CATHODIC PROTECTION SYSTEMS

USE OF SACRIFICIAL OR GALVANIC ANODES ON IN-SERVICE BRIDGES

NYSDOT OFFICE OF OPERATIONS
TRANSPORTATION MAINTENANCE DIVISION
BRIDGE MAINTENANCE

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INTRODUCTION

CORROSION CONTROL USING GALVANIC CATHODIC PROTECTION

> This section provides application information, design examples, and reference tables for the use of galvanic cathodic protection systems for in-service reinforced concrete structures.

An overview of the various strategies that might be considered by the Bridge Maintenance Engineer in the rehabilitation of reinforced concrete structures is provided in NCHRP Report 558 Chapter 5 “Extension of Service Life with Repair and Corrosion Mitigation Options.” The strategies can be divided into two categories; corrosion protection and corrosion control.

The overview includes discussions on the methods typically used with NYSDOT. These include, reinforcing bar coatings, overlays, waterproofing membranes, and penetrating sealers. These strategies function to provide corrosion protection and are applicable for replacement projects or for repairs to elements with minimal levels of rebar corrosion.

In more aggressive environments, a strategy of adding corrosion control techniques to standard repair procedures has been proven to provide the most effective repair. Typical corrosion control materials are corrosion inhibitors and galvanic cathodic protection systems.

Corrosion inhibitors are chemical compounds either added to the repair material, applied directly to the rebar, or both. Calcium nitrite is the most commonly used corrosion inhibitor and has a long history of good performance. Nonetheless, in test patches in concrete with high levels of chloride ions “the nitrite inhibitor used in conjunction with patch repair material on field structures did not provide any benefit” (NCHRP Report page 29).

The Federal Highway Administration has stated that “cathodic protection is the only rehabilitation technique that has proven to stop corrosion in salt-contaminated bridge decks regardless of the chloride content in concrete” (NCHRP Report, page 34).

Cathodic protection can be grouped into two basic types of systems: impressed current and galvanic cathodic systems. An impressed current system is achieved by driving a low-voltage direct current (generally less than 50 volts) from a relatively inert anode material, through the concrete, to the reinforcing bars. The current is distributed to the reinforcing bars by an anodic material. This procedure is very costly and requires specialized services to design and verify the system is working properly.

Galvanic cathodic protection (also called galvanic anode system) is based on the principles of dissimilar metal corrosion and the relative position of specific metals in the galvanic series. No external power source is needed with this type of system, and much less maintenance is required. Patch-repair and plug-type anodes are examples of galvanic anodes.

As stated in NCHRP Report 558, when selecting a cathodic protection system for a given structure, several issues need to be considered:

- Long-term rehabilitation: the system is most effective for if a long-term repair (5 to 10 years) is desired.
- Electrical continuity: a closed electrical circuit is required for proper functioning of the system.
- Chloride concentrations: if the levels are in sufficient concentration to initiate corrosion, cathodic protection may be the only viable method of rehabilitation.
- Alkali-silica reaction: cathodic protection increases alkalinity at the steel-concrete interface, thereby theoretically accelerating the alkali-silica reaction, although this condition has never been reported.

Questions or comments regarding this material should be forwarded to the Bridge Maintenance Program Engineer in the Office of Operations.

References:

NCHRP Report 558 Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements.

Vector Corrosion Technologies
www.vector-corrosion.com

The Euclid Chemical Company
www.euclidchemical.com

PRODUCTS LIST

Supplier	Product Name	Description	Contact
Vector	Galvashield XP+	“Hockey puck” with 100 grams of zinc	(813) 830-7566 www.vector-corrosion.com
	Galvashield XP	“Hockey puck” with 65 grams of zinc	
	Galvashield CC 65	Moderate steel density	
	Galvashield CC 100	High steel density	
	Galvashield CC 135	Slim fit style	
Sika Corp	Galvashield XP+	Same as Vector	1-800-933-7452 www.sikaconstruction.com
	Galvashield CC 65, 100, 135	Same as Vector	
BASF	Corrstops	Same as Vector Galvashield XP	1-800-526-1072 www.basf.com
Euclid	Sentinel-GL	“V-notch” block with 40 grams of zinc	1-800-321-7628 www.euclidchemical.com

Steel Density Ratio

The number and spacing of anodes is determined by the steel density ratio. The ratio is a calculation of the surface area of the reinforcing steel to the area of repair.

Product manufacturers supply spacing tables based on the steel density ratio for each anode type. Anodes are estimated to provide 5 to 15 years of corrosion protection.

Steel density ratios based on rebar spacing have been calculated for rebar sizes 5, 6, and 7 bars and are located in the appendix of this module. Spacing for Euclid's Sentinel-GL is based on categories of heavy, medium, and light reinforcement. The tables are color coded and grouped to facilitate this designation.

The protective current supplied by sacrificial anodes will decrease slowly with time as zinc corrosion products accumulate. The recommended anode spacing provided by the manufacturers provides a balance between desired service life and reasonable cost. Altering the anode spacing will change the service life, but the relationship between the spacing and the service life is not linear. Doubling the anode spacing (therefore halving the anode cost) will reduce the expected service life by much more than half. Halving the anode spacing will extend the expected service life by more than double, but at greatly increased cost.

Since the corrosion products of zinc occupy more volume than the original zinc, means must be provided to accommodate this expansion. Vector encapsulates the zinc in a high alkaline environment to chemically control expansion. Euclid allows for the expansion of the zinc corrosion by-products by using compressible materials within the encasement.

STEEL DENSITY TABLES

Corroded Bars

Galvashield XP+ TABLE 1.0

Steel Density Ratio	Maximum Spacing (in)
< 0.2	28
0.21 - 0.40	24
0.41 - 0.54	20
0.55 - 0.67	18
0.68 - 0.80	16
0.81 - 0.94	15
0.95 - 1.07	14
1.08 - 1.20	13

Non-Corroded Bars

Galvashield XP+

TABLE 2.0

Steel Density Ratio	Maximum Spacing (in)
< 0.3	30
0.31 - 0.6	28
0.61 - 0.9	26
0.91 - 1.2	22
1.2 - 1.5	20
1.51 - 2.0	17

Galvashield XP

TABLE 3.0

Steel Density Ratio	Maximum Spacing (in)
< 0.3	30
0.31 - 0.6	24
0.61 - 0.9	20
0.91 - 1.2	17

TABLE 4.0 Maximum Sentinel-GL Anode Spacing (in)

Steel Density Ratio	Highly Corrosive Environment[1]	Slightly Corrosive Environment[2]
< 0.50 (light)	24	30
0.50 – 1.0 (moderate)	18	24
> 1.0 (heavy)	12	18

1. Characterized by a large amount of corrosion damage. Chloride content >about 5 lbs/yd^3
2. Characterized by a small amount of corrosion damage. Chloride content <about 5 lbs/yd^3

