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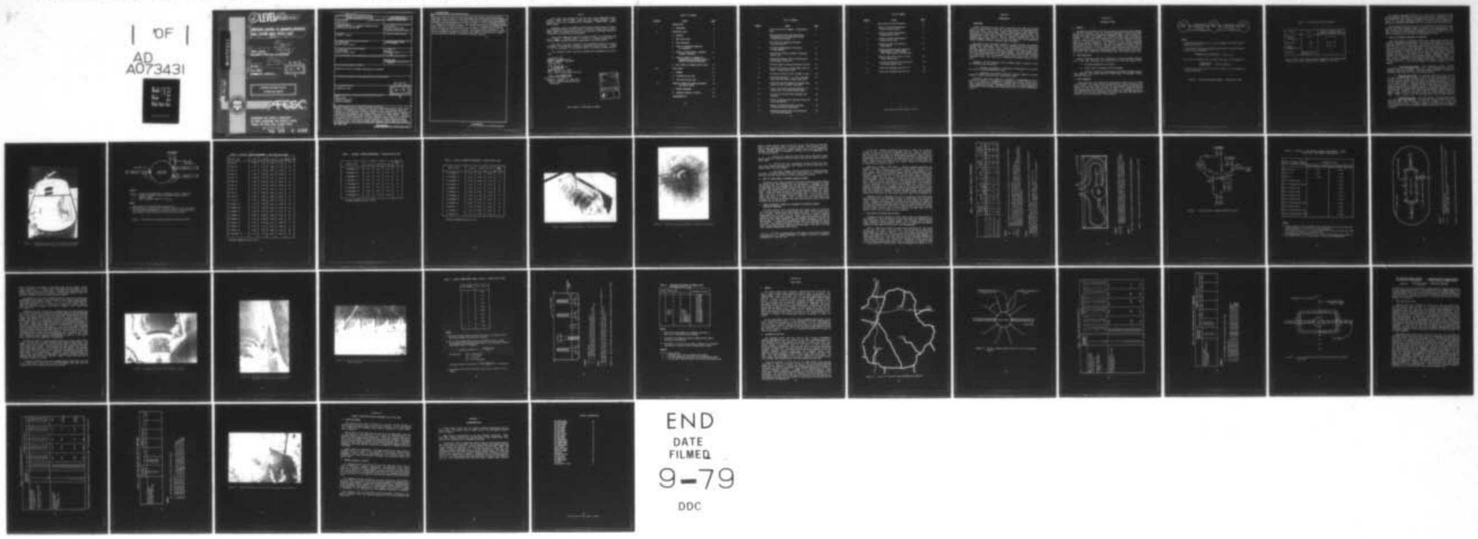

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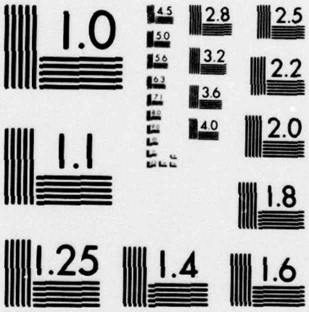
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CORROSION CONTROL OF HARDENED INTERSITE CABLE SYSTEM (HICS) SPLICE CASE.

⑯ 2054

⑩ THOMAS F. LEWICKI

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DIRECTORATE OF OPERATIONS AND MAINTENANCE

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Several thousand splice cases are in use on the hardened intersite cable system between the Stragegic Air Command's Minuteman silos. These splice cases are exposed to severe galvanic corrosion caused by interconnection with the graphite impregnated, polyethylene cable sheath which acts as a large cathode. The Air Force Civil Engineering Center conducted laboratory and field tests to determine the magnitude of corrosion for the three different splice cases in use and to develop the surface potential criteria necessary to achieve adequate cathodic protection (CP). Test results showed that aluminum splice cases fail quicker

than cast iron, and that bronze splice cases with bronze connecting hardware experience little corrosion. The interconnection of dissimilar metals (graphite and splice case) resulted in the surface potential criteria being significantly different from the standard CP criteria of either a -.85 volt surface potential or a negative 300 millivolt shift. The revised criteria for an aluminum splice case called for a surface potential of -.55 volt or a negative 409 millivolt shift, whereas the cast iron splice case required a surface potential of -.34 volt or a negative 510 millivolt shift. The revised surface potential criteria and the procedure developed to determine the degree of corrosion can be used on any underground metallic system with dissimilar metals.

PREFACE

This report was prepared by the Air Force Civil Engineering Center (AFCEC), Tyndall AFB FL 32403, under Job Order Number 20544C15. Final technical review was accomplished by Detachment 1 (CEEDO) ADTC, Tyndall AFB FL 32403.

Effective 1 March 1979 CEEDO and AFCEC became directorates of the Air Force Engineering and Services Center, located on Tyndall AFB FL 32403. CEEDO became the Engineering and Services Laboratory and AFCEC became the Directorate of Operations and Maintenance.

This report summarizes work done between November 1975 and March 1979 by Mr. Thomas F. Lewicki (AFCEC). Lt Robert J. Gunning and Maj Roger J. Girard (CEEDO) assisted him with preparation of the final report.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

BACKGROUND

Several thousand cast iron splice cases were used when the Hardened Intersite Cable System (HICS) was installed between the Minuteman silos during the 1960s. Since then, several hundred splice cases prematurely failed due to corrosion and were replaced with aluminum splice cases. The aluminum splice cases also corroded, so bronze splice cases were used with significantly better results. However, several thousand cast iron and aluminum splice cases are still in use and these will fail prematurely unless a method is found to mitigate their corrosion.

The splice case corrosion failures occurred because the graphite impregnated, polyethylene cable sheath on the HICS was electrically continuous with the splice case. This interconnection of dissimilar materials resulted in severe galvanic corrosion of the splice case, since the cable sheath acted as a very large cathode. The only feasible solutions to this problem would be to apply cathodic protection and to replace the failed cast iron and aluminum splice cases with a more corrosion resistant splice case, such as a fiberglass reinforced plastic splice case.

Therefore, HQ SAC requested that the AFCEC conduct research to meet the following test objectives:

a. Develop a procedure to determine the magnitude of corrosion for cast iron and aluminum splice cases.

b. Determine the surface potential criteria required to obtain adequate cathodic protection for these splice cases.

Laboratory tests were conducted to determine the magnitude of corrosion and to develop a technique for determing the surface potential criteria. The tests were completed at Tyndall AFB FL using actual splice cases furnished by HQ SAC. Subsequent field tests were then conducted at a Minuteman missile complex near Whiteman AFB MO to verify the laboratory results.

SECTION II

LABORATORY TESTS

A. ANALYSIS

The degree of galvanic corrosion occurring on the splice cases depends on several variables, such as electrical potential between the anode (splice case) and cathode (graphite impregnated cable), soil resistivity, proximity of anode to cathode, and relative surface areas of anode and cathode. In most cases the cathode area is at least 3000 times greater than the anode (Figure 1) so the splice case will be subject to a high density of current discharge. The majority of this current discharge would logically occur where the cable enters the splice case which further accelerates corrosion failure. Finally, the amount of current flow is directly proportional to the electrical potential difference between the splice case and the graphite impregnated cable. Based on this, the aluminum splice case should fail much quicker than the bronze splice case.

B. TEST OBJECTIVES

Several laboratory tests were conducted to verify the above analysis and to meet the following test objectives for each type splice case:

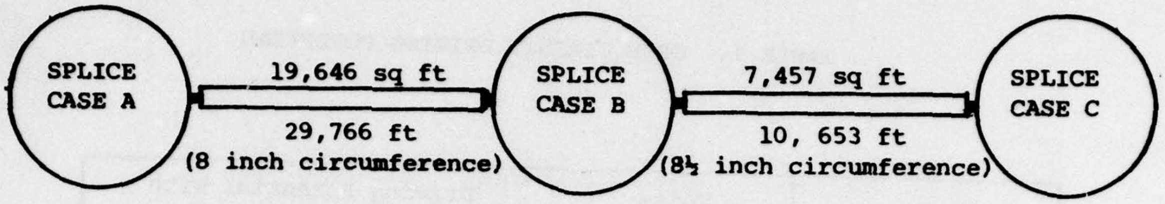
a. Determine magnitude of corrosion.

b. Locate areas of maximum current discharge.

c. Develop a method for determining the minimum cathodic protection required. The method should be field usable to determine surface potential criteria.

C. TEST APPARATUS

Field conditions were simulated by placing each splice case in a large steel trough. The inside of the trough was well coated to insulate the splice case and cable from the steel, so that galvanic corrosion would be confined to just the splice case and the cable. The troughs were filled with approximately 330 gallons of water which was chemically altered to represent the corrosive environment for splice cases near Whiteman AFB MO (pH of 6 and soil resistivity of 1160 ohm-cm).



Notes:

1. Assume that Splice Case B is a 2 foot diameter ball whose surface area is 12.56 sq ft.

2. If one half of each cable affects Splice Case B, then the surface area of cable involved is:

$$\frac{19{,}646 \text{ sq ft} + 7{,}457 \text{ sq ft}}{2} = 13{,}551 \text{ sq ft}$$

3. The ratio of graphite area to splice case area in this example is:

$$\frac{13{,}551 \text{ sq ft}}{12.56 \text{ sq ft}} \approx 1{,}080 \text{ or } \underline{1100 \text{ to } 1}$$

4. In this case, the splice case will be subject to a high density of current discharge.

Figure 1. Surface Area Ratio Example - Cable/Splice Case

TABLE 1. OPEN CIRCUIT DRIVING POTENTIAL

Metal	Volts	Driving Potential with Respect to Graphite (Volts)
Aluminum (Alclad 35)	-1.01	1.01 to 1.11
Cast Iron	-.68	.68 to .79
Bronze (Composition G)	-.38	.38 to .48
Graphite	not listed, but usually 0 to +.1	0.0

Note: Typical open-circuit potential measured with copper sulfate reference electrode. (from AFM 88-9, Chapter 4, Table 4-2)

The graphite impregnated cables were curved around inside the trough and kept beneath the water surface as much as possible. Although this did not provide the same anode to cathode surface area ratios found in the field, it was still considered sufficient to meet the test objectives since more representative data would be available from the field tests.

