APPENDIX C
EXAMPLES OF GALVANIC CATHODIC PROTECTION DESIGN

C-1. Purpose.

The examples that follow show how to use the design procedure explained in paragraphs 2-1 and 2-2.

C-2. Aircraft multiple hydrant refueling system.

Galvanic cathodic protection is designed for a standard aircraft hydrant refueling system as shown in figure C-1. This design is for a system not yet installed.

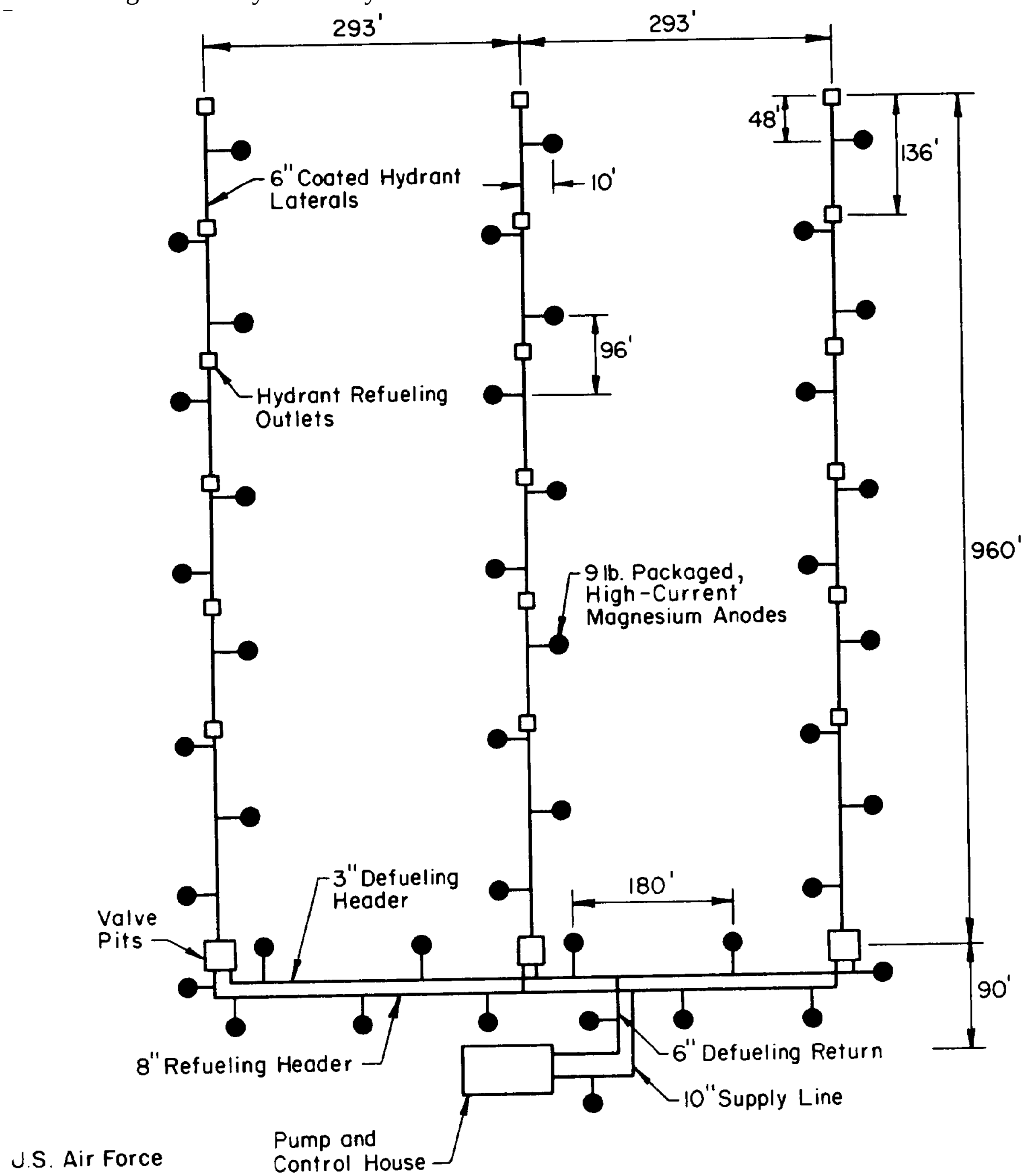

Figure C-1. Galvanic anode cathodic protection for hydrant refueling system.

a. Design data.