STEPS FOR USE OF SACRIFICIAL ANODES ON IN-SERVICE BRIDGES

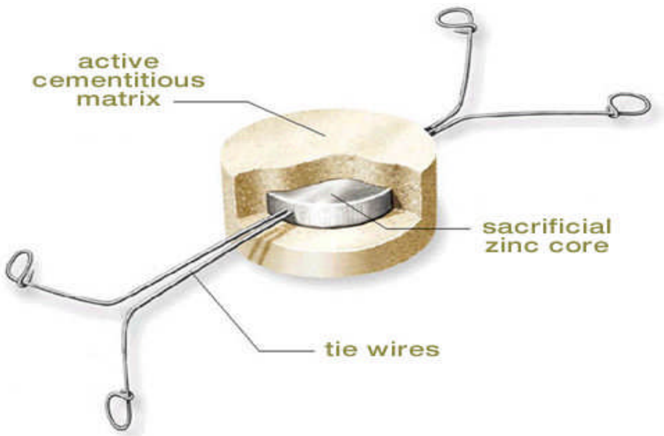
1. Determine if the use of sacrificial anodes are a cost effective strategy for the necessary repair.
2. Determine rebar types and repair material options. Galvanic anodes are not effective in materials with electrical resistivity greater than 15,000 ohm-cm.
    i. Many polymer, fly ash, and silica fume-based repair materials cannot be used in conjunction with sacrificial anodes.
    ii. Additional steps are necessary if the rebars are epoxy coated.
    iii. Low Volume Shotcrete: Repairs performed by low volume shotcrete using Dry-Pak-It methodology and materials with galvanic anodes do not exhibit improved performance over similar repairs done without the use of galvanic anodes.
3. Determine the numbers of anodes required by calculating the density of the reinforcing steel. (See attachment for sample calculation.)
4. Place the anodes accordingly as to the type of project being conducted. For pre-stressed/post-tensioned concrete structures, provide an electrical connection between the wires strands and the anodes. For top and bottom mat protection an electrical connection must be provided to the bottom mat of bridge deck reinforcing steel.

OPEN PATCHING

Galvanic protection systems utilize sacrificial anodes that naturally generate an electrical current to mitigate corrosion of the reinforcing steel. In concrete structures, zinc anodes are typically used. Galvanic protection for concrete can be classified into two categories: targeted protection for concrete repair, and distributed systems for blanket protection.

Discrete anodes are used to provide targeted protection around concrete patches, and can also be placed into drilled holes on a grid pattern in sound concrete to provide distributed protection.   Galvashield® XP and Sentinel-GL embedded zinc anodes are examples of discrete zinc anodes that are used to provide targeted protection for concrete patch repair.

Discrete zinc anodes are normally intended to provide corrosion protection for only the top mat of reinforcing steel; since the top mat is usually where concrete is chloride contaminated and where corrosion takes place. In unusual cases it may be necessary to provide sufficient current to provide protection to both mats of reinforcing steel.



Galvashield® XP+ anode (above) Euclid Sentinel-GL (below)

Example Calculation for Deck Repair
Using Sentinel-GL Anodes

Assumption: #5 bars (0.625” diameter) on 8” center both directions in a highly corrosive environment.

1. **Calculate top mat steel density ratio using the formula:**

$$(\pi)\ \frac{(\text{bar diameter})}{(\text{bar spacing})} = \text{ratio}$$

Top mat longitudinal bar ratio:	(π) (0.625/8) = 0.245
+ Top mat transverse bar ratio:	(π) (0.625/8) = 0.245
Total top mat steel density ratio =	**0.490**

2. **Determine anode spacing using Table 4.0:**

From Table 4.0: for Steel Density Ratio <0.5 in Highly Corrosive Environment, **Maximum Anode Spacing = 24 in.**
But since the ratio is very close to 0.5, a reasonable choice could be **21 in.**

Example Calculation for Column Repair
Using Sentinel-GL Anodes

Assumption: #11 bars (1.375” diameter) vertical on 6” center, and #4 ties (0.500” diameter) on 12” center in a highly corrosive environment.

1. **Calculate steel density ratio using the formula:**

$$(\pi)\ \frac{(\text{bar diameter})}{(\text{bar spacing})} = \text{ratio}$$

Vertical bar steel density ratio:	(π) (1.375/6)	= 0.720
+ Tie bar steel density ratio:	(π) (0.500/12)	= 0.131
Total top mat steel density ratio =		**0.851**

2. **Determine anode spacing using Table 4.0:**

From Table 4.0: for Steel Density Ratio 0.5–1.0 in Highly Corrosive Environment, **Maximum Anode Spacing = 18 in.**

Example: Determining Number of Anodes Needed for Deck Repair using Steel Density Ratio Tables

Description of Repair: Moderately Reinforced Slab (Bridge Deck) #5 bars @ 12” x 14” spacing

Repair Dimensions: 48” (transverse) x 60” (longitudinal)

1. Determine Steel Density Ratio using tabulated values

No. 5 bars

Spacing (in)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	*0.79*	*0.72*	*0.67*	*0.64*	*0.61*	*0.59*	*0.57*	*0.56*	*0.54*	*0.53*	*0.52*	*0.52*	*0.51*	*0.50*	*0.50*	0.49	0.49	0.48	0.48	0.47	0.47
6	*0.72*	*0.65*	*0.61*	*0.57*	*0.55*	*0.52*	*0.51*	0.49	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.42	0.42	0.41	0.41	0.41
7	*0.67*	*0.61*	*0.56*	*0.53*	*0.50*	0.48	0.46	0.44	0.43	0.42	0.41	0.40	0.40	0.39	0.38	0.38	0.37	0.37	0.37	0.36	0.36
8	*0.64*	*0.57*	*0.53*	0.49	0.46	0.44	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33	0.33	0.32
9	*0.61*	*0.55*	*0.50*	0.46	0.44	0.41	0.40	0.38	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.30
10	*0.59*	*0.52*	0.48	0.44	0.41	0.39	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.29	0.28	0.28	0.27
11	*0.57*	*0.51*	0.46	0.42	0.40	0.37	0.36	0.34	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.26
12	*0.56*	0.49	0.44	0.41	0.38	0.36	0.34	0.33	0.31	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.24
13	*0.54*	0.48	0.43	0.40	0.37	0.35	0.33	0.31	0.30	0.29	0.28	0.27	0.27	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.23
14	*0.53*	0.47	0.42	0.39	0.36	0.34	0.32	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22
15	*0.52*	0.46	0.41	0.38	0.35	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21
16	*0.52*	0.45	0.40	0.37	0.34	0.32	0.30	0.29	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.20	0.20
17	*0.51*	0.44	0.40	0.36	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19
18	*0.50*	0.44	0.39	0.35	0.33	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19
19	*0.50*	0.43	0.38	0.35	0.32	0.30	0.28	0.27	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19	0.18
20	0.49	0.43	0.38	0.34	0.32	0.29	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18
21	0.49	0.42	0.37	0.34	0.31	0.29	0.27	0.26	0.24	0.23	0.22	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18	0.17
22	0.48	0.42	0.37	0.33	0.31	0.29	0.27	0.25	0.24	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17
23	0.48	0.41	0.37	0.33	0.30	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17	0.16
24	0.47	0.41	0.36	0.33	0.30	0.28	0.26	0.25	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16
25	0.47	0.41	0.36	0.32	0.30	0.27	0.26	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.16

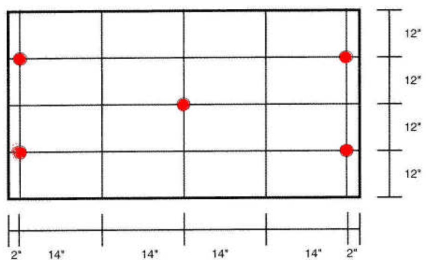
Tabulated values represent steel density ratios

