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An Introduction to Sacrificial Anode Cathodic Protection

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1. INTRODUCTION. The basic principle of cathodic protection using sacrificial anodes is the electrochemical cell. As in the case of impressed current cathodic protection, high energy (potential) electrons are forced to flow from the anode to the structure to be protected. The structure-to-electrolyte potentials required for protection are identical to those for impressed current cathodic protection systems. The high potential electrons are generated through the corrosion of an active metal such as magnesium or zinc. In this type of system, the anode material is consumed, or sacrificed in the process, and the anodes must be periodically replaced in order to obtain continued protection. In order to minimize periodic anode replacement, sufficient anode material is normally provided so that the anode replacement interval is a desired number of years. Common practice for buried systems is to design the system for a 10- to 15-year anode life. For submerged systems, or for buried systems where anode replacement is difficult, longer (20- to 30-year) anode life is often used as a design criteria.

1.1 ADVANTAGES OF SACRIFICIAL ANODE CATHODIC PROTECTION SYSTEMS. The primary advantage of sacrificial anode cathodic protection systems over impressed current cathodic protection systems is their simplicity and reliability. There are fewer critical components such as rectifiers in sacrificial anode systems. The critical cable from the anode to the impressed current anodes which is prone to failure is not a factor in sacrificial anode cathodic protection systems. The anode-to-structure cable in sacrificial anode systems is at a negative (protected) potential. Sacrificial anode cathodic protection systems are also in some cases less costly to install and maintain than impressed current cathodic protection systems. This is particularly true for systems with small current requirements (0.5 A or less per 100 lineal feet of structure). There are no power costs or costs associated with furnishing power at a remote site associated with sacrificial anode cathodic protection systems. Another major advantage of sacrificial anode cathodic protection systems is the nearly zero probability that interference problems will be experienced when this type of system is used. Sacrificial anode cathodic protection systems are commonly of the distributed anode type. This is usually necessary because of the limited driving potential of the anode materials used.

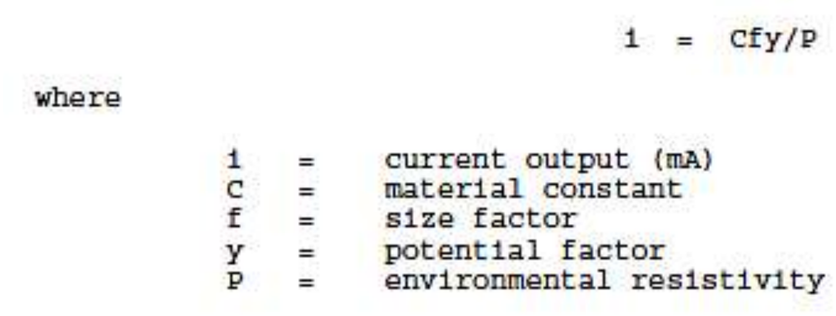
1.2 DISADVANTAGES OF SACRIFICIAL ANODE CATHODIC PROTECTION SYSTEMS. The primary disadvantages of sacrificial anode cathodic protection systems are associated with the limited driving potential between the structure and the anode materials used. This limits the current output of the anodes and restricts the area of structure which can be protected using a single anode. Anode consumption is also inherent in sacrificial anode systems and allowances for periodic anode replacement must be made.

2. SACRIFICIAL ANODE CATHODIC PROTECTION SYSTEM DESIGN PROCEDURES. The basic principles for the design of sacrificial anode cathodic protection systems are: first, the total amount of current is determined, then the output per anode is determined. Then the number of anodes required and the life of the anodes is determined. If desired, the system parameters (anode size or type) are adjusted to give desired system performance, primarily to achieve desired anode life.

3. DETERMINATION OF CURRENT REQUIRED FOR PROTECTION. The first step in the design of sacrificial anode type cathodic protection systems is the determination of the total current required for the system. This fixes the current to be supplied by the sacrificial anodes.

4. DETERMINATION OF ANODE OUTPUT. The output of a single anode in the environment is determined. This may be determined by a simplified method which uses standard factors for the type and size of anode to be used and for the structure-to-electrolyte potential desired. Single anode output can also be determined by using the driving potential between the anode and the structure and the total circuit resistance. The anode-to-electrolyte resistance is a major factor in most cases. This method is essentially identical to the design procedure for impressed current systems.

4.1 SIMPLIFIED METHOD FOR COMMON SITUATIONS. The formula given below can be used to estimate the output of zinc or magnesium anodes in environments where the resistivity is above 500 ohm-cm. The following formula gives a good approximation of current output in many cases and can be used to check the results of the more detailed procedure outline.



$$i = Cfy/P$$

where

i = current output (mA)
C = material constant
f = size factor
y = potential factor
P = environmental resistivity

4.2 DETERMINATION OF OUTPUT USING ANODE-TO-ELECTROLYTE RESISTANCE. As in the case of impressed current systems, this method determines the total resistance of the cathodic protection circuit including anode-to-electrolyte, structure-to-electrolyte resistance, and the resistance of all electrical connections and splices. Then, using the difference between the anode potential and the protected structure potential, the current output is determined using Ohm's Law.

4.2.1 CALCULATION OF ANODE-TO-ELECTROLYTE RESISTANCE. As in the case of impressed current systems, the resistance between the anode and the environment is commonly the highest resistance in the cathodic protection circuit. This is particularly true when the anodes are located a small distance (10 feet or less) from the structure to be protected.

The anode-to-electrolyte resistance can be calculated using simplified equations which are adapted to the most common situations, or the more complex but more general basic equations. Simplified expressions for the determination of the anode-to-electrolyte resistance for a single vertical anode is given.. This formula is valid for sacrificial and impressed current anodes. The basic equations given are valid for sacrificial anode and impressed current systems. In some cases, it is desirable to use groups of two or three sacrificial anodes in order to provide the required current or anode life using stock size anodes. In this case, the paralleling factors given can be used to calculate the equivalent resistance of the anodes in parallel. In some cases where this method is used, an adjustable resistor or nichrome wire resistor is installed in the anode-to-structure cable to limit the current to the required value. In this case, the determination of the anode-to-electrolyte resistance is used to calculate the value of the resistor required.

4.2.2 DETERMINATION OF STRUCTURE-TO-ELECTROLYTE RESISTANCE. The structure-to-electrolyte resistance is commonly disregarded in the design of sacrificial anode cathodic protection systems since it is usually small with respect to the anode-to-electrolyte resistance.

4.2.3 CONNECTING CABLE RESISTANCE. The connecting cable resistance is determined by the size and length of cables used. The selection of appropriate wire sizes is described. No. 12 AWG solid copper wires are commonly supplied on sacrificial anodes and No. 10 AWG wires are commonly used as connecting cables. These wires have a resistance of 1.02 and 1.62 ohms per 1,000 feet, respectively. Since connecting cables are short and currents are low in most sacrificial anode cathodic protection systems, connecting cable resistance can usually be neglected.

4.2.4 RESISTANCE OF CONNECTIONS AND SPLICES. The need to maintain low resistance throughout the life of the sacrificial anode cathodic protection system is more important than the initial resistance of connections. Although deterioration of connections in sacrificial anode cathodic protection systems is protected, the connections are still subject to corrosion resulting in increased resistance. As in the case of impressed current cathodic protection systems, the number of connections should be kept to an absolute minimum, and they should be very carefully assembled, insulated, inspected, and installed. The number and location of each connection should be installed per the system design and not at the discretion of the installer.

4.2.5 TOTAL CIRCUIT RESISTANCE. The total circuit resistance (usually only the anode-to-electrolyte resistance is a major factor) is then determined adding all of the resistances of the circuit elements.

4.2.6 ANODE-TO-STRUCTURE POTENTIAL. The potential difference between the anode and the protected structure is then determined. In most cases, the open circuit anode potential and a structure potential (for steel) of -850 mV versus copper/copper sulfate is used. Other structure potential criteria can be used as necessary. Use of an anode potential lower than the open circuit potential may be required when anode outputs are high as in very low resistivity environments.

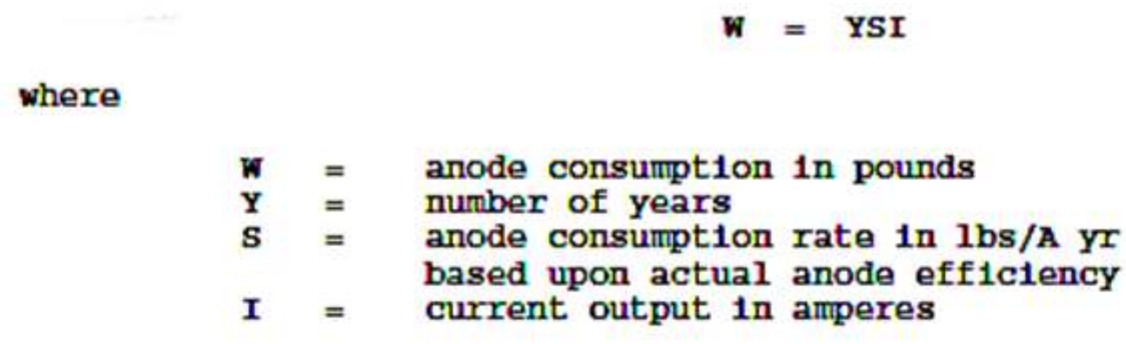
4.2.7 ANODE OUTPUT CURRENT. The anode output current is then determined from the circuit resistance and the structure-to-anode potential using Ohm's Law.

