, *Chardon, Ohio*

ELGARD Corporation, a subsidiary of ELTECH Systems Corporation, is backed by ELTECH Systems' 20 years of experience as the world's leading producer of non-consumable anodes. More than a million anodes currently in service testify to the products' dependability and performance. In excess of $25 million has been spent by ELTECH in anode research and development. As a result, the technology behind the ELGARD mesh anode has produced the most highly researched and proven anode material available today for use on concrete structures. In addition to extensive in-house testing, it has been tested by independent private laboratories and the FHWA.

ELTECH

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PRINTED IN U.S.A., Rev. 11-90

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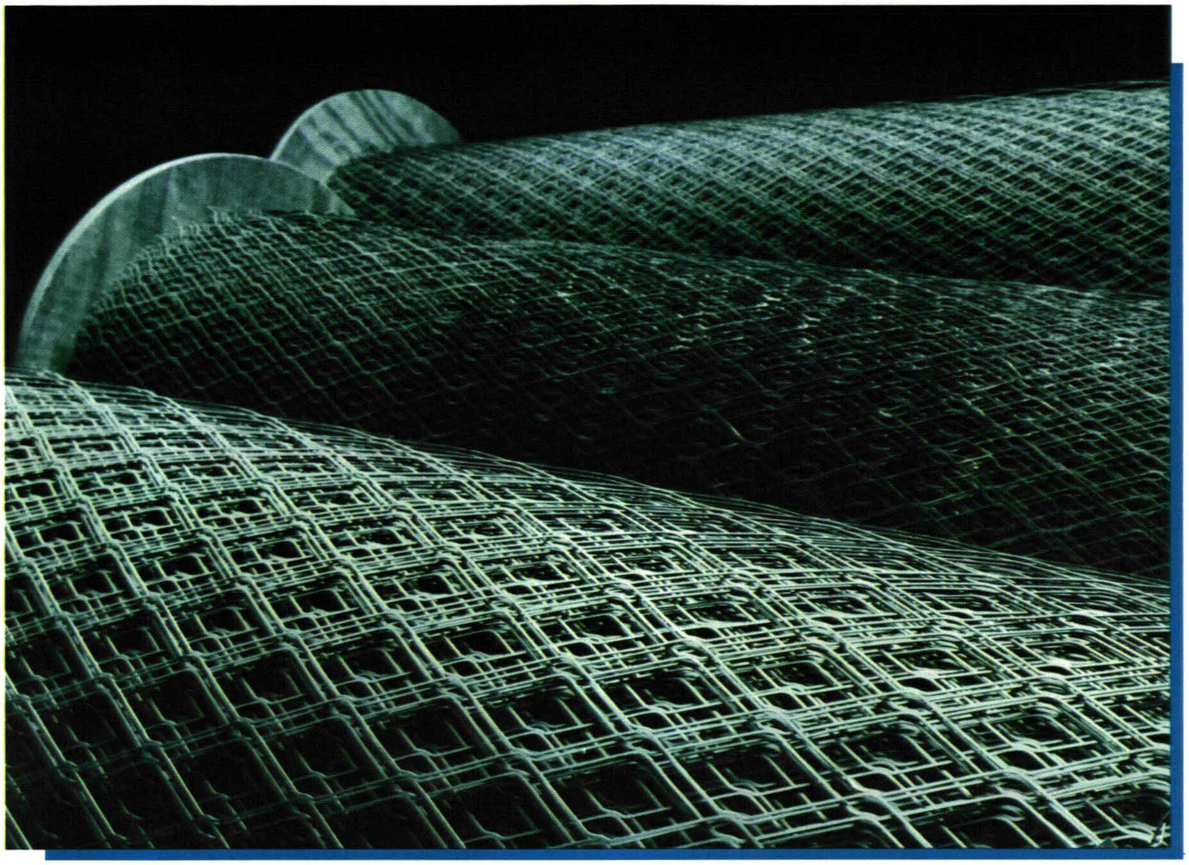
ELGARD™ DATA SHEET

Anode Mesh



Advanced Cathodic Protection System for Steel-Reinforced Concrete

Description:
ELGARD Anode Mesh is a key component of the ELGARD CP System. It is composed of a precious metal oxide catalyst sintered to a highly expanded titanium mesh substrate. ELGARD's proprietary CP technology is based on the dimensionally stable anode (DSA®) which draws upon patents granted and pending. Applications include structures such as bridge decks, substructures, sidewalks and abutments, elevated expressways, tunnels, parking garages, and industrial facilities.

Special Features:
- The ELGARD Anode Mesh does not affect the surrounding concrete and remains unchanged in shape, geometry, and dimension during its lifetime.
- The ELGARD Anode Mesh provides low electrical resistance, chemical stability, and much redundancy in the number of electrical paths.
- The ELGARD Anode Mesh is simple to install. Standard construction crews unroll the lightweight anode onto the concrete surface. The anode cuts easily with hand tools and can be flexibly bent, wrapped, and fitted around drains, curbs, columns, and other irregular configurations.

ELGARD™ Anode Mesh

MATERIAL SPECIFICATIONS

	150 Anode Mesh	210 Anode Mesh	300 Anode Mesh
MAXIMUM CONCRETE STRUCTURE CURRENT DENSITY	2.0 mA/ft²	2.7 mA/ft²	3.9 mA/ft²
CATALYST			
Composition	Mixed precious metal oxide	Mixed precious metal oxide	Mixed precious metal oxide
Specificity	Oxygen	Oxygen	Oxygen
Maximum anode-concrete interface current density	13 mA/ft²	13 mA/ft²	13 mA/ft²
MESH			
Composition	Titanium Gr. 1	Titanium Gr. 1	Titanium Gr. 1
Width of roll	45 in	4 ft	4 ft
Length	267 ft	250 ft	250 ft
Diamond dimension	3 in LWD x 1⅓ in SWD	3 in LWD x 1⅓ in SWD	2 in LWD x 0.92 in SWD
Resistance lengthwise (45 in wide)	.026 ohm/ft	.014 ohm/ft	.008 ohm/ft
Resistance widthwise with current distributor	.007 ohm/ft	.005 ohm/ft	.004 ohm/ft
Bending radius	3/32 in	3/32 in	3/32 in
Bending radius in mesh plane	50 ft	50 ft	50 ft
CURRENT DISTRIBUTOR			
Width	.5 in	.5 in	.5 in
Thickness	.040 in	.040 in	.040 in
Typical distance separating current distributors (mesh lengthwise)	100 ft	100 ft	100 ft
Typical distance separating power feeds (mesh widthwise)	30 ft	30 ft	30 ft
TITANIUM SUBSTRATE PROPERTIES			
Density	0.163 lb/in³	0.163 lb/in³	0.163 lb/in³
Melting point	3040°F	3040°F	3040°F
Coefficient of thermal expansion	4.8×10^{-6} in/in/°F	4.8×10^{-6} in/in/°F	4.8×10^{-6} in/in/°F
Modulus of elasticity	14.9×10^{6} PSI	14.9×10^{6} PSI	14.9×10^{6} PSI
Thermal conductivity @ room temperature	9.0 BTU/hr/ft²/°F/ft	9.0 BTU/hr/ft²/°F/ft	9.0 BTU/hr/ft²/°F/ft
Specific heat @ room temperature	0.124 BTU/lb/°F	0.124 BTU/lb/°F	0.124 BTU/lb/°F
Resistivity	56×10^{-6} ohm-cm	56×10^{-6} ohm-cm	56×10^{-6} ohm-cm
Weldability	Good	Good	Good
Tensile strength	35,000 PSI min	35,000 PSI min	35,000 PSI min
Yield strength, 0.2% offset	25,000 PSI min	25,000 PSI min	25,000 PSI min
Elongation, sheet > .025 thick	24% min	24% min	24% min
Chemical composition	0.08 C 0.20 Fe 0.03 N 0.18 O 0.015 H max	0.08 C 0.20 Fe 0.03 N 0.18 O 0.015 H max	0.08 C 0.20 Fe 0.03 N 0.18 O 0.015 H max