Heavy
Moderate
Light

For 12” x 14” spacing, the Steel Density Ratio is 0.30

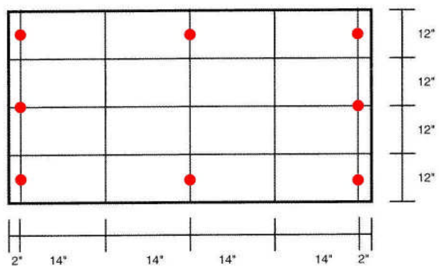
Galvashield XP+ & Galvashield XP

From tabulated values:
Spacing = 30 in (max.)
Number of Anodes = 5



Sentinel-GL

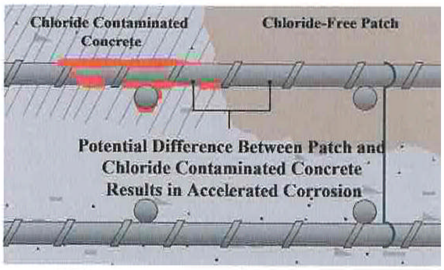
From tabulated values:
Spacing = 24 in (max.)
Number of Anodes = 9



Installation Instructions

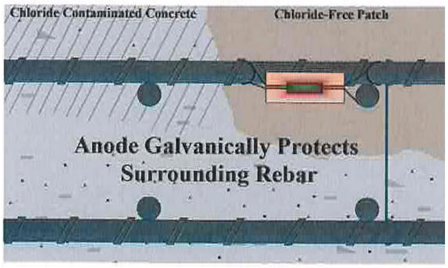
Prior to installation, the "Installation Instructions" bulletin shall be thoroughly examined for details on the placement and use of manufacturer's units. Concrete shall be removed from around and behind all corroding rebar, in accordance with good concrete repair practice (ICRI Guideline No. 03730). Securely fasten the unit to clean reinforcing steel using a suitable wire twisting tool to eliminate free movement, and to ensure a good electrical connection. Steel continuity within the patch should be verified with an appropriate meter. If discontinuous steel is present, re-establish continuity with steel tie wires. Following the unit installation, electrical connection between the unit tie wires and the clean reinforcing bar should be confirmed with an appropriate meter. The location and spacing of the units shall be as specified by the designer.

The anodes are typically tied on the side or beneath the exposed rebar as close as practical to the surrounding concrete making sure than enough space is left to fully encapsulate the unit in the repair. Minimum cover over the units must be 20 mm (3/4 in.). Units can be placed on a grid pattern throughout the repair to protect a second mat of steel if required. With the units in a position, complete the repair using a suitable repair material with resistivity less than 15,000 ohm-cm. If higher resistance repair materials are to be used, pack manufacturer's mortar between the unit and the substrate to provide a conductive path to the substrate, the complete repair.



"Ring Anode" (without Galvashield XP+)

A standard tie wire will work, if there is continuity to start with. If there is none you will need to weld either a heavy gage wire #1 or a piece of rebar between the mats.



Galvashield XP+ prevents "Ring Anode" Corrosion

Health and Safety

As with all cement-based materials, contact with moisture can release alkalis which may be harmful to exposed skin. Anodes should be handled with suitable gloves and other personal protective equipment in accordance with standard procedures for handling cementitious materials. Additional safety information is included in the Material Safety Data Sheet.

Installation Instructions and **Health and Safety** information can be found for each product on the manufacturer's websites.

PLUG-TYPE ANODES

Installation Instructions

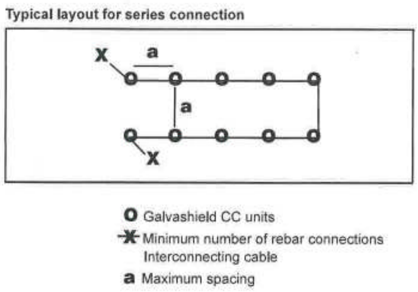
The location and spacing of the Galvashield® CC units shall be on a grid pattern as specified by the engineer. Using a rebar locator, locate all existing steel within the area designated for protection and mark areas to drill unit installation holes. When possible, units should be installed a minimum of 4 in. (100 mm) from reinforcing grid.

Series Connection – a single circuit shall contain no more than 10 Galvashield® CC units. Drill a minimum of two ½ in. (12 mm) rebar connection holes per string of anodes. Saw cut a single continuous groove approximately ¼ in. (6mm) wide by ½ in. (12 mm) deep into the concrete to interconnect rebar connection holes and anode connection holes.

Individual Connection – drill one rebar connection hole per unit location. Saw cut a groove approximately ¼ in. (6 mm) wide by ½ in. (12 mm) deep into the concrete to interconnect the rebar connection hole and anode connection hole.

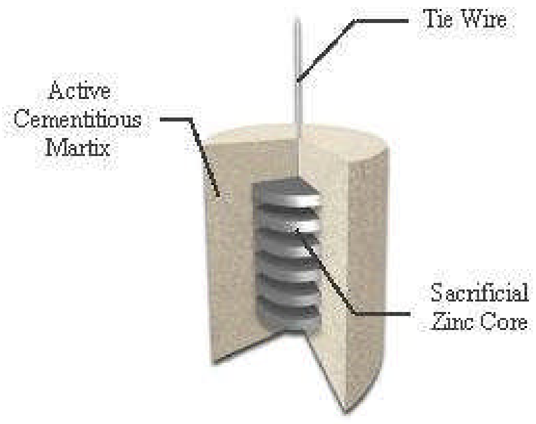
Reinforcing steel connections should be made using the Vector Rebar Connection Kit. Place the weighted end of the connector into the drilled hole until the steel coil contacts the reinforcing steel. Feed the steel connector wire through the Vector Setting Tool and set into place by striking with a hammer.

Connect the units directly to the rebar connection wire using the supplied wire connector. If installing in series, connect the units to the interconnecting cable with a wire connector (cable and wire connectors are available as the Vector Anode Connection Kit). Verify continuity between unit locations and rebar connections with a multi-meter. A resistance of 1 ohm or less is acceptable.

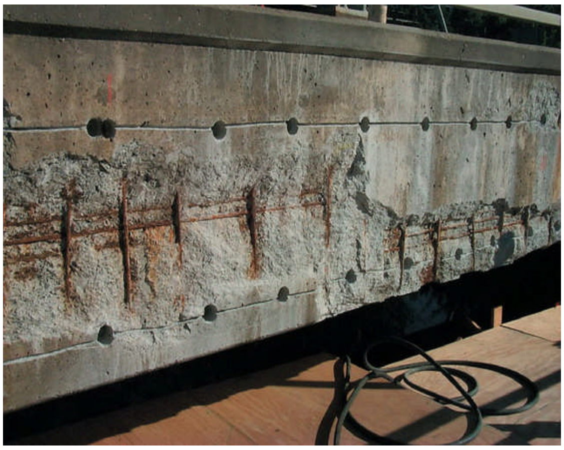


Drill holes as per the dimensions listed above to accommodate the anodes. Presoak the units for a minimum of 10 to a maximum of 30 minutes in a shallow water bath. Galvashield Embedding Mortar Embedding mortar should be wet cured or cured with a curing compound and protected from traffic for 24 hours. Place the mixed embedding mortar into the bottom ⅔ of each hole and slowly press in the unit allowing the mortar to fill the annular space ensuring there are no air voids between the unit and the parent concrete. The minimum unit cover depth shall be ¾ in. (20 mm). Place wires into grooves and top off unit holes and saw cuts flush to the concrete surface with embedding mortar.