4.3 FIELD MEASUREMENT OF ANODE OUTPUT. Calculations, as in the case of impressed current systems, can only give approximations of anode-to-electrolyte resistance under actual conditions. While these calculations can be used for an initial system design, the actual anode output encountered is often sufficiently different from the calculated value to require adjustment or modification of the system. This is more of a problem for sacrificial anode systems than for impressed current systems since the output potential is not adjustable in sacrificial anode systems. In areas where the soil resistivity varies with location, a field measurement must be made at each anode location. Often the only remedy for low anode output is to add additional anodes to the system. High anode output can be remedied by installing current limiting resistors in the anode lead wires, but this should be avoided where possible. The actual anode output can best be determined by actual field measurements. Anode output is best determined by installing an anode at the actual site of the installation and attaching it to the structure to be protected. The anode output is measured using a current shunt

(0.01 or 0.1 ohm) installed in the anode lead wire. As a single anode is unlikely to polarize the structure to the desired potential, correction of the anode output for structure potential is usually required. This can be done using the structure potential factor in the simplified equation given, or by determining the anode-to-electrolyte resistance based upon the actual potential difference achieved and the anode output current.

5. DETERMINATION OF NUMBER OF ANODES REQUIRED. After the output per anode is determined, the number of anodes required for protection is calculated. This is done by dividing the total output by the output per anode. In practice, approximately 10 percent more anodes are installed to allow for inaccuracies in system design, seasonal variations in anode output, and decreased anode output as the anodes are consumed. Installation of a limited percentage of additional anodes is not wasteful because, if the system is properly adjusted, additional anodes simply result in longer anode life.

6. DETERMINATION OF ANODE LIFE. The anode life is calculated based upon the current flow, anode weight, and anode efficiency. The calculation involves the number of ampere hours produced by an anode per pound on anode material consumed. Anode consumption can be calculated using the formula:

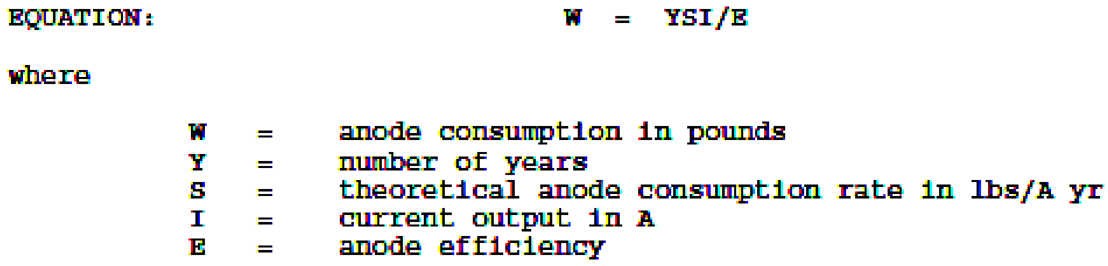


$$W = YSI$$

where

W = anode consumption in pounds
Y = number of years
S = anode consumption rate in lbs/A yr based upon actual anode efficiency
I = current output in amperes

For some anode materials, the anode efficiency is dependent upon anode current density as shown in Figure 1. For these materials, the anode consumption can be calculated using the formula:



EQUATION: $$W = YSI/E$$

where

W = anode consumption in pounds
Y = number of years
S = theoretical anode consumption rate in lbs/A yr
I = current output in A
E = anode efficiency

For the standard alloy magnesium material, the anode efficiency is essentially constant above 250 mA/ft² of anode area. If the anode efficiency is low at the anode current density at which it is operated, anode material is wasted due to self corrosion. At an anode efficiency of 50 percent, one-half of the anode material is consumed by self corrosion and one-half is consumed in providing protective current. If the desired anode life is not obtained using an initially selected anode material and size, a different sized anode or one of a different material is substituted and the process repeated in an iterative manner until a system with the desired characteristics is obtained.

7. SEASONAL VARIATION IN ANODE OUTPUT. Anode output will vary as the resistivity of the environment changes. Seasonal variations associated with soil moisture in buried systems or seawater dilution in estuaries may result in changes in anode output. Fortunately, in most cases the current required for protection is also reduced when the resistivity of the environment increases so that this effect is partially self-compensating. In some cases, however, anode output will fall below or above the limits for protection and the system will require seasonal adjustment or augmentation in order to provide adequate protection.

8. SACRIFICIAL ANODE MATERIALS.

8.1 MAGNESIUM. Magnesium is the most commonly used sacrificial anode material for the protection of buried structures. Magnesium anodes are also used for the protection of the interiors of water tanks and heaters, heat exchangers and condensers, and waterfront structures. Magnesium anodes are available as castings and extrusions weighing from 1 to 200 pounds, and in a wide variety of shapes. Two anode compositions are commonly used. They are the standard alloy and a "high potential" alloy. The composition of each alloy is given in para. 8.1.1.

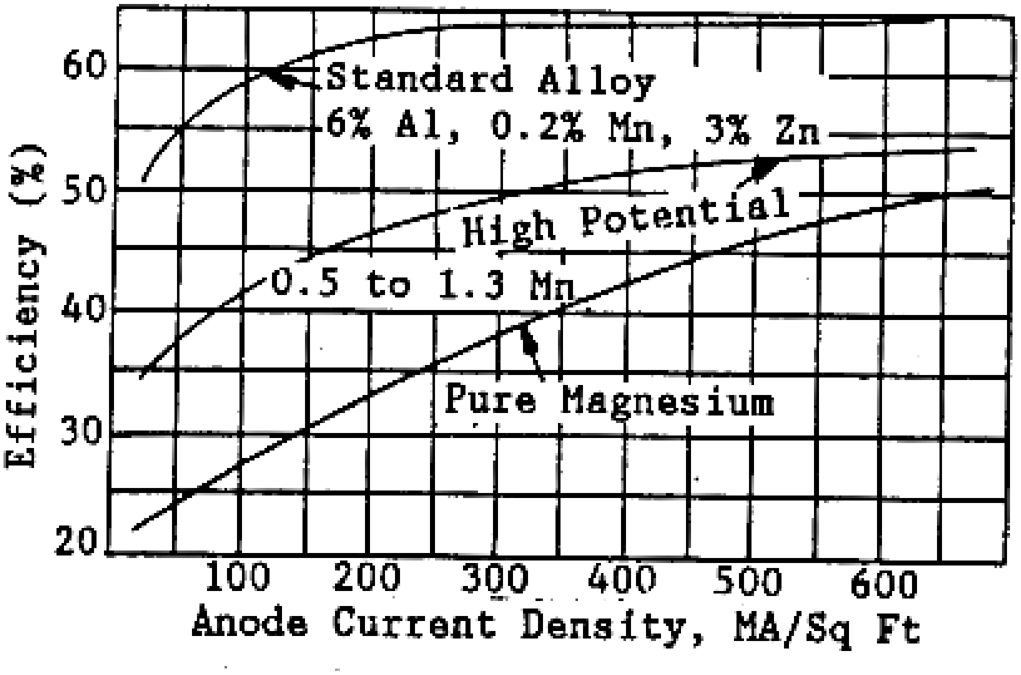


Figure 1

Efficiency versus current density – magnesium anodes

8.1.1 COMPOSITION. The composition of both the standard alloy and high potential magnesium allow are given below:

Element	Standard	High Potential
Aluminum	5.3 - 6.7%	0.1% max
Manganese	0.15% min	0.5 - 1.3%
Zinc	2.5 - 3.5%	-
Copper	0.02% max	0.02% max
Silicon	0.1% max	-
Iron	0.003% max	0.03% max
Nickel	0.002% min	0.001% max
Other metals	0.3% max	0.3% max total 0.05% max each
Magnesium	Remainder	Remainder

8.1.2 ANODE EFFICIENCY. The theoretical efficiency of magnesium is 1,000 ampere hours per pound or 8.8 lbs/A-yr. The efficiency of magnesium alloys used for cathodic protection seldom exceeds 65 % of this theoretical value due to self-consumption. The efficiency of both the standard alloy and high potential alloy magnesium alloys is dependent on the current densities on their surfaces. The efficiency of the standard alloy is higher than the efficiency of the high potential allow. Thus, the high potential alloy should only be used when its higher driving potential is required (usually in soil resistivities above 12,000 ohm-cm). For design purposes, 50 percent is used for the efficiency of both types.

8.1.3 POTENTIALS. The open circuit potential of the standard alloy is approximately -1.55 V versus copper/copper sulfate. The open circuit potential of the high potential alloy is approximately -1.75 V versus copper/copper sulfate.

8.1.4 SIZES. Magnesium anodes are available in a wide variety of sizes and shapes as shown in Tables 1 through 6. In addition to the sizes shown, magnesium alloy anode material is available as a "ribbon" anode which consists of a 10-gauge steel wire surrounded by standard alloy magnesium 3/8 by ¾ inch. Magnesium ribbon anodes are used in situations such as inside casings where the space available is limited, or to protect small diameter utility cables.