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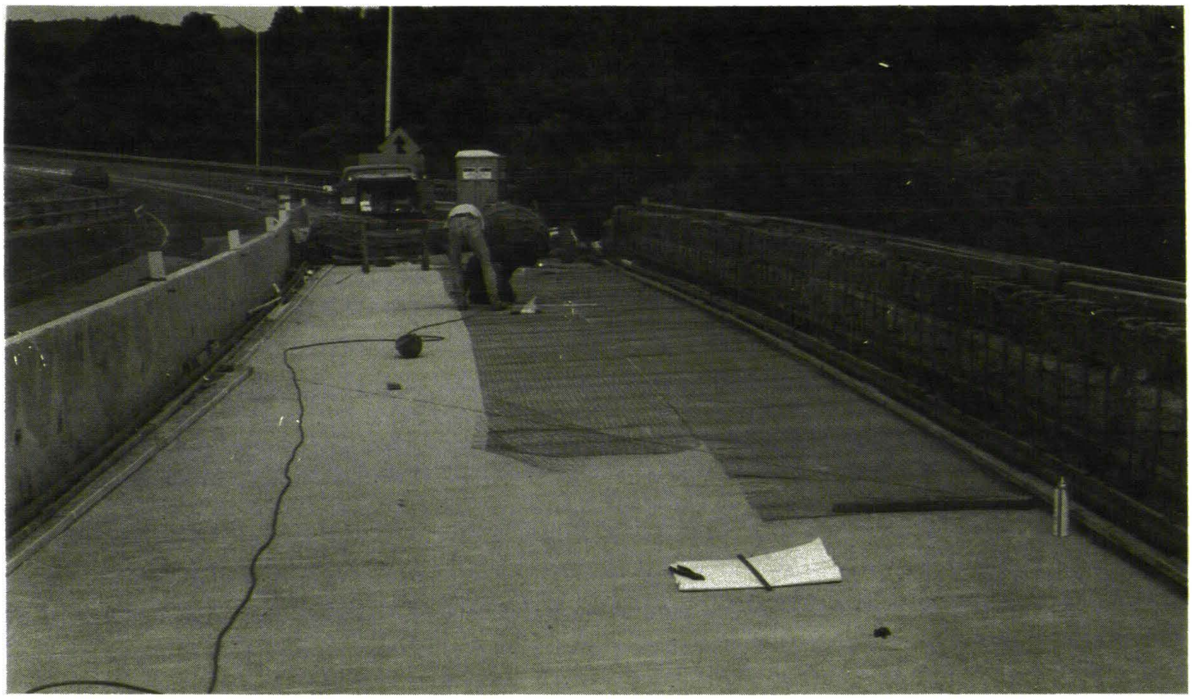
Public Works City, County and State February, 1992

Why Connecticut is Using Cathodic Protection

WILLIAM R. STARK and STEVEN F. DAILY

Mr. Stark is Program Administrator, Bridge Rehabilitation Unit, Connecticut Department of Transportation, Wethersfield, Connecticut. Mr. Daily is Regional Sales Manager, ELGARD Corporation, a Subsidiary of ELTECH Systems Corporation, Chardon, Ohio.



■ INSTALLING anode mesh. The system arrests corrosion by driving a low voltage current into the reinforcing steel.

Why Connecticut Is Using Cathodic Protection

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and
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Mr. Stark is Program Administrator, Bridge Rehabilitation Unit, Connecticut Department of Transportation, Wethersfield, Connecticut. Mr. Daily is Regional Sales Manager, ELGARD Corporation, Chardon, Ohio.

THE nation's deteriorating infrastructure, including bridges, has received much attention in recent years. But declining state and federal funds have delayed many rehabilitative programs. Over the past few years, this dilemma of greater need bumping against more limited resources has worsened.

Complicating matters, states are confronted with hard choices at three levels to allocate their available resources:

- Infrastructure versus other concerns, such as crime fighting and improved schools.
- Competing infrastructure programs, such as bridges, sewers, highways, and water supply.
- Within a bridge rehabilitation budget, which bridges should be repaired.

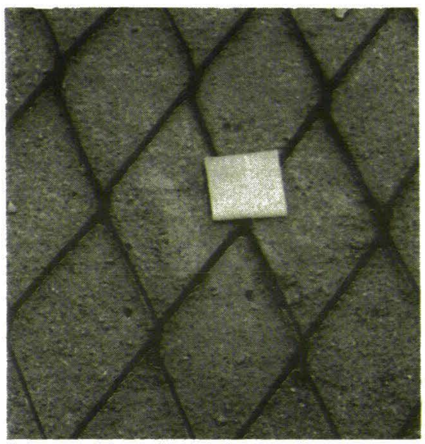
Almost a decade ago, a single tragic event forced Connecticut to bypass these considerations and move quickly. The sudden collapse of the Mianus River Bridge on June 28, 1983 compelled the state's legislature to act on a delayed highway and bridge program. Former Transportation Commissioner J. William Burns noted, "It gave instant wisdom to many of the political decision makers who were hiding from the realities of life for many years."

Loss of life and displacement of traffic along one of the state's busiest commercial and commuter expressways triggered the enactment of Connecticut's pacesetting Ten-Year Transportation Infrastructure Renewal Program. A budget of $1.12 billion, about one-fifth of the total $5.5-billion renewal program, was allocated for rehabilitating and replacing structurally deficient bridges. State funds raised through bonds were supplemented by $530 million in federal funds.

The Bridge Inspection Unit of the Connecticut Department of Transportation (ConnDot) identified 1,620 bridges, from a total highway system of 3,500 bridges, for emergency repair and renewal. The common denominator for many of these bridges, rated poor to fair by the inspection unit, was corrosion induced deterioration to decks and steel reinforcement.

As a densely populated state, Connecticut generates very high passenger and commercial traffic volume. Minimizing downtime and commuter inconvenience were important factors to be considered. Connecticut's 20-year bond agreements required comparable long-term solutions. ConnDot preferred rehabilitating structurally sound bridges rather than deck replacement where repairs could be reasonably expected to provide 20 years of added service.

Connecticut is ahead of schedule on its infrastructure renewal program, with 300 bridges yet to be repaired by 1994. Rehabilitation was usually less time-consuming and more cost-effective than deck replacement. Cost savings have been reapplied to the program. As a result, the same budget now includes 19 additional bridges or a total of 1,639.



■ CLOSE-UP shows titanium-based anode mesh fastened in place on a bridge deck.

Increasing Usage

Cathodic protection (CP) is gaining increasing usage in ConnDot's program as a long-lived rehabilitation technology that will stop corrosion in reinforced concrete. "We tend to be a conservative department," says ConnDot's Director of Engineering, Daniel Coffey, "but I'm willing to consider better ways. When we repair a deck that has high chlorides, and can buy another 15 to 20 years, this is a good use of our dollars. CP can help us reach that goal, so I think it will grow in popularity as the years go on."

Over the past ten years, ConnDot has conducted field trials of various rehabilitation methods for salt-contaminated and freeze-thaw environments, frequently triple-teaming membranes and epoxy-coated rebar with asphalt wear surfaces. Based on extensive evaluation of CP, Michael M. Kasinskas, Division of Research, reports that Connecticut's findings reinforce the FHWA position "that cathodic protection is the only effective means for preventing and arresting corrosion of steel in concrete."

Connecticut has identified 30 to 40 potential CP candidates. CP systems have already been installed on four bridge decks, including three recent ELGARD™ CP installations. Ten additional bridges are scheduled for CP rehabilitation by the end of 1992. Coffey expects that another dozen installations will be completed by program conclusion in 1994.

In addition to the ten-year program, ConnDot has begun a second effort that will rehabilitate and renew additional bridges that have more recently been identified by ConnDot's Bridge Inspection Unit. Coffey expects to see additional CP candidates included on this list.

CP was chosen to prolong the life of Connecticut's corroding bridge decks in the following applications:

- The objective is to achieve at least an added 20-year service life.
- The chloride content is high in the concrete surrounding the upper mat of steel (typically more than one lb per cu yd).
- The deck is structurally sound and compressive strength exceeds 3,000 psi.
- The bottom slab does not show extensive areas of cracking that allow intrusion of water.
- The deck is bare and the superstructure (beams) cannot carry additional dead load created by an asphalt overlay. AASHTO specifications require a minimum load rating of HS 16.2 to carry all legal live loading over a structure in Connecticut.

Corrosion of embedded rebar is caused primarily by the concrete's absorption of deicing salts in the form of a brine solution. The solution serves as an electrolyte and increases the concrete's electrical conductivity.

CP arrests corrosion in reinforced concrete by lowering the active corrosion potentials of the reinforcing steel. Current is supplied by an external DC power source from an outside anode embedded in the concrete, but separated from the rebar. The current flows through the concrete to the rebar. By changing the rebar into a non-corroding cathode, the electrical current neutralizes the corrosive effect of chloride ions. The protected rebar will not rust once CP is installed.

Without CP, the destructive effects of chloride ions created by road salts and coastal seaspray are irreversible. Once corrosion or rusting activity spreads to the reinforcing steel, the only long-term options available—at drastically differing costs—are deck replacement or CP renovation.

Connecticut's first CP system was installed by Harco Technologies in 1985, in cooperation with the FHWA's Demonstration Projects Division. The Middlefield bridge (No. 3048) is located on Route 66 eastbound along the Meriden-Middlefield Town Line, in the central part of the state.

Damage Triples

Built in 1970, the bridge has an ADT of about 8,000 vehicles. Deicing salts are regularly applied during snow and ice removal operations. A 1983 survey indicated that 30 sq ft of deck area had delaminated. Within two years, the damaged area had tripled.