(1) Average soil resistivity is 5000 ohm-centimeters.

(2) Effective coating resistance at 25 years will be 2500 ohms per square foot, as suggested by the manufacturer.

(3) Design for 90 percent coating efficiency, based on experience.

(4) Design for 25-year life.

(5) Design for 1 milliampere per square foot of bare pipe after polarization (corrosion history of area indicates this value is adequate).

(6) Magnesium packaged-type anodes must be used (soil resistivity is greater than 2000 ohm-centimeters).

(7) System is insulated well enough from foreign structures.

(8) All piping is mill-coated with hot-applied coal-tar enamel and wrapped with asbestos felt. Coating has been tested over the trench for holidays and defects have been corrected. Coating is assumed better than 99.5 percent perfect at installation.

b. Computations (fig C-1).

(1) Find the total outside area of liquid fuel pipes serving the hydrant refueling area (table C-1).

Table C-1. Outside area of liquid fuel pipes

Pipe size (in.)	Pipe length (ft)	Pipe area (sq ft/ft)
3 (defueling header)	2 x 293 = 586	586 x 0.916 = 537
6 (defueling return)	90	90 x 1.734 = 156
8 (refueling header)	2 293 = 586	586 x 2.258 = 1323
10 (supply line)	90	90 x 2.82 254
6 (hydrant laterals)	3 x 960 = 2880	2880 x 1.734 = 4994
Total area of POL pipe in square feet		=7264

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(2) Some experience has shown that steel in this type soil can be cathodically protected with approximately 1 milliampere per square foot of uncoated surface. Thus, find the required current based on this value and using equation 2-1:

$$I = (A)(I')(1.0 - CE)$$
$$= (7264 \text{ sq ft})(1.0 \text{ mA/sq ft})(1.0 - 0.8)$$
$$= 726 \text{ mA}.$$

(3) Calculate the number of anodes needed based on maximum groundbed resistance limitations.

(a) Select a 9-pound anode, 3.5 by 3.5 by 13 inches, from table 2.4. Driving potential as provided by the manufacturer is 0.9 volt.

(b) Calculate total circuit resistance using equation 2-3:

$$R_T = \frac{\Delta E}{I},$$

$$R_T = \frac{0.9}{0.726} \times 1.23 \text{ ohms}.$$

(c) Calculate structure-to-electrolyte resistance from equation 2-4:

$$R_c = \frac{R}{N}$$

$$R_c = \frac{2500 \text{ ohms/sq ft}}{7264 \text{ sq ft}}$$

$$R_c = 0.345 \text{ ohm.}$$

(d) Find maximum allowable groundbed resistance using equation 2-2:

$$R_T = R_a + R_w + R_c$$

1.23 ohm = R_a + 0.345 ohm (assume R_w is negligible)

0.89 ohm = R_a

(e) Calculate number of anodes from equation 2-6:

$$N = \frac{(0.0052)(\rho)}{(R_a)(L)}[1n\frac{8L}{d} - 1],$$

$$N = \frac{(0.0052)(500 \text{ ohm}-\text{cm})}{(0.89 \text{ ohm})(1.42 \text{ ft})}[1n\frac{(8)(1.42 \text{ ft})}{(0.5 \text{ ft})} - 1]$$

(values for L and D from supplier.)

N = 44 anodes.

(4) Calculate number of anodes based on system's life expectancy and using equation 2-7:

$$N = \frac{(L)(I)}{49.3 \text{ (W)}},$$

$$N = \frac{(25 \text{ yr})(726 \text{ mA})}{49.3 \text{ (9 lb/anode)}},$$

N = 41 anodes.

(5) Select number of anodes. Since 44 anodes are required to meet maximum allowable groundbed resistance *(e* above), that will be the number used.

(6) Select groundbed layout. Determine the area to be covered by each anode using equation 2-8:

$$A = \frac{A_T}{N}$$

$$A = \frac{7264 \text{ sq ft}}{44 \text{ anodes}}$$

A = 164 sq/ft anode.

(7) Find anode spacing (table C-2).

Table C-2. Requirements for anode spacing

Pipe section	Pipe area (sq ft)	Number *of* anodes	Pipe length *(ft)*	Anode spacing *(ft)*
Laterals	4994	30	2880	96
Headers	1860	12	1172	98
Supply and return lines	410	2	180	90

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(8) Calculate life-cycle cost as recommended in paragraph 2-2. Comparisons with other anode sizes and types will yield the most economical design.

c. *Placement.* Locate anodes as shown in figure C-1.

