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A Zn ANODE CATHODIC PROTECTION SYSTEM ON THE AFDL-20

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Project NY 450 004-4
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OBJECT OF PROJECT

To find or develop materials and techniques for arresting and/or preventing rusting or weathering of marine structures, shore establishment facilities, construction equipment and materials during normal usage and storage.

OBJECT OF SUBPROJECT

To develop satisfactory methods for employing "Cathodic Protection" to prevent or inhibit rusting of metallic equipment by use of inert anodes with rectifiers and sacrificial anodes made of magnesium, aluminum or zinc; to determine the suitability of employing electrolytic action to remove rust scales from clean surfaces as well as depositing rust-inhibitive coatings on clean steel surfaces.

OBJECT OF REPORT

To describe the adequacy, maintenance requirements, and cost of a zinc anode cathodic protection system for the exterior hull of AFDL-class floating drydocks.

RESULTS

A zinc anode cathodic protection system comprised of six 60-lb anodes suspended around the hull periphery performed adequately for approximately 18 months in a sea water environment. Operational maintenance was required for removal of the anodes during relocation of the drydock and for periodic measurement of the hull potential. If a galvanic anode system is preferred to an impressed current system on the basis of simplicity, cost and maintenance, zinc is recommended.

SUMMARY

The Bureau of Yards and Docks requested the Laboratory to find methods for preventing corrosion of metallic equipment such as floating drydocks, storage tanks, buried pipes, marine structures and shore establishment facilities. Experiments were conducted to develop "Cathodic Protection", using sacrificial anodes of zinc on an AFDL-class floating drydock.

The cathodic protection system performed satisfactorily for 18 months in a sea water environment. Six 60-lb anodes were suspended around the hull periphery of the AFDL-20. No electrical maintenance was necessary, though operational maintenance was required for removal of the anodes for relocation and periodic inspections. Insulation of the hull from adjacent metallic structures was continuously maintained.

Results show that surface corrosion significantly was reduced and pitting eliminated with a minimum danger of accelerated paint deterioration. Anodes of special high-purity zinc can be used for extensive periods in sea water without forming hard anodic films that impede the current-producing capabilities of the anode.

If a galvanic anode system is preferred to an impressed current system on the basis of simplicity, cost and maintenance, zinc is recommended.

INTRODUCTION

The cost and effectiveness of cathodic protection for AFDL-class floating drydock hulls vary with location, type of cathodic protection system and proficiency of maintenance personnel. Inert anode systems of varying degrees of complexity have been reported,[1,2] each of which requires close supervision of protective electrical parameters by maintenance personnel familiar with corrosion and electrical principles. A galvanic anode system using magnesium for the source of protection current has been described[3] in which several methods of current control were used. Here close supervision of the protective current and associated polarization was required, but maintenance of the electrical distribution system was negligible. Maintenance personnel for this type of system must have an understanding of corrosion principles but do not need a comprehensive electrical background.

Both the galvanic anode and inert anode systems mentioned can cause severe blistering to a paint coating system if excessive polarization occurs at the coated surface. Therefore, in those instances where personnel limitations are such that optimum conditions cannot be maintained, a system with self-limiting characteristics with respect to corrosion and coating requirements is desirable.

The relatively low open-circuit potential, high-current efficiency and reasonable cost of high-purity zinc make it attractive for use as an anode in a low resistivity electrolyte.

This study was to determine the adequacy, maintenance requirements, and cost of a zinc anode cathodic protection system for the exterior hull of an AFDL-class floating drydock.

DESIGN CONSIDERATIONS

Three principle factors influence the design of a zinc anode system: (a) current requirement, (b) life expectancy, and (c) electrolyte resistivity. These quantities must be determined as accurately as possible prior to the design. Of these, current requirements and electrolyte resistivity will determine the minimum number of anodes and their approximate location. The desired life of the system can be determined by calculating the amount of additional zinc, in the form of additional or larger size anodes, required to supply the total estimated ampere hours of current.