The CP system installed on the Middlefield bridge deck was a non-overlay, or slotted system, using conductive polymer concrete as the anode material. Three separate zones were installed in the deck, which has a surface area of 5,200 sq ft. The CP system was energized by a rectifier controller, with a remote monitoring system so vital functions of the system could be stored and transferred to the state research facility. This capability facilitated the monitoring of voltage and current changes, as well as the effects of deicing salts, climate conditions, and other variables.

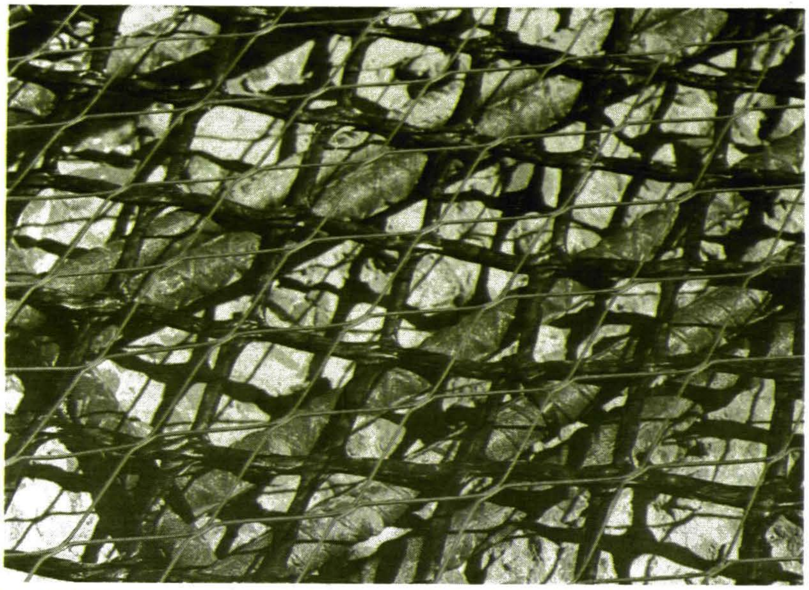
In the five years following CP installation, only two small 6 in. x 6 in. delaminations have been noted: one a hollow area and the other a surface spall. Neither appears to be directly related to the CP system. Kasinskas does not know whether the hollow area is new, attributable to extensive jackhammering during system installation, or was possibly missed in previous deck surveys. The surface spall was probably not caused by corrosion.

Kasinskas says that the Middlefield installation provided ConnDot with "an in-depth understanding and appreciation of cathodic protection which until recently has been unavailable." He has recommended that CP be installed in future ConnDot projects. The detailed findings of the CP project appear in a final report ("Evaluation of a Retrofitted Cathodic Protection System in a Bridge Deck," prepared by Michael M. Kasinskas, July, 1988, [Report No. 1008-F-88-4]).

Coffey points out that no two bridge applications in Connecticut are exactly alike. Each has special characteristics and needs. ConnDot has incorporated CP in a variety of repair sequences:

- Slotted system with conductive polymer.
- Titanium ribbon anode with epoxy-coated rebar and monolithic pour of standard class F concrete.
- Titanium mesh anode with uniform (depth) overlay of latex modified concrete (LMC).
- Titanium mesh anode with monolithic (non-uniform) pour of LMC.

Titanium-ribbon anode systems often are preferred when the deck either does not require an overlay or load factors must be considered. ConnDot's research department has also experimented with teaming CP and epoxy-coated rebar. Kasinskas explains that breaks in the surface of epoxy-coated rebar can result in high current densities and degraded per-



■ PLASTIC spacer mesh isolates the anode mesh from the steel reinforcement.

formance. Small pin holes and scratches in the coating can sometimes occur during installation. Application of CP to the reinforcing steel will protect the holidays (voids) in the epoxy coating and improve its performance in corrosive environments.

Recently, ConnDot has found additional benefit in covering titanium-based anode mesh with a monolithic pour procedure, rather than using the two-step procedure (patching and overlay). Installation for a monolithic pour using CP requires removing delaminated concrete, exposing the steel, and placing a plastic spacer mesh on top of the rebar before unrolling the anode mesh. Once the anode is positioned, concrete is then poured in one step to fully encapsulate anode, spacer mesh, and rebar. ConnDot reports that the monolithic pour:

- Eliminates the need for two surface preparations, which can jeopardize newly patched areas.
- Cures considerably faster than the two-step process: one week versus three weeks.
- Provides good bonding from a design perspective.
- Minimizes commuter inconvenience by opening the road to traffic much faster than the previous curing process.

Big Difference Noted

The monolithic pour was first applied on a ramp located in Farmington. ConnDot experimented with the monolithic pour procedure using Dow-LMC overlay on one portion of the deck and the two-step method on the other. The side with the monolithic pour was open to traffic in one week. The two-step method required three weeks to cure.

Later, ConnDot cored the monolithic-pour areas and found good consolidation around the spacer mesh, anode mesh, and rebar.

ConnDot retained and continues to use two engineering liaison consulting firms to leverage limited resources and staff, monitor design activities, and supervise other design consultants. The firms, Greiner Engineering and Close, Jensen & Miller are both located in Connecticut.

Greiner's Jim Platosh credits ELGARD Corporation's design and engineering systems' support for helping Connecticut better utilize CP technology. In addition to working directly with ConnDot's consultants, ELGARD also supervises onsite installation of its CP systems.

A small percentage of bridges (estimated at one percent) will continue to deteriorate annually but, through maintenance and inspection, ConnDot plans to maintain these on a timely basis. Connecticut has committed $60 million annually, raised from gasoline taxes, car registration fees, and associated licenses, toward ongoing rehabilitation and renewal of its bridges. □□□

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John E. Taylor is the Regional Director of the New York State Department of Transportation's Capital District Region. For more, *see page 18.*

The "Show Me" State Shows Off Cathodic Protection

MICHAEL R. TIGHE

Mr. Tighe is Vice President and General Manager, ELGARD Corporation, an ELTECH Systems Company, Chardon, Ohio.

MISSOURI is known as the "Show Me" state because of its pragmatic approach to change. But the state can be a national pacesetter when newness offers promising returns. A case in point: Missouri leads North America in using cathodic protection (CP) to extend performance life for salt-contaminated and corroded concrete bridges.

Beginning with its first full-scale installation in 1975, Missouri today has 126 bridge CP systems in place or underway, almost half of all CP applications in the U.S. The state hopes to extend the performance life of these bridges by 20 years and longer. Replacing heavily traveled bridges would have cost far more. And more than cost is involved. Since most of these are continuous reinforced concrete bridges — which can extend across three or more supports — located near urban segments of the interstate, replacement at the present time would have considerably inconvenienced the commuting public. Conventional repair methods proved unsuccessful for limiting corrosion on Missouri's bridges, many built in the late 50s and early 60s.

"CP provided the only system that stops corrosion in areas with heavy concentrations of salt," explains Jack Moberly, assistant bridge engineer, Missouri Highway and Transportation Department. "We had a problem of spalling concrete in these decks and found that repair in negative moment areas using reinforcing was no longer effective. The various repair methods we tried led to redistribution of moments in the structures."

Missouri relied upon the concrete box girder and voided slab designs to keep abreast of the interstate construction boom three and four decades ago. Compared to traditional steel girder design, these bridges were faster and cheaper to install without the same periodic painting and upkeep. "We thought we had a maintenance-free bridge," explains Moberly.

About 200 continuous concrete bridges are concentrated in the urban areas of Kansas City, St. Louis, Warrensburg, and St. Joseph. These subsequently became prime CP candidates because of their vulnerability to corrosion from salt contamination. Federally mandated use of road salts to deice interstates in the late 1950s set into motion destructive forces that the state had not anticipated. The ionized salts seeped into the concrete and corroded the embedded rebar. The corroded material expanded to three times the volume of the displaced steel, thereby eventually causing cracks in the surrounding concrete. Within ten years of construction, heavy concentrations of deicing salts led to spalling and deterioration.

"Concrete is not permanent," says Bob Girard, senior materials research engineer. "But if CP helps us gain 20 to 30 years more service from our continuous concrete structures, we'll be delighted."

■ **INSTALLING the anode for a cathodic protection system. This proprietary anode is composed of a mixed precious metal oxide catalyst sintered to a titanium mesh.**

Photo courtesy Missouri Highway and Transportation Department

Missouri tried and rejected a number of conventional repair methods to prolong the structural life of its salt-contaminated decks. "We have tried a number of sealants but none have worked satisfactorily," reports Bill Brandel, senior structural detailer and a 26-year veteran with the Highway and Transportation Department.

