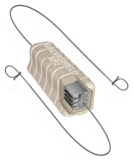
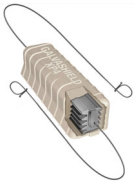
1

Galvanic Anode Sizing and Spacing





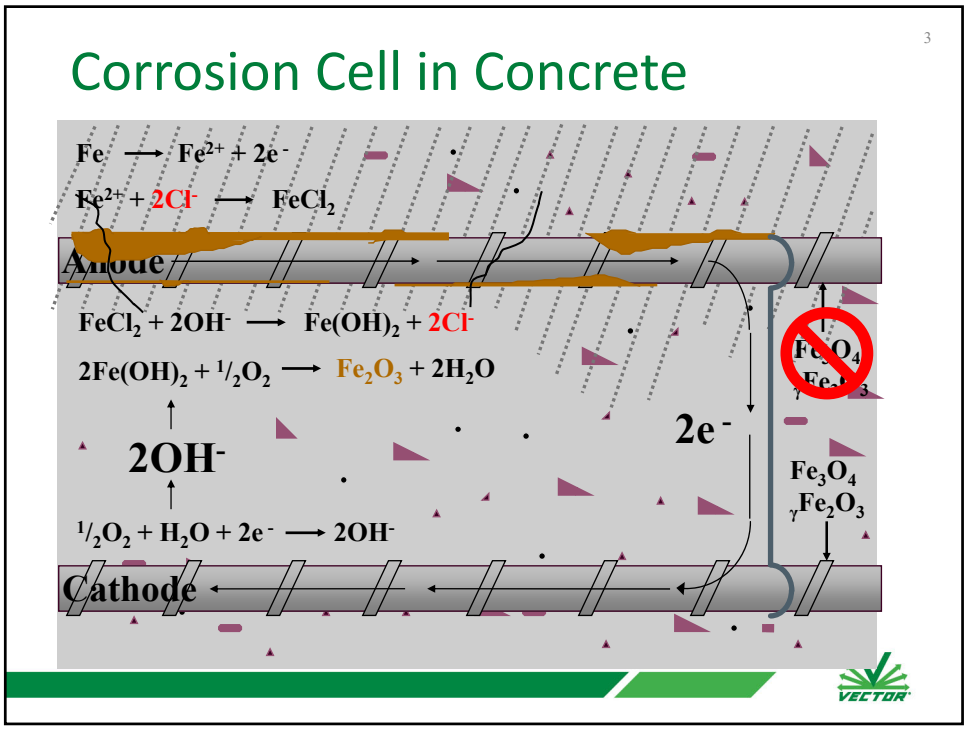
Erik Thorp
Vector Corrosion Technologies
erikt@vector-corrosion.com