Previous studies[1,2,3] have shown that as few as one and as many as 18 anodes have been used to provide adequate current distribution for an AFDL-class floating drydock. Limitations in available free space below and adjacent to a hull can necessitate the use of a complex anode system. Past experience with a magnesium anode system indicates that two anode positions on each side of the hull are sufficient at a depth of [illegible] feet. Current requirements of between 2 and 14 amp have been found by the Laboratory and a current as high as 79 amp has been used in another study[4]. Extreme conditions of highly polluted or rapidly moving water can increase current requirements.

The use of high-purity zinc has been emphasized to insure that exfoliation of anodic by-products will not be hindered by a tenaciously adhering film which would restrict current output. An open-circuit potential of 1.10 volts to copper sulfate normally is accepted for zinc in sea water. This value has been found to vary between 1.050 and 1.100 volts, depending on adjacent water conditions and the deterioration rate of the anode. Because of some voltage drop in the electrolyte, the cathode is seldom polarized to the full zinc open-circuit potential. Thus, the maximum structure potential obtainable inherently is limited to a value considered safe for the standard anti-fouling hot plastic paint system in use on most naval floating structures.

The electrochemical equivalent of zinc is 3.3875×10^{-4} grams per coulomb. With 100 per cent efficiency 1 lb of anode material will provide 372 amp hr of current. Efficiencies of 90 per cent have been reported for zinc[5]. Initial current densities of the order of 32 ma per sq cm (4.96 ma per sq in) which decreased in time to densities of 12 ma per sq cm (1.89 ma per sq in) and less, depending on anode composition, have been reported in synthetic sea water studies[5].

Idealized assumptions relating driving voltage, electrolyte resistivity, polarization, and current density have shown that cathode current density and polarization generally are linear and inversely proportional to electrolyte resistivity[6,7]. The [illegible] driving voltage between zinc and a protected steel surface, nominally 200 millivolts, restricts the use of a simple zinc anode array for floating equipment to use in a relatively low resistivity electrolyte. Other workers have found it difficult to achieve protection in a relatively high resistivity environment of fresh or brackish water even with an impressed current system[8,9].

INSTALLATION DESCRIPTION

The AFDL-20 is located in the harbor at Port Hueneme, California, where water salinity and corrosivity is considered typical of unpolluted sea water[10]. Because the drydock occasionally is moved to different parts of the harbor for mooring, a suspended anode system which could be hauled aboard the dock during moving was chosen as the most practical.

A combined anode electrical lead and supporting cable of no. 4 AWG neoprene insulated, multi-strand electrical wire 36 ft long was used for each anode. Five amp .01 ohm shunts were incorporated into each circuit to permit monitoring of current requirements. To facilitate current measurements the shunts were mounted on "A" deck in terminal boxes. The lead cable was tied off to one of the railing stanchions on "A" deck for strain relief before entering the terminal box. Terminal boxes and lead connection were bolted to a 1/4-in. thick steel plate edge welded to "A" deck. Three anode positions were used on each side of the dock as shown in Figure 1.

Commercially available special high-grade zinc anodes* weighing 60 lb each were chosen as optimum size for handling and for their rated current output. The anodes were 60 in. long and had a nominal cross section of 4 sq in. The 1/4-in. diameter galvanized steel core was threaded on each end and bolted to the suspension cable with a soldered lug. A compounded neoprene sealer was applied over the connection ends to minimize galvanic deterioration of the zinc in this area. The completed connection is shown in Figure 2 and a suspended anode is shown in Figure 3.

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* The manufacturer claimed 99.99 per cent zinc with maximum impurities of .006 per cent lead, .0015 per cent iron, .004 per cent cadmium and 0.00 per cent aluminum. Laboratory spectrographic analysis confirmed this composition.