Missouri Chooses CP – Dick Stratfull's Legacy

The box girder and voided slabs, particularly those with a concrete arch beam popular during the construction period, could not be replaced easily or economically. Many of the bridges were located in areas where detours and extended interruption would have imposed a major burden on the commuting public. Replacing two-lane bridges, many carrying up to 80,000 vehicles daily, would require building temporary accesses, which would incur lost time for commuters. Brandel recalls that in 1974 an electrical engineer in the construction division named Al Goodding followed the California-based efforts of Dick Stratfull, a corrosion engineer with Caltrans, to develop a CP system that would halt the corrosion.

The Highway and Transportation Department invited Stratfull, credited as the father of cathodic protection for reinforced concrete, to fly in, view several bridges, and determine whether his coke breeze-pancake anode technique might work here, too. "We're basically a very conservative state when it comes to design," explains Moberly, "but we had a real problem. Our choice was to either use CP or replace the bridges."

Bob Girard, a member of the original team that evaluated the CP method, was convinced that CP could play a role. "We believed CP the only alternative that would allow us to gain longevity for the structures without incurring a big replacement program. We looked at the theory behind CP, felt that it was sound, and thought we would be able to overcome any minor problems associated with its usage."

Girard points out that while CP held promise for the reinforced concrete application, its merits for arresting corrosion in conventional steel were already well established. Federal regulation had mandated CP on all interstate oil and gas pipelines. CP usage dates back to the early 1900s, and by 1974, the pipeline, oil rig, and shipping industries had been applying CP for over 50 years.

Missouri's efforts were supported by the Federal Highway Administration's (FHWA) pilot demonstration program through technical and financial assistance. The FHWA later endorsed CP as the only rehabilitation technique that stops corrosion in a salt-contaminated deck, claiming that its use could save billions of dollars.

First CP Steps

In 1975, Missouri rehabilitated its first seven bridges using the Stratfull method. A primary pancake anode was epoxied to the bridge deck and wired to a rectifier. The deck and primary anodes were then covered with a 2-in. layer of asphaltic coke breeze mixture, a high-carbon material known as a good conductor of electricity, and overlayed with 2 in. (minimum) of porphyry aggregate asphaltic concrete as a wearing surface.

"We know that the anode pad system worked, but the coke breeze was susceptible to movement," reports Signal and Lighting Engineer Tom Ryan. "From an overlay point of view we sought a lighter weight system that would be easier to apply without moving as readily. When we installed the first system, people thought that CP would heat the deck," recalls Girard. "But we believed that through continued education of our people we could eventually get the true purpose and technology across to them."

Ten years of monitoring and evaluation followed, led by a team that included Missouri's Highway and Transportation engineers, Dick Stratfull, and Donald Jackson, senior project manager, FHWA Demonstration Project Division. From 1975 to 1985, engineers monitored CP performance with monthly testing and visual examination of the bridges. Test results confirmed that the systems were functioning well.

Today five of the original seven coke asphalt bridges are in operation. The other two were recently dismantled during a project to widen the decks for accommodating increased traffic flow and larger trucks. Removal provided an opportunity to more thoroughly evaluate CP performance at this particular site. Initial examination of the slab and rebar on the first portion of the deck to be removed confirms that CP has successfully arrested the spread of corrosion. However, the second portion — the middle part of the existing deck most remote from the pie-shaped anodes — did have fracture planes. More extensive evaluation will lead to a formal report within a year.

"We're pretty well satisfied with these systems and think they have saved Missouri a great deal of money," reports Moberly.

CP Advancements

From 1984 to 1989, Missouri installed CP on an additional 119 voided slab and box girder bridges, leaving only 74 of the targeted 200 bridges remaining.

During this time Missouri has stayed abreast of new advancements and refinements in CP technology. Following the pancake anode, the state moved next to a conductive grout method developed by the FHWA and installed in slot and mound designs. Then a different anode was used, a flexible polymeric material enclosing a stranded copper wire core. This system was covered with a latex modified or low slump concrete overlay.

In 1986, Missouri began to install and monitor a promising new CP technique in conjunction with the FHWA demonstration program. This system, installed on major bridges and parking garages worldwide, uses a proprietary anode composed of a mixed precious metal oxide catalyst and sintered to a titanium mesh or ribbon form. This ELGARD anode is designed to be compatible within its surrounding concrete environment and can sustain the design current discharge for the life of the rehabilitation — 25 years or longer. It can be installed with a wide variety of conventional concrete covers and offers great redundancy in available electrical paths. To date, Missouri has installed this titanium-based anode system on 17 bridges.

In the 15 years since Missouri's first CP installation, the state continues to carefully monitor and evaluate each system. "We like to tell others about the simplicity of the CP system," says Bob Girard. "If you take the time to understand the system, conduct proper inspections to ensure that everything is installed and running properly, and keep good records, there is no reason why it shouldn't work," said Girard.

He adds that the FHWA and manufacturers provide helpful documents and "cookbook" procedures that are easy to understand and apply. "Pay attention to the manufacturer's instructions for evaluating the readings," he says.

During the first year following installation, Missouri monitors CP bridge projects monthly by collecting and analyzing readings for current flow, voltage, reference cell, and rebar probe activity. Adjustments are made as needed.

Beyond the first year, bi-monthly readings generally are adequate, although the structure's age can determine the monitoring frequency. Missouri also conducts an annual depolarization test for each of its CP bridges. A simple technique, it involves measuring the IR-free voltage change of the steel immediately after current shut-off and four hours later. If this change is about 100 millivolts, the steel is considered to be sufficiently protected.

Through continuous data collection and record keeping, Missouri engineers also monitor the influence of environmental conditions. "You must look at system stability with respect to moisture conditions and understand that reading fluctuations may not relate to the cells themselves. Accurate data will reflect these environmental conditions and allow you to piece together the true picture," explains Girard.

Properly maintained CP systems will work well. "However, if you don't take care of the system, problems occur," explains Ryan, who is responsible for the state's electrical systems, including traffic signals and street lighting. He hastens to add that "the extra time and dollars needed for CP maintenance are small relative to maintenance of other bridges."

The Critical Factor

A good maintenance and monitoring system will extend your bridge life, says Ryan. He believes that properly trained personnel who understand, maintain, and monitor Missouri's CP systems provide the critical factor to assure system integrity. He explains that "The time and money necessary to train your personnel to use and evaluate these systems, and then make the necessary operating decisions are sound investments. And just like anything else involved in bridge maintenance, the information you gain can be applied to other bridges."

Rectifiers are simple systems to understand, says Ryan, who adds that Missouri is considering remote monitoring of its rectifier systems. One option utilizes a hand-held gathering device that can download stored information directly to a computer.

"If we have a bridge that we feel doesn't justify replacing because the deck is fairly sound, CP is the only way to go," says Bill Brandel, senior structural detailer. "CP is still the cheapest system that is workable and will extend the life of the bridge over a number of years." □□□

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APPENDIX C

APPENDIX C

As Built Drawings

C3

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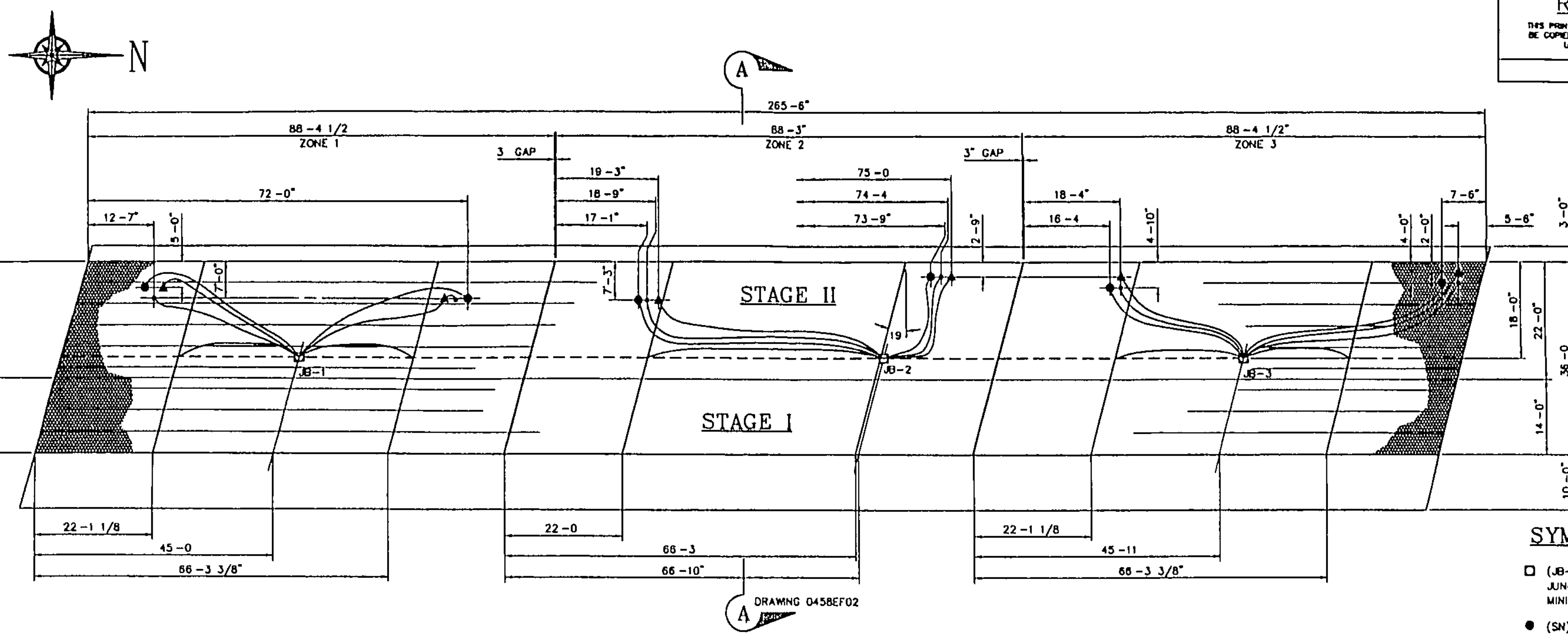