1

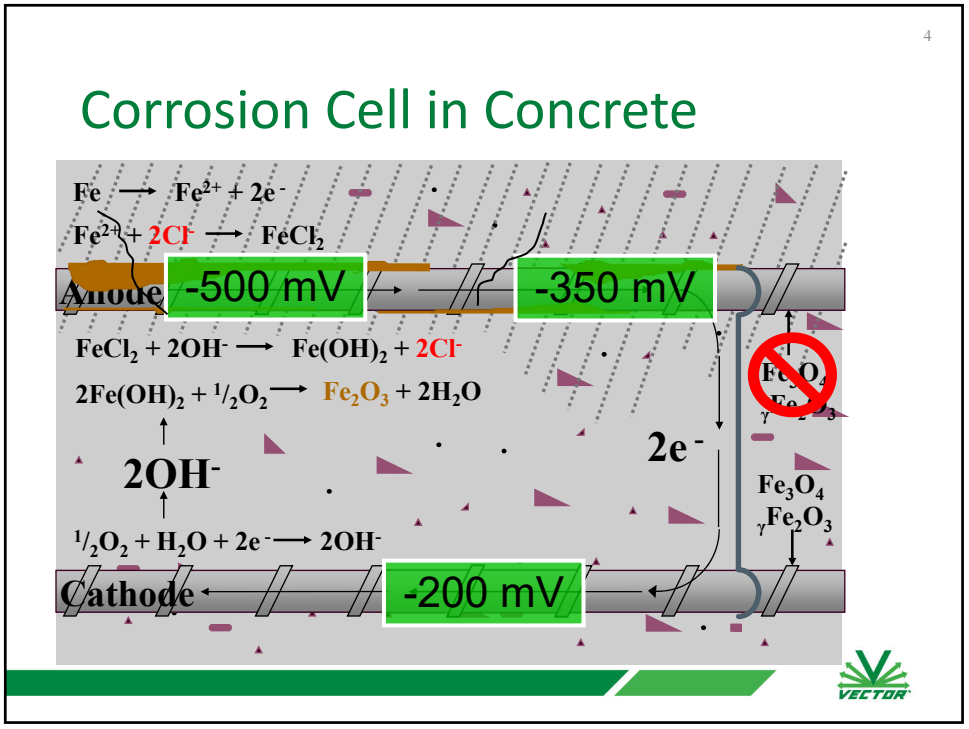
2

Anode Basics

2


3
Corrosion Cell in Concrete
Fe → Fe2+ + 2e-
Fe2+ + 2Cl- → FeCl2
Anode
FeCl2 + 2OH- → Fe(OH)2 + 2Cl-
2Fe(OH)2 + 1/2O2 → Fe2O3 + 2H2O
2OH-
2e-
Fe3O4
γFe2O3
1/2O2 + H2O + 2e- → 2OH-
Cathode
VECTOR

3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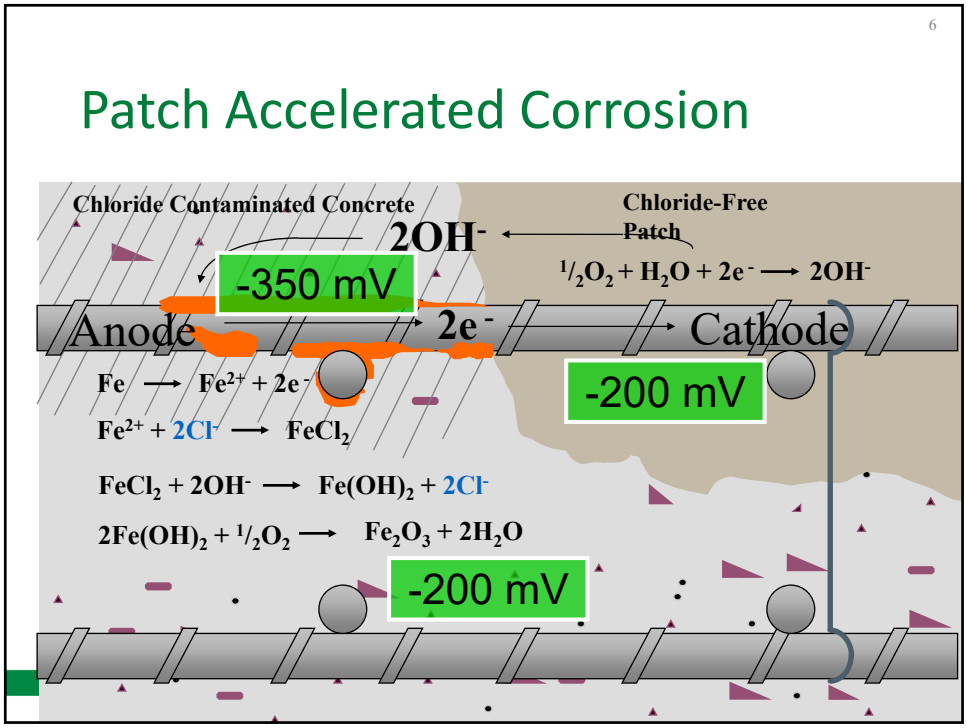
Corrosion Cell in Concrete
Fe → Fe2+ + 2e-
Fe2+ + 2Cl- → FeCl2
Anode
-500 mV
-350 mV
FeCl2 + 2OH- → Fe(OH)2 + 2Cl-
2Fe(OH)2 + 1/2O2 → Fe2O3 + 2H2O
2OH-
2e-
Fe3O4
γFe2O3
1/2O2 + H2O + 2e- → 2OH-
Cathode
-200 mV
VECTOR

4


5
"Chip and Patch" Repair Method

5


6
Patch Accelerated Corrosion
Chloride Contaminated Concrete
Chloride-Free Patch
2OH-
-350 mV
½O2 + H2O + 2e- → 2OH-
Anode
2e-
Cathode
-200 mV
Fe → Fe2+ + 2e-
Fe2+ + 2Cl- → FeCl2
FeCl2 + 2OH- → Fe(OH)2 + 2Cl-
2Fe(OH)2 + ½O2 → Fe2O3 + 2H2O
-200 mV