On the basis of information reported on the current densities obtainable from zinc,[5] it was calculated that each anode could supply approximately 1.0 amp of current at operating potential levels. The average required total current was estimated at 6 amperes, or about 105,000 amp hr for a

2-year period. Six 60-lb anodes operating at 90 per cent efficiency theoretically could supply about 120,000 amp hr based on the 372 amp hr per lb electrochemical equivalent value.

The drydock initially was moored adjacent to a pier supported by wood piling and had no permanent metallic connections with shore utilities. Therefore, no insulating precautions were necessary.

Potential and current measurements were taken on a weekly schedule at six positions around the hull. All potential values were made by potentiometer type measurements and are reported negative with respect to a copper sulfate half-cell.

RESULTS AND DISCUSSION

Preliminary studies of the current-producing capabilities of the 60 lb anodes showed an initial current of 0.9 amp per anode can be obtained to a surface polarized to 960 millivolts. When initial installation of the zinc anode system was made on 15 April 1955, the potential level was at 760 mv and average currents of 2.4 amp per anode were measured. The 2.4 amp represents a current density of 5.0 ma per sq in. which agrees closely with reported values. If a linear relationship is assumed between output current density and potential, as shown in Figure 4, the extrapolated line intercepts the potential ordinate at a value of 1085 millivolts, or the approximate open-circuit potential of zinc. Current outputs of as much as 1.30 amperes, to a surface polarized at 740 millivolts, were obtained from these anodes after 18 month's exposure. There was no serious decrease in current output because of film formation, although a thick, porous coating had accumulated on the anodes.

Records of potential and current values from 5 April 1955 to 1 May 1957 are shown in Figure 6. Current values were too erratic to determine anode current efficiency over an extended period, but the values were useful to provide current requirement data for the hull. The relatively poor condition of the boot-topping paint at the beginning of the study caused large fluctuations in current requirements for small changes in draft level. Although the potential was increasing slightly with the initial installation of six anodes, it was evident additional current would be needed to bring the polarization up to the protected range. Two pieces of magnesium strip, 5 ft long, were added to the system after 40 days and increased the potential to approximately 1.00 volt as shown in Figure 6. The six zinc anodes were unable to maintain the high potential, and a gradual decrease to 770 mv occurred. No additional zinc was added to the system because repainting of the drydock boot-top area was planned.

Low potentials recorded after 120 days resulted from removal of the anodes during relocation of the drydock. Cleaning and painting of the boot-top area was performed by listing the hull during the period of 170 to 200 days. A resultant decrease in current requirements from about 14.0 amp to 5.0 amp was noted after painting, with an accompanying increase in average potential to approximately 900 millivolts. The hull remained under protection for 302 days or until 15 January 1956 when the anodes were removed for quinquennial reconditioning of the hull.

Two test coupons which had been coupled to the hull and suspended in 5 ft of water adjacent to the hull for 8 months were removed, cleaned, and weighed. Losses of 7.3 and 4.3 grams per sq ft per yr were recorded. Previous unprotected coupon results showed that normal corrosion is 100 to 125 grams per sq ft per year.

Inspection of the hull in drydock prior to reconditioning indicated excellent performance of the hot plastic system and poor performance of the boot-top coating. The condition of the hull prior to cleaning is shown in Figures 7 and 8. A detailed report of the inspection was made[11].

The AFDL-2C was permanently moored about 3 months later. The six original anodes were reinstalled. To determine the effect of film formation on the current discharge capabilities, three anodes were wire brushed and three anodes were left in their original conditions when replaced in service. The current output of the three clean anodes was twice that of the unclean anodes immediately after immersion. However, after 4 day's exposure the output current for all anodes was approximately equal.

Total current requirements had decreased from 8.45 amp at 827 mv before reconditioning to 2.06 amp at 1015 mv after reconditioning. The two amidship anodes were removed after 334 days to determine the effect on the potential level. A decrease of approximately 50 mv resulted. The ability of zinc to respond to changes in potential is shown in Figure 5.