8.1.5 CURRENT OUTPUT. Current output from magnesium anodes should be determined from formulae or by field measurement.

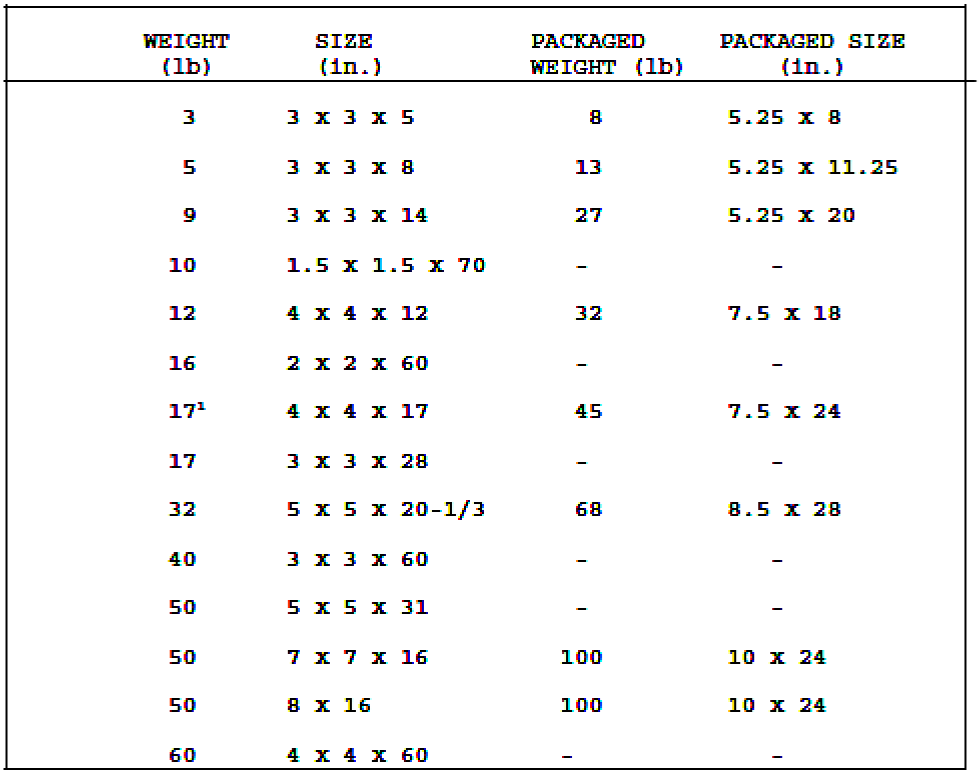
8.1.6 BACKFILL. FOR SOIL INSTALLATIONS, the use of backfill is highly desirable and is required in all cases. Composition of typical backfill material for use with magnesium anodes is given below:

Composition of Backfill for Magnesium Anodes

Gypsum	75%
Bentonite	20%
Sodium Sulfate	5%

Anodes are available in prepackaged permeable cloth bags filled with prepared backfill. Prepackaged anodes are commonly supplied with an outer impermeable wrapping such as plastic. The impermeable wrapping must be removed from these anodes prior to installation.

8.2 ZINC. Zinc anodes are commonly available in weights from 5 pounds to 250 pounds in the form of plates, bars, and rods as described in Tables 7 through 10. Zinc is also available as ribbon anodes in 5/8- by 7/8-inch, 1/2- by 9/16-inch, and 11/32- by 15/32-inch sizes, each with a 1/10-inch-diameter galvanized steel wire core. Zinc anodes are most commonly used in immersion service either in fresh or salt water. They are, however, occasionally used in the protection of buried structures when special circumstances are encountered. Two zinc anode compositions are commonly available. They are a standard alloy formulated for use in fresh water and soil and an alloy specially formulated for use in seawater. The composition of these alloys is given in para. 8.2.1.



WEIGHT (lb)	SIZE (in.)	PACKAGED WEIGHT (lb)	PACKAGED SIZE (in.)
3	3 x 3 x 5	8	5.25 x 8
5	3 x 3 x 8	13	5.25 x 11.25
9	3 x 3 x 14	27	5.25 x 20
10	1.5 x 1.5 x 70	-	-
12	4 x 4 x 12	32	7.5 x 18
16	2 x 2 x 60	-	-
17[1]	4 x 4 x 17	45	7.5 x 24
17	3 x 3 x 28	-	-
32	5 x 5 x 20-1/3	68	8.5 x 28
40	3 x 3 x 60	-	-
50	5 x 5 x 31	-	-
50	7 x 7 x 16	100	10 x 24
50	8 x 16	100	10 x 24
60	4 x 4 x 60	-	-

1 Most common size used.

NOTE: Core material for soil anodes is a galvanized, open pitch, spiral-wound strip 3/8-inch inside diameter (id), 1/2-inch outside diameter (od). Connecting wire for soil anodes is a 10-foot length of single-strand No. 12 American Wire Gage (AWG) thermoplastic waterproof (TW) insulated copper wire, silver-soldered to the core with the joints sealed against moisture. Special connecting wires or lengths other than 10 feet are available.

Table 1

Standard alloy magnesium anodes

Standard sizes for use in soil

WEIGHT (lb)	SIZE (in.)	TYPE OF CORE
20	3.5 x 3.5 x 26	3/4-in. diam galvanized pipe core, flush ends.
50	7 x 7 x 16	Threaded 3/4-in. diam galvanized pipe extending 1 inch both ends, flush ends optional.
50	7 x 7 x 16	1/2-in. diam galvanized eyebolt core.
50	8 x 16	3/4-in. diam galvanized pipe core, flush ends.
50	8 x 16	1/2-in. diam galvanized eyebolt core.
100	7 x 7 x 32	3/4-in. diam galvanized pipe core, flush ends.
100	7 x 7 x 32	1/2-in. diam galvanized eyebolt core.
100	8 x 32	3/4-in. diam galvanized pipe core, flush ends.
100	8 x 32	1/2-in. diam galvanized eyebolt core.

Table 2

Standard alloy magnesium anodes

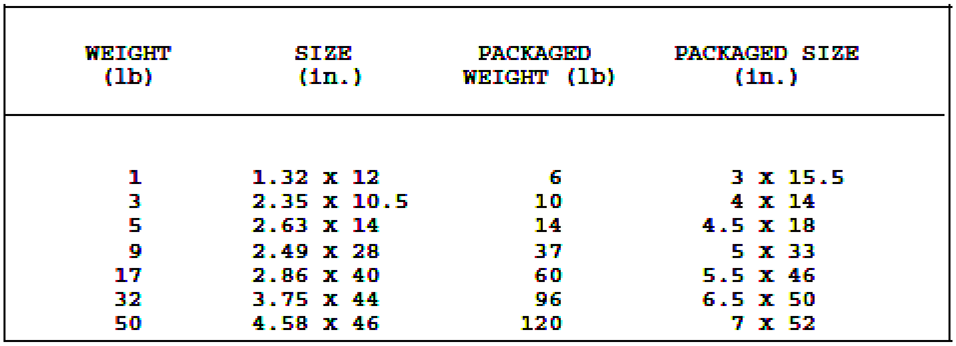
Standard sizes for use in water

WEIGHT (lb)	SIZE (in.)	TYPE OF CORE
15	4 x 8 x 8	3/4-in. bolt
24	2 x 9 x 18	1/4- x 2-in. straps
44	4 x 9 x 18	1/2- x 2-in. straps
60	7 x 9 x 18	3/4-in. bolt

Table 3

Standard alloy magnesium anodes

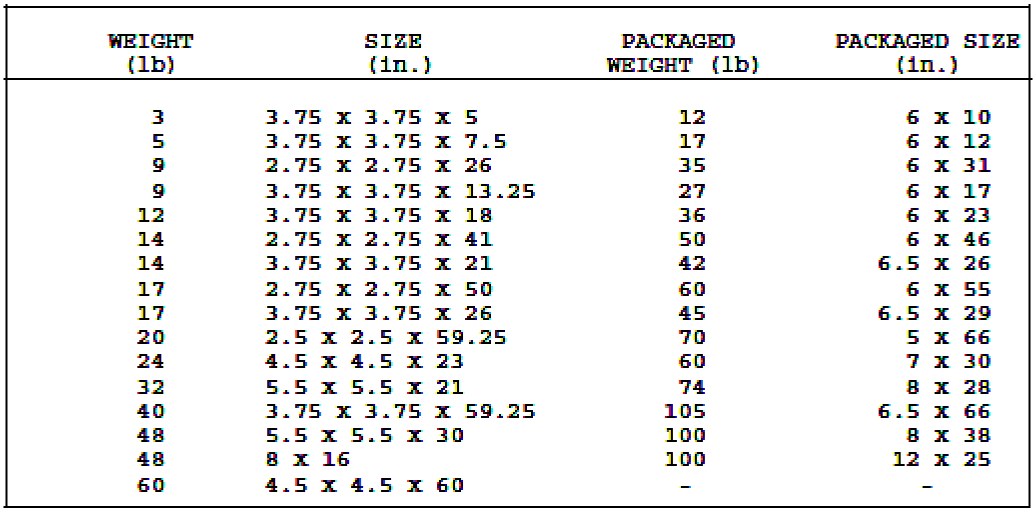
Standard sizes for condensers and heat exchangers



WEIGHT (lb)	SIZE (in.)	PACKAGED WEIGHT (lb)	PACKAGED SIZE (in.)
1	1.32 x 12	6	3 x 15.5
3	2.35 x 10.5	10	4 x 14
5	2.63 x 14	14	4.5 x 18
9	2.49 x 28	37	5 x 33
17	2.86 x 40	60	5.5 x 46
32	3.75 x 44	96	6.5 x 50
50	4.58 x 46	120	7 x 52