6

7

8

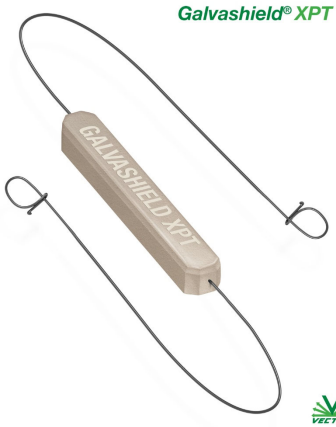
9

Halo Effect

9

10

Type 1 Galvanic Anodes



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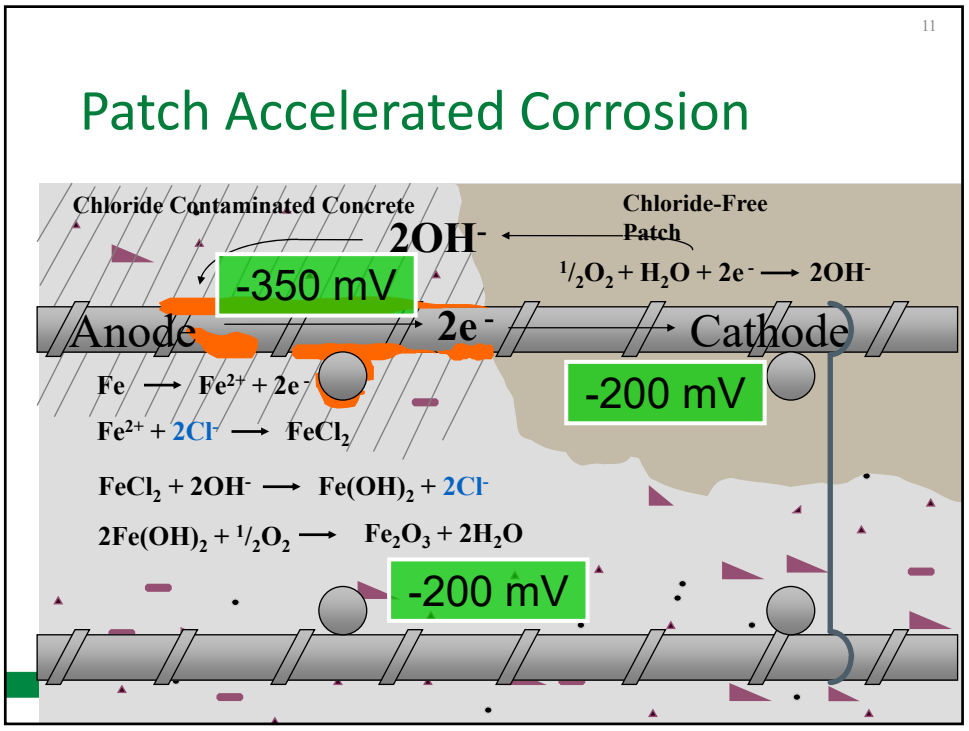
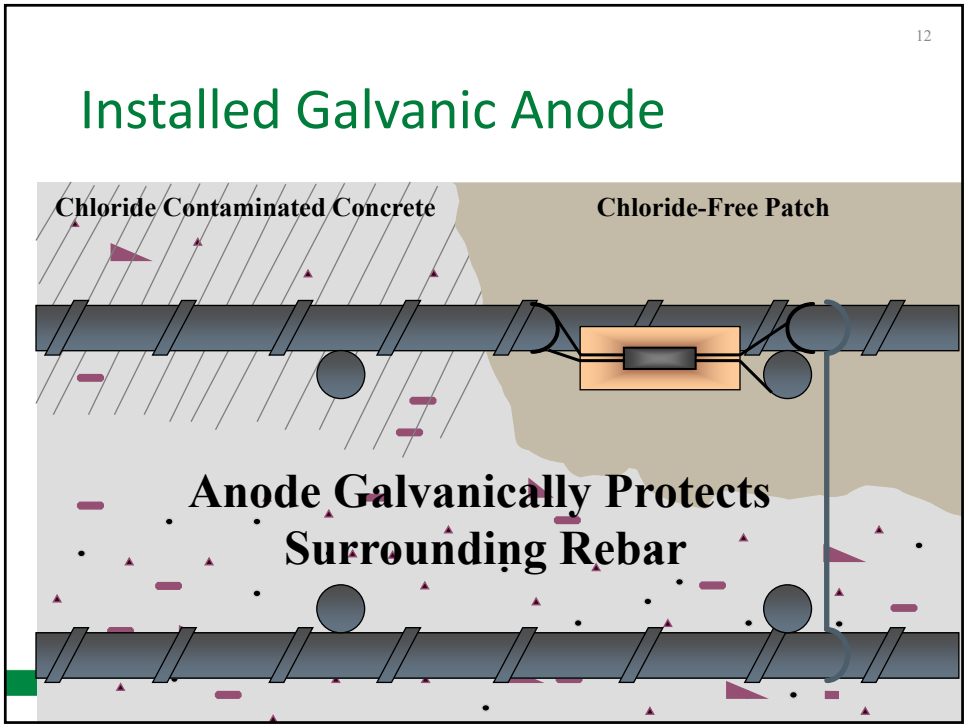