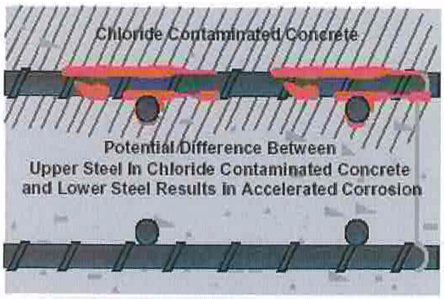
PLUG-TYPE ANODES



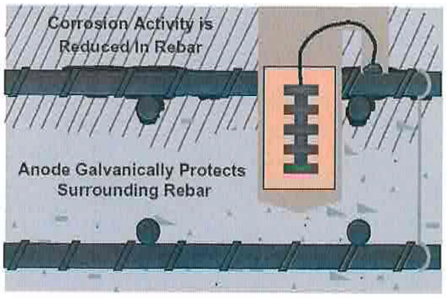
Placement of Galvashield® CC in concrete beam



A standard tie wire will work, if there is continuity to start with. If there is none you will need to weld either a heavy gage wire #1 or a piece of rebar between the mats.



Cloride contamination causes corrosion in reinforced concrete



Galvashield CC mitigates active corrosion

Tables 5.0, 6.0, 7.0

Design Criteria

Standard Units

Unit Type	Description	Unit Size diameter x length	Minimum Hole Size diameter x depth
Galvashield CC65	Standard unit for moderate steel density	1 ¾ x 2 ½ in. (46 x 62 mm)	2 x 3 ¾ in. (50 x 95 mm)
Galvashield CC100	Larger unit for higher steel density	1 ¾ x 4 in. (46 x 100 mm)	2 x 5 ⅛ in. (50 x 130 mm)
Galvashield CC135	Slim-fit for congested reinforcement	1 ⅛ x 5 ⅜ in. (29 x 135 mm)	1 ¼ x 6 ½ in. (32 x 165 mm)

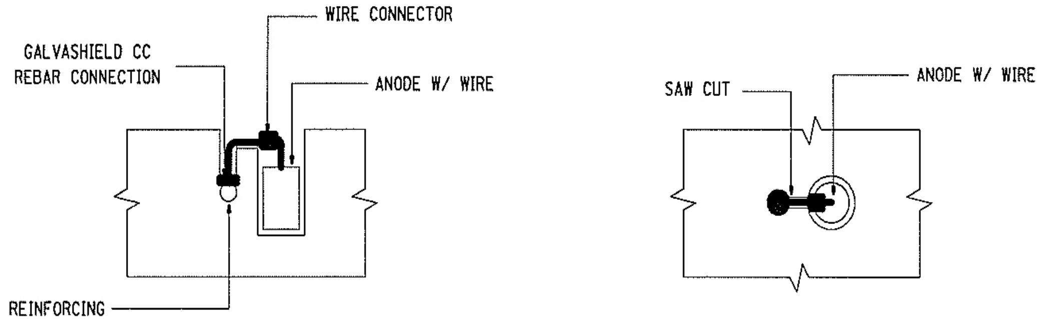
Galvashield CC65 and CC135

Steel density ratio (steel surface area/concrete surface area)	Maximum grid dimensions* in. (mm)
< 0.2	28 in. (700 mm)
0.21 - 0.4	24 in. (600 mm)
0.41 - 0.54	20 in. (500 mm)
0.55 - 0.67	18 in. (450 mm)
0.68 - 0.80	16 in. (400 mm)
0.81 - 0.94	15 in. (380 mm)
0.95 - 1.07	14 in. (355 mm)
1.08 - 1.2	13 in. (335 mm)

Galvashield CC100

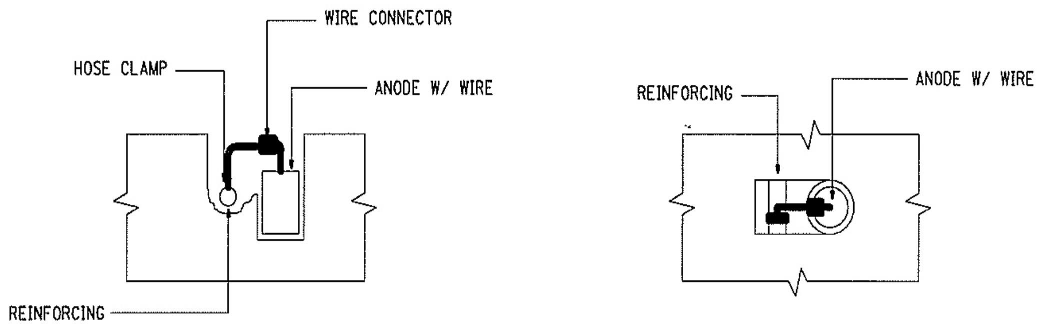
Steel density ratio (steel surface area/concrete surface area)	Maximum grid dimensions* in. (mm)
0.55 - 0.94	20 in. (500 mm)
0.95 - 1.17	18 in. (450 mm)
1.18 - 1.41	16 in. (400 mm)
1.42 - 1.64	15 in. (380 mm)
1.65 - 1.88	14 in. (355 mm)
1.89 - 2.11	13 in. (335 mm)

*Maximum grid dimensions are based on typical conditions. Spacing should be reduced as appropriate for severe environments or to extend the expected service life of the anode.



TYPICAL REINFORCING CONNECTION IN DRILLED HOLE

N.T.S.



TYPICAL REINFORCING CONNECTION IN CONCRETE EXCAVATION

N.T.S.

PRESTRESS CONCRETE REPAIR

NOTES

1. DRILL OR CHIP HOLE FOR REINFORCING CONNECTION.
2. DRILL HOLE FOR ANODE PLACEMENT. REFER TO GALVASHIELD CC DATA SHEET FOR MAXIMUM SPACING GUIDELINES.
3. MAKE SAW CUT FOR WIRE CONNECTION AS REQUIRED.
4. CONNECT WIRE LEAD TO REINFORCING STEEL WITH HOSE CLAMP OR EXPANSION GALVASHIELD CC REBAR CONNECTION KIT.
5. ENSURE ALL CONNECTIONS OF DISSIMILAR METALS ARE COATED WITH SILICONE OR EPOXY TO PREVENT CORROSION.
6. INSTALL ANODE AND GROUT IN HOLES AND SAW CUT. ANY REPAIR MATERIAL USED SHALL NOT BE EPOXY BASED.

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. | B.I.N. | COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

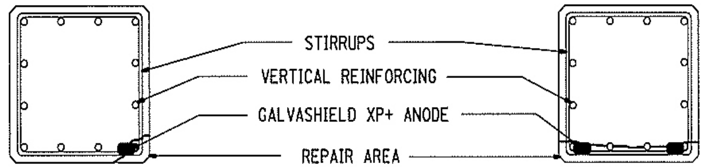
SIGNATURE | DATE

GALVASHIELD CC
INSTALLATION DETAILS

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

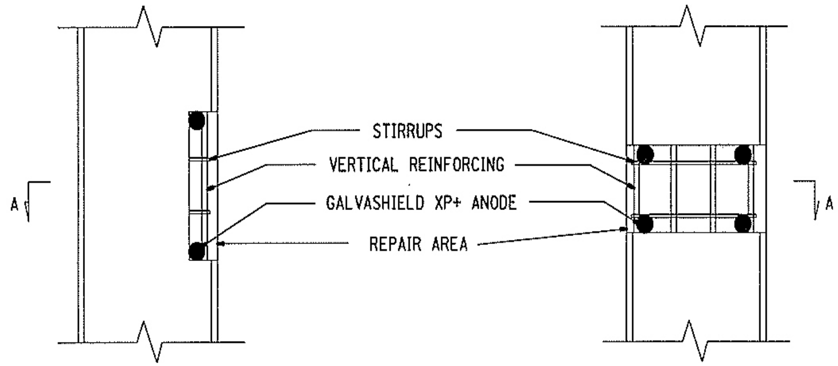
REGION | DATE | DRAWING NO.