PLAN VIEW DECK

SYMBOL LEGEND

- ☐ (JB-1) ACCESS HOLE WITH JUNCTION BOX (6 X 6 X 6 MINIMUN)
- ● (SN) SYSTEM NEGATIVE
- ▲ (RC) REFERENCE CELL
- ↷ (RCG) REFERENCE CELL GROUND
- — — — UNDERDECK CONDUIT

0462EF02	STAGING SECTION VIEWS
0462EF03	STANDARD DETAILS
0462EF04	STANDARD DETAILS
0462EF05	STANDARD DETAILS
0462EF06	ELECTRICAL SCHEMATIC

REFERENCE DRAWINGS

JOB TITLE
IOWA DEPARTMENT OF TRANSPORTATION

DWG TITLE
ELGARD CATHODIC PROTECTION SYSTEM OF PENNSYLVANIA AVE. OVER I-235 DES MOINES IOWA PLAN VIEW BRIDGE DECK AS-BUILT

REV	REVISION DESCRIPTION	DATE	BY	CHKD	APP'D
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B	DRAWING NUMBER WAS 0458EF01	02-92	RLM	LCL	LCL
C	AS-BUILT	12 92	RLM	LCL	LCL

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CHK'D [signature]	02-10-92	A

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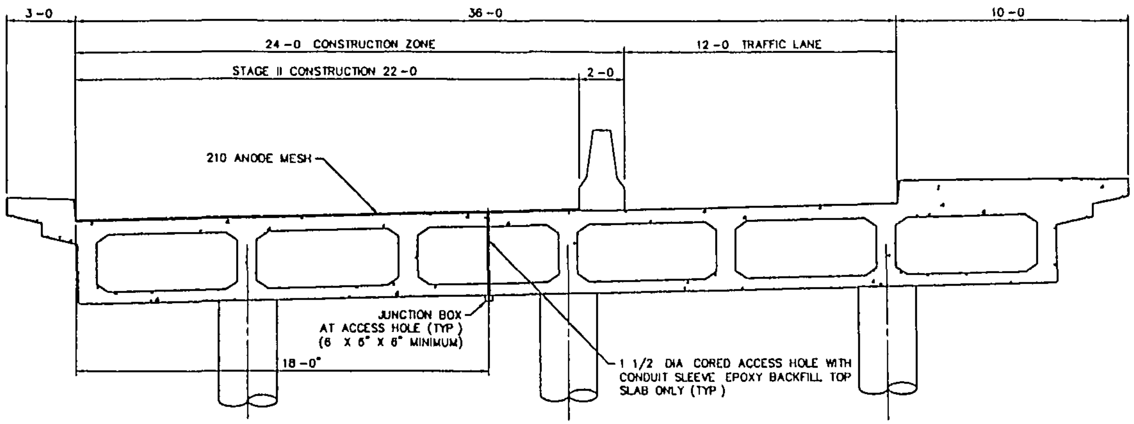
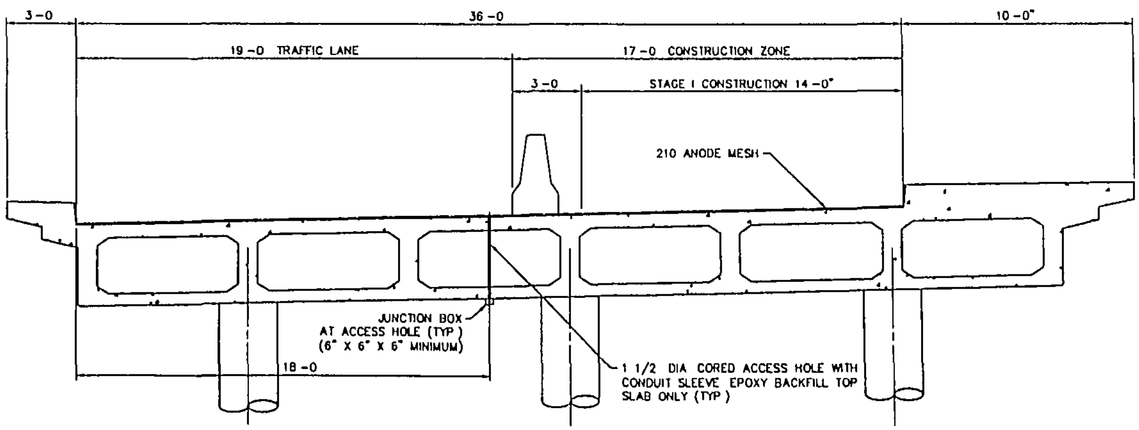


SECTION A-A
STAGE II



SECTION A-A
STAGE I

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0462EF01 PLAN VIEW BRIDGE DECK

REFERENCE DRAWINGS

JOB TITLE
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DWG TITLE
ELGARD CATHODIC PROTECTION SYSTEM
OF PENNSYLVANIA AVE. OVER I-235
DES MOINES IOWA
STAGING SECTION VIEWS

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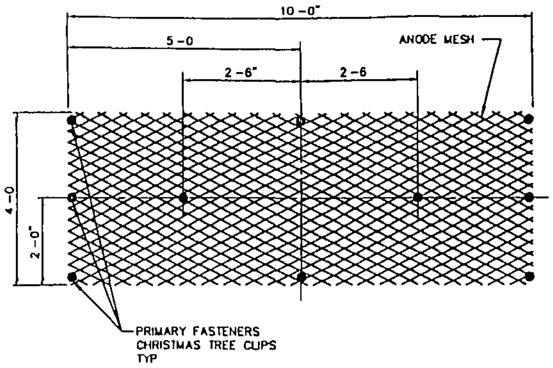
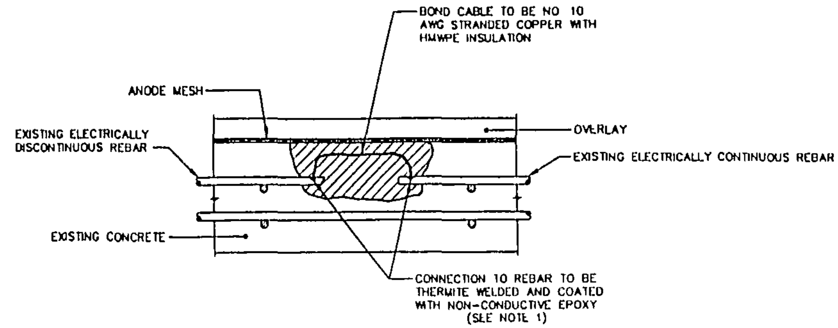


ANODE FASTENER LAYOUT
(N T S)



REBAR CONTINUITY DETAIL
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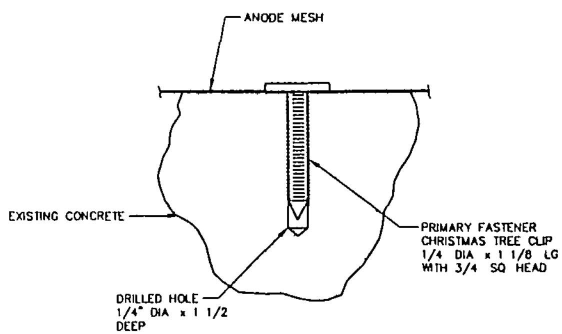

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CHRISTMAS TREE CLIP
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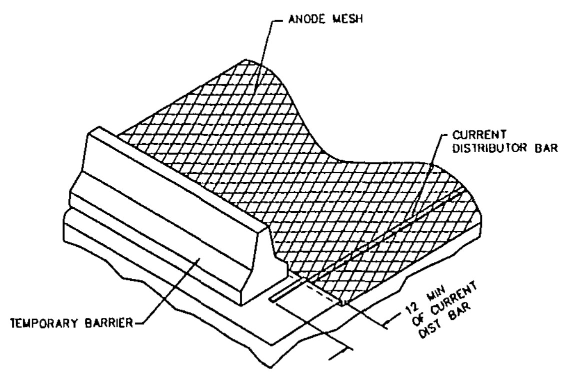