11
Patch Accelerated Corrosion
Chloride Contaminated Concrete
Chloride-Free Patch
2OH-
-350 mV
1/2O2 + H2O + 2e- → 2OH-
Anode
2e-
Cathode
-200 mV
Fe → Fe2+ + 2e-
Fe2+ + 2Cl- → FeCl2
FeCl2 + 2OH- → Fe(OH)2 + 2Cl-
2Fe(OH)2 + 1/2O2 → Fe2O3 + 2H2O
-200 mV

11


12
Installed Galvanic Anode
Chloride Contaminated Concrete
Chloride-Free Patch
Anode Galvanically Protects
Surrounding Rebar

12

13

Design Questions

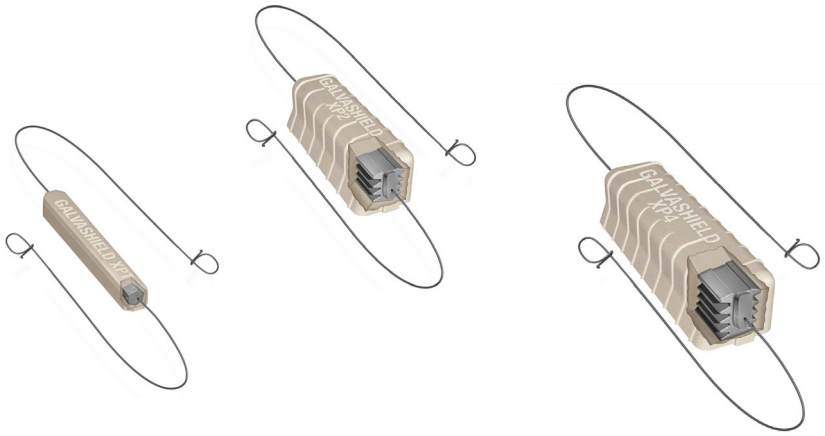
Which anode?

Spacing?

13

14

Galvashield® XP Product Range



14

15

Anode Spacing* for Low to Moderate Corrosion Risk (Chloride Content < 0.8% or Carbonated Concrete)

Protection Level	Corrosion Prevention						Corrosion Control			
Galvashield® Anode	XPT/XPC**		XP2		XP4		XP2		XP4	
Steel Density Ratio	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
<0.3	750	30	750	30	750	30	600	24	750	30
0.31 - 0.6	600	24	700	28	750	30	500	20	700	28
0.61 - 0.9	500	20	650	26	750	30	400	16	550	22
0.91 - 1.2	450	18	550	22	750	30	350	14	450	18
1.21 - 1.5	400	16	500	20	675	27	250	10	425	17
1.51 - 1.8	350	14	450	18	600	24	200	8	375	15
1.81 - 2.1	300	12	425	17	550	22	175	7	350	14

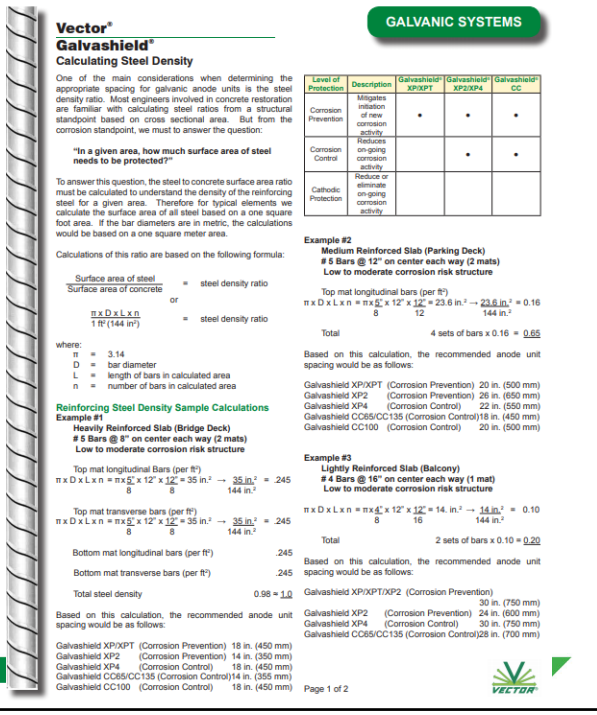
Anode Spacing* for High Corrosion Risk (Chloride Content 0.8% to 1.5%)