Table 4

Standard alloy magnesium anodes – elongated



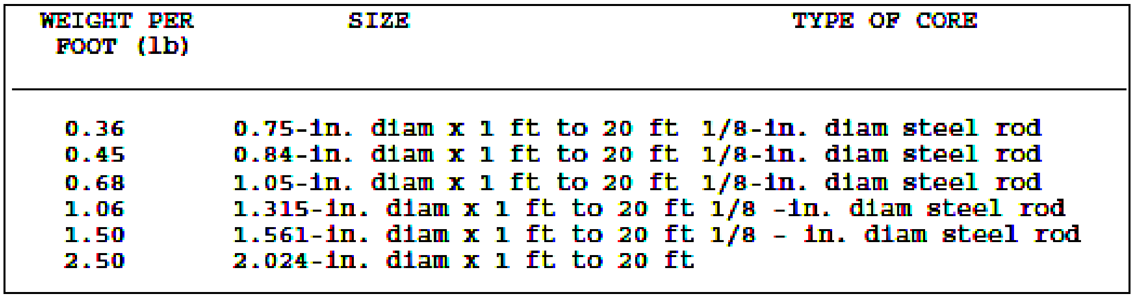
WEIGHT (lb)	SIZE (in.)	PACKAGED WEIGHT (lb)	PACKAGED SIZE (in.)
3	3.75 x 3.75 x 5	12	6 x 10
5	3.75 x 3.75 x 7.5	17	6 x 12
9	2.75 x 2.75 x 26	35	6 x 31
9	3.75 x 3.75 x 13.25	27	6 x 17
12	3.75 x 3.75 x 18	36	6 x 23
14	2.75 x 2.75 x 41	50	6 x 46
14	3.75 x 3.75 x 21	42	6.5 x 26
17	2.75 x 2.75 x 50	60	6 x 55
17	3.75 x 3.75 x 26	45	6.5 x 29
20	2.5 x 2.5 x 59.25	70	5 x 66
24	4.5 x 4.5 x 23	60	7 x 30
32	5.5 x 5.5 x 21	74	8 x 28
40	3.75 x 3.75 x 59.25	105	6.5 x 66
48	5.5 x 5.5 x 30	100	8 x 38
48	8 x 16	100	12 x 25
60	4.5 x 4.5 x 60	-	-

NOTE: Core material is a galvanized 20-gauge perforated steel strip.. Anodes longer than 24 inches have a 9-gauge core. The connecting wire is a 10-foot length of solid No. 12 AWG TW insulated copper wire, silver-soldered to the core with joints sealed against moisture. Special wires or other lengths are available.

Table 5

High potential alloy magnesium anodes

Standard sizes for soil and water

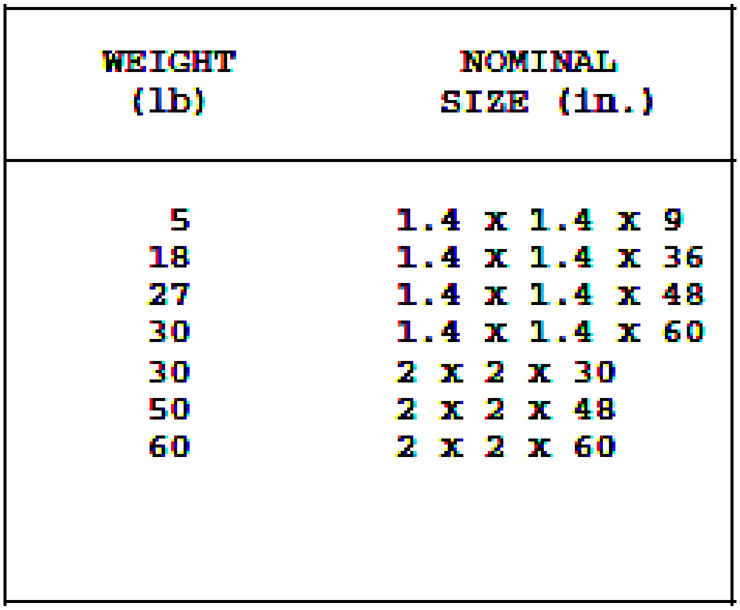


WEIGHT PER FOOT (lb)	SIZE	TYPE OF CORE
0.36	0.75-in. diam x 1 ft to 20 ft	1/8-in. diam steel rod
0.45	0.84-in. diam x 1 ft to 20 ft	1/8-in. diam steel rod
0.68	1.05-in. diam x 1 ft to 20 ft	1/8-in. diam steel rod
1.06	1.315-in. diam x 1 ft to 20 ft	1/8 -in. diam steel rod
1.50	1.561-in. diam x 1 ft to 20 ft	1/8 - in. diam steel rod
2.50	2.024-in. diam x 1 ft to 20 ft	

Table 6

Standard Alloy Magnesium Anodes

Standard Size Extruded Rod for Water Tanks and Water Heaters



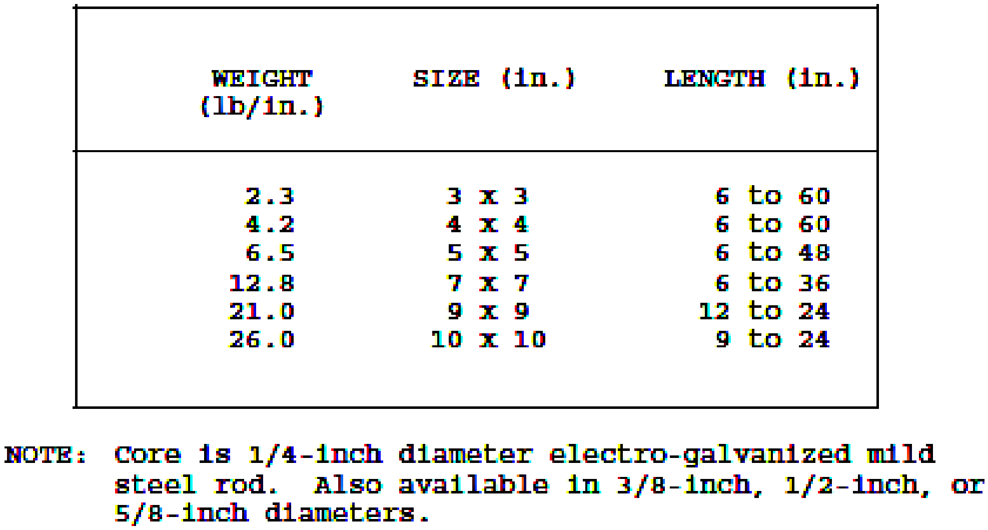
WEIGHT (lb)	NOMINAL SIZE (in.)
5	1.4 x 1.4 x 9
18	1.4 x 1.4 x 36
27	1.4 x 1.4 x 48
30	1.4 x 1.4 x 60
30	2 x 2 x 30
50	2 x 2 x 48
60	2 x 2 x 60

NOTE: Core for standard anodes shown is 1/4-inch diameter electrogalvanized mild steel rod.

Table 7

Zinc Anodes - Standard Sizes

for Underground or Fresh Water



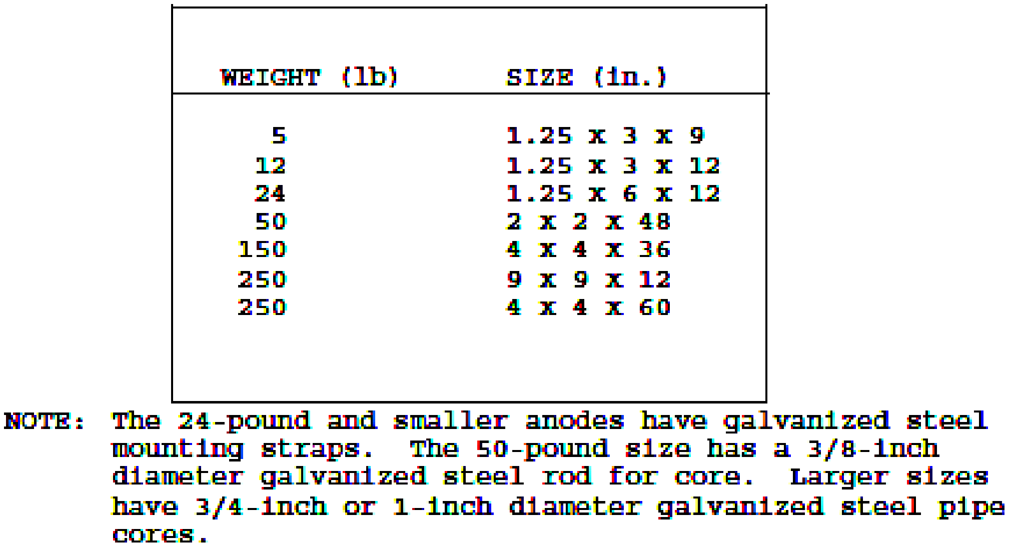
WEIGHT (lb/in.)	SIZE (in.)	LENGTH (in.)
2.3	3 x 3	6 to 60
4.2	4 x 4	6 to 60
6.5	5 x 5	6 to 48
12.8	7 x 7	6 to 36
21.0	9 x 9	12 to 24
26.0	10 x 10	9 to 24

NOTE: Core is 1/4-inch diameter electro-galvanized mild steel rod. Also available in 3/8-inch, 1/2-inch, or 5/8-inch diameters.

Table 8

Zinc Anodes - Special Sizes for

Underground or Fresh Water



WEIGHT (lb)	SIZE (in.)
5	1.25 x 3 x 9
12	1.25 x 3 x 12
24	1.25 x 6 x 12
50	2 x 2 x 48
150	4 x 4 x 36
250	9 x 9 x 12
250	4 x 4 x 60

NOTE: The 24-pound and smaller anodes have galvanized steel mounting straps. The 50-pound size has a 3/8-inch diameter galvanized steel rod for core. Larger sizes have 3/4-inch or 1-inch diameter galvanized steel pipe cores.