C-3. Alternative calculations.

The design examples in paragraphs C-4 and C-5 below use calculations that differ from those used in the text and in paragraph C-2. Exposure to different methods of calculation should help the design engineer to better understand the design procedure.

C-4. Underground steel storage tank.

Galvanic cathodic protection is designed for an underground steel storage tank shown in figure C-2. The tank is already installed and current requirement tests have been made.

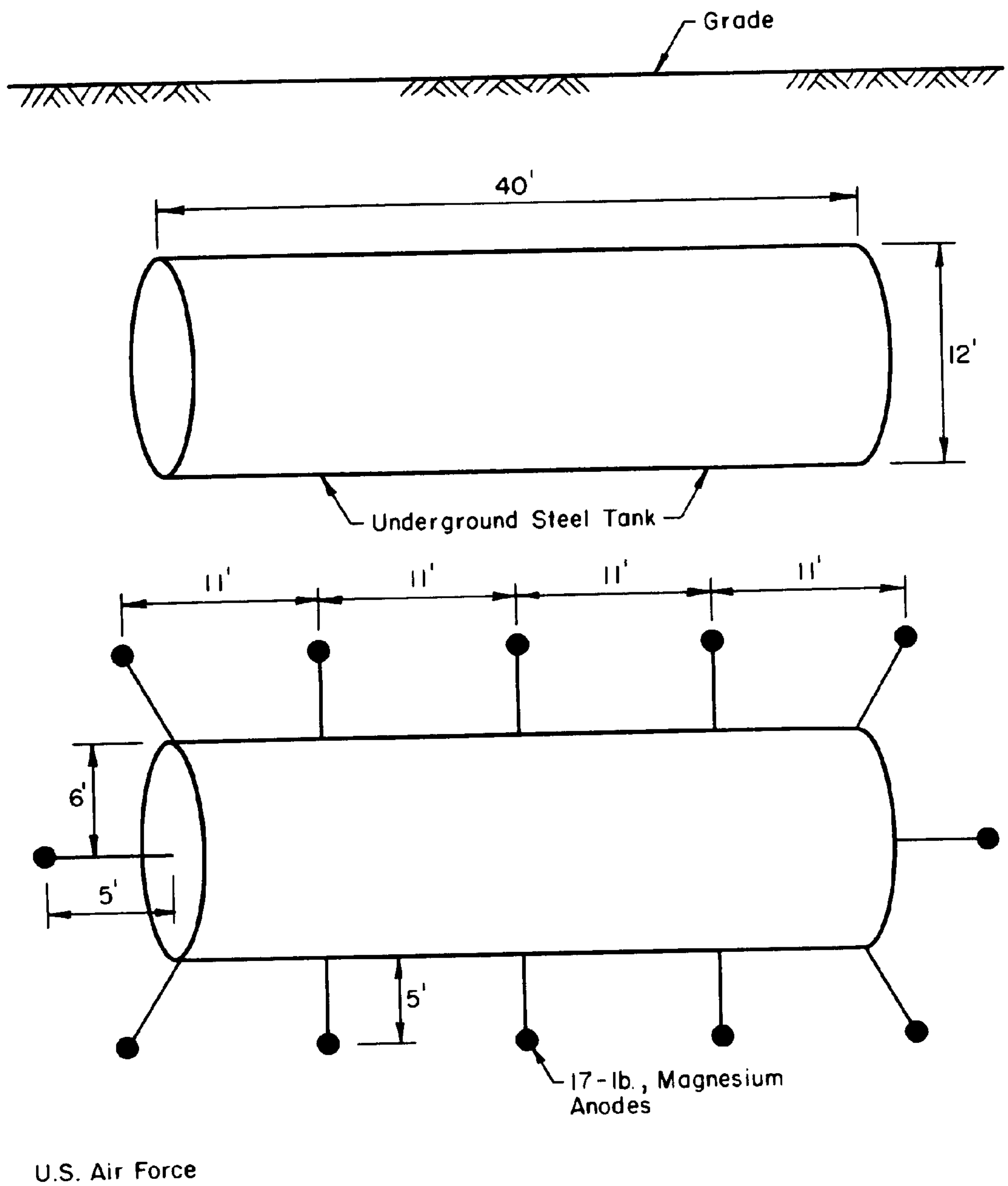

Figure C-2. Galvanic anode cathodic protection for underground steel storage tank.