Protection Level	Corrosion Prevention						Corrosion Control	
Galvashield® Anode	XPT/XPC**		XP2		XP4		XP4	
Steel Density Ratio	mm	in.	mm	in.	mm	in.	mm	in.
<0.3	600	24	750	30	750	30	600	24
0.31 - 0.6	500	20	600	24	700	28	500	20
0.61 - 0.9	400	16	500	20	650	26	400	16
0.91 - 1.2	350	14	450	18	550	22	350	14
1.21 - 1.5	250	10	400	16	500	20	250	10
1.51 - 1.8	200	8	350	14	450	18	200	8
1.81 - 2.1	175	7	300	12	425	17	150	6

For extremely high corrosion risk applications (> 1.5% Chloride), contact Vector for assistance.

Note: Chloride content is based on percent by weight of cement.

15



Vector® Galvashield®

Calculating Steel Density

One of the main considerations when determining the appropriate spacing for galvanic anode units is the steel density ratio. Most engineers involved in concrete restoration are familiar with calculating steel ratios from a structural standpoint based on cross sectional area. But from the corrosion standpoint, we must to answer the question:

"In a given area, how much surface area of steel needs to be protected?"

To answer this question, the steel to concrete surface area ratio must be calculated to understand the density of the reinforcing steel for a given area. Therefore for typical elements we calculate the surface area of all steel based on a one square foot area. If the bar diameters are in metric, the calculations would be based on a one square meter area.

Calculations of this ratio are based on the following formula:

$$\frac{\text{Surface area of steel}}{\text{Surface area of concrete}} = \text{steel density ratio}$$

or

$$\frac{\pi \times D \times L \times n}{1\ ft^2\ (144\ in^2)} = \text{steel density ratio}$$

where:
- π = 3.14
- D = bar diameter
- L = length of bars in calculated area
- n = number of bars in calculated area

Reinforcing Steel Density Sample Calculations

Example #1
Heavily Reinforced Slab (Bridge Deck)
 # 5 Bars @ 8" on center each way (2 mats)
Low to moderate corrosion risk structure

Top mat longitudinal Bars (per ft²)

$\pi \times D \times L \times n = \pi \times \frac{5}{8}" \times 12" \times \frac{12"}{8} = 35\ in.^2 \rightarrow \frac{35\ in.^2}{144\ in.^2} = .245$

Top mat transverse bars (per ft²)

$\pi \times D \times L \times n = \pi \times \frac{5}{8}" \times 12" \times \frac{12"}{8} = 35\ in.^2 \rightarrow \frac{35\ in.^2}{144\ in.^2} = .245$

Bottom mat longitudinal bars (per ft²) .245

Bottom mat transverse bars (per ft²) .245

Total steel density 0.98 = 1.0

Based on this calculation, the recommended anode unit spacing would be as follows:

Galvashield XP/XPT (Corrosion Prevention) 18 in. (450 mm)
Galvashield XP2 (Corrosion Prevention) 14 in. (350 mm)
Galvashield XP4 (Corrosion Control) 18 in. (450 mm)
Galvashield CC65/CC135 (Corrosion Control) 14 in. (355 mm)
Galvashield CC100 (Corrosion Control) 18 in. (450 mm)

GALVANIC SYSTEMS

Level of Protection	Description	Galvashield® XP/XPT	Galvashield® XP2/XP4	Galvashield® CC
Corrosion Prevention	Mitigates initiation of new corrosion activity	•	•	•
Corrosion Control	Reduces on-going corrosion activity		•	•
Cathodic Protection	Reduce or eliminate on-going corrosion activity			

Example #2
Medium Reinforced Slab (Parking Deck)
 # 5 Bars @ 12" on center each way (2 mats)
Low to moderate corrosion risk structure

Top mat longitudinal bars (per ft²)

$\pi \times D \times L \times n = \pi \times \frac{5}{8}" \times 12" \times \frac{12"}{12} = 23.6\ in.^2 \rightarrow \frac{23.6\ in.^2}{144\ in.^2} = 0.16$

Total 4 sets of bars x 0.16 = 0.65

Based on this calculation, the recommended anode unit spacing would be as follows:

Galvashield XP/XPT (Corrosion Prevention) 20 in. (500 mm)
Galvashield XP2 (Corrosion Prevention) 26 in. (650 mm)
Galvashield XP4 (Corrosion Control) 22 in. (550 mm)
Galvashield CC65/CC135 (Corrosion Control) 18 in. (450 mm)
Galvashield CC100 (Corrosion Control) 20 in. (500 mm)