DESIGN SUPERVISOR | JOB MANAGER | DESIGNED BY | CHECKED BY | ESTIMATED BY | DRAFTED BY | CHECKED BY



SECTION A-A - CORNER & FACE REPAIRS

N.T.S.



ELEVATION OF CORNER & FACE REPAIRS

N.T.S.

COLUMN REPAIR

NOTES

1. REMOVED DAMAGED CONCRETE AS WITH STANDARD REPAIR METHODS.
2. REPLACE / CLEAN CORRODED REINFORCING STEEL.
3. ENSURE ALL EXPOSED REINFORCING STEEL IS SECURELY FASTENED TOGETHER WITH TIE WIRE TO PROVIDE GOOD CONTINUITY.
4. ATTACH GALVASHIELD XP+ ANODES TO CLEAN REINFORCING STEEL AT SPACING OUTLINED IN CONTRACT SPECIFICATION. REFER TO GALVASHIELD XP+ DATA SHEET FOR MAXIMUM SPACING GUIDELINES.
5. POUR BACK REPAIR AREA WITH MATERIAL AS PER CONTRACT SPECIFICATION. ANY REPAIR MATERIAL USED SHALL NOT BE EPOXY BASED.

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. B.I.N. COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

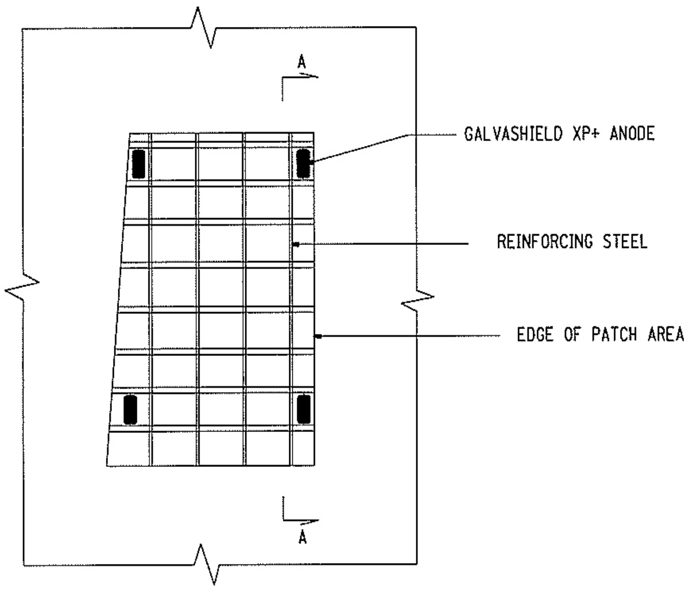
SIGNATURE DATE

GALVASHIELD XP+
INSTALLATION COLUMN REPAIR

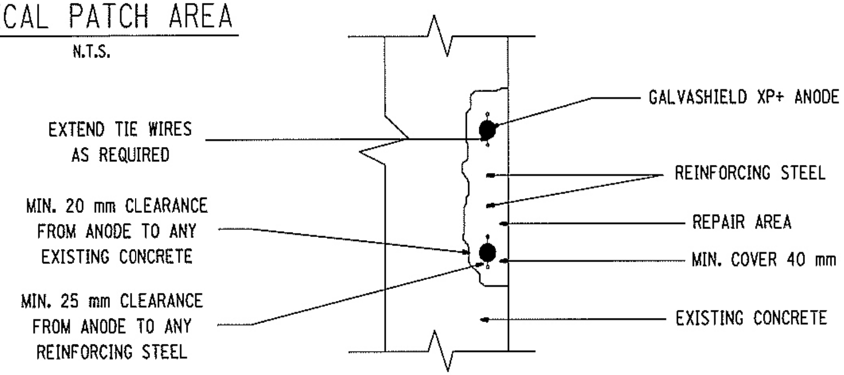
STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

REGION	DATE	DRAWING NO.

DESIGN SUPERVISOR · JOB MANAGER · DESIGNED BY · CHECKED BY · ESTIMATED BY · DRAFTED BY · CHECKED BY



TYPICAL PATCH AREA
N.T.S.



SECTION A-A
N.T.S.

SHOTCRETE REPAIR

NOTES

1. REMOVED DAMAGED CONCRETE AS WITH STANDARD REPAIR METHODS.
2. REPLACE / CLEAN CORRODED REINFORCING STEEL.
3. ENSURE ALL EXPOSED REINFORCING STEEL IS SECURELY FASTENED TOGETHER WITH TIE WIRE TO PROVIDE GOOD CONTINUITY.
4. ATTACH GALVASHIELD XP+ ANODES TO CLEAN REINFORCING STEEL AT SPACING OUTLINED IN CONTRACT SPECIFICATION. REFER TO GALVASHIELD XP+ DATA SHEET FOR MAXIMUM SPACING GUIDELINES. ATTACH EACH END OF GALVASHIELD XP+ ANODE TO ADJACENT PARALLEL REINFORCING STEEL BARS ON EDGE TO PROVIDE MINIMUM SHADOW AREA FOR SHOTCRETING. EXTEND TIE WIRES WITH REBAR WIRE AS REQUIRED. ENSURE MINIMUM SPACING OF 25 mm BETWEEN ANODES AND ANY REINFORCING STEEL, MINIMUM SPACING OF 20 mm BETWEEN ANODES AND ANY EXISTING CONCRETE AND PROVIDE A MINIMUM OF 40 mm CONCRETE COVER.
5. POUR BACK REPAIR AREA WITH SHOTCRETE AS PER CONTRACT SPECIFICATION. ANY REPAIR MATERIAL USED SHALL NOT BE EPOXY BASED.

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. | B.I.N. | COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