The aluminum and bronze splice cases furnished for this test were new and had two cables attached to them. In addition, the aluminum splice case had an epoxy resin coating which appeared to be in good condition. The cast iron splice case provided was used and had three cables. Figure 2 shows a typical test set-up using an aluminum splice case.

D. TESTS TO DETERMINE MAGNITUDE OF CORROSION

The cable sheath on the HICS consists of a copper shield covered with graphite impregnated polyethylene. This sheath is normally electrically continuous with the splice case but for this test the sheath was insulated from the splice case. The cable sheath and the splice case were then connected by a wire to regain continuity, and to permit measurement of the galvanic corrosion current on each cable. The total corrosion current was then calculated, as the sum of the currents from each cable returning through the wires to the splice case. Figure 3 graphically shows the galvanic corrosion current flow and measurement technique. Tables 2, 3 and 4 show a sampling of the galvanic corrosion currents which were measured for each of the three different splice cases. I_T may not exactly be the total of I_1, I_2, and I_3 because of internal resistance of the ammeter.

1. <u>Cast Iron Splice Case</u>. The corrosion current steadily increased over a 90 day period from 3.25 to 5.23 milliampers (ma) where it remained relatively constant. Corrosion damage consisted of generally uniform surface corrosion with some isolated pitting.

2. <u>Aluminum Splice Case</u>. A startling result of the lab test was the fact that the initial corrosion current for the coated splice case was so high, since corrosion can only occur at holidays in the coating. The initial corrosion current was 4.99 ma but it rapidly decreased to a steady .10 ma within 20 days. Corrosion damage was confined to holidays in the epoxy resin coating as evidenced by the white tubercule formations of aluminum oxide which are visible in Figure 4. The high resistance of this aluminum oxide is probably what caused the significant reduction in corrosion current. However, even this corrosion current caused substantial damage, since all of the corrosion current was concentrated at the holidays. Figure 5 shows a pit 40 mils deep after only 60 days exposure.

3. <u>Bronze Splice Case</u>. Corrosion Current from the bronze splice case was higher than expected. The corrosion current between the splice case and cable sheeth started at 0.96 ma, increased to 1.99 ma, and settled down to 1.6 ma. Corrosion damage to the bronze was not expected to be significant since the galvanic potential between bronze and graphite is small.

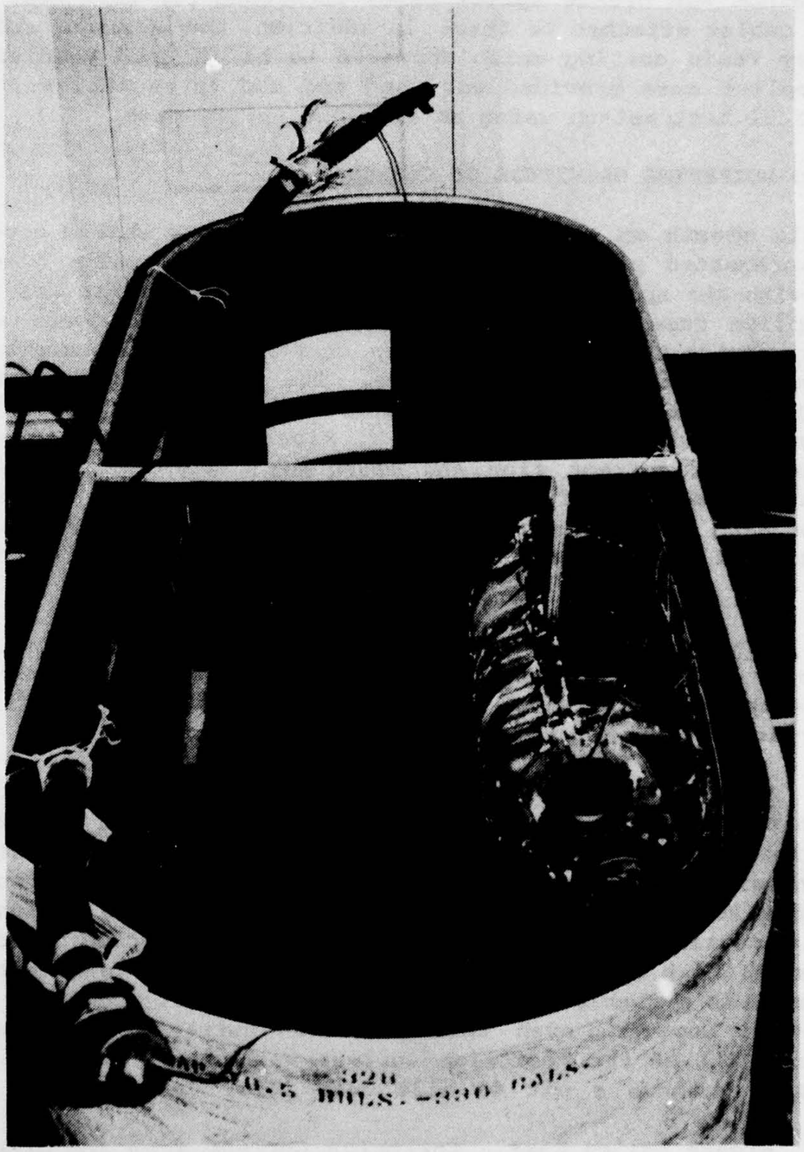
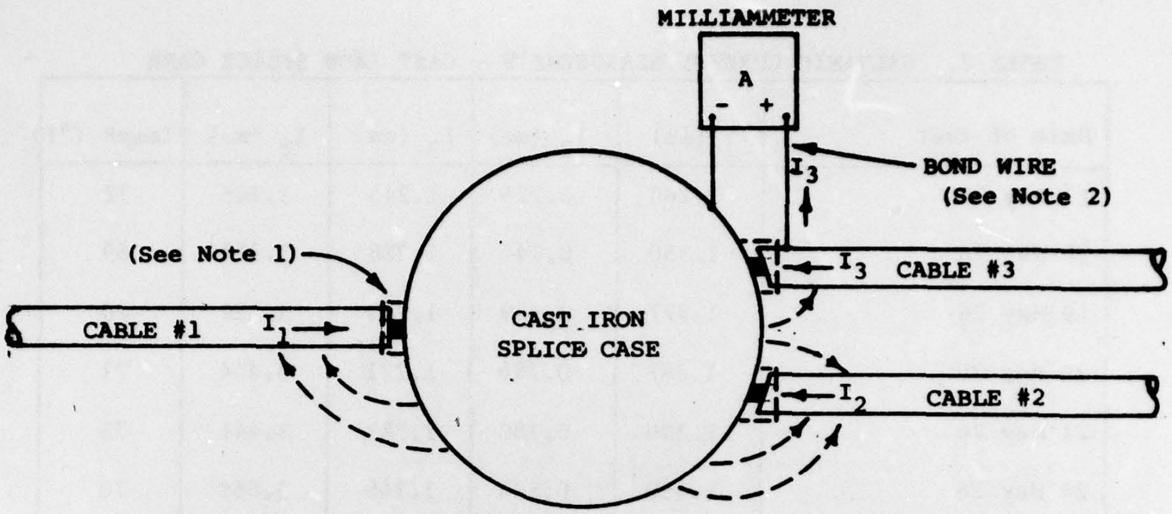


Figure 2. Aluminum Splice Case and Two Graphite Impregnated Cables Positioned Inside a Coated Steel Trough



Legend:

⟶ I_1 = Direction and magnitude of corrosion current in Cable #1.
- - ► = Galvanic corrosion current from anode (splice case) to cathode (cable).
I_T = Total corrosion current is $I_1+I_2+I_3$.

Notes:

1. Cable sheath is insulated from the splice case.
2. External bond wire electrically connects cable sheath to the splice case and permits measurement of corrosion current. Other bond wires were shorted to the case while current was being measured.

Figure 3. Test Set-up For Measuring Galvanic Corrosion Current

TABLE 2. GALVANIC CURRENT MEASUREMENTS - CAST IRON SPLICE CASE

Date of test	I_1 (ma)	I_2 (ma)	I_3 (ma)	I_T (ma)	Temp* (°F)
17 May 76	1.280	0.725	1.245	3.245	72
18 May 76	1.350	0.742	1.286	3.378	69
19 May 76	1.377	0.769	1.283	3.429	70
20 May 76	1.387	0.786	1.271	3.444	71
21 May 76	1.380	0.780	1.281	3.441	73
24 May 76	1.450	0.874	1.345	3.669	70
25 May 76	1.438	0.859	1.306	3.603	68
26 May 76	1.426	0.857	1.264	3.547	70
27 May 76	1.455	0.910	1.306	3.671	72
29 June 76	1.524	1.095	1.396	4.015	75
9 July 76	1.559	1.086	1.429	4.074	73
10 August 76	1.550	1.293	1.485	4.328	70
11 August 76	1.551	1.291	1.481	4.323	70
12 August 76	1.527	1.273	1.375	4.175	69
16 August 76	1.509	1.280	1.386	4.175	68
18 August 76	1.511	1.268	1.390	4.169	67
23 August 76	1.443	1.250	1.227	3.920	77
24 August 76	1.475	1.247	1.246	3.968	79
25 August 76	1.520	1.324	1.396	4.240	80
14 September 76	1.910	1.730	1.590	5.230	72

*Average temperature was 71.67°F.