a. *Design data.*
(1) Tank diameter is 12 feet.
(2) Tank length is 40 feet.
(3) Design for 80 percent coating efficiency, based on experience.
(4) Design for 15-year life.
(5) Current requirement is 0.7 ampere.
(6) Packaged 17-pound standard magnesium anodes must be used.
(7) The tank is insulated well enough from foreign structures.

b. *Computations.*
(1) Find the minimum weight of anodes required for the tank using equation C-I:

$$W = \frac{YSI}{E}, \qquad \text{(eq C-1)}$$

where Y = 15 years, S = 8.8 pounds per ampere-year, I = 0.7 ampere, and E = 0.50 efficiency. Thus,

$$W = \frac{(15\ \text{yr})(8.8\ \text{lb/A-yr})(0.7\ \text{A})}{0.50},$$

W= 184.8 lb.

(2) Find the number of magnesium anodes (17 pounds each) required:

$$N = \frac{184.8}{17} = 10.9 \text{ (use 12 anodes for symmetry).}$$

c. *Placement.* Locate anodes as shown in figure C-2.

C-5. Gas distribution system.

Galvanic cathodic protection is designed for a gas distribution system in a housing area as shown in figure C-3.

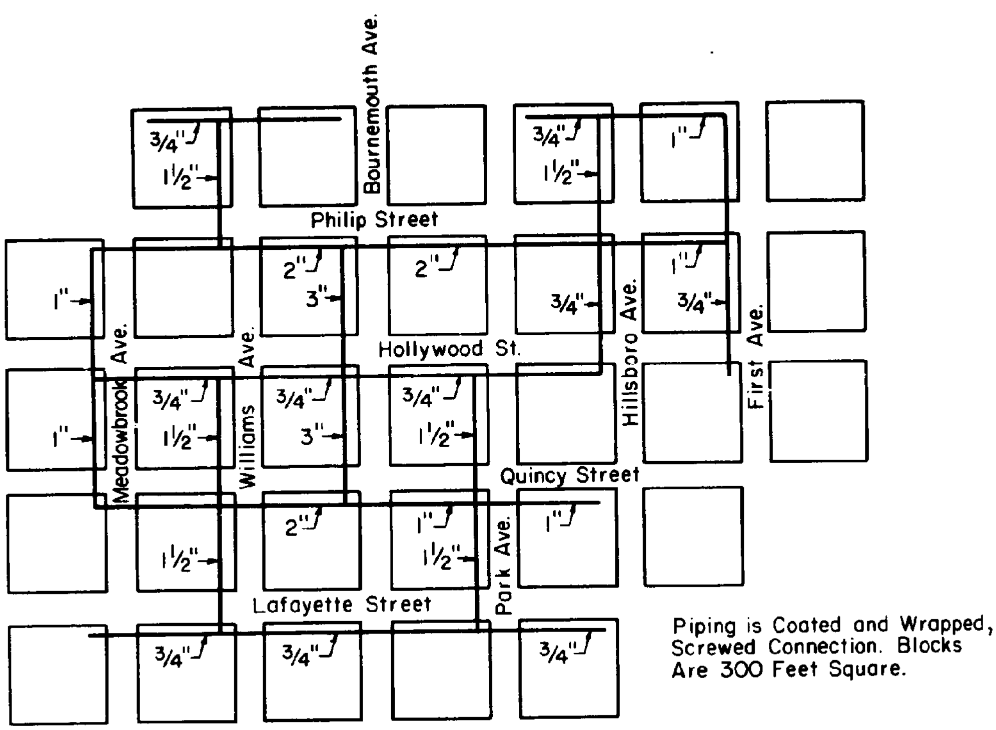

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Figure C-3. Layout of gas piping in residential district.

a. Design data.

(1) Average soil resistivity is 4500 ohm-centimeters.
(2) Design for 90 percent coating efficiency, based on experience.
(3) Design for 15-year life.
(4) Design for 2 milliamperes per square foot of bare pipe.
(5) Packaged-type magnesium anodes must be used.
(6) Insulating couplings are used on all service taps. Mains are electrically isolated from all other metal structures in the area.
(7) All pipe has been precoated at the factory and wrapped with asbestos felt. The coating has been tested over the trench for holidays and defects have been corrected. The coating is considered to be better than 99.5 percent perfect when installed.

b. Computations.