An initial potential of 945 mv was recorded. The drydock draft level was 7.0 feet. The drydock was lowered to a 21.5-ft draft level and the potential decreased to 712 millivolts. Although the drydock remained submerged the zinc anodes were able to increase the potential to 800 mv in 1 hour.

The two amidship anodes were returned to service after 462 days as the average potential level approached 800 millivolts. Intermittent high and low potential values recorded during the period from 460 to 700 days apparently were caused by shorting of part of the pier structure to the hull. The hull was moored adjacent to a new section of pier which had a foundation of steel "H" piling. Electrical contact among the piling, bollards and cleats on the pier was evident from potential measurements taken between the bollards and the sea water. Initially, insulation from the pier was obtained through the use of special manila mooring lines. Wire rope loops were spliced to the pier ends of the manila mooring lines to reduce abrasion. All metallic cables, added temporarily for the storm season, resulted in erratic bonding to the pier.

As anode surface area decreased from use, the current output decreased until it was impossible to maintain protection with the six original anodes. One anode had deteriorated to the extent of partially being separated from the iron core as shown in Figure 11. New anodes were added by bolting them to the original suspension cable and anode as shown in Figures 9 and 10. After installation of new anodes in all six positions the potential returned to a protected range.

COST OF INSTALLATION

Direct costs for material and installation of the zinc anode system on the AFDL-20 are listed:

1.	Sixty-pounds special high grade zinc anodes, six at $13.00	$ 78.00
2.	Shunts, 5 amp external, six at $7.00	42.00
3.	Terminal boxes, six at $10.00	60.00
4.	Stranded electrical cable No. 4 AWG, 210 ft at 0.35 per ft	73.50
5.	Miscellaneous connection materials	10.00
6.	Installation, labor, and material	100.00
	Total Cost	$ 363.50

These costs reflect the expense of several features which ordinarily would not be required. The shunts, terminal boxes, and relatively long lengths of cable were needed to facilitate taking anode current measurements. The anode lead cables without shunts or terminal boxes could be connected at any convenient location near the water line so that replacement anodes could be added as required.

Additional costs of potential measurement equipment or of insulating the dry-dock from adjacent metallic structures would depend on local needs.

CONCLUSION

The zinc anode system on the AFDL-20 performed adequately for approximately 18 months with no electrical maintenance. Operational maintenance was required for removal of anodes from the water while moving the drydock and for periodic checks on the potential level of the hull. Insulation of the hull from adjacent metallic structures must be maintained continuously.

Scheduled measurement of the protective current has shown that the required 2 to 14 amp was adequately supplied by zinc anodes suspended on the periphery of the hull.

Hull potential values and test coupon results indicate that surface corrosion was reduced significantly and pitting was eliminated with a minimum danger of accelerated paint deterioration. Anodes of special high-purity zinc can be used for extensive periods in sea water without forming hard anodic films to impede the current-producing capabilities of the anode.

Low driving voltage of 200 mv between the zinc and a protected steel surface requires a low resistivity electrolyte such as undiluted sea water if a simple anode array is to be used.

RECOMMENDATIONS

Variations in water resistivity, type of mooring, availability and reliability of external sources of electrical power, competency of operating personnel and available funds are factors which must be considered in the choice of a cathodic protection system. If a galvanic anode system is preferred to an impressed current system on the basis of simplicity, cost, and maintenance, zinc is recommended.

PLANS

No further plans for studying the use of galvanic anodes for the exterior hulls of floating drydocks are contemplated.

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11. NAVCERELAB LR-R-010, Inspection of the Exterior Hull of Floating Drydock AFDL-20, E. R. Streed, 7 March 1956.