Example #3
Lightly Reinforced Slab (Balcony)
 # 4 Bars @ 16" on center each way (1 mat)
Low to moderate corrosion risk structure

$\pi \times D \times L \times n = \pi \times \frac{4}{8}" \times 12" \times \frac{12"}{16} = 14.\ in.^2 \rightarrow \frac{14\ in.^2}{144\ in.^2} = 0.10$

Total 2 sets of bars x 0.10 = 0.20

Based on this calculation, the recommended anode unit spacing would be as follows:

Galvashield XP/XPT/XP2 (Corrosion Prevention) 30 in. (750 mm)
Galvashield XP2 (Corrosion Prevention) 24 in. (600 mm)
Galvashield XP4 (Corrosion Control) 30 in. (750 mm)
Galvashield CC65/CC135 (Corrosion Control) 28 in. (700 mm)

Page 1 of 2

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17

Anode Spacing

Based upon steel layout

Steel Density Ratio

(Surface Area)

Consider all steel within influence of anode

17

18

Steel Density Ratio

$$\frac{\text{Surface Area of Steel}}{\text{Surface Area of Concrete}} = \frac{3.14 \times L \times D \times N}{1 \text{ sq.ft (144 sq.in.)}}$$

L = Length of bars

D = Diameter of bars

N = Number of bars

18

19

Abutment

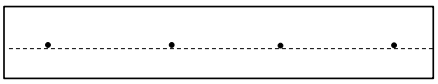
#5's at 18" on center
Horizontal and Vertical

19

20

Abutment

#5's at 18" on center
Horizontal and Vertical



3.14 x (5/8)" x 12" x 2 bars = 47 sq.in.

.

20

21

Abutment

#5's at 18" on center Horizontal and Vertical

3.14 x (5/8)" x 12" x 2 bars = 47 sq.in.

.

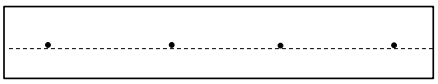
Area = 12" x 12" = 144 sq.in.

21

22

Abutment

#5's at 18" on center Horizontal and Vertical



3.14 x (5/8)" x 12" x 2 bars = 47 sq.in.

.

Area = 12" x 12" = 144 sq.in.

47 sq.in. / 144 sq.in. = .33

22

23

Abutment

#5's at 18" on center
Horizontal and Vertical

3.14 x (5/8)" x 12" x 2 bars = 47 sq.in.

.

Area = 12" x 12" = 144 sq.in.

47 sq.in. / 144 sq.in. = .33

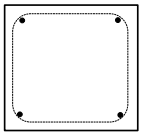
Steel Density Ratio = .33

23

24

Column

12" square column
4 x #9's
#4 ties at 12" on center



24

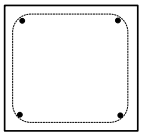
25

Column

12” square column

4 x #9’s

#4 ties at 12” on center



3.14 x (9/8)” x 12” x 4 bars = 170 sq.in.

25

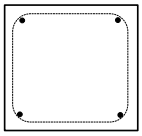
26

Column

12” square column

4 x #9’s

#4 ties at 12” on center



3.14 x (9/8)” x 12” x 4 bars = 170 sq.in.
3.14 x (4/8)” x 8” x 4 sides = 50 sq.in.

26

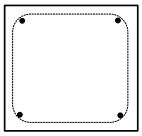
27

Column

12” square column

4 x #9’s

#4 ties at 12” on center



3.14 x (9/8)” x 12” x 4 bars = 170 sq.in.
3.14 x (4/8)” x 8” x 4 sides = 50 sq.in.

Area = 12” x 12” x 4 sides = 576 sq.in.

27

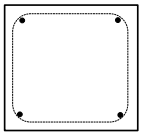
28

Column

12” square column

4 x #9’s

#4 ties at 12” on center



3.14 x (9/8)” x 12” x 4 bars = 170 sq.in.
3.14 x (4/8)” x 8” x 4 sides = 50 sq.in.

Area = 12” x 12” x 4 sides = 576 sq.in.

(170 sq.in. + 50 sq.in.) / 576 sq.in. = .38

Steel Density Ratio = .38

28

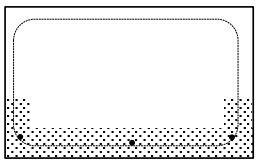
29

Bottom of Beam

18” on bottom of beam plus 6” up sides

3 x #7’s

#4 ties at 12” on center



29

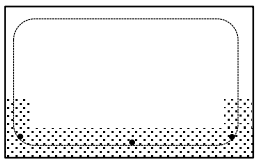
30

Bottom of Beam

18” on bottom of beam plus 6” up sides

3 x #7’s

#4 ties at 12” on center



3.14 x (7/8)” x 12” x 3 bars = 99 sq.in.