(1) Find the total outside area of piping (table C-3).
(2) Find the area of bare pipe to be protected cathodically based on 90 percent coating efficiency:

$$A = 4288 \times 0.1$$

$$A = 429 \text{ sq. ft.}$$

(3) Find the maximum protective current required based on 2 milliamperes per square foot of bare metal:

$$I = 2 \times 429$$

$$I = 858 \text{ mA or } 0.858 \text{ A.}$$

Table C-3. Dimensions for finding outside area of pipe

Pipe size (in.)	Pipe lingth (ft)	Pipe area (sq ft/lin ft)	Pipe area (sq ft)
3	600	0.916	550
2	1500	0.622	933
1½	1800	0.497	894
1	2400	0.344	826
	3900	0.278	1084
Total area of pipe in square feet			4288

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(4) Find the weight of anode material required based on maximum current requirement and 15-year life. Use equation C-1:

$$W = \frac{YSI}{E},$$

where Y = 15 years, S = 8.8 pounds per ampere-year, I = 0.858 ampere, and E = 0.50 efficiency. Thus,

$$W = \frac{(15 \text{ yr})(8.8 \text{ lb/A-yr})(0.858 \text{ A})}{0.50},$$

$$W = 227 \text{ lb.}$$

Note that the 227-pound value is based on an output current of 0.86 ampere for the cathodic protection system's full design life, 15 years. Strictly speaking, this is not the true condition, because current output after new installation is much less due to the high coating efficiency. The average current requirement at first may be as low as 0.03 milliampere per square foot of pipe.

(5) Find the current output to ground for a single 17-pound standard packaged magnesium anode using equation C-2:

$$i = \frac{Cfy}{P}, \qquad \text{(eq C-2)}$$

where C = 120,000, a constant for well coated structures using magnesium, f = 1.00 (table C-4), y = 1.00 (table C-5), P = 4500 ohm-centimeters. Thus,

$$i = \frac{120{,}000 \times 1.00 \times 1.00}{4500 \text{ ohm-cm}}$$

i = 26.7 mA.

Because the structure is well coated, anode spacing will be relatively large.

Table C-4. Galvanic anode size factor (f)

Anode weight	Standard anodes	Size factor (f)
3	(packaged)	0.53
5	(packaged)	0.60
9	(packaged)	0.71
17	(packaged)	1.00
32	(packaged)	1.06
50	(packaged-anode dimension 8” dia x 16")[a]	1.09
50	(packaged-anode dimension 5” x 5” x 31”	1.29
	Long anodes	
9	(2.75” x 2.75" x 26” backfill 6” x 31”)	1.01
10	(1.5” x 1.5” x 72” backfill 4” x 78”)	1.71
18	(2” x 2” x 72” backfill 5” x 78”)	1.81
20	(2.5” x 2.5”x “60” backfill 5” x 66”)	1.60
40	(3.75” x 3.75” x 60” backfill 6.5” x 66”)	1.72
42	(3” x 3” x 72” backfill 6” x 78”)	1.90
	Extra-long anodes	
15	(1.6” dia x 10’ backfilled to 6” din)	2.61
20	(1.3” x 20’ backfilled to 6” din)	4.28
25	(2” dia x 10’ backfilled to 8” din)	2.81

[a]In this table, “denotes inches, ‘ denotes feet.

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Table C-5. Structure potential factor (y)

Structure-to-electrolyte potential (volts, relative to copper-copper sulfate)	Magnesium structure factor (y)	Zinc structure factor (y)
-0.70	1.14	1.60
-0.80	1.07	1.20
-0.85	1.00	1.00
-0.90	0.93	0.80
-1.00	0.79	0.40
-1.10	0.64	0.00
-1.20	0.50	0.00

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(6) Find the number of anodes (n) required from equation C-3:

$$n = \frac{I}{i}, \qquad \text{(eq C-3)}$$

where I = 858 milliamperes and i = 26.7 milliamperes. Thus,

$$n = \frac{858}{26.7}$$

n = 32.1 (use 32 anodes).

(7) Find the anode distribution.

(a) Pipe area protected by one anode:

A = 4288/32

A = l34 sq ft/anode.

(b) Find the anode division (table C-6).

Table C-6. Dimensions for finding anode division

Pipe size (in.)	Pipe area (sq ft)	Pipe length (ft)	Number of anodes	Anode spacing (ft)
3	550	600	4	150
2	933	1500	7	214
1½	895	1800	7	257
1	826	2400	6	400
¾	1084	2900	8	488
Total number of anodes			32	

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