Table 9

Zinc Anodes - Standard Sizes for Use in Seawater

WEIGHT (lb/in.)	SIZE (in.)	LENGTH (in.)
0.5	1.4 x 1.4	6 to 60
1	2 x 2	6 to 60
2.3	3 x 3	6 to 60
4.2	4 x 4	6 to 60
6.5	5 x 5	6 to 48
12.8	7 x 7	6 to 36
21.0	9 x 9	9 to 24
23.4	9 x 10	9 to 24
26.0	10 x 10	9 to 24

NOTE: A variety of cores are available with the different sizes.

Table 10

Zinc Anodes - Special Sizes for Use in Seawater

8.2.1 COMPOSITION. The compositions of the standard zinc alloy and the alloy formulated for use in seawater are given below:

Element	Standard Alloy[1]	Seawater Alloy[2]
Aluminum	0.005% max	0.10 - 0.50%
Cadmium	0.003% max	0.025 - 0.15%
Iron	0.00014% max	0.005% max
Lead	0.003% max	0.006% max
Copper	-	0.005% max
Silicon	-	0.125% max
Zinc	Remainder	Remainder

[1] Specification ASTM B-148, Type II

[2] Specification ASTM B-148, Type I; or MIL-A-18001H

8.2.2 ANODE EFFICIENCY. The theoretical anode consumption for zinc is 23.5 lbs/A yr or 372 ampere hours per pound (A hr/lb). The efficiency of zinc is greater than that of magnesium. The efficiency of zinc is commonly 90 percent to 95 percent regardless of current output. For design purposes, 90 percent is used for the efficiency of zinc.

8.2.3 POTENTIALS. The open circuit potential of both commonly used zinc anode materials is -1.10 V in most soils or natural waters. The relative potential between zinc and iron is dependent upon temperature. At temperatures above ambient, the potential difference between the two materials is reduced. In some fresh waters, the potential can reverse at temperatures above 140 degrees F. Zinc should not be used to protect steel in such cases as hot water heaters.

8.2.4 SIZES. Both standard alloy and seawater type zinc anodes are available in a wide variety of sizes and shapes. Anodes used in soil usually have a galvanized mild steel rod core. This core is attached to the anode cable during installation of the anode. In both fresh water and seawater applications the anode is often attached directly to the structure to be protected by welding or bolting the steel rod, pipe, or strap core to the structure. When suspended in water, the core is extended by welding on a steel extension. For suspended systems, the use of a cable continuity bond is recommended to insure that the resistance between the anode and the structure is minimized. Sizes and shapes of commercially available zinc alloys for cathodic protection are given in Tables 11 through 15. In addition, zinc ribbon anodes 5/8 by 7/8 inch weighing 1.2 pounds per foot (lb/ft) for seawater use are available. Two sizes of zinc ribbon anodes are available in the standard alloy: 1/2 by 9/16 inch weighing 0.6 lb/ft, and 11/32 by 15/32 inch weighing 0.25 lb/ft. All three of these commercially available zinc ribbon anodes have a 1/10-inch steel core.

8.2.5 CURRENT OUTPUT. The current output of zinc anodes may be determined either by calculations or by field measurements. When used without backfill, zinc anodes can become covered with nonconductive corrosion products which can reduce their current output. Seawater alloy anodes are specially formulated to reduce this tendency in seawater. When used in soil containing high levels of oxygen, carbonates, or phosphates, backfill should be used with zinc anodes in order to reduce the possibility of the buildup of these corrosion products.

8.2.6 BACKFILL. Two typical compositions of backfill used with zinc anodes in soils are given below:

Material	Type 1	Type 2

Hydrated gypsum	75%	50%
Bentonite	20%	50%
Sodium sulfate	5%	

7.8.3 ALUMINUM. Aluminum sacrificial anodes are a more recent development than either zinc or magnesium alloys. Their primary use is in the protection of structures in seawater. However, there is a potential for their use in fresh water or in soil. When the original anodes used are aluminum alloy and their performance has been satisfactory they should be replaced with anodes of the same type. Early formulations of aluminum alloys for use as a sacrificial anode contained mercury. While the amount of mercury contained in the alloy is small, the mercury tends to concentrate in the anode stubs which remain after the bulk of the anode has been consumed. Precautions should be taken during removal of the stubs, especially by methods which generate heat, to prevent mercury poisoning. Mercury containing aluminum alloy anode stubs must be disposed of properly.

8.3.1 COMPOSITION. The compositions of most aluminum alloy anodes are proprietary. Typical compositions of three proprietary alloys are given below:

Element	Type I	Type II	Type III
Zinc	0.35% - 0.50%	3.5% - 5.0%	3.0%
Silicon	0.10% max	-	0.1%
Mercury	0.035% - 0.048%	0.035% - 0.048%	-
Indium	-	-	0.015%
Aluminum	Remainder	Remainder	Remainder

The Type I alloy is formulated for submersion in full strength seawater. The Type II alloy is formulated for use when the anode may become immersed in bottom sediments. The Type III alloy is formulated for use in bottom sediments, full strength seawater, or in brackish water.

8.3.2 ANODE EFFICIENCY. Type I aluminum anodes have a consumption rate of approximately 1,250 A hrs/lb or 6.8 lbs/A yr. Type II aluminum anodes in bottom sediments have a reduced efficiency and a consumption rate of approximately 770 A hrs/lb or 11.4 lbs/A yr. Type III aluminum anodes have a consumption rate of approximately 1,150 A hrs/lb or 7.6 lbs/A yr.

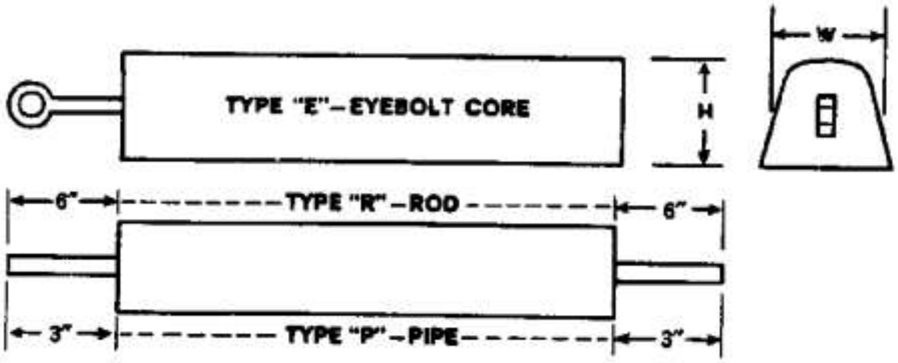
8.3.3 POTENTIALS. The potential of Type I and Type II aluminum anodes is -1.10 V versus copper/copper sulfate. Type III anodes have a slightly higher driving potential of -1.15 V versus copper/copper sulfate.

8.3.4 SIZES. Aluminum alloy anodes have been developed primarily for the protection of marine structures. They are available in a wide variety of sizes and shapes as shown in Tables 11 through 15. The bracelet anodes described in Table 15 are shown in Figure 2. These bracelet anodes are used for the protection of submerged pipelines and may also be used on pipe pilings.

8.3.5 CURRENT OUTPUT. The current output of aluminum anodes can be determined either by calculations or by field measurements. The current output for some sizes of aluminum anodes is provided by anode manufacturers and is calculated using an assumed structure potential of -850 mV versus copper/copper sulfate and an environmental resistivity of 20 ohm-cm. These values should be considered as estimates only and should be verified by calculations of tests.

9. OTHER SYSTEM COMPONENTS.

9.1 CONNECTING WIRES. Proper selection of cable size, type of insulation, and routing is necessary for proper and reliable system operation. Only copper cables should be used in any cathodic protection installation. High connection resistances and difficulty in making welded connections associated with the use of aluminum wires precludes their use in cathodic protection.



Unless otherwise specified, the following steel core size will be supplied;

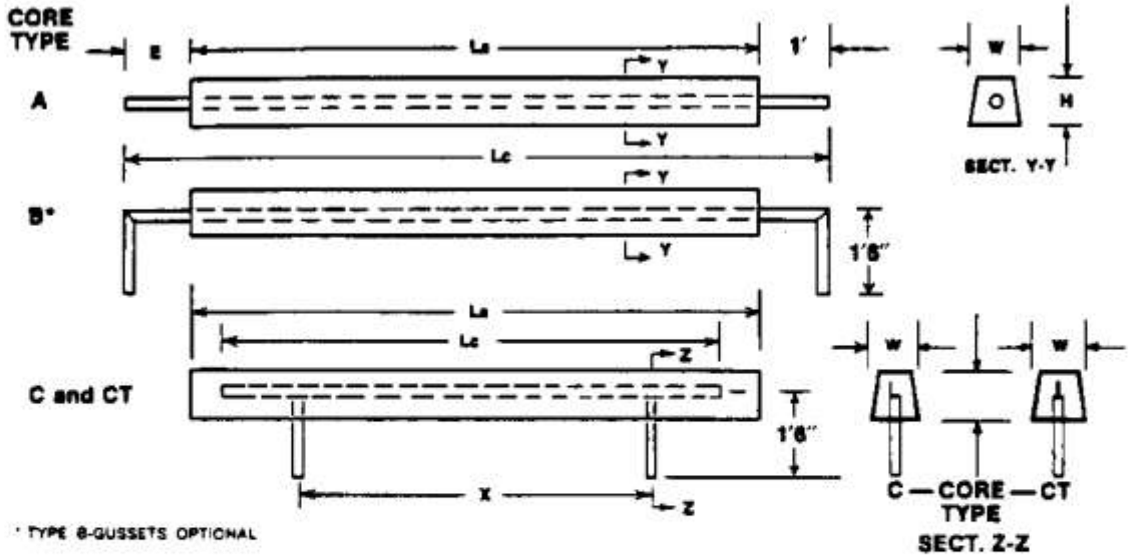
Type "E"–½" Eyebolt
Type "P"–STD ¾" Pipe
Type "R"–½" Dia. Rod

ANODE NO.	NOMINAL WEIGHT (lb)	LENGTH (in.)	WIDTH (in.)	HEIGHT (in.)	CORE TYPE
A-240	240	24	10	10	E, P, or R
A-175	175	36	7	7	"
A-120	120	12	10	10	"
A-120-1	120	24	7	7	"
A-120-2	120	48	5	5	"
A-100	100	60	4	4	"
A-90	90	18	7	7	"
A-90-1	90	36	5	5	"
A-60	60	12	7	7	"
A-60-1	60	24	5	5	"
A-60-2	60	38	4	4	"
A-30	30	34	3	3	"

NOTE: All dimensions and weights shown are nominal.