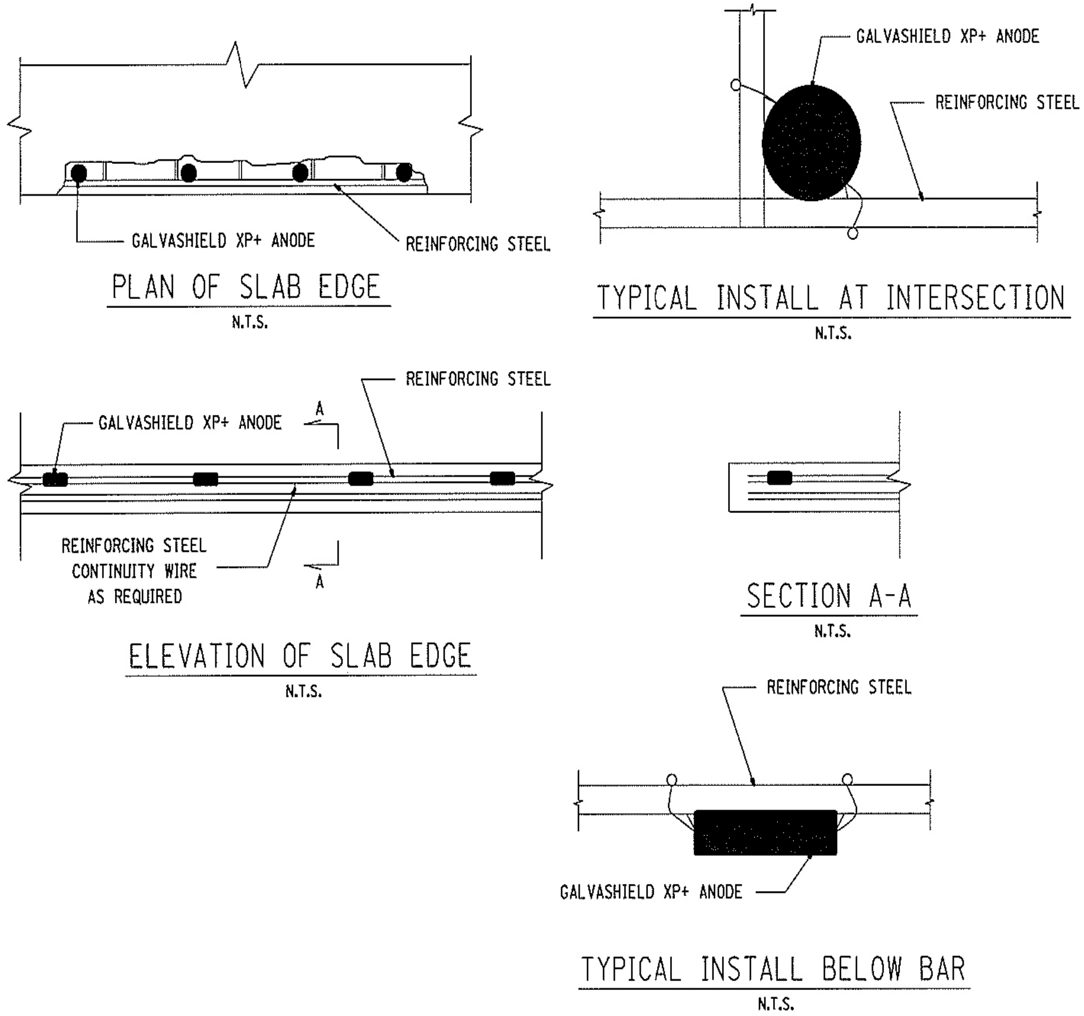
SIGNATURE | DATE

GALVASHIELD XP+
INSTALLATION SHOTCRETE REPAIR

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

REGION | DATE | DRAWING NO.

DESIGN SUPERVISOR | JOB MANAGER | DESIGNED BY | CHECKED BY | ESTIMATED BY | DRAFTED BY | CHECKED BY



SLAB EDGE REPAIR

NOTES

1. REMOVED DAMAGED CONCRETE AS WITH STANDARD REPAIR METHODS.
2. REPLACE / CLEAN CORRODED REINFORCING STEEL.
3. ENSURE ALL EXPOSED REINFORCING STEEL IS SECURELY FASTENED TOGETHER WITH TIE WIRE TO PROVIDE GOOD CONTINUITY.
4. ATTACH GALVASHIELD XP+ ANODES TO CLEAN REINFORCING STEEL AT SPACING OUTLINED IN CONTRACT SPECIFICATION. REFER TO GALVASHIELD XP+ DATA SHEET FOR MAXIMUM SPACING GUIDELINES.
5. POUR BACK REPAIR AREA WITH REPAIR MATERIAL AS PER CONTRACT SPECIFICATION. ANY REPAIR MATERIAL USED SHALL NOT BE EPOXY BASED.

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. | B.I.N. | COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

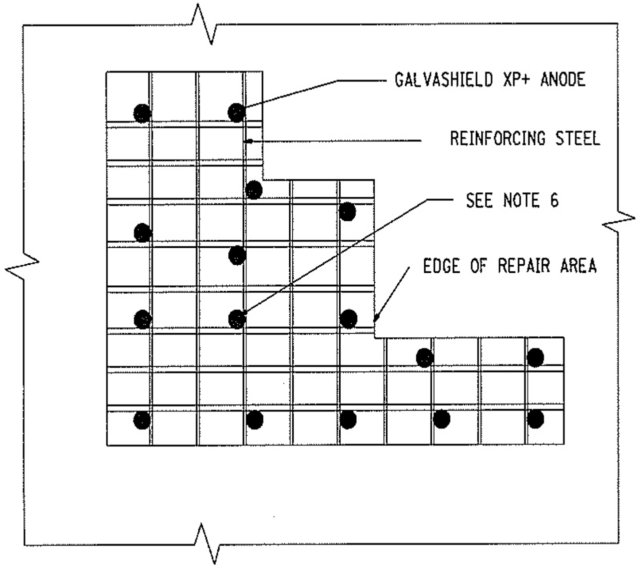
SIGNATURE | DATE

GALVASHIELD XP+
SPECIFICATION SLAB EDGE REPAIR

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

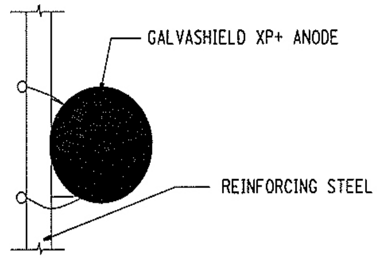
REGION | DATE | DRAWING NO.

DESIGN SUPERVISOR | JOB MANAGER | DESIGNED BY | CHECKED BY | ESTIMATED BY | DRAFTED BY | CHECKED BY



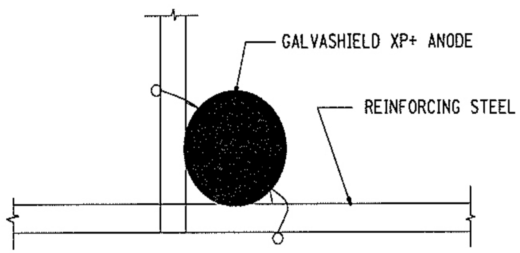
TYPICAL LAYOUT FOR SLAB REPAIR

N.T.S.



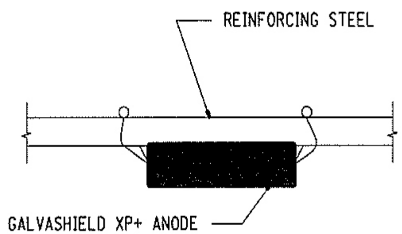
TYPICAL INSTALL BESIDE BAR

N.T.S.



TYPICAL INSTALL AT INTERSECTION

N.T.S.



TYPICAL INSTALL BELOW BAR

N.T.S.

NOTES

1. REMOVED DAMAGED CONCRETE AS WITH STANDARD REPAIR METHODS.
2. REPLACE / CLEAN CORRODED REINFORCING STEEL.
3. ENSURE ALL EXPOSED REINFORCING STEEL IS SECURELY FASTENED TOGETHER WITH TIE WIRE TO PROVIDE GOOD CONTINUITY.
4. ATTACH GALVASHIELD XP+ ANODES TO CLEAN REINFORCING STEEL AT AN EVEN SPACING WITHIN THE PATCH AREA OR AS OUTLINED IN THE CONTRACT SPECIFICATION. REFER TO GALVASHIELD XP+ DATA SHEET FOR MAXIMUM SPACING GUIDELINES.
5. POUR BACK REPAIR AREA WITH REPAIR MATERIAL AS PER CONTRACT SPECIFICATION. ANY MATERIAL USED SHALL NOT BE EPOXY BASED.
6. GALVASHIELD XP+ ANODES ARE GENERALLY ONLY INSTALLED ALONG THE PERIMETER OF THE REPAIR AREA WHERE ALL CHLORIDE CONTAMINATED CONCRETE HAS BEEN REMOVED. GALVASHIELD XP+ ANODES SHOULD BE PLACED ON A GRID PATTERN WITHIN THE INTERIOR OF THE REPAIR AREA WHEN CHLORIDE CONTAMINATED CONCRETE EXISTS IN CONTRACT WITH THE REINFORCING STEEL.