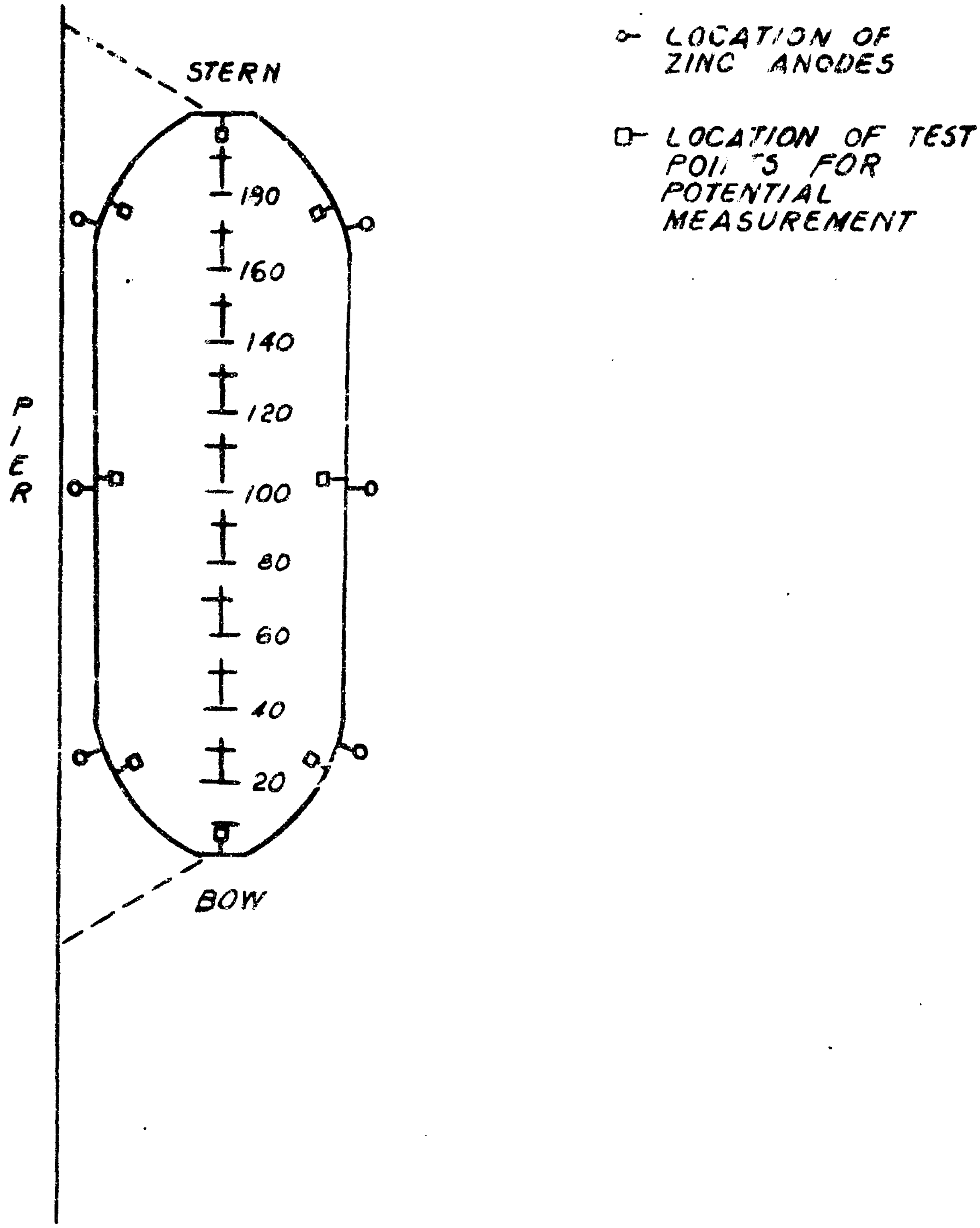


FIGURE 1.