30

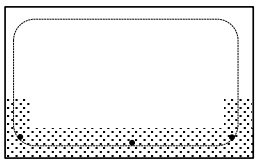
31

Bottom of Beam

18” on bottom of beam plus 6” up sides

3 x #7’s

#4 ties at 12” on center



3.14 x (7/8)” x 12” x 3 bars = 99 sq.in.
3.14 x (4/8)” x (14”+(4”x2 sides)) x (12’/12”) = 35 sq.in.

31

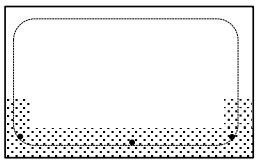
32

Bottom of Beam

18” on bottom of beam plus 6” up sides

3 x #7’s

#4 ties at 12” on center



3.14 x (7/8)” x 12” x 3 bars = 99 sq.in.
3.14 x (4/8)” x (14”+(4”x2 sides)) x (12’/12”) = 35 sq.in.

Area = (18” bottom +(6” ht. x 2)) x 12” length = 360 sq.in.

32

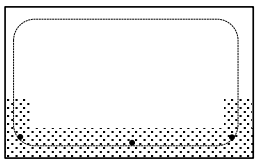
33

Bottom of Beam

18" on bottom of beam plus 6" up sides

3 x #7's

#4 ties at 12" on center



3.14 x (11/8)" x 12" x 3 bars = 155 sq.in.
3.14 x (4/8)" x (14"+(4"x2 sides)) x (12'/12") = 35 sq.in.

Area = (18" bottom +(6" ht. x 2)) x 12" length = 360 sq.in.

(99 sq.in. + 35 sq.in.) / 360 sq.in. = .37

33

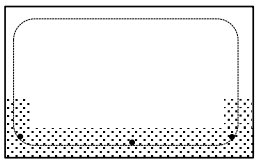
34

Bottom of Beam

18" on bottom of beam plus 6" up sides

3 x #7's

#4 ties at 12" on center



3.14 x (11/8)" x 12" x 3 bars = 155 sq.in.
3.14 x (4/8)" x (14"+(4"x2 sides)) x (12'/12") = 35 sq.in.

Area = (18" bottom +(6" ht. x 2)) x 12" length = 360 sq.in.

(155 sq.in. + 35 sq.in.) / 360 sq.in. = .37
Steel Density Ratio = .37

34

35

Abutment
SDR = .33
20" spacing

Column
SDR = .38
20" spacing

Beam
SDR = .37
20" spacing

Anode Spacing* for Low to Moderate Corrosion Risk (Chloride Content < 0.8% or Carbonated Concrete)

Protection Level	Corrosion Prevention						Corrosion Control			
Galvashield® Anode	XPT/XPC**		XP2		XP4		XP2		XP4	
Steel Density Ratio	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
<0.3	750	30	750	30	750	30	600	24	750	30
0.31 - 0.6	600	24	700	28	750	30	500	20	700	28
0.61 - 0.9	500	20	650	26	750	30	400	16	550	22
0.91 - 1.2	450	18	550	22	750	30	350	14	450	18
1.21 - 1.5	400	16	500	20	675	27	250	10	425	17
1.51 - 1.8	350	14	450	18	600	24	200	8	375	15
1.81 - 2.1	300	12	425	17	550	22	175	7	350	14

Anode Spacing* for High Corrosion Risk (Chloride Content 0.8% to 1.5%)

Protection Level	Corrosion Prevention						Corrosion Control	
Galvashield® Anode	XPT/XPC**		XP2		XP4		XP4	
Steel Density Ratio	mm	in.	mm	in.	mm	in.	mm	in.
<0.3	600	24	750	30	750	30	600	24
0.31 - 0.6	500	20	600	24	700	28	500	20
0.61 - 0.9	400	16	500	20	650	26	400	16
0.91 - 1.2	350	14	450	18	550	22	350	14
1.21 - 1.5	250	10	400	16	500	20	250	10
1.51 - 1.8	200	8	350	14	450	18	200	8
1.81 - 2.1	175	7	300	12	425	17	150	6

For extremely high corrosion risk applications (> 1.5% Chloride), contact Vector for assistance.

Note: Chloride content is based on percent by weight of cement.