SLAB PATCH REPAIR

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. | B.I.N. | COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

SIGNATURE | DATE

GALVASHIELD XP+
INSTALLATION SLAB PATCH REPAIR

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

REGION | DATE | DRAWING NO.

DESIGN SUPERVISOR | JOB MANAGER | DESIGNED BY | CHECKED BY | ESTIMATED BY | DRAFTED BY | CHECKED BY

Compatible Repair Materials

GALVANIC SYSTEMS

When incorporating galvanic corrosion protection systems into your rehabilitation plans, it is important that compatible repair materials and bonding agents be used. This list contains proprietary materials that are believed to be suitable for use with galvanic systems, it is not intended to be an exclusive list of approved materials.

Product	*Manufacturer*
C 1107 Grout	Bonsal
C 928 Repair Mortar	Bonsal
Commercial Anchor Cement	Bonsal
Fast Set Cement Mix	Bonsal
Poly-Mod Repair Mortar	Bonsal
Rapid Patch VR	Bonsal
Vinyl Concrete Patch	Bonsal
Forment	Conproco
Set	Conproco
Deep Pour EX	BASF Building Systems
LA40	BASF Building Systems
R310	BASF Building Systems
Five Star Construction Grout	Five Star Products
Five Star Grout	Five Star Products
FX 228	Fox
FX 263	Fox
FX 70-8	Fox
FX 70-8 DP	Fox
FX-225	Gemite
F80 Rocket Patch	Gemite
Control	Gemite
CP01	JE Tomes and Associates
CP02	JE Tomes and Associates
CT40	JE Tomes and Associates
CT40L	JE Tomes and Associates
Formflo CT-60	JE Tomes and Associates
Formflo X15	JE Tomes and Associates
Latex Liquid Mortar	King Package Materials
P38	King Package Materials
F.A. Concrete Repair	Sika Corporation
FA-S10	Sika Corporation
SikaSet Roadway Patch 2000	Sika Corporation
Sika Grout 212	Sika Corporation
Sika Grout 300 PT	Sika Corporation
Sika Quick 1000	Sika Corporation
Sika Quick 2500	Sika Corporation
Sika Repair 222 w/water	Sika Corporation
Sika Repair 223 w/water	Sika Corporation
Sikacrete 211	Sika Corporation
SikaShot NS	Sika Corporation
Sika Grout 328	Sika Corporation

Compatible Repair Materials
for Use with Sentinel-GL Anodes

Product	Supplier
Eucocrete	Euclid Chemical Co.
Eucopatch	Euclid Chemical Co.
Form & Pour CP	Euclid Chemical Co.
ThinTop Supreme	Euclid Chemical Co.
ConcreteTop Supreme	Euclid Chemical Co.
Euco Verticoat	Euclid Chemical Co.
EucoShot-LR	Euclid Chemical Co.
Corr-Bond	Euclid Chemical Co.
Express Repair	Tamms
Spray Mortar	Tamms
SpeedCrete PM	Tamms
SpeedCrete Redline	Tamms
SikaRepair 222	Sika Corp.
SikaRepair 223	Sika Corp.
MasterFlow 713	Master Builders (BASF)
MasterFlow 928	Master Builders (BASF)
MasterPatch 230VP	Master Builders (BASF)
MasterPatch 240CR	Master Builders (BASF)
Powermix Patch	Power Crete
PowerGrout P	Power Crete
Polyfast LPL	Dayton Superior
Re-Crete 20	Dayton Superior

Appendix

Tables for determining spacing for Sentinel-GL anodes for No. 5, No. 6 and No. 7 reinforcement bars.

No. 5 bars																						
		Spacing (in)																				
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	5	*0.79*	*0.72*	*0.67*	*0.64*	*0.61*	*0.59*	*0.57*	*0.56*	*0.54*	*0.53*	*0.52*	*0.52*	*0.51*	*0.50*	*0.50*	0.49	0.49	0.48	0.48	0.47	0.47
	6	*0.72*	*0.65*	*0.61*	*0.57*	*0.55*	*0.52*	*0.51*	0.49	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.42	0.42	0.41	0.41	0.41
	7	*0.67*	*0.61*	*0.56*	*0.53*	*0.50*	0.48	0.46	0.44	0.43	0.42	0.41	0.40	0.40	0.39	0.38	0.38	0.37	0.37	0.37	0.36	0.36
	8	*0.64*	*0.57*	*0.53*	0.49	0.46	0.44	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33	0.33	0.32
S	9	*0.61*	*0.55*	*0.50*	0.46	0.44	0.41	0.40	0.38	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.30
p	10	*0.59*	*0.52*	0.48	0.44	0.41	0.39	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.29	0.28	0.28	0.27
a	11	*0.57*	*0.51*	0.46	0.42	0.40	0.37	0.36	0.34	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.26
c	12	*0.56*	0.49	0.44	0.41	0.38	0.36	0.34	0.33	0.31	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.24
i	13	*0.54*	0.48	0.43	0.40	0.37	0.35	0.33	0.31	0.30	0.29	0.28	0.27	0.27	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.23
n	14	*0.53*	0.47	0.42	0.39	0.36	0.34	0.32	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22
g	15	*0.52*	0.46	0.41	0.38	0.35	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21
(in)	16	*0.52*	0.45	0.40	0.37	0.34	0.32	0.30	0.29	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.20	0.20
	17	*0.51*	0.44	0.40	0.36	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19
	18	*0.50*	0.44	0.39	0.35	0.33	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19
	19	*0.50*	0.43	0.38	0.35	0.32	0.30	0.28	0.27	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19	0.18
	20	0.49	0.43	0.38	0.34	0.32	0.29	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18
	21	0.49	0.42	0.37	0.34	0.31	0.29	0.27	0.26	0.24	0.23	0.22	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18	0.17
	22	0.48	0.42	0.37	0.33	0.31	0.29	0.27	0.25	0.24	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17
	23	0.48	0.41	0.37	0.33	0.30	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17	0.16
	24	0.47	0.41	0.36	0.33	0.30	0.28	0.26	0.25	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16
	25	0.47	0.41	0.36	0.32	0.30	0.27	0.26	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.16