PLAN DIAGRAM OF CATHODIC PROTECTION SYSTEM FOR THE AFDL-20

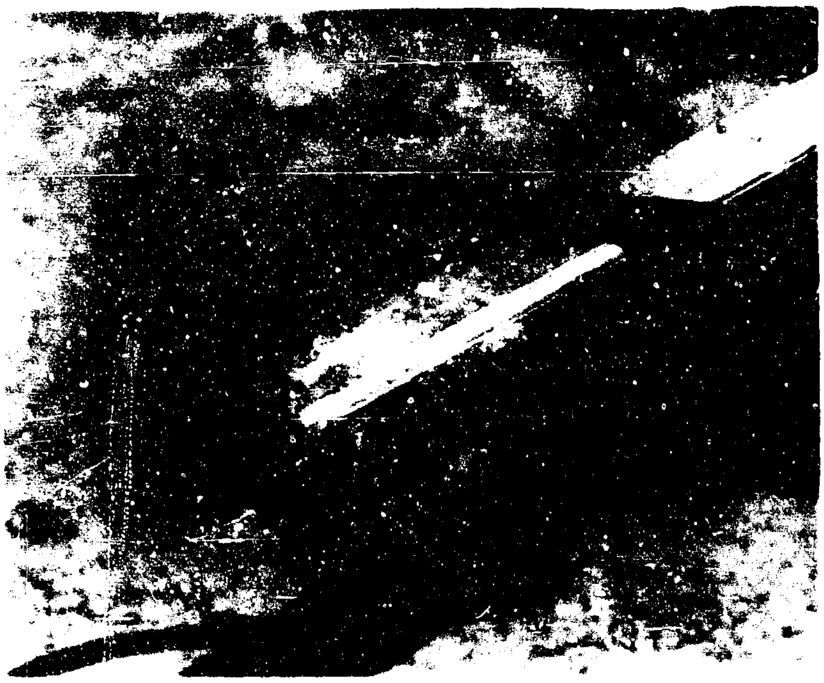


Figure 2. Completed anode connection with neoprene covering.

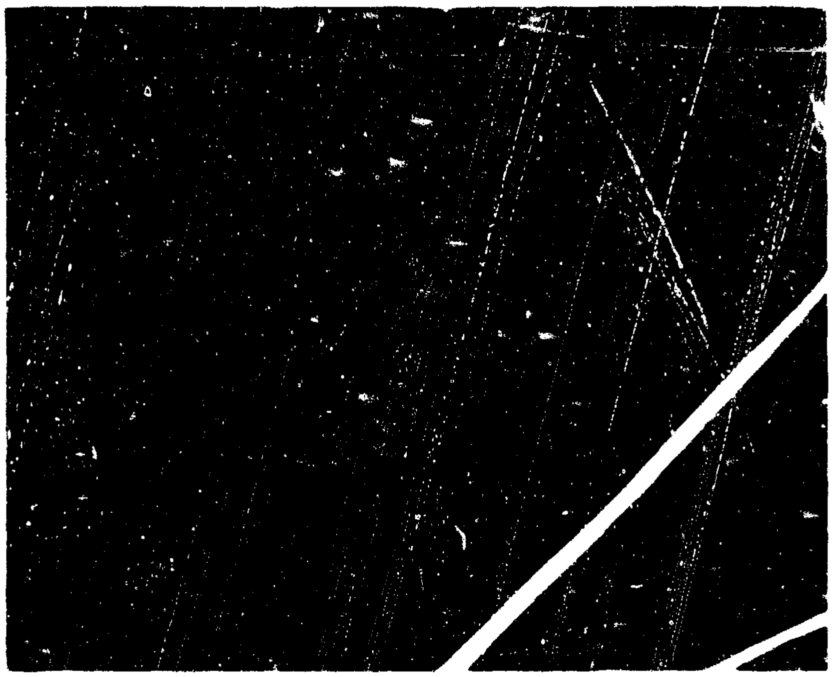


Figure 3. Suspended zinc anode ready for immersion.