Table 11

Aluminum pier and piling anodes – standard sizes



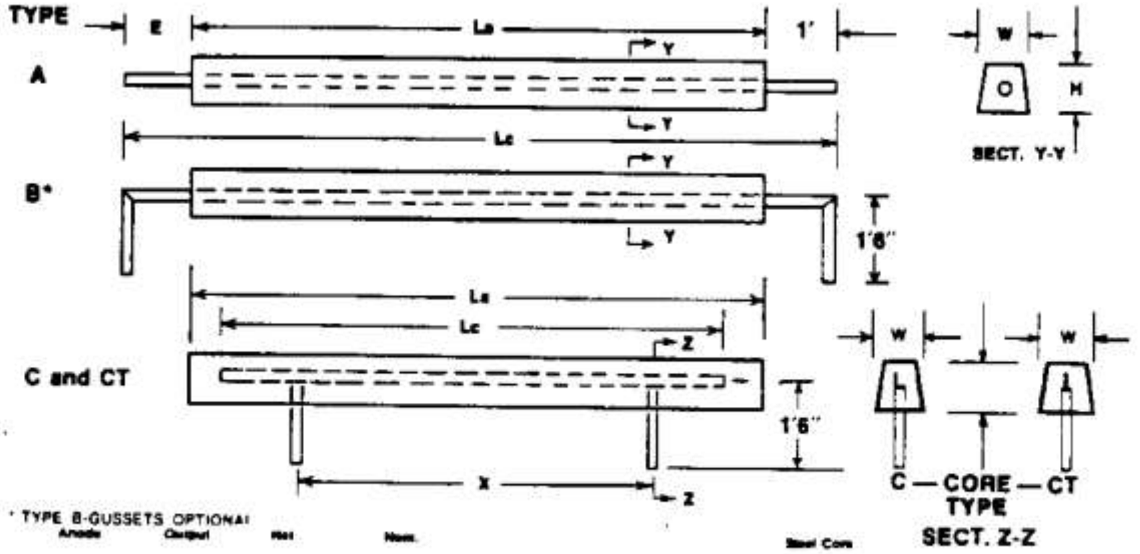
* TYPE B-GUSSETS OPTIONAL

Anode No.	Net Al Wt.	WxH	La	Lc	X	Steel Core		
						Type	Schedule	
A 375	325	6-1/2" x 6-1/2"	8'	10'	-	A	2" schedule 80 pipe	
A 875	725	9-1/2" x 9-1/2"	8'	10'	-	A	4" schedule 80 pipe	
B 385	325	6-1/2" x 6-1/2"	8'	10'	-	B	2" schedule 80 pipe	
B 910	725	9-1/2" x 9-1/2"	8'	10'	-	B	4" schedule 80 pipe	
							Internal	Legs-Pipe
C 360	325	6-1/2" x 6"	8'	7'	5'	C	2" x 2" x 1/4" angle	2" schedule 80
C 405	370	6-1/2" x 6-1/2"	8'	7'	5'	C	2" x 2" x 1/4" angle	2" schedule 80
CT 840	725	9-1/2" x 8-1/2"	8'	7'	5'	CT	"T" 4" D. x 5-1/4" H. (ST4WF)	4" schedule 80

Table 12

Type I aluminum alloy anodes

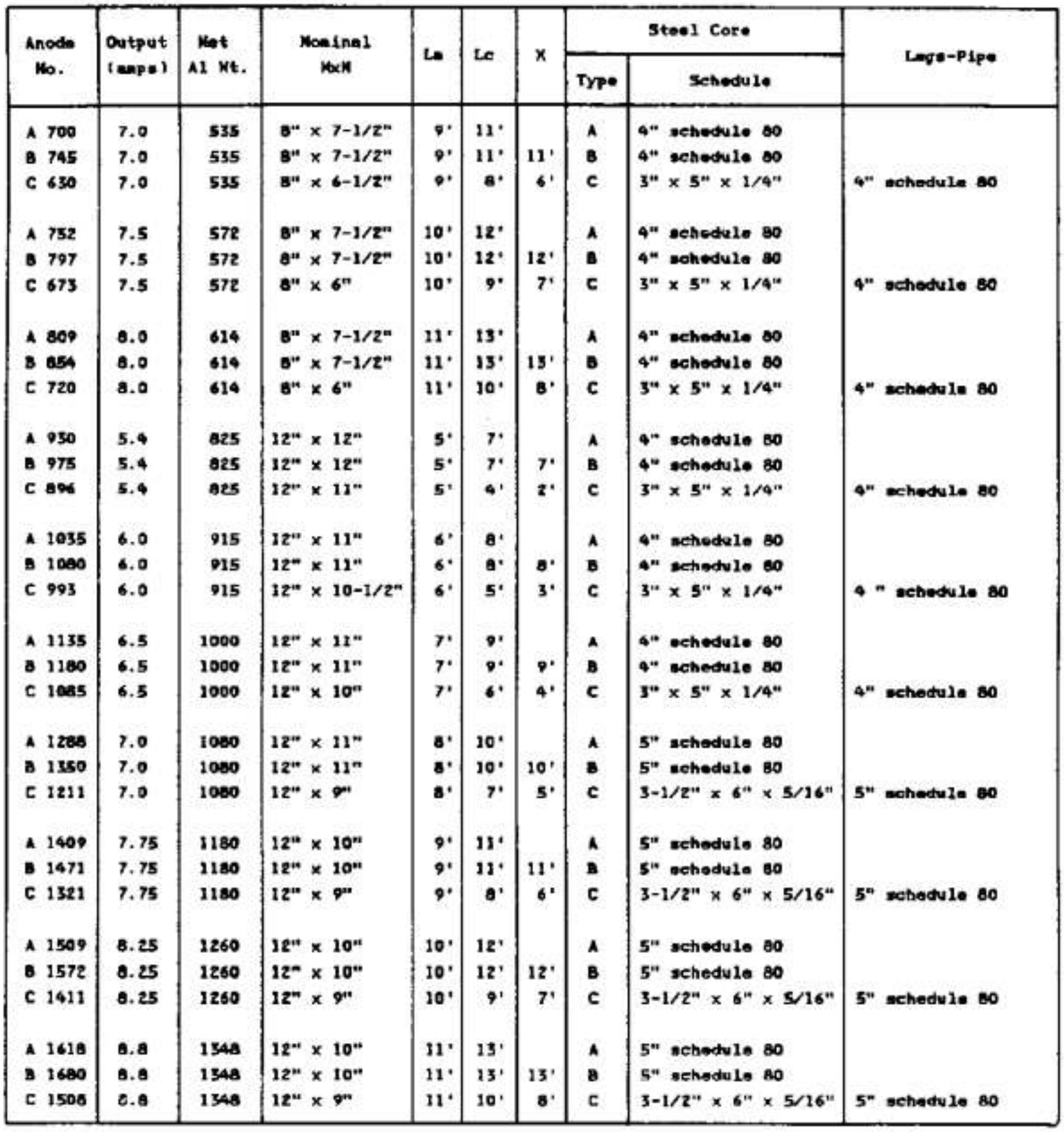
Standard sizes for offshore use



Anode No.	Output (amps)	Net Al Wt.	Nominal WxH	La	Lc	X	Steel Core		Legs-Pipe
							Type	Schedule	
A 420	4.75	365	8" x 8"	5'	7'		A	2-1/2" schedule 80	
B 442	4.75	365	8" x 8"	5'	7'	7'	B	2-1/3" schedule 80	
C 406	4.75	365	8" x 7-1/2"	5'	4'	2'	C	3" x 3" x 1/4"	2-1/2" schedule 80
A 469	5.33	408	8" x 7-1/2"	6'	8'		A	2-1/2" schedule 80	
B 492	5.33	408	8" x 7-1/2"	6'	8'	8'	B	2-1/2" schedule 80	
C 453	5.33	408	8" x 7"	6'	5'	3'	C	3" x 3" x 1/4"	2-1/2" schedule 80
A 519	5.90	450	8" x 7-1/2"	7'	9'		A	2-1/2" schedule 80	
B 542	5.90	450	8" x 7-1/2"	7'	9'	9'	B	2-1/2" schedule 80	
C 503	5.90	450	8" x 6-1/2"	7'	6'	4'	C	3" x 3" x 1/4"	2-1/2" schedule 80
A 567	6.45	490	8" x 7"	8'	10'		A	2-1/2" schedule 80	
B 590	6.45	490	8" x 7"	8'	10'	10'	B	2-1/2" schedule 80	
C 548	6.45	490	8" x 6-1/2"	8'	7'	5'	C	3" x 3" x 1/4"	2-1/2" schedule 80