Tabulated values represent steel density ratios

Heavy
Moderate
Light

No. 6 bars

Spacing (in)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	*0.94*	*0.86*	*0.81*	*0.77*	*0.73*	*0.71*	*0.69*	*0.67*	*0.65*	*0.64*	*0.63*	*0.62*	*0.61*	*0.60*	*0.60*	*0.59*	*0.58*	*0.58*	*0.57*	*0.57*	*0.57*
6	*0.86*	*0.79*	*0.73*	*0.69*	*0.65*	*0.63*	*0.61*	*0.59*	*0.57*	*0.56*	*0.55*	*0.54*	*0.53*	*0.52*	*0.52*	*0.51*	*0.50*	*0.50*	*0.50*	0.49	0.49
7	*0.81*	*0.73*	*0.67*	*0.63*	*0.60*	*0.57*	*0.55*	*0.53*	*0.52*	*0.50*	0.49	0.48	0.48	0.47	0.46	0.45	0.45	0.44	0.44	0.43	0.43
8	*0.77*	*0.69*	*0.63*	*0.59*	*0.56*	*0.53*	*0.51*	0.49	0.48	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.40	0.40	0.39	0.39
9	*0.73*	*0.65*	*0.60*	*0.56*	*0.52*	*0.50*	0.48	0.46	0.44	0.43	0.42	0.41	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.36	0.36
10	*0.71*	*0.63*	*0.57*	*0.53*	*0.50*	0.47	0.45	0.43	0.42	0.40	0.39	0.38	0.37	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33
11	*0.69*	*0.61*	*0.55*	*0.51*	0.48	0.45	0.43	0.41	0.40	0.38	0.37	0.36	0.35	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31
12	*0.67*	*0.59*	*0.53*	0.49	0.46	0.43	0.41	0.39	0.38	0.36	0.35	0.34	0.33	0.33	0.32	0.31	0.31	0.30	0.30	0.29	0.29
13	*0.65*	*0.57*	*0.52*	0.48	0.44	0.42	0.40	0.38	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.28	0.28	0.28
14	*0.64*	*0.56*	*0.50*	0.46	0.43	0.40	0.38	0.36	0.35	0.34	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.26
15	*0.63*	*0.55*	0.49	0.45	0.42	0.39	0.37	0.35	0.34	0.33	0.31	0.30	0.30	0.29	0.28	0.27	0.27	0.26	0.26	0.26	0.25
16	*0.62*	*0.54*	0.48	0.44	0.41	0.38	0.36	0.34	0.33	0.32	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.25	0.25	0.25	0.24
17	*0.61*	*0.53*	0.48	0.43	0.40	0.37	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.23
18	*0.60*	*0.52*	0.47	0.43	0.39	0.37	0.35	0.33	0.31	0.30	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23
19	*0.60*	*0.52*	0.46	0.42	0.39	0.36	0.34	0.32	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.22	0.22
20	*0.59*	*0.51*	0.45	0.41	0.38	0.35	0.33	0.31	0.30	0.29	0.27	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22	0.22	0.21
21	*0.58*	*0.50*	0.45	0.41	0.37	0.35	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22	0.21	0.21	0.21
22	*0.58*	*0.50*	0.44	0.40	0.37	0.34	0.32	0.30	0.29	0.28	0.26	0.25	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.21	0.20
23	*0.57*	*0.50*	0.44	0.40	0.36	0.34	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.20
24	*0.57*	0.49	0.43	0.39	0.36	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.19
25	*0.57*	0.49	0.43	0.39	0.36	0.33	0.31	0.29	0.28	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19

No. 7 bars

Spacing (in)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	**1.10**	**1.01**	*0.94*	*0.89*	*0.86*	*0.82*	*0.80*	*0.78*	*0.76*	*0.75*	*0.73*	*0.72*	*0.71*	*0.70*	*0.69*	*0.69*	*0.68*	*0.67*	*0.67*	*0.66*	*0.66*
6	**1.01**	*0.92*	*0.85*	*0.80*	*0.76*	*0.73*	*0.71*	*0.69*	*0.67*	*0.65*	*0.64*	*0.63*	*0.62*	*0.61*	*0.60*	*0.60*	*0.59*	*0.58*	*0.58*	*0.57*	*0.57*
7	*0.94*	*0.85*	*0.79*	*0.74*	*0.70*	*0.67*	*0.64*	*0.62*	*0.60*	*0.59*	*0.58*	*0.56*	*0.55*	*0.55*	*0.54*	*0.53*	*0.52*	*0.52*	*0.51*	*0.51*	*0.50*
8	*0.89*	*0.80*	*0.74*	*0.69*	*0.65*	*0.62*	*0.59*	*0.57*	*0.56*	*0.54*	*0.53*	*0.52*	*0.51*	*0.50*	0.49	0.48	0.47	0.47	0.46	0.46	0.45
9	*0.86*	*0.76*	*0.70*	*0.65*	*0.61*	*0.58*	*0.56*	*0.53*	*0.52*	*0.50*	0.49	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.42	0.42	0.42
10	*0.82*	*0.73*	*0.67*	*0.62*	*0.58*	*0.55*	*0.52*	*0.50*	0.49	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.41	0.40	0.39	0.39	0.38
11	*0.80*	*0.71*	*0.64*	*0.59*	*0.56*	*0.52*	*0.50*	0.48	0.46	0.45	0.43	0.42	0.41	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.36
12	*0.78*	*0.69*	*0.62*	*0.57*	*0.53*	*0.50*	0.48	0.46	0.44	0.43	0.41	0.40	0.39	0.38	0.37	0.37	0.36	0.35	0.35	0.34	0.34
13	*0.76*	*0.67*	*0.60*	*0.56*	*0.52*	0.49	0.46	0.44	0.42	0.41	0.39	0.38	0.37	0.36	0.36	0.35	0.34	0.34	0.33	0.33	0.32
14	*0.75*	*0.65*	*0.59*	*0.54*	*0.50*	0.47	0.45	0.43	0.41	0.39	0.38	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31
15	*0.73*	*0.64*	*0.58*	*0.53*	0.49	0.46	0.43	0.41	0.39	0.38	0.37	0.36	0.34	0.34	0.33	0.32	0.31	0.31	0.30	0.30	0.29
16	*0.72*	*0.63*	*0.56*	*0.52*	0.48	0.45	0.42	0.40	0.38	0.37	0.36	0.34	0.33	0.32	0.32	0.31	0.30	0.30	0.29	0.29	0.28
17	*0.71*	*0.62*	*0.55*	*0.51*	0.47	0.44	0.41	0.39	0.37	0.36	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.28	0.28	0.27
18	*0.70*	*0.61*	*0.55*	*0.50*	0.46	0.43	0.40	0.38	0.36	0.35	0.34	0.32	0.31	0.31	0.30	0.29	0.28	0.28	0.27	0.27	0.26
19	*0.69*	*0.60*	*0.54*	0.49	0.45	0.42	0.39	0.37	0.36	0.34	0.33	0.32	0.31	0.30	0.29	0.28	0.28	0.27	0.26	0.26	0.25
20	*0.69*	*0.60*	*0.53*	0.48	0.44	0.41	0.39	0.37	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25
21	*0.68*	*0.59*	*0.52*	0.47	0.44	0.41	0.38	0.36	0.34	0.33	0.31	0.30	0.29	0.28	0.28	0.27	0.26	0.26	0.25	0.25	0.24
22	*0.67*	*0.58*	*0.52*	0.47	0.43	0.40	0.37	0.35	0.34	0.32	0.31	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23
23	*0.67*	*0.58*	*0.51*	0.46	0.42	0.39	0.37	0.35	0.33	0.32	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.23
24	*0.66*	*0.57*	*0.51*	0.46	0.42	0.39	0.36	0.34	0.33	0.31	0.30	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22
25	*0.66*	*0.57*	*0.50*	0.45	0.42	0.38	0.36	0.34	0.32	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22

Tabulated values represent steel density ratios

Heavy
Moderate
Light