TABLE 3. GALVANIC CURRENT MEASUREMENTS - ALUMINUM SPLICE CASE

DATE OF TEST	I_1 (ma)	I_2 (ma)	I_T (ma)	TEMP* (°F)
3 September 76	2.56	2.34	4.99	79
7 September 76	1.13	1.10	2.23	62
8 September 76	1.40	1.24	2.64	67
9 September 76	1.46	1.29	2.75	68
13 September 76	0.64	0.73	1.37	75
16 September 76	0.99	0.86	1.85	75
20 September 76	0.030	0.027	0.057	70
23 September 76	0.051	0.053	0.104	74

*Average temperature was 71.25°F.

TABLE 4. GALVANIC CURRENT MEASUREMENTS - BRONZE SPLICE CASE

DATE OF TEST	I_1 (ma)	I_2 (ma)	I_T (ma)	TEMP* (°F)
17 November 76	0.431	0.535	0.966	70
18 November 76	0.530	0.578	1.108	70
19 November 76	0.535	0.580	1.150	71
30 November 76	0.659	0.732	1.391	71
2 December 76	0.817	0.713	1.530	71
3 December 76	0.950	0.845	1.800	70
14 December 76	1.050	0.936	1.990	71
20 December 76	0.830	0.799	1.630	70
27 December 76	0.684	0.783	1.467	70
4 January 77	0.720	0.820	1.540	69
17 January 77	0.763	0.865	1.628	70
24 January 77	0.771	0.871	1.640	69

*Average temperature was 70.17°F.

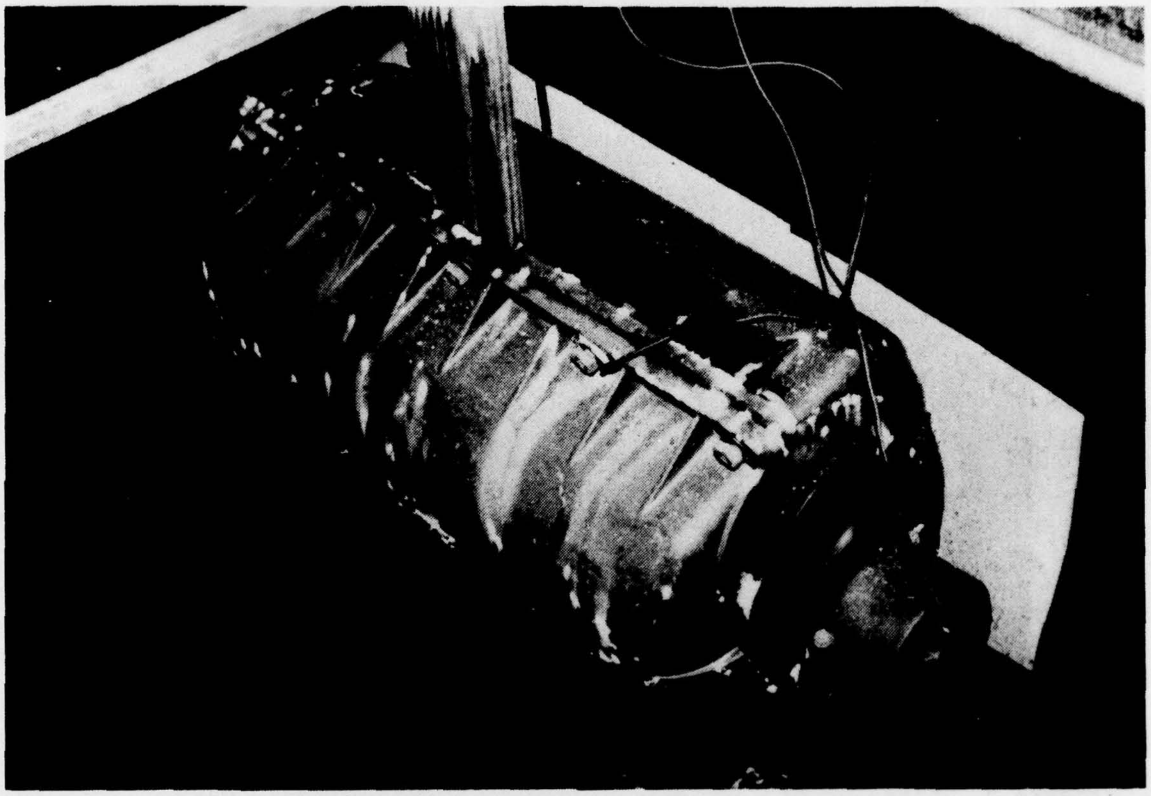


Figure 4. Corroded Aluminum Splice Case After 60 Days Exposure

Figure 5. Close-up of Corrosion Damage to Aluminum Splice Case

However, bronze splice cases have failed in the field when the stainless steel bolts sustained severe corrosion damage. This problem of bolt failure appeared peculiar to bronze splice cases only so additional testing, as described in paragraph G, Section II, was accomplished with the following results:

a. Most of the stainless steel bolts used on the first bronze splice cases were anodic to both the splice case and the graphite impregnated cable.

b. Bronze bolts were subsequently used but these had stainless steel washers and nuts which were anodic to the bolt and thus sustained severe corrosion damage.

c. The bolts, washers, and nuts should be of similar material and have a natural galvanic potential either equal to or slightly more positive than the splice case in order to minimize corrosion.

E. TEST TO LOCATE AREAS OF MAXIMUM CURRENT DISCHARE

The Earth Current Meter principle* was used to measure current leaving the splice case and flowing into the electrolyte. Although an earth current meter was not available for the lab tests, the principle was used by measuring two copper-copper sulfate half cell electrodes in the electrolyte, one placed close to the splice case and one placed four inches away. These electrode positions were moved radially around the splice case to find the area of greatest potential drop. In all three splice cases, the point of maximum corrosion turned out to be the end of the splice case close to a cable. Also, in every case, the direction of the current flow in the electrolyte was away from the splice case, indicating corrosion of the splice case.

F. TESTS TO DEVELOP A METHOD FOR DETERMING THE MINIMUM CATHODIC PROTECTION REQUIRED

The most accurate way of determining when splice cases are protected is to use earth current electrodes against the splice case at every splice case location. Since these splice cases are deep, a surface potential measurement above ground over the splice case would save an enormous amount of time, labor and equipment. This method was used both in the lab and during the field tests to develop surface potential criteria for splice cases. It should be recognized that when this technique is used in the field, the surface potential criteria will be valid only for splice cases of the same material, buried at the same depth, and tied to the same size, graphite-impreganted cable sheath.

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*Practical Applications of the Earth Current Meter, by Burton McCollum and K. H. Logan, Department of Commerce, Bureau of Standards, Washington DC, Paper No. 351.

In the lab, cathodic protection was used to reduce the corrosion current to zero at the point of maximum corrosion. Table 5 shows the currents of the splice case, the cables, and the rectifier with the rectifier on and off. Also shown is the potential between E_1 and E_2 and the structure-to-earth potentials of the splice case, close (⅜ inch above the splice case) and at the surface of the electrolyte (5 inches above the case). Figure 6 shows the test set-up. Figure 7 shows the circuitry used to measure the rectifier current.

Referring to Table 5 and Figure 7, without cathodic protection the galvanic corrosion current (I_{sc}) is equal to the sum of currents in each cable (I_{ca}). When cathodic protection is applied, the polarity of I_{sc} will reverse before the potential between the electrodes becomes zero. Therefore, I_{sc} is negative when corrosion of the splice case is stopped by cathodic protection, and I_{ca} is much greater with cathodic protection current flowing. When the rectifier is off, the structure-to-earth potential decreases as the electrode is moved farther away from the splice case. This is because the potential is influenced more by the graphite when the electrode is further away from the splice case. The structure-to-earth potential, E_4, is greater than E_3 when the rectifier is on, because the potential is influenced more by the impressed current anode when the electrode is farther away from the splice case. Also, a potential drop caused by rectifier current flowing through the electrolyte between the electrode and the splice case will add to the potential E_4.

Influence from an anode bed will not be a problem in the field since the anode bed will be thousands of feet to miles away from the splice cases. However, potential drop through the electrolyte (IR drop) is always a problem when measuring structure-to-earth potentials, especially on bare structures (requiring high current) in high resistivity soils. The potentials measured in the field to develop the criteria will include IR drop, these criteria will be valid only for the same type, size and depth of splice case in similar soil resistivity.

G. BOLT TESTS FOR BRONZE SPLICE CASES

Although corrosion damage to bronze splice cases was insignificant in the laboratory, they have failed in the field when the stainless steel bolts sustained severe corrosion damage. This problem of bolt failure seems limited to bronze splice cases only, so additional laboratory testing, as described in this section, was accomplished.