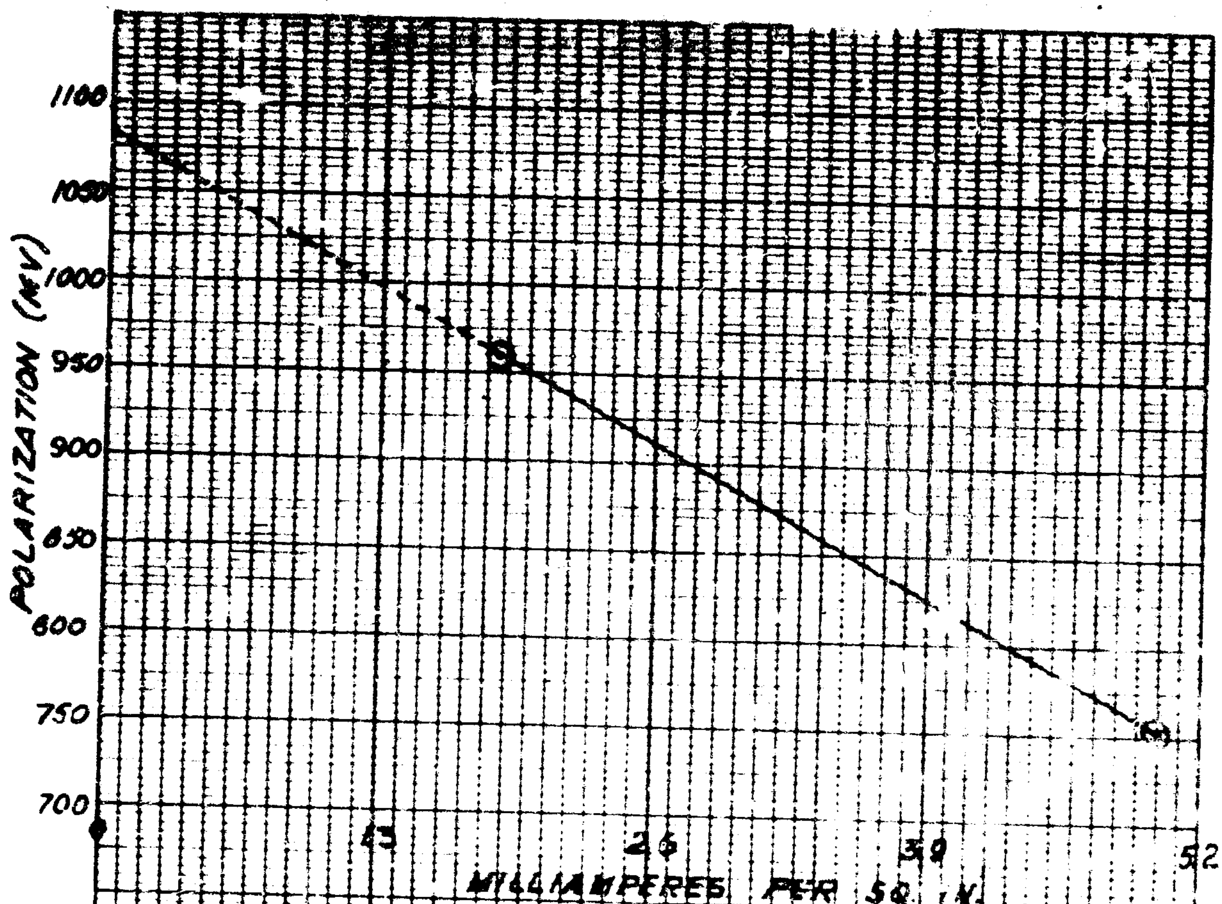


FIGURE 4
THE INITIAL ANODE CURRENT DENSITY OBTAINED WITH NEW ZINC IN THE APDL-20 SYSTEM