Table 13

Type III aluminum alloy anodes for offshore use



Anode No.	Output (amps)	Net Al Wt.	Nominal MxM	La	Lc	X	Steel Core		Legs-Pipe
							Type	Schedule	
A 700	7.0	535	8" x 7-1/2"	9'	11'		A	4" schedule 80	
B 745	7.0	535	8" x 7-1/2"	9'	11'	11'	B	4" schedule 80	
C 630	7.0	535	8" x 6-1/2"	9'	8'	6'	C	3" x 5" x 1/4"	4" schedule 80
A 752	7.5	572	8" x 7-1/2"	10'	12'		A	4" schedule 80	
B 797	7.5	572	8" x 7-1/2"	10'	12'	12'	B	4" schedule 80	
C 673	7.5	572	8" x 6"	10'	9'	7'	C	3" x 5" x 1/4"	4" schedule 80
A 809	8.0	614	8" x 7-1/2"	11'	13'		A	4" schedule 80	
B 854	8.0	614	8" x 7-1/2"	11'	13'	13'	B	4" schedule 80	
C 720	8.0	614	8" x 6"	11'	10'	8'	C	3" x 5" x 1/4"	4" schedule 80
A 930	5.4	825	12" x 12"	5'	7'		A	4" schedule 80	
B 975	5.4	825	12" x 12"	5'	7'	7'	B	4" schedule 80	
C 896	5.4	825	12" x 11"	5'	4'	2'	C	3" x 5" x 1/4"	4" schedule 80
A 1035	6.0	915	12" x 11"	6'	8'		A	4" schedule 80	
B 1080	6.0	915	12" x 11"	6'	8'	8'	B	4" schedule 80	
C 993	6.0	915	12" x 10-1/2"	6'	5'	3'	C	3" x 5" x 1/4"	4 " schedule 80
A 1135	6.5	1000	12" x 11"	7'	9'		A	4" schedule 80	
B 1180	6.5	1000	12" x 11"	7'	9'	9'	B	4" schedule 80	
C 1085	6.5	1000	12" x 10"	7'	6'	4'	C	3" x 5" x 1/4"	4" schedule 80
A 1288	7.0	1080	12" x 11"	8'	10'		A	5" schedule 80	
B 1350	7.0	1080	12" x 11"	8'	10'	10'	B	5" schedule 80	
C 1211	7.0	1080	12" x 9"	8'	7'	5'	C	3-1/2" x 6" x 5/16"	5" schedule 80
A 1409	7.75	1180	12" x 10"	9'	11'		A	5" schedule 80	
B 1471	7.75	1180	12" x 10"	9'	11'	11'	B	5" schedule 80	
C 1321	7.75	1180	12" x 9"	9'	8'	6'	C	3-1/2" x 6" x 5/16"	5" schedule 80
A 1509	8.25	1260	12" x 10"	10'	12'		A	5" schedule 80	
B 1572	8.25	1260	12" x 10"	10'	12'	12'	B	5" schedule 80	
C 1411	8.25	1260	12" x 9"	10'	9'	7'	C	3-1/2" x 6" x 5/16"	5" schedule 80
A 1618	8.8	1348	12" x 10"	11'	13'		A	5" schedule 80	
B 1680	8.8	1348	12" x 10"	11'	13'	13'	B	5" schedule 80	
C 1506	8.8	1348	12" x 9"	11'	10'	8'	C	3-1/2" x 6" x 5/16"	5" schedule 80

Table 13 (continued)

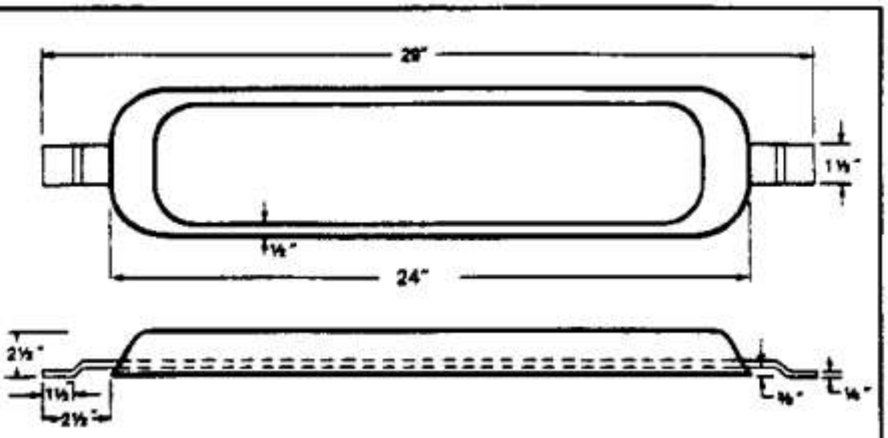
Type III aluminum alloy anodes for offshore use

CAT. NO.
G-1-29H

WT./ANODE
29 lbs.

NOM. DIMENSIONS
24" x 5" x 2½"

CURRENT RATING
4 AMPERE—YEARS

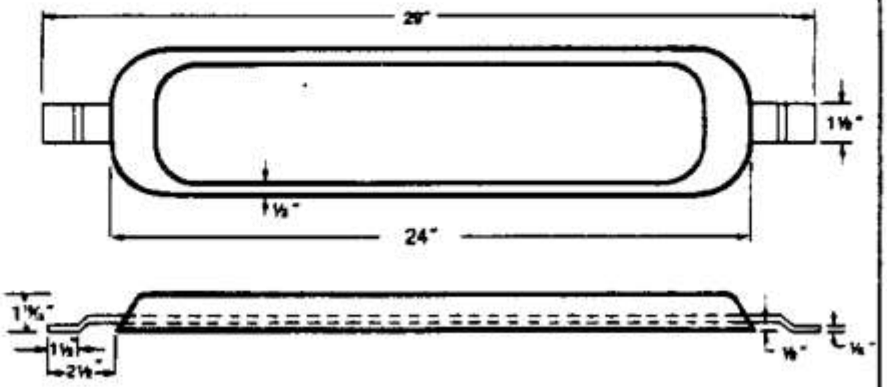


CAT. NO.
G-1-23H

WT./ANODE
23 lbs.

NOM. DIMENSIONS
24" x 5" x 1¹⁵⁄₁₆"

CURRENT RATING
3 AMPERE—YEARS



CAT. NO.
G-2-15H

WT./ANODE
15½"lbs.

NOM. DIMENSIONS
21½" x 5" x 1⅜"

CURRENT RATING
2 AMPERE—YEARS

Note: Also available: G-1-15H same as G-2-15H except has single longitudinal strap

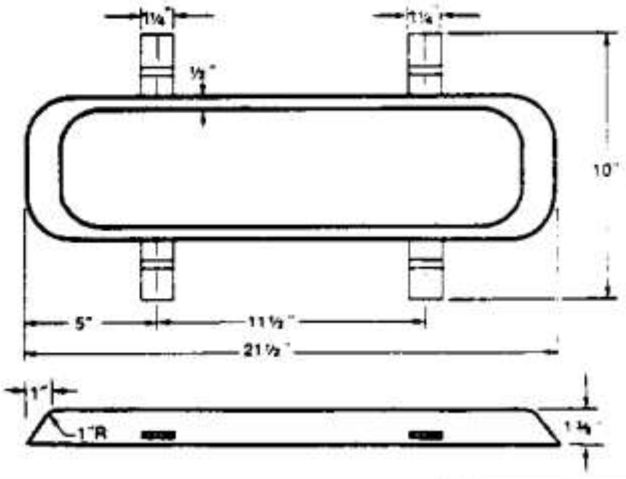


Table 14

Aluminum alloy hull anodes – standard sizes

(Types I, II and III)

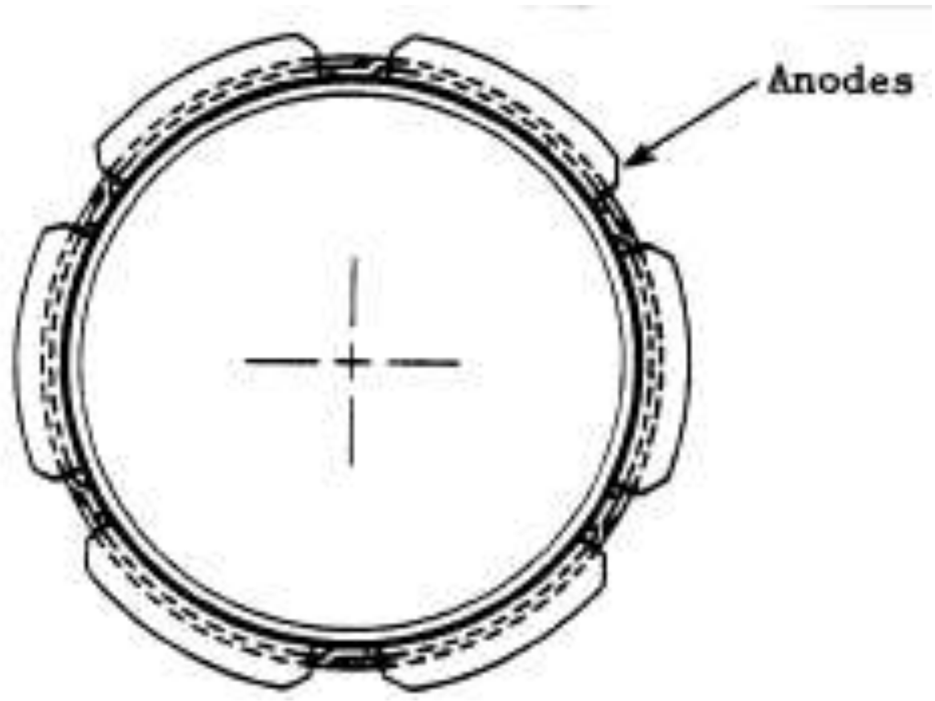
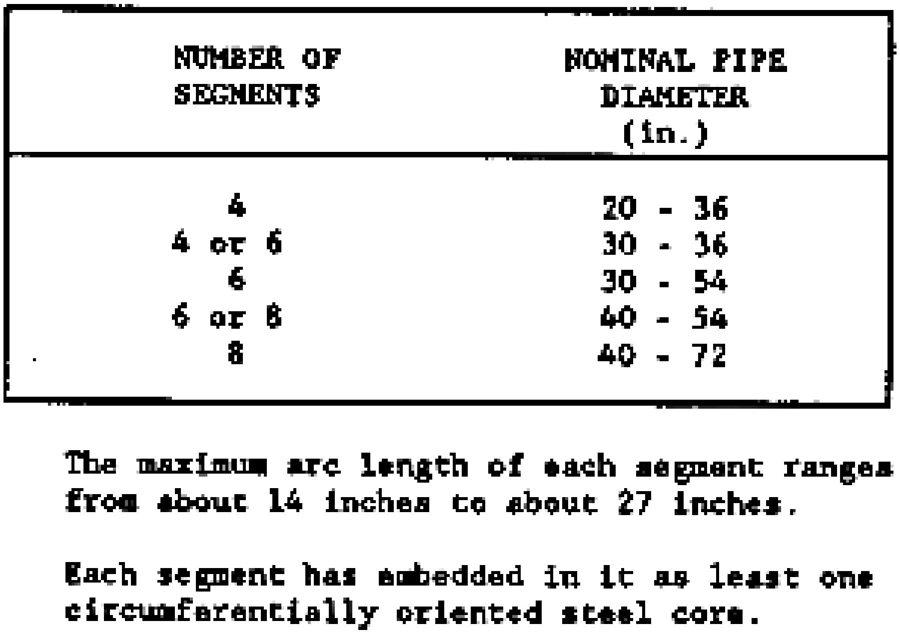