Table 6 shows the structure-to-electrolyte potentials for the bronze splice case, the cables, and each bolt. The set-up used to make these measurements is shown in Figure 8. With the cables isolated from the splice case (open circuit), the potentials of the cables with respect to a $CuSo_4$ electrode were -0.038 volts and -0.040 volts and the potential of the bronze splice case, with the electrode held at the center of the case (away from any bolts), was -0.085 volts. Potentials of the splice case with the $CuSo_4$ electodes positioned close to each bolt are listed in Table 6. These potentials indicate that, with the exception of bolts 2, 7, 9,

TABLE 5. GALVANIC CURRENT AND POTENTIAL MEASUREMENTS

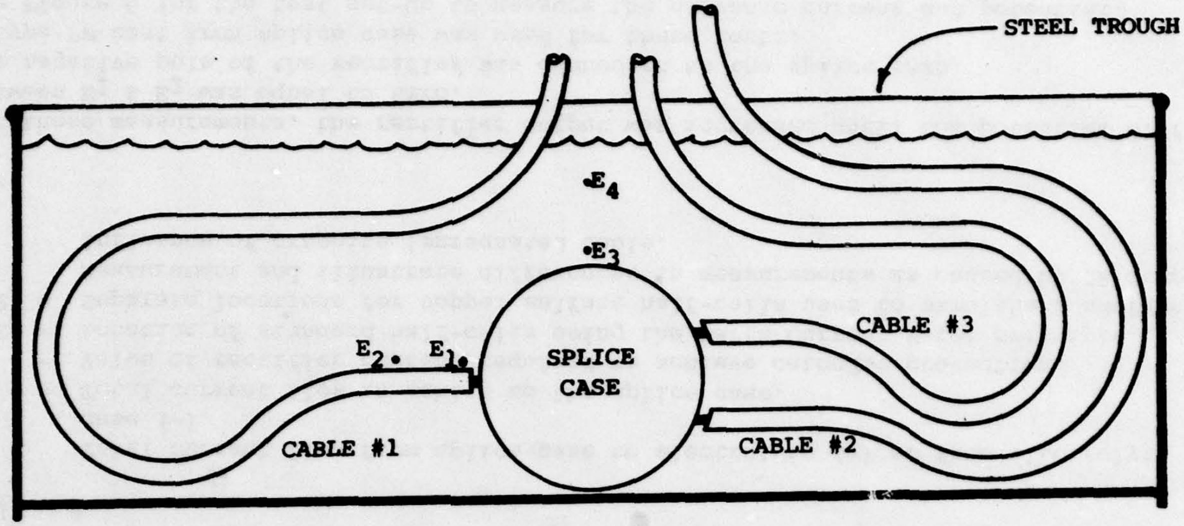
	Potential Between E_1 & E_2 (mv)		I_{sc} (ma)		I_{ca} (ma)		I_r (ma)		E_3 (mv) (½ inch above S.C.)		E_4 (mv) (5 inches above S.C.)	
			See Figure 7									
	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON
Cast Iron Splice Case	+73	0	13.5	-22	13.5	26	0	48	-.690	-.710	-.688	-.750
Aluminum Splice Case	+14	0	1.65	-0.6	1.65	2.4	0	3	-.693	-.739	-.692	-.739
Bronze Splice Case	+280	0	2.0	-49	2.0	68	0	117	-.255	-.489	-.210	-.839

Legend:

I_{sc} = Total current flow from splice case to electrolyte (+) or from electrolyte to splice case (-).
I_{ca} = Total current flow in cables to the splice case.
I_r = Value of rectifier current required to achieve cathodic protection.
E_1 & E_2 = Location of standard half-cells using the Earth Current Meter principle.
E_3 & E_4 = Separate locations for copper sulfate half-cells used to simulate a surface potential measurement and illustrate differences in measurements as caused by IR drop and strong influence of graphite impregnated cable.

Notes:

1. For these measurements, the rectifier output was increased until the potential difference between E_1 & E_2 was equal to zero.
2. The negative pole of the rectifier was connected to the splice case.
3. A type-FW cast iron splice case was used for these tests.
4. See Figure 6 for the test set-up to measure the galvanic current and potential.



__Legend:__

E_1 & E_2 = Location of standard half cells using the Earth Current Meter Principle.
E_3 & E_4 = Separate locations for copper sulfate half cells used to simulate a surface potential measurement and illustrate differences in measurments as caused by IR drop and the strong influence of the graphite impregnated cable.

__Notes:__

1. See Table 5 for the results of the galvanic current and potential measuremrnts.

Figure 6. Set-up for Galvanic Current and Potential Measurement in the Lab

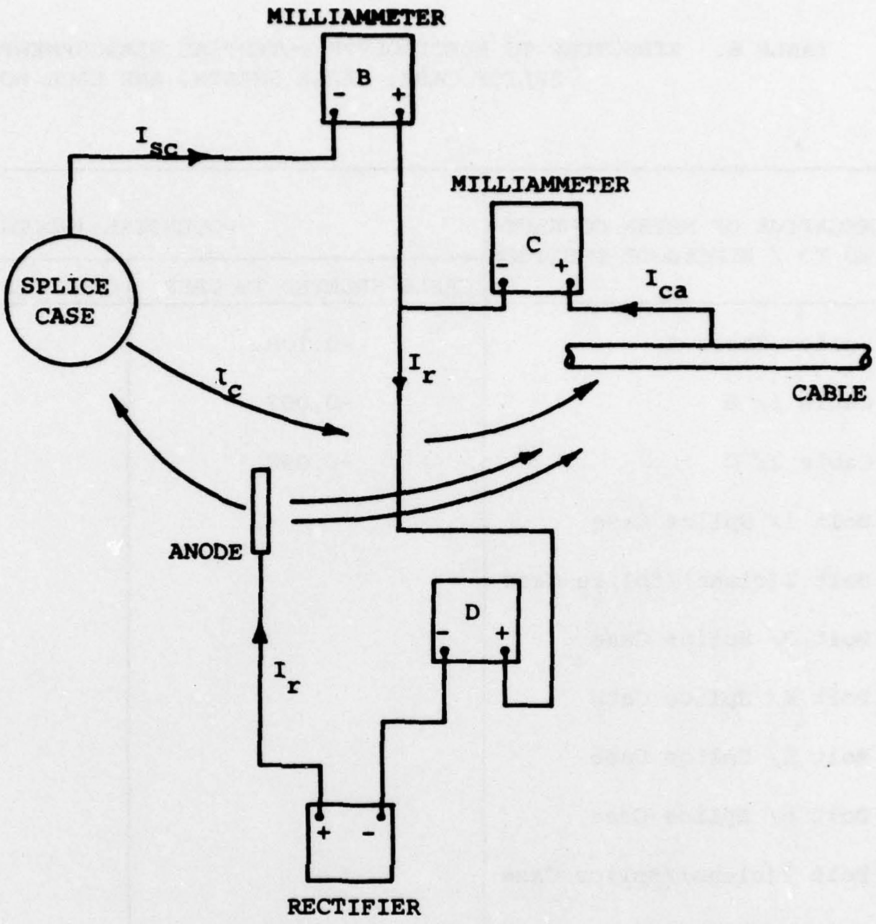


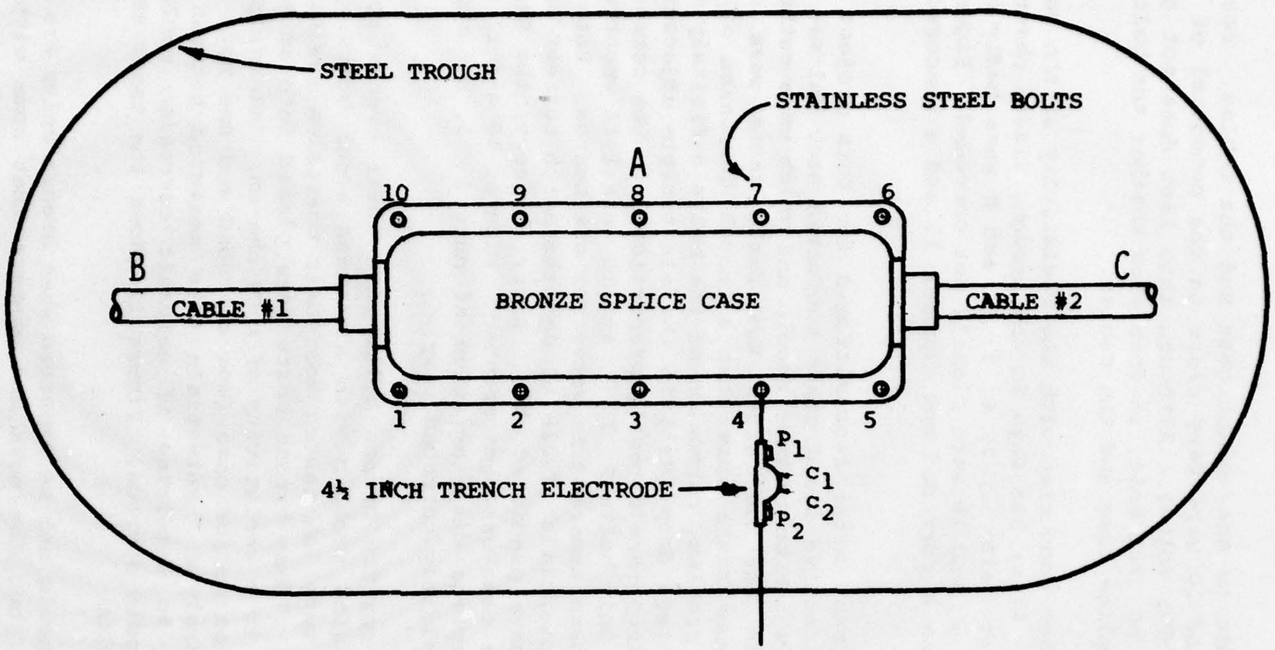
Figure 7. Circuitry Used to Measure Rectifier Current

TABLE 6. STRUCTURE TO ELECTROLYTE POTENTIAL MEASUREMENTS - BRONZE SPLICE CASE, CABLE SHEATH, AND EACH BOLT

NEGATIVE OF METER CONNECTED TO / ELECTRODE POSITION	POTENTIAL (VOLTS)	
	CABLE SHORTED TO CASE	CABLE ISOLATED FROM CASE
Splice Case/ A	-0.108	-0.085
Cable 1/ B	-0.097	-0.038
Cable 2/ C	-0.098	-0.040
Bolt 1/ Splice Case		-0.200
Bolt 2(clean)/Splice Case		-0.080
Bolt 3/ Splice Case		-0.170
Bolt 4/ Splice Case		-0.179
Bolt 5/ Splice Case		-0.150
Bolt 6/ Splice Case		-0.120
Bolt 7(clean)/Splice Case		-0.095
Bolt 8/ Splice Case		-0.250
Bolt 9(clean)/Splice Case		-0.091
Bolt 10(clean)/Splice Case		-0.086

Notes:

1. Negative of meter was connected to each individual bolt and the electrode placed adjacent to the bolt for these measurements.
2. The surface of bolts 2, 7, 9, and 10 were clean, while the other bolts had a thin film of corrosion products on them.
3. These measurements were taken before the six-month exposure test (Table 7).
4. See Figure 8 for the lab set-up used to obtain these measurements.