35

36

Vector® Galvashield®
Calculating Steel Density

One of the main considerations when determining the appropriate spacing for galvanic anode units is the steel density ratio. Most engineers involved in concrete restoration are familiar with calculating steel ratios from a structural standpoint based on cross sectional area. But from the corrosion standpoint, we must to answer the question:

"In a given area, how much surface area of steel needs to be protected?"

To answer this question, the steel to concrete surface area ratio must be calculated to understand the density of the reinforcing steel for a given area. Therefore for typical elements we calculate the surface area of all steel based on a one square foot area. If the bar diameters are in metric, the calculations would be based on a one square meter area.

Calculations of this ratio are based on the following formula:

$$\frac{\text{Surface area of steel}}{\text{Surface area of concrete}} = \text{steel density ratio}$$

or

$$\frac{\pi \times D \times L \times n}{1\ ft^2\ (144\ in^2)} = \text{steel density ratio}$$

where:
π = 3.14
D = bar diameter
L = length of bars in calculated area
n = number of bars in calculated area

Reinforcing Steel Density Sample Calculations

Example #1
Heavily Reinforced Slab (Bridge Deck)
 # 5 Bars @ 8" on center each way (2 mats)
Low to moderate corrosion risk structure

Top mat longitudinal Bars (per ft²)
$\pi \times D \times L \times n = \pi \times \frac{5}{8}" \times 12" \times \frac{12"}{8} = 35\ in.^2 \rightarrow \frac{35\ in.^2}{144\ in.^2} = .245$

Top mat transverse bars (per ft²)
$\pi \times D \times L \times n = \pi \times \frac{5}{8}" \times 12" \times \frac{12"}{8} = 35\ in.^2 \rightarrow \frac{35\ in.^2}{144\ in.^2} = .245$

Bottom mat longitudinal bars (per ft²) .245
Bottom mat transverse bars (per ft²) .245
Total steel density 0.98 = 1.0

Based on this calculation, the recommended anode unit spacing would be as follows:

Galvashield XP/XPT (Corrosion Prevention) 18 in. (450 mm)
Galvashield XP2 (Corrosion Prevention) 14 in. (350 mm)
Galvashield XP4 (Corrosion Control) 18 in. (450 mm)
Galvashield CC65/CC135 (Corrosion Control) 14 in. (355 mm)
Galvashield CC100 (Corrosion Control) 18 in. (450 mm)

GALVANIC SYSTEMS

Level of Protection	Description	Galvashield® XP/XPT	Galvashield® XP2/XP4	Galvashield® CC
Corrosion Prevention	Mitigates initiation of new corrosion activity	•	•	•
Corrosion Control	Reduces on-going corrosion activity		•	•
Cathodic Protection	Reduce or eliminate on-going corrosion activity			

Example #2
Medium Reinforced Slab (Parking Deck)
 # 5 Bars @ 12" on center each way (2 mats)
Low to moderate corrosion risk structure

Top mat longitudinal bars (per ft²)
$\pi \times D \times L \times n = \pi \times \frac{5}{8}" \times 12" \times \frac{12"}{12} = 23.6\ in.^2 \rightarrow \frac{23.6\ in.^2}{144\ in.^2} = 0.16$

Total 4 sets of bars x 0.16 = 0.65

Based on this calculation, the recommended anode unit spacing would be as follows:

Galvashield XP/XPT (Corrosion Prevention) 20 in. (500 mm)
Galvashield XP2 (Corrosion Prevention) 26 in. (650 mm)
Galvashield XP4 (Corrosion Control) 22 in. (550 mm)
Galvashield CC65/CC135 (Corrosion Control) 18 in. (450 mm)
Galvashield CC100 (Corrosion Control) 20 in. (500 mm)

Example #3
Lightly Reinforced Slab (Balcony)
 # 4 Bars @ 16" on center each way (1 mat)
Low to moderate corrosion risk structure

$\pi \times D \times L \times n = \pi \times \frac{4}{8}" \times 12" \times \frac{12"}{16} = 14.\ in.^2 \rightarrow \frac{14\ in.^2}{144\ in.^2} = 0.10$

Total 2 sets of bars x 0.10 = 0.20

Based on this calculation, the recommended anode unit spacing would be as follows:

Galvashield XP/XPT/XP2 (Corrosion Prevention) 30 in. (750 mm)
Galvashield XP2 (Corrosion Prevention) 24 in. (600 mm)
Galvashield XP4 (Corrosion Control) 30 in. (750 mm)
Galvashield CC65/CC135 (Corrosion Control) 28 in. (700 mm)

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Questions

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