Figure 2

Aluminum alloy bracelet anodes



NUMBER OF SEGMENTS	NOMINAL PIPE DIAMETER (in.)
4	20 - 36
4 or 6	30 - 36
6	30 - 54
6 or 8	40 - 54
8	40 - 72

The maximum arc length of each segment ranges from about 14 inches to about 27 inches.

Each segment has embedded in it at least one circumferentially oriented steel core.

Table 15

Aluminum alloy bracelet anodes – standard sizes

9.1.1 DETERMINATION OF CONNECTING WIRE SIZE AND TYPE. As the currents in sacrificial anode cathodic protection systems are usually quite low, the size of conductors is normally more a function of mechanical strength than of resistance. In systems where sacrificial anodes are used as distributed anodes along the protected structure and are connected to a collector wire, the collector wire size should be No. 10 AWG. No. 12 AWG wire is the minimum size that should be used on individual anodes.

As connecting wires in sacrificial anode cathodic protection systems are themselves cathodically protected, insulation is not as critical as in portions of impressed current cathodic protection systems. Type TW, Type RHW-USE, or polyethylene insulation may be used. Anode lead wires should never be used to suspend, carry, or install the anode. Anode cables are commonly No. 12 AWG with Type TW insulation. Unless otherwise necessary, other connecting wires should be No. 12 AWG solid copper for single anodes. When currents larger than 1 A flow in any portion of a sacrificial anode circuit, the most economic wire size should be determined using the methods outlined. Instead of the cost of power used in the determination of economic wire size for impressed current cathodic protection systems, the cost of additional anodes to overcome the resistive losses should equal the annual fixed costs for the cable size being analyzed.

9.2 CONNECTIONS AND SPLICES. Wire splices and connections should be kept to an absolute minimum and the type of connection used should have both low resistance, high reliability, and good resistance to corrosion. Connections should be made using either exothermic or mechanical connections. Insulation of underground connections should be made by using encapsulation in epoxy or insulation with hot coal-tar enamel followed by wrapping with pipeline felt. Above grade connections, such as in test stations, are usually mechanical connections and should be carefully taped in order to prevent corrosion due to the entry of moisture. The following connections are required for sacrificial anode systems:

- Connection between anode(s) and structure.
- Connection between cable and anode (usually factory made or connection is attached to cast-in-core)
- Necessary bonds and test wires

The need for additional connections and splices should be carefully evaluated. As in the case for impressed current systems, the location of all necessary splices and connections should be specifically shown on the design drawings. The need for additional splices and connections should be determined by the designer of the system and not left to the discretion of the installer.

9.3 BONDS AND INSULATING JOINTS. Bonds and insulating joints are required for some sacrificial anode cathodic protection systems. Guidelines presented should be used for all bonds and insulating joints.

9.4 TEST STATION LOCATION AND FUNCTION. The most common type of test station used in sacrificial anode cathodic protection systems is the current potential test station shown in Figure 3. In this test station, the anode lead wire is connected to the structure lead using a 0.01-ohm resistor (shunt) which is used to measure the current output by measuring the voltage drop across the shunt. The second structure lead is used to measure the structure potential using a noncurrent carrying connection thus eliminating any potential drop along the conductor. The second structure connection can also be used as a spare if the primary structure connection is damaged. Test stations for sacrificial anode cathodic protection systems can either be the flush-mounted or above grade type. If flush-mounted test stations are used, the soil exposed in the bottom of t test station can be used to measure the structure-to-electrolyte potential Location of such test stations directly over the structure is often advantageous as any IR drops due to current flowing through the soil are minimized. Other test stations used in sacrificial anode cathodic protection systems are: the potential test station, the soil contact tes station, the line current (IR Drop) test station, the insulating joint test station, the casing insulation test station, and the bond test station. These test stations are identical to those described.

9.5 BACKFILL. The use of backfill in soil applications for the type of anode materials used in sacrificial anode cathodic protection systems described in the section on each anode material. When prepackaged anodes are used, the impermeable wrapping must be removed from these anodes prior to installation.

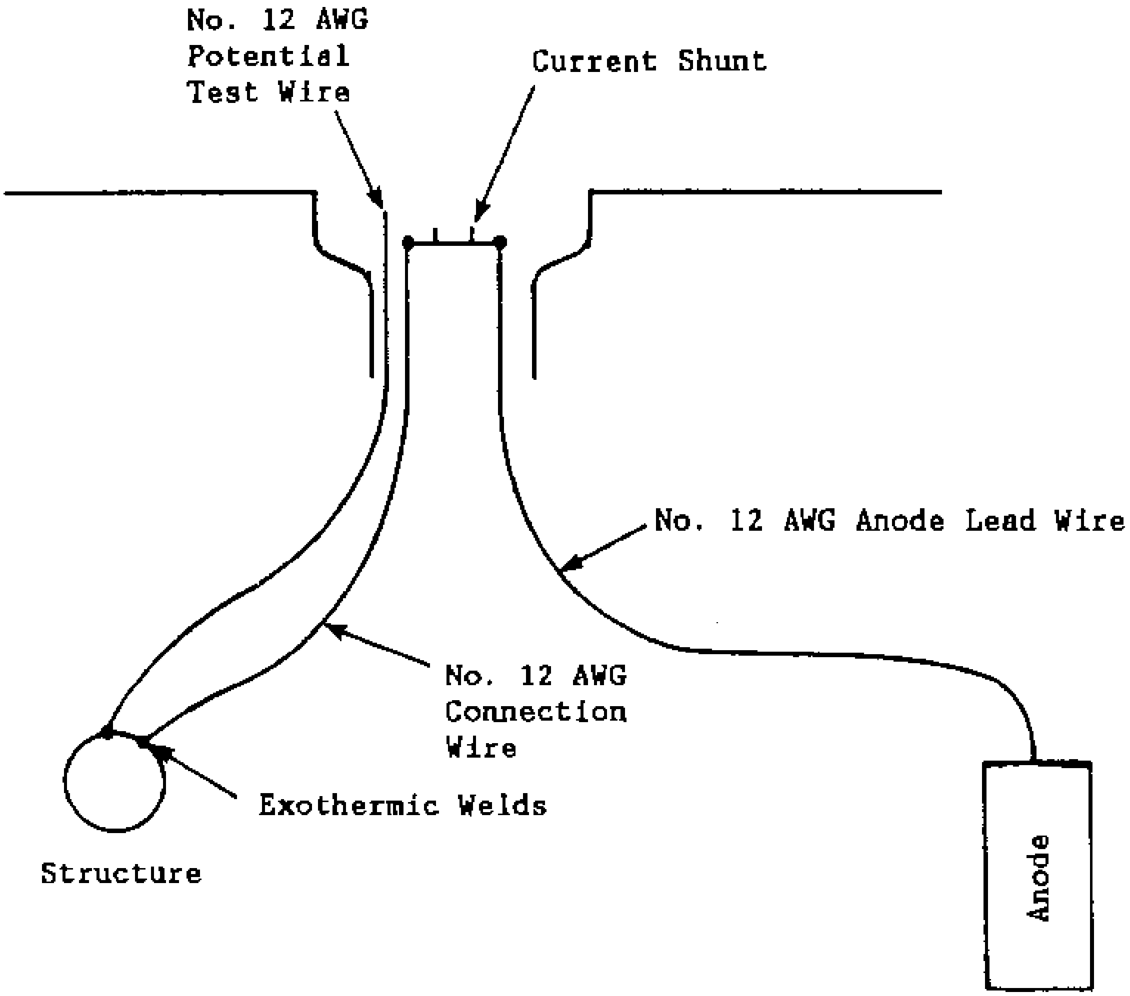


Figure 3

Current-potential test station