Legend:

A,B,&C = Electrode positions for the structure-to-electrolyte potential measurements. (see Table 6 for data)

P_1 & P_2 = Electrode positions used to measure the voltage drop due to corrosion current. (see Table 7 for data)

Figure 8. Lab Set-up for Earth Current Meter Tests at Bolts- Bronze Splice Case

and 10, the bolts are anodic to the splice case and the cables. Potentials of bolts 2, 7, 9, and 10 were very close to the potential of the bronze case (-0.080 to -0.095 volts). Although this test does not give the open circuit potential of each bolt, it does show whether the bolt is anodic or cathodic to the splice case and the cables.

An exposure test was then conducted with the resistivity of the water maintained at 1400 ohm-cm. After 155 days in the trough, visual observation showed that the nuts or bolts 1, 3, 4, 5, 6, and 8 were badly corroded and that bolts 2, 7, 9, and 10 were clearly not corroded. Figure 9 shows the difference between a corroded nut (number 1) and a noncorroded nut (number 10).

Although the earth current meter requisitioned for this project did not arrive in time for the active field tests conducted near Whitman AFB MO, it was used to detect which bolts were anodic and which were cathodic around the bronze case in the lab after the field tests were completed. The results of these tests show that although corrosion of the bronze case will not be a problem, corrosion of the bolts definitely will be. Table 7 shows the voltage drop (Ee') in the electrolyte adjacent to the bolts. These voltage drops are directly proportional to the corrosion current that causes them. Only bolts 2, 7, 9, and 10 were left uncorroded after the splice case had been immersed in water for six months. Both the structure-to-electrolyte potentials (Table 6) and the earth current meter readings (Table 7) could have predicted this. After 1½ years, the trough was drained and the splice case was photographed. Figures 10 and 11 show that corrosion caused complete disintegration of nuts 1, 3, 4, and 8. Nuts 5 and 6 were also completely corroded away.

HQ SAC has begun to specify bronze bolts with their bronze splice cases to avoid the corrosion problem with stainless steel bolts. Two bronze bolts from HQ SAC were lab tested for their corrosion resistance with bronze splice cases. These bronze bolts were placed into an electrolyte that was adjusted to a resistivity of 1000 ohm-cm. Two stainless steel bolts from the bronze splice case (one corroded and one not) were also placed in the electrolyte. Potentials were measured between the bolts, nuts, and washers to determine if galvanic corrosion could be expected and which ones would corrode. Figure 12 shows the tests set-up and Table 8 shows the results.

A corrosion problem should not be expected when bronze bolts are used on a bronze splice case, but the nuts and washers that come with the bronze bolts are stainless steel and will corrode.

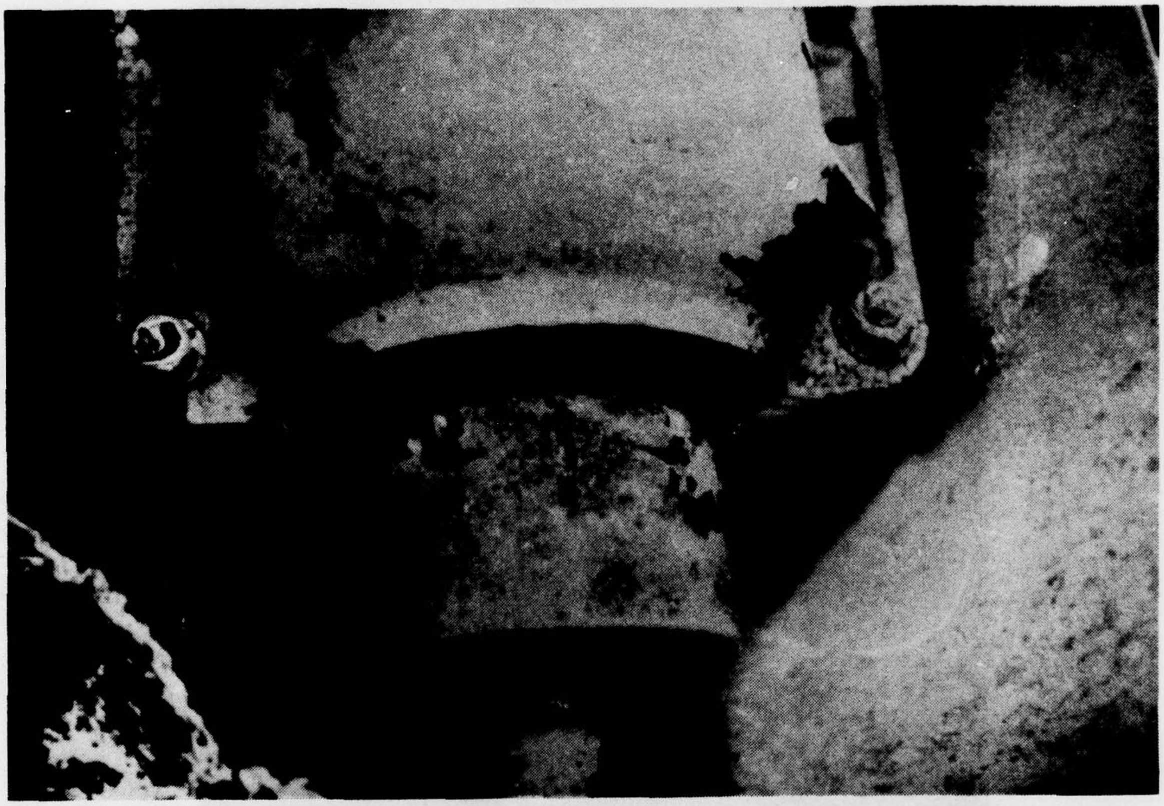


Figure 9. Corrosion to Bolts 10 and 1 (Right to Left)

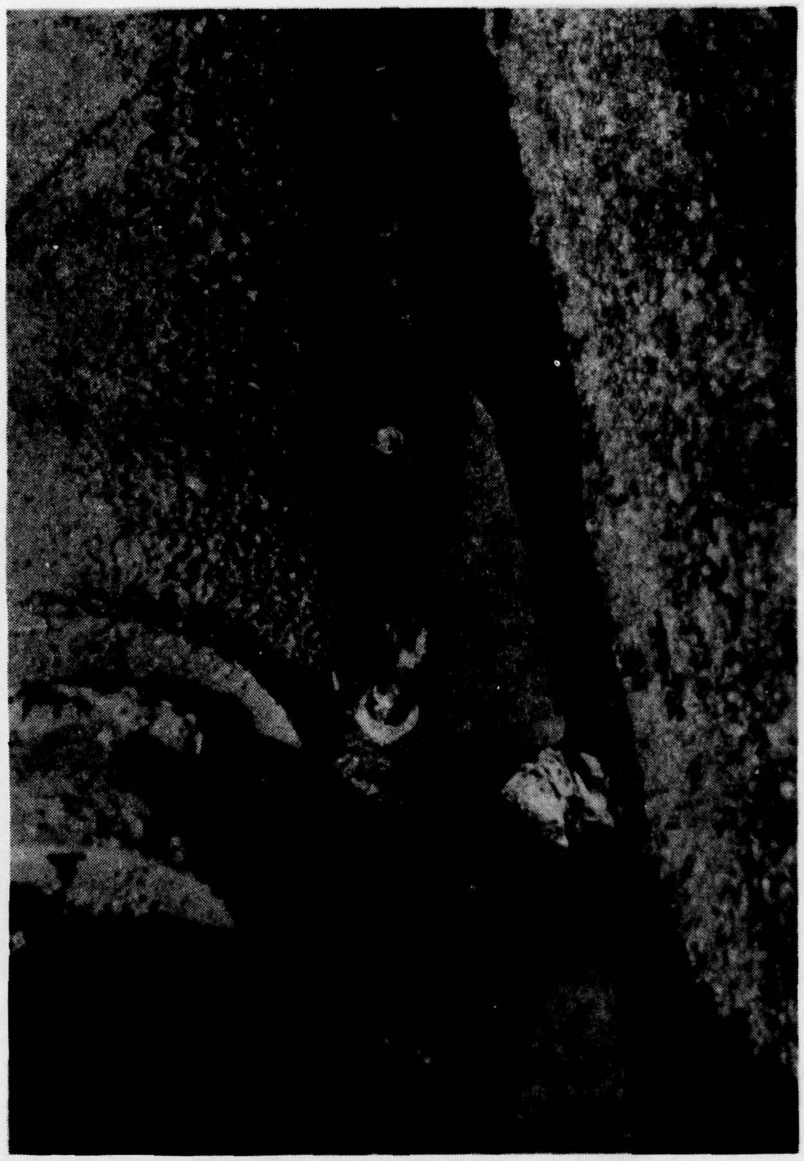


Figure 10. Stainless Steel Nuts 1, 3, and 4 Corroded Away After 1½ Years in Water (Lab Test)