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SPLICE DETAIL
(N T S)

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OF PENNSYLVANIA AVE. OVER I-235
DES MOINES IOWA
STANDARD DETAILS

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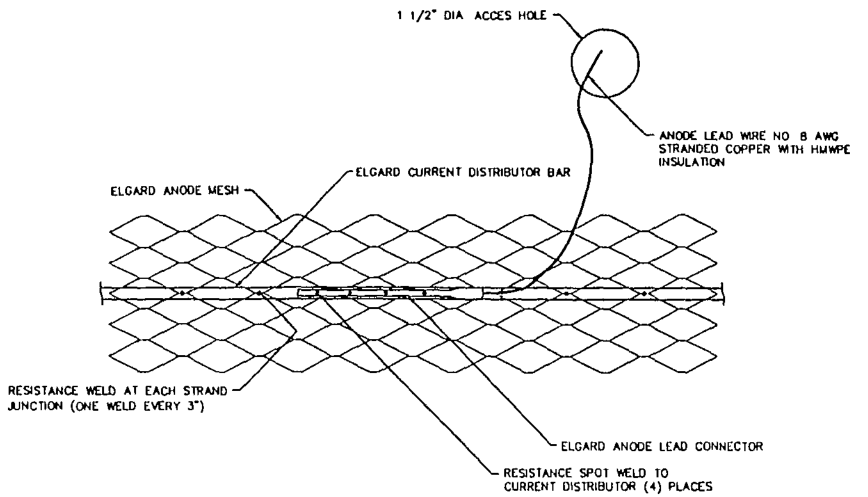

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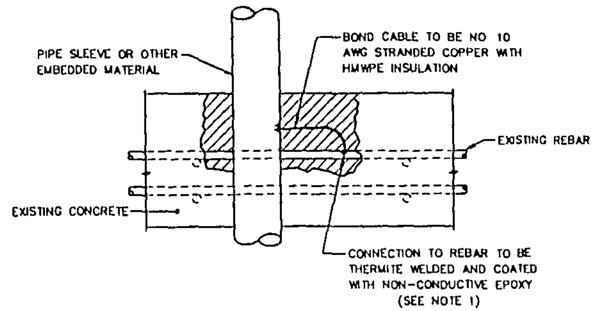

EMBEDDED STEEL BONDING DETAIL
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0462EF02	STAGING SECTION VIEWS

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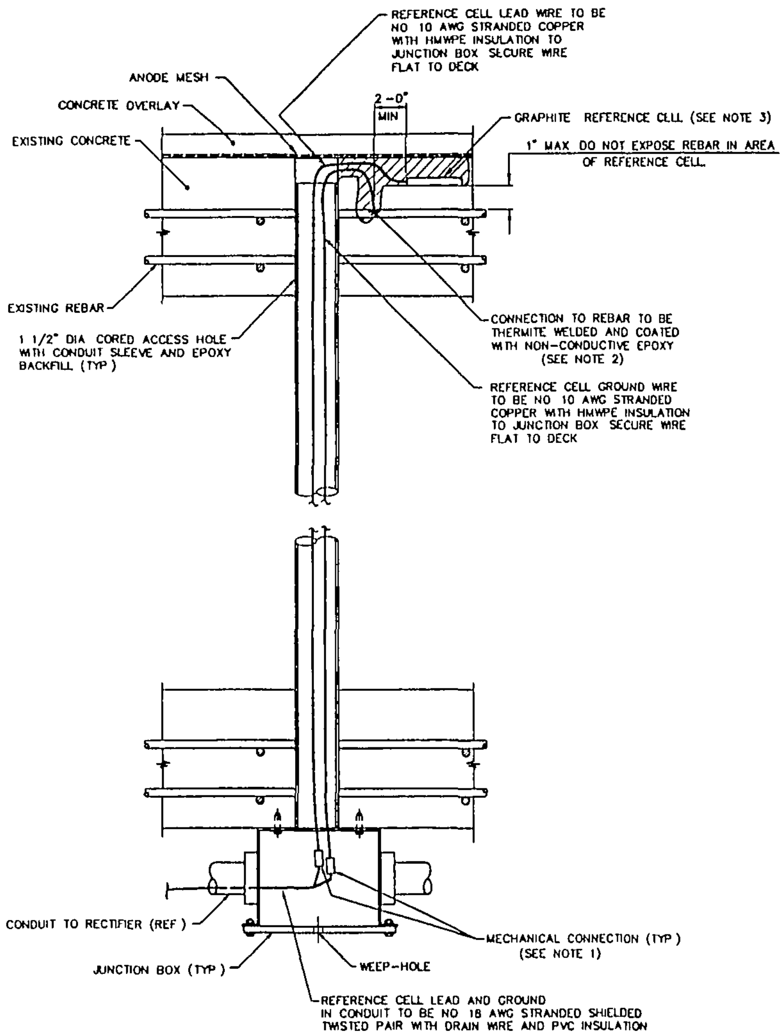

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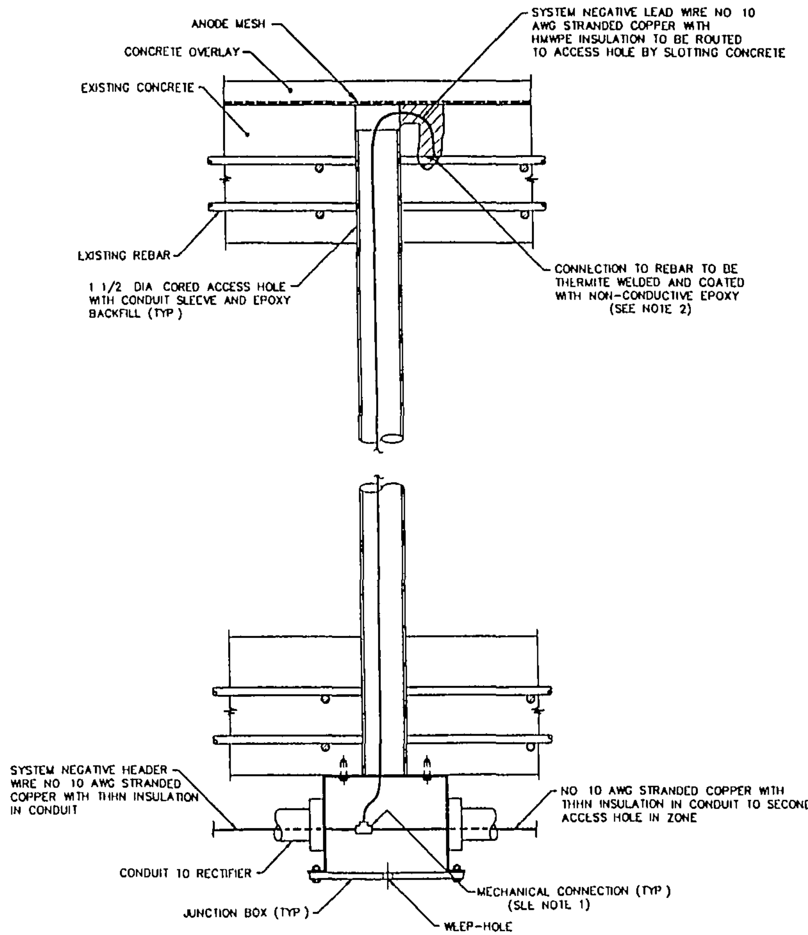

SYSTEM NEGATIVE CONNECTION DETAIL

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1) UNLESS OTHERWISE NOTED SPLICES MADE IN JUNCTION BOXES BENEATH DECK SHALL BE MECHANICALLY CONNECTED (CRIMP CONNECTION) AND INSULATED IN A HEAT-SHRINKABLE MATERIAL SUCH AS ALPHA'S SERIES FIT-700 OR 3M SCOTCH E-Z SEAL 2200
2) AFTER THERMITE WELDED CONNECTION IS MADE GENTLY TAP AND REMOVE SLAG FROM WELD
3) INSTALL REFERENCE CELL AT A MAXIMUM OF 1" BUT DO NOT EXPOSE REINFORCING STEEL AT LOCATIONS INDICATED

0462EF01	PLAN VIEW BRIDGE DECK
0462EF02	STAGING SECTION VIEWS

REFERENCE DRAWINGS

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ELGARD CATHODIC PROTECTION SYSTEM OF PENNSYLVANIA AVE. OVER I-235 DES MOINES IOWA
STANDARD DETAILS