Figure 11. Stainless Steel Nut Number 8 Corroded Away After 1½ Years in Water (Lab Test)

TABLE 7. EARTH CURRENT METER TESTS AT BOLTS - BRONZE SPLICE CASE

BOLT NUMBER	Ee' (volts)
1	+.240
2	+.010
3	+.240
4	+.162
5	+.340
6	+.090
7	-.007
8	+.215
9	+.015
10	-.006

Notes:

1. The Earth Current Meter *Principal* was used to determine which bolts were anodic and which were cathodic.

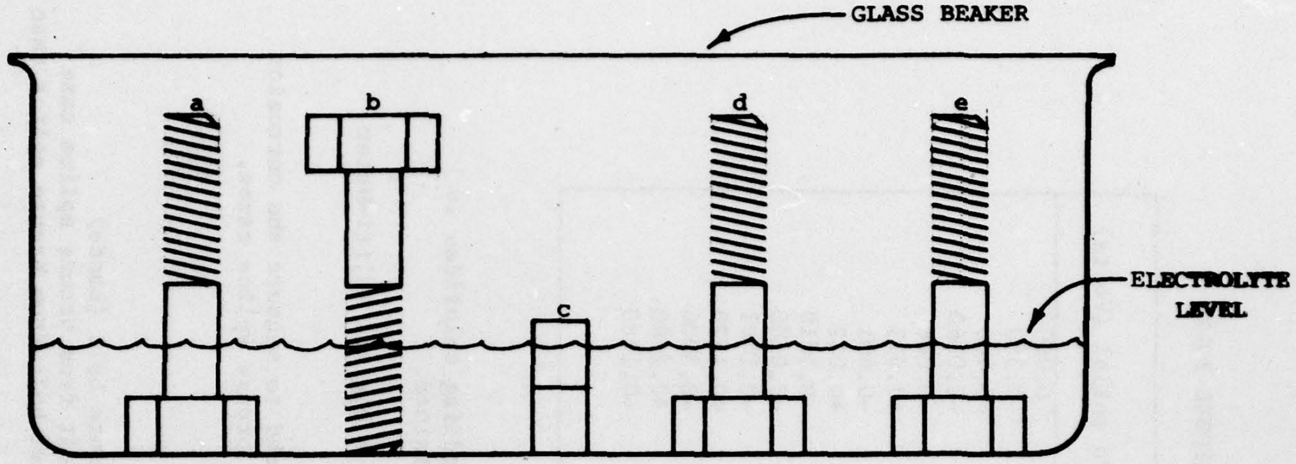
2. Ee' is the voltage drop between electrodes P_1 and P_2. These voltage drops are directly proportional to the corrosion current that causes them. For Example:

$$\text{corrosion current (i)} = \frac{(R)(Ee')(I_c)}{E_c}$$

For Bolt #5,
$Ee' = +.340$ volts
$E_c = 1.15$ volts
$I_c = 17.5$ ma
$R = 6.6$ (constant)

$$\text{Corrosion Current For Bolt \#5} = \frac{(6.6)(.340)(17.5)}{1.15} = 34 \text{ ma/sq ft}$$

3. See Figure 8 for the test set-up used to get the data in this table.



Legend:

a & b = Bronze bolts.
c = Stainless steel nut from bronze bolt (anode).
d = Corroded stainless steel bolt from bronze splice case.
e = Non-corroded stainless steel bolt from bronze splice case.

Notes:

1. The stainless steel nuts and washers for bolts b, d, and e were also immersed in the electrolyte but are not shown here. Bolt b had 4 washers.
2. See table 8 for results of the tests illustrated here.

Figure 12. Set-up to Measure Corrosion Resistance of Bronze Bolts for Bronze Splice Cases

TABLE 8. CORROSION RESISTANCE OF BRONZE BOLTS FOR BRONZE SPLICE CASES

Meter Connections		Potential (Volts)
+	−	
a	b	0.0005
c	a	−0.380
c	b	−0.400
d	a	−0.0160
e	a	−0.006
d	e	+0.013
d	b	−0.001
e	b	+0.042
d (nut)	e (nut)	−0.4810
c (nut)	e (nut)	−0.0280
d (bolt)	e (bolt)	−0.1601
b	b_1 (washer)	+0.1520
b	b_2 (washer)	−0.3000
b	b_3 (washer)	+0.2900
b	b_4 (washer)	+0.1880

Notes:

1. Electrolyte was formualted by adding chlorides to water until 1000 ohm-cm was obtained.

2. Potentials were measured using a Digital Muliti-Meter (polarity as indicated).

3. See Figure 12 for the set-up used to measure the corrosion resistance of bronze bolts for bronze splice cases.

Legend:

a & b = bronze bolts
c = stainless steel nut from bonze bolt (anode)
d = corroded stainless steel bolt from bronze splice case
e = non-corroded stainless steel bolt from bronze splice case

SECTION III

FIELD TESTS

A. GENERAL

The earth current meter principle, which was proven in the lab, was used to detect anodic areas along two splice cases in the field. Two copper-copper sulfate electrodes were used to make measurements on an aluminum and a cast iron splice case at a missile complex near Whiteman AFB, MO. Figure 13 shows a portion of the hardened intersite cable system. The outer cable circle has a diameter of about 10 miles. All of the cable sheaths are electrically connected to themselves and to the underground steel structures at the missile sites. Therefore, any cathodic protection applied to the missile structures will spill over onto the cables and the splice cases. Figure 13 also shows the location of the splice cases on the cable between B-1 and B-2. Cathodic protection rectifiers are located at site LCF B-1 and site LF B-2. These rectifiers are designed to protect the underground metallic facilities at these two sites.

A cast iron splice case at site E and an aluminum splice case at site L were excavated and tested. It was determined that the aluminum splice case at site L is affected only by the rectifyer at LF B-2. The magnitude of the corrosion currents leaving the splice cases was detected by placing two electrodes close to the splice case and moving them radially around the case as shown in Figure 14. The potentials measured are shown in Table 9 and Table 10.

B. ALUMINUM SPLICE CASE

The aluminum splice case was tied to one 7½ inch circumference graphite-impregnated cable at a depth of four feet. Maximum corrosion on the aluminum splice case occurred at position 10 (Table 9 and Figure 14). The corrosion current leaving the splice case and traveling to the cable sheath caused a potential drop in the earth of 38.4 millivolts. Structure-to-earth potentials were measured with the electrode positioned as shown in Figure 15. Structure-to-earth potential number 19 was the highest negative leading indicating the strongest anodic area. Structure-to-earth potential reading number 18 was taken at the top of the bank. All other readings at site "L" were taken within the ditch. For this reason, location number 18 was used to determine the surface potential at which the aluminum splice case was adequately protected.

With the rectifier at LF B-2 set at 10.5 amps output, it can be seen from Table 9 that the corrosion current at the two-electrode position number 10 was reduced to a level that caused a potential drop between the electrodes of only 8.4 millivolts and a surface potential at structure-to-earth potential location number 18 of -502 millivolts. Since there was a natural potential difference of 4 millivolts between the two electrodes, the potential drops at position 10 were corrected to 34.4 millivolts with the current off and 4.4 millivolts with the current on. The potential required at the surface of the ground (at position 18) was calculated by the expression:

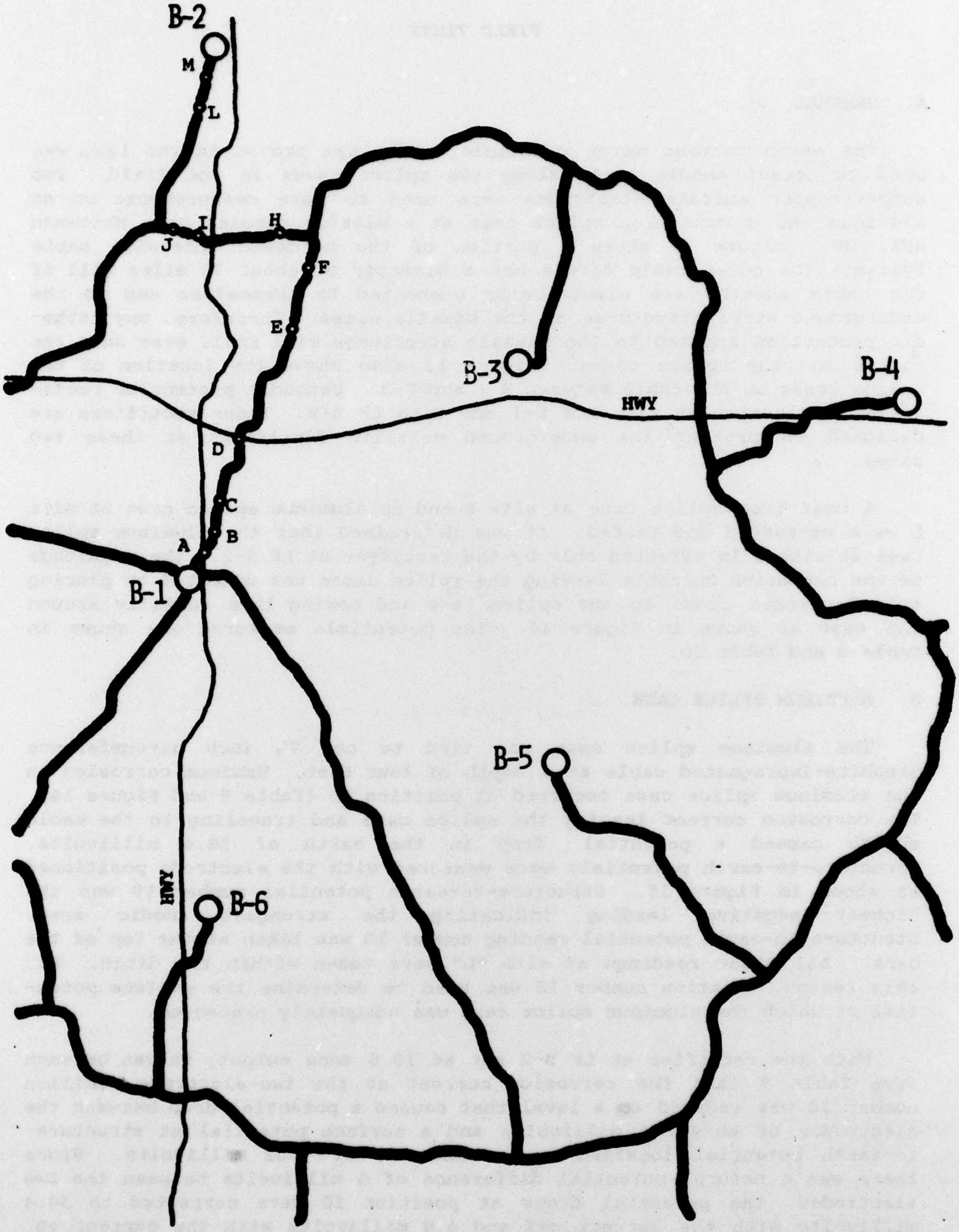


Figure 13. A Portion of the Hics Near Whiteman AFB, Missouri

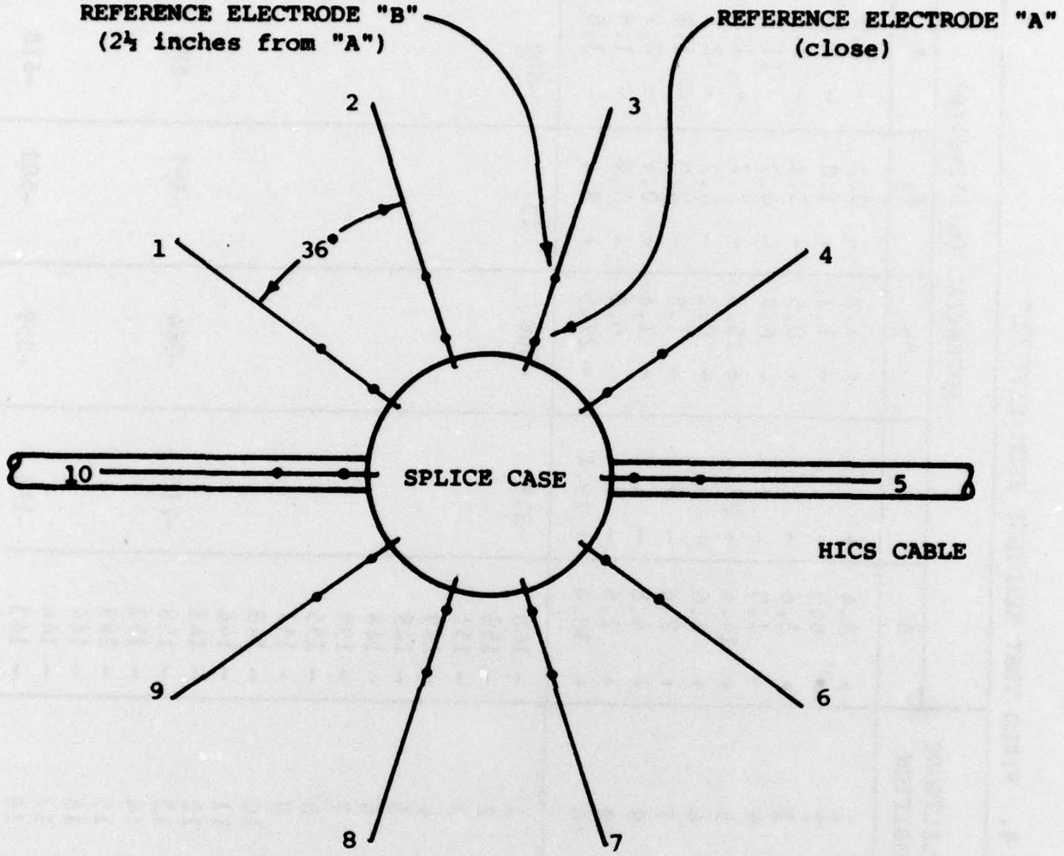


Figure 14. Set-up to Measure Earth Potential Drop (Two Electrode Method)

TABLE 9. FIELD TEST READINGS FROM SITE "L"

	ELECTRODE POSITION	POTENTIAL (millivolts)					
		A	A_1	A_2	A_3	A_4	A_5
Earth Potential Drop/ Two Electrode Method (See Figure 14)	1	+ 5.4	+ 2.6	+ 1.2	- 0.2	- 2.0	- 2.3
	2	+ 6.3	+ 1.4	+ 1.1	+ 1.0	- 2.0	- 1.1
	3	+ 3.6	+ 1.3	+ 0.5	- 1.1	- 3.1	- 3.0
	4	- 1.0	- 3.5	- 6.7	- 4.9	- 11.3	- 8.5
(natural potential between electrodes = +4 mv)	5	+ 24.4	+ 22.4	+ 15.3	+ 7.7	+ 1.1	- 5.9
	6	+ 5.6	+ 5.1	+ 0.2	- 0.2	- 2.1	- 4.2
	7	+ 2.4	- 0.4	- 1.6	- 2.0	- 1.8	- 17.7
	8	+ 4.8	- 1.2	+ 1.4	+ 0.4	- 2.2	- 15.2
	9	+ 2.6	- 1.4	0.0	- 0.9	- 1.6	- 3.6
	10	+ 38.4	+ 19.4	+ 27.5	+ 8.4	- 3.6	- 12.5
Structure-to-Earth Potential/Single Electrode (See Figure 15)	1	- 168	-218	-368	-497	-602	-713
	2	- 158					
	3	- 151					
	4	- 149					
	5	- 148					
	6	- 148					
	7	- 199					
	8	- 155					
	9	- 151					
	10	- 148					
	11	- 146					
	12	- 145					
	13	- 158	-210	-364	-497	-605	-717
	14	- 152					
	15	- 149					
	16	- 144					
	17	- 144					
	18	- 143	-194	-359	-502	-618	-738

TABLE 9. FIELD TEST READINGS FROM SITE "L" (CONCLUDED)

	ELECTRODE POSITION	POTENTIAL (millivolts)					
		A	A_1	A_2	A_3	A_4	A_5
Structure-to-Earth Potential/Single Electrode (continued)	19	- 248					
	20	- 160					
	21	- 150					
	22	- 150					
	23	- 147					
	24	- 147					

Legend:

All "A" readings taken on an aluminium splice case.

A = both rectifiers off
A_1 = rectifier LCF B-1 at 0 amps; rectifier LF B-2 at 0.9 amps.
A_2 = rectifier LCF B-1 at 0 amps; rectifier LF B-2 at 5 amps.
A_3 = rectifier LCF B-1 at 0 amps; rectifier LF B-2 at 10.5 amps.
A_4 = rectifier LCF B-1 at 0 amps; rectifier LF B-2 at 16.5 amps.
A_5 = rectifier LCF B-1 at 0 amps; rectifier LF B-2 at 22.5 amps.

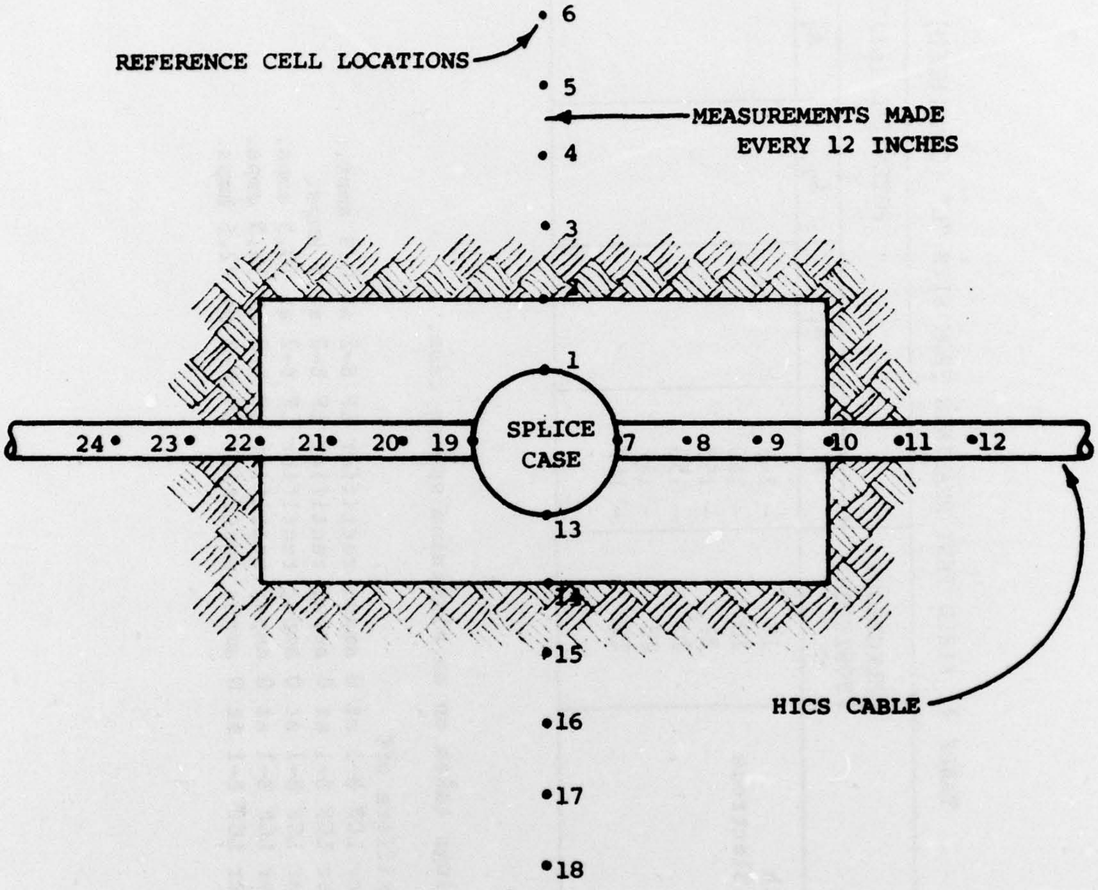


Figure 15. Set-up to Measure Structure-to-Earth Potentials (Single Electrode)

$$\frac{\text{two electrode change obtained}}{\text{two electrode change needed}} = \frac{\text{surface potential change obtained}}{\text{surface potential change needed}}$$

$$\text{Therefore:} \quad \frac{38.4 \text{ mv} - 8.4 \text{ mv}}{34.4 \text{ mv}} = \frac{-502 \text{ mv} - (-143 \text{ mv})}{X}$$

Solving for X; the surface potential change needed for adequate protection of the aluminum splice case is -409 millivolts. This change added to the original surface potential of -143 millivolts gives a surface potential of -552 millivolts. The structure-to-earth potential required for adequate protection of this aluminum splice case is -552 millivolts measured at the surface of the ground.

C. CAST IRON SPLICE CASE

Similar tests were conducted at site E on a cast iron splice case. The data taken is shown in Table 10. A review of the data for the cast iron splice case will show that the potential drop readings do not all logically become more negative as the rectifier output increases. Investigation of this illogical phenomenon revealed that readings could not be duplicated because once moved, the two electrodes could not be put back in the exact same spot. In addition, it was difficult to maintain the exact same spacing between the two electrodes (see Figure 16). Time did not permit repeating all the measurements which would involve keeping the electrodes in the same position while the outputs of the two recifiers were changed through the six different values for each of the ten sets of readings. It can also be seen from the data that the potential drop caused by corrosion current could not be reduced substantially with both rectifiers turned all the way up and so there was no reason to repeat all of these readings.

Apparently the rectifers were located too far away. For this reason a temporary ground bed and rectifier was set up approximately 400 feet from the splice case. The water was pumped out of the hole and the potential drop test was repeated using two electrodes at 10 different positions (Figure 14). The highest corrosion current was detected at position 10. The potential drop at position 10 caused by this current, without moving the two electrodes, was 58.4 millivolts. The two electrodes were left in the same position while the temporary rectifier was cycled on and off. The current output from the temporary rectifier was increased until the potential drop between the two electrodes was reduced to zero. At this point all corrosion was stopped or nullified by cathodic protection. While the temporary rectifier was cycled on and off at this level of current, structure-to-earth surface potential was measured at the top of bank (position number 18). This surface potential was -170 millivolts with the temporary rectifier off and was -340 millivolts with the temporary rectifier on. Both B-1 and B-2 rectifiers were off. The original potential of +170 mv subtracted from -340 mv gives a required change in potential of 510 millivolts for this cast iron splice case.

TABLE 10. FIELD TEST READINGS FROM SITE "E"

	ELECTRODE POSITION	POTENTIAL (millivolts)					
		B	B_1	B_2	B_3	B_4	B_5
Earth Potential Drop/ Two Electrode Method (See Figure 14) (natural potential between electrodes = +4 mv)	1	+ 61.2	+ 45.5	+ 51.1	+ 50.9	+ 55.2	+ 56.7
	2	+ 31.7	+ 31.2	+ 28.6	+ 22.0	+ 28.9	+ 29.9
	3	+ 25.8	+ 15.6	+ 15.9	+ 31.9	+ 17.0	+ 28.0
	4	+ 23.8	+ 38.6	+ 38.5	+ 38.0	+ 40.5	+ 35.5
	5	+ 53.4	+ 53.3	+ 48.7	+ 51.6	+ 52.5	+ 53.9
	6	+ 61.9	+ 65.9	+ 65.8	+ 67.3	+ 65.2	+ 64.0
	7	+ 74.0	+ 59.5	+ 61.3	+ 60.7	+ 52.7	+ 53.2
	8	+ 72.5	+ 66.3	+ 63.2	+ 68.2	+ 64.1	+ 57.8
	9	+ 55.0	+ 59.8	+ 64.3	+ 67.8	+ 62.7	+ 60.2
	10	+ 57.2	+ 51.9	+ 47.3	+ 39.3	+ 38.4	+ 38.7
	10*	+ 58.4					
Structure-to-Earth Potential/Single Electrode (See Figure 15)	1	- 360	-188	-184	-489	-461	-386
	2	- 368					
	3	- 373					
	4	- 028					
	5	- 101					
	6	- 106	+191	+197	-108	- 78	- 63 (stray)
	7	- 268					
	8	- 049					
	9	+ 045					
	10	+ 073					
	11	+ 098					
	12	+ 122					
	13	- 262	-203	-193	-501	-470	-320 (stray)
	14	+ 001					
	15	+ 070					
	16	+ 114					
	17	+ 119					
	18	+ 170	+213	+203	-105	- 67	- 72

*Potential drop measurements repeated without moving electrodes. (See paragraph C of Section III)

TABLE 10. FIELD TEST READINGS FROM SITE "E" (CONCLUDED)

	ELECTRODE	POTENTIAL (millivolts)					
	POSITION	B	B_1	B_2	B_3	B_4	B_5
Structure-to-Earth Potential/Single Electrode (continued)	19	- 322					
	20	- 145					
	21	- 026					
	22	+ 052					
	23	+ 077					
	24	+ 086					

<u>Legend</u>:

All "B" readings taken on a cast iron splice case.

B = Both rectifiers off.
B_1 = Rectifier LCF B-1 at 0 amps; rectifier LF B-2 at 0.9 amps
B_2 = Rectifier LCF B-1 at 3.75 amps; rectifier LF B-2 at 5 amps.
B_3 = Rectifier LCF B-1 at 10 amps; rectifier LF B-2 at 10.5 amps.
B_4 = Rectifier LCF B-1 at 15.6 amps; rectifier LF B-2 at 16.5 amps.
B_5 = Rectifier LCF B-1 at 21.8 amps; rectifier LF B-2 at 22.5 amps.

Figure 16. Measuring Potential Drop in Electrolyte (Two Electrode Method)

SECTION IV

CATHODIC PROTECTION SURVEY PROCEDURES FOR SPLICE CASE

A. SURVEY PROCEDURE

The earth current meter principle is the most accurate method of determining when splice cases are protected; however, use of this method as a routine survey procedure would require excavation of every splice case in question.

Splice cases of the same material, buried at the same depth, and tied to the same size cable sheath as those tested at Whiteman AFB can be surveyed without any costly excavation. This survey uses an M3M multimeter and the standard structure-to-earth potential procedure to measure the surface potential at ground level above the splice case. This measurement is then compared with the criteria developed during this effort to determined how much cathodic protection is needed for adequate corrosion resistance.

Splice cases not conforming to the same conditions as those tested at Whiteman AFB will have to be surveyed by the earth current meter principle. Once criteria is developed for each different splice case configureation, then the multimeter technique can be used to survey every splice case.

B. SURFACE POTENTIAL CRITERIA

An aluminum splice case buried at four feet deep and tied to one 7½ inch circumference graphite impregnated polyethyelene cable sheath requires a structure-to-earth potential of -552 millivolts or more negative (with respect to a copper-copper sulfate reference electrode placed over the splice case at the surface of the earth) or a change in potential of 409 millivolts in the negative direction for adequate cathodic protection.

For adequate cathodic protection of a cast iron splice case buried at four feet and tied to one 8 inch circumference graphite impregnated polyethyelene cable sheath, a structure-to-earth potential of -340 millivolts or more negative (with respect to a copper-copper sulfate reference electrode placed over the splice case at the surface of the earth) or a change in potential of 510 millivolts in the negative direction is required.

As a general rule, if the surface area of the cable is greater or the depth is greater, then the required potential will be less negative and vice versa.

SECTION V

RECOMMENDATIONS

1. Bronze splice cases will not require cathodic protection, but all bolts, nuts, and washers used in repair work or new installation should also be bronze.

2. Many missile installations do not have cathodic protection. Those that have reported failed and replaced splice cases should have first priority for installation of cathodic protection.

3. A follow-on study to categorize splice cases as they are now used in the field should be initiated. Splice cases should be grouped according to the splice case material, the depth buried, and the size, types, and number of cables connected to it. Surface potential criteria for each category should be developed using the earth current meter. The degree of variation in the first few criteria should indicate whether or not each splice case configuration requires a different set of surface potential criteria. An earth current meter and consultant services are available at the Air Force Engineering and Services Center, Tyndall AFB, Florida.

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