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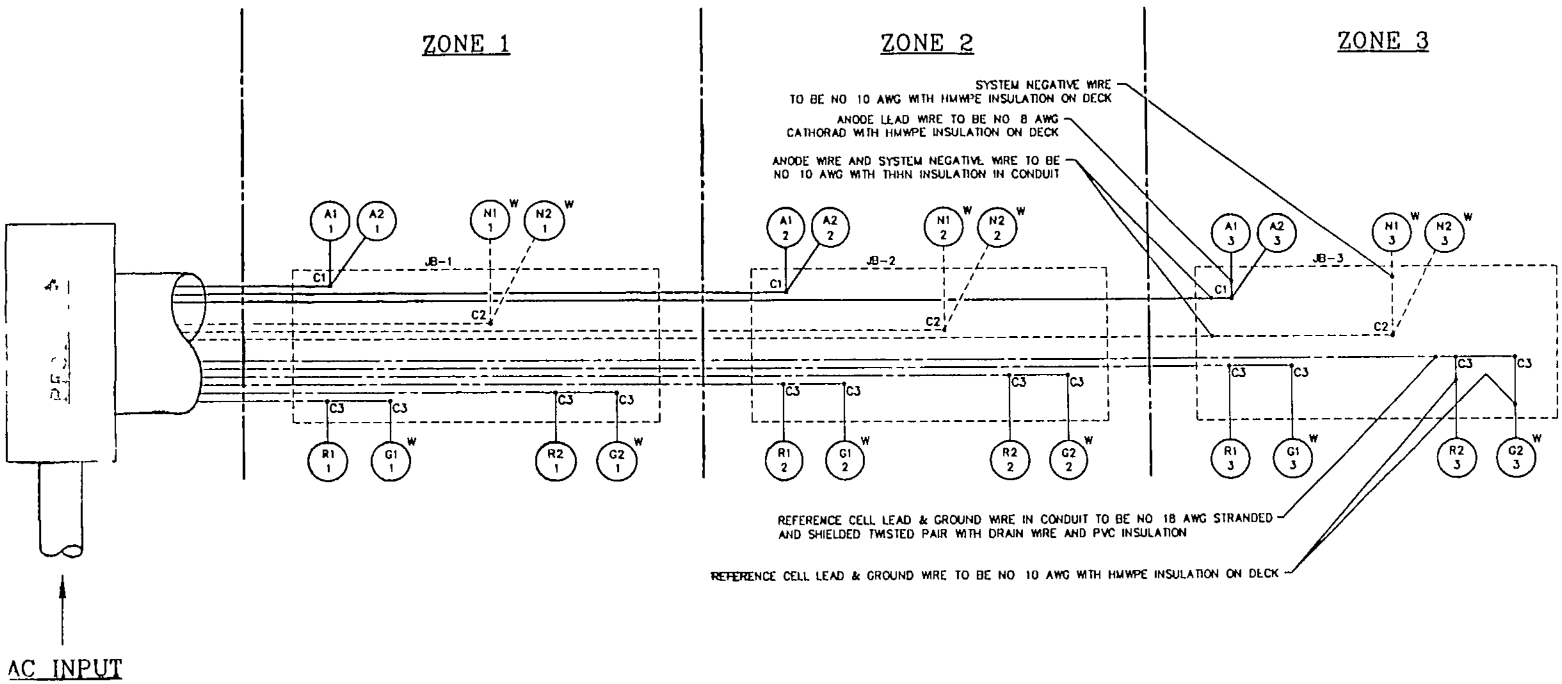
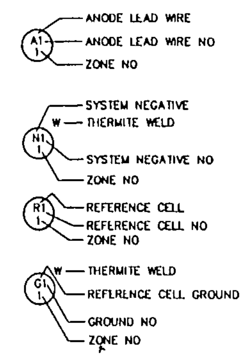


SYMBOL LEGEND



SPLICE CONNECTIONS

C1 (2) NO 8 AWG TO (1) NO 10 AWG
C2 (2) NO 10 AWG TO (1) NO 10 AWG
C3 (1) NO 10 AWG TO (1) NO 18 AWG

0462EF01	PLAN VIEW BRIDGE DECK
0462EF02	STAGING SECTION VIEWS

REFERENCE DRAWINGS

JOB TITLE
IOWA DEPARTMENT OF TRANSPORTATION

DWG TITLE
ELGARD CATHODIC PROTECTION SYSTEM
OF PENNSYLVANIA AVE. OVER I-235
DES MOINES IOWA
ELECTRICAL SCHEMATIC

12-22-92 PW 3 22 RUSS

REV	REVISION DESCRIPTION	DATE	BY	CHKD	APP'D	REV	REVISION DESCRIPTION	DATE	BY	CHKD	APP'D
A	ORIGINAL ISSUE	02 92	RLM	[illegible]	[illegible]						
B	DRAWING NUMBER WAS 0456EF06	02 92	RLM	[illegible]	[illegible]						
C	AS BUILT	12 92	RLM	[illegible]	[illegible]						

TOLERANCES
FRACTIONS ±
XX ±
XXX ±
ANGLES ±
UNLESS OTHERWISE SPECIFIED

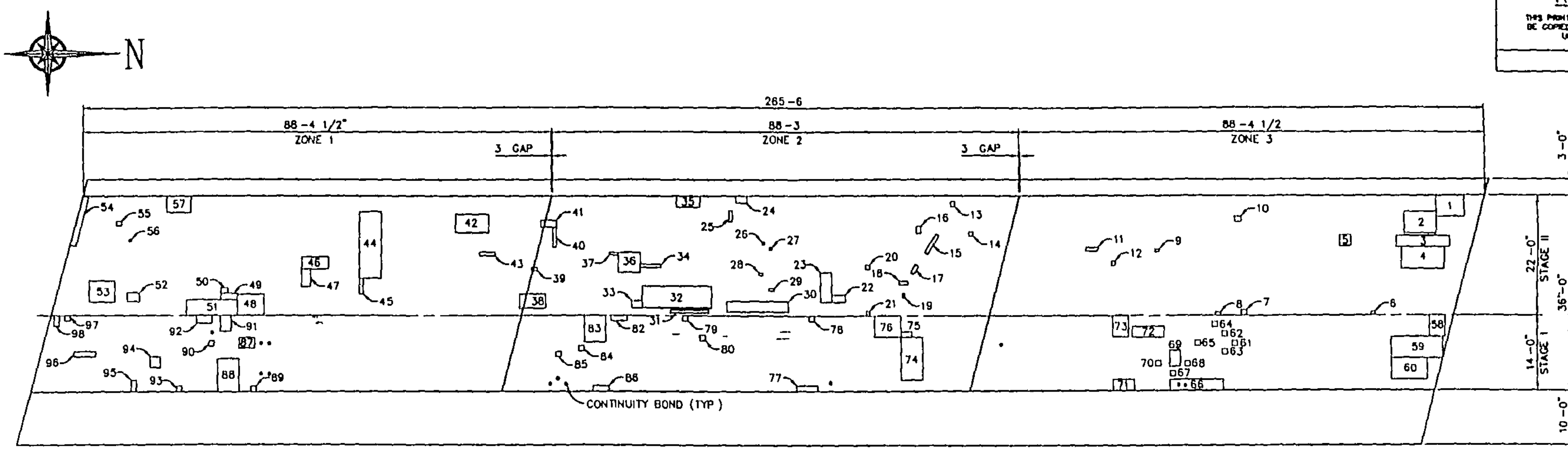
DWG APPROVALS	DATE	REV
[signature]	02-10-92	A
[signature]	12-14-92	C
DRAWN [signature]	02-04-92	A
CHK'D [signature]	02-10-92	A

JOB APPROVALS	DATE

ELGARD Corporation
A Subsidiary of ELTECH Systems Corp
100 Seventh Avenue Suite 300
Chardon Ohio 44024
ELTECH

FILE NAME: 0462EF06
ENG NO: 0462
DWG UNIT NO: 0462EF06
REV: C

A2



PLAN VIEW DECK

LOCATION	DELAM SIZE
1	48 X 65"
2	48 X 75
3	24" X 124
4	48 X 100
5	24 X 27"
6	8" X 10
7	12 X 12"
8	7 X 12"
9	6" X 10
10	12 X 15
11	8" X 28"
12	8" X 10
13	9 X 12
14	9 X 9
15	8 X 48"
16	10" X 16
17	8 X 22
18	8 X 20"
19	5 X 10"
20	10 X 10"
21	8" X 10"
22	16" X 31"
23	26" X 66
24	16" X 25"
25	8" X 25"
26	6" X 6"
27	6" X 6"
28	6" X 10"
29	6 X 12"
30	23" X 140"

LOCATION	DELAM SIZE
31	7 X 86
32	48 X 157
33	16 X 24
34	7 X 48"
35	25" X 53"
36	44 X 48
37	6" X 20
38	32" X 60
39	7 X 14"
40	8" X 43"
41	15" X 36"
42	40" X 75"
43	8 X 36"
44	48" X 146"
45	8 X 34"
46	27" X 60"
47	20 X 40"
48	48 X 61
49	15 X 37"
50	12 X 16"
51	36 X 116"
52	20" X 28"
53	48 X 57"
54	13" X 110"
55	9" X 12
56	5 X 8"
57	38" X 56"
58	36" X 48"
59	48 X 120"
60	47" X 84"

LOCATION	DELAM SIZE
61	12 X 12
62	12 X 12
63	12" X 12
64	12 X 12
65	12 X 12
66	24 X 120
67	12 X 12
68	12" X 12"
69	24" X 36
70	12 X 12
71	24" X 48
72	24" X 72"
73	36" X 48"
74	48 X 96
75	12" X 24"
76	48 X 60"
77	12 X 48"
78	12" X 12
79	12 X 12
80	12 X 12
81	12" X 12
82	12" X 36"
83	48" X 60"
84	12" X 12"
85	12" X 12"
86	12" X 36"
87	24" X 36"
88	48" X 72"
89	12 X 12"
90	12" X 12"

LOCATION	DELAM SIZE
91	24 X 36
92	18" X 36
93	12" X 12
94	24" X 24
95	12" X 24
96	12 X 48
97	12" X 12"
98	12 X 24"

RESTRICTED

NOTES

REFERENCE DRAWINGS

JOB TITLE
IOWA DEPARTMENT OF TRANSPORTATIC

DWG TITLE
ELGARD CATHODIC PROTECTION SYSTEM
OF PENNSYLVANIA AVE. OVER I-235
DES MOINES IOWA
SPACER MESH LOCATIONS

REV	REVISION DESCRIPTION	DATE	BY	CHKD	APP'D	REV	REVISION DESCRIPTION	DATE	BY	CHKD	APP'D
A	ORIGINAL ISSUE AS-BUILT	12 92	RH								

TOLERANCES
FRACTIONS ±
.XX ±
.XXX ±
ANGLES ±
UNLESS OTHERWISE

DWG APPROVALS	DATE	REV
	12-11-92	A
DRAWN	12-11-92	A
CHK D	12-11-92	A

JOB APPROVALS DATE

ELGARD Corporation
A Subsidiary of ELTECH Systems Corp
100 Seventh Avenue Suite 300
Chardon Ohio 44024
ELTECH

FILE NAME
0462EF07

ENG NO
0462

DWG UNIT NO
0462EF07

PM 2 47 RUSS

A3

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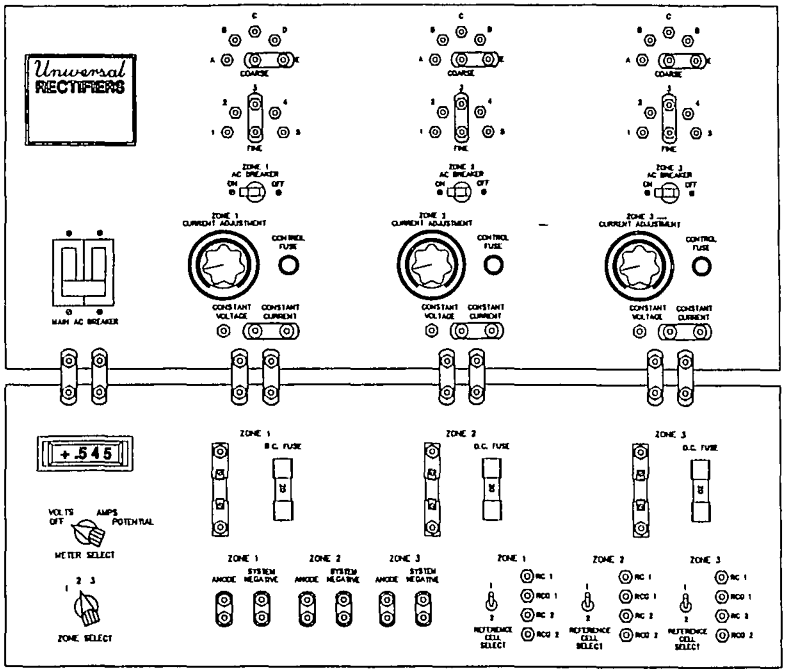
UNAUTHORIZED PERSONNEL

NOTES



REFERENCE DRAWINGS

JOB TITLE
IOWA DEPARTMENT OF TRANSPOR

DWG TITLE
ELGARD CATHODIC PROTECTION SY
OF PENNSYLVANIA AVE. OVER I-2
DES MOINES IOWA
RECTIFIER LAYOUT

REV	REVISION DESCRIPTION	DATE	BY	CHKD	APP'D	REV	REVISION DESCRIPTION	DATE	BY	CHKD	APP'D
A	ORIGINAL ISSUE	12 92									

TOLERANCES
FRACTIONS ±
XX ±
XXX ±
ANGLES ±
UNLESS OTHERWISE SPECIFIED

DWG APPROVALS	DATE	REV
	12-22-92	A
DRAWN	12-22-92	A
CHK'D	12-22-92	A

JOB APPROVALS | DATE

ELGARD Corporation
A Subsidiary of ELTECH Systems Corp
100 Seventh Avenue Suite 300
Chardon Ohio 44024
ELTECH

FILE NAME 0462EF08 | ENG 0
DWG UNIT NO 0462EF08

12-22-92 PW 3 04 RUSS

APPENDIX B

APPENDIX D

Start Up and Depolarization Data

Iowa Department of Transportation
Pennsylvania Avenue Bridge over I-235
Startup Data Sheet

Data Taken By: SDS **Rectifier Serial No:** 920944
Date: 10/2/92 **Weather Conditions:** Sunny, 65 Degrees Fahrenheit

Zone No.	Reference Cell No.	Resistance SN/RCN (DC) ohms	Resistance Anode/SN (AC) ohms	DC mV SN/RCN	DC mV Anode/SN	Rebar Static Potential (mV) vs Graphite
1	1	2 2/2 3	0 58	0 0	188	-72
	2	2 2/2 4		0 0		-99
2	1	2 9/3 0	0 74	0 0	168	-65
	2	3 0/3 2		0 0		-168
3	1	3 5/3 5	0 88	0 0	35	-91
	2	3 8/3 2		0 1		-3

Zone No.	Zone Voltage (Volts)	Current Output (Amps)	Reference Cell No.	Rebar "On" Potential	Rebar "Instant Off" Potential
1	2.5	3.2	1	-391	-339
			2	-473	-398
2	3.1	3.2	1	-466	-367
			2	-467	-417
3	3.3	3.2	1	-367	-240
			2	-302	-161

NOTES: Reference Cell Ground Wire is the White Wire from the Shielded Twisted Pair
Reference Cell Wire is the Black Wire from the Shielded Twisted Pair

Iowa Department of Transportation
Pennsylvania Avenue Bridge over I-235
Depolarization Test

Data taken by: SDS

Date: 11/13/92

Rectifier Serial No.: 920944

Weather: 28 Degrees F, Cold and Windy

	Elapsed Time,min.	Actual Time of Reading	Rebar Static Potential RC mV = -mV vs. Reference Cell					
			Zone No. 1		Zone No. 2		Zone No. 3	
			RC-1	RC-2	RC-1	RC-2	RC-1	RC-2
			mV	mV	mV	mV	mV	mV
On Potential	0	8 14	695	872	929	939	549	358
Instant-Off Potential	<1 sec	8·15	486	599	607	667	262	117
	1	8 16	410	505	495	573	131	28
	2	8 17	361	457	440	530	86	2
	3	8 18	333	427	405	504	59	18
	4	8 19	308	405	379	488	41	25
	5	8 20	291	388	361	476	30	27
	6	8 21	275	372	341	465	22	26
	7	8 22	262	360	330	457	17	24
	8	8 23	254	352	322	453	15	22
	9	8 24	249	347	317	450	14	20
	10	8 25	241	346	309	445	12	16
	20	8 35	199	301	270	420	27	23
	30	8 45	176	281	250	404	46	53
	40	8 55	164	270	239	394	57	68
	50	9 05	155	259	230	384	64	76
	60	9 15	150	252	223	377	68	79
	90	9 45	141	239	211	362	71	77
	120	10.15	142	224	200	345	53	70
	150	10 45	138	222	198	342	54	68
	180	11 15	132	216	194	334	52	65
	210	11 45	129	211	190	328	50	62
	240	12 15	125	206	186	322	48	59
	DELTA		361	393	421	345	214	58

Delta is the difference between readings at "Instant-Off" and "Time 240"

NOTES

Settings Before Testing
Zone 1 3 2 A, 3 0 V
Zone 2· 3 2 A, 3 6 V
Zone 3 3 2 A, 3 6 V

Settings After Testing
Zone 1. 2 8 A, 2 4 V
Zone 2 2 8 A, 3 0 V
Zone 3 3 2 A, 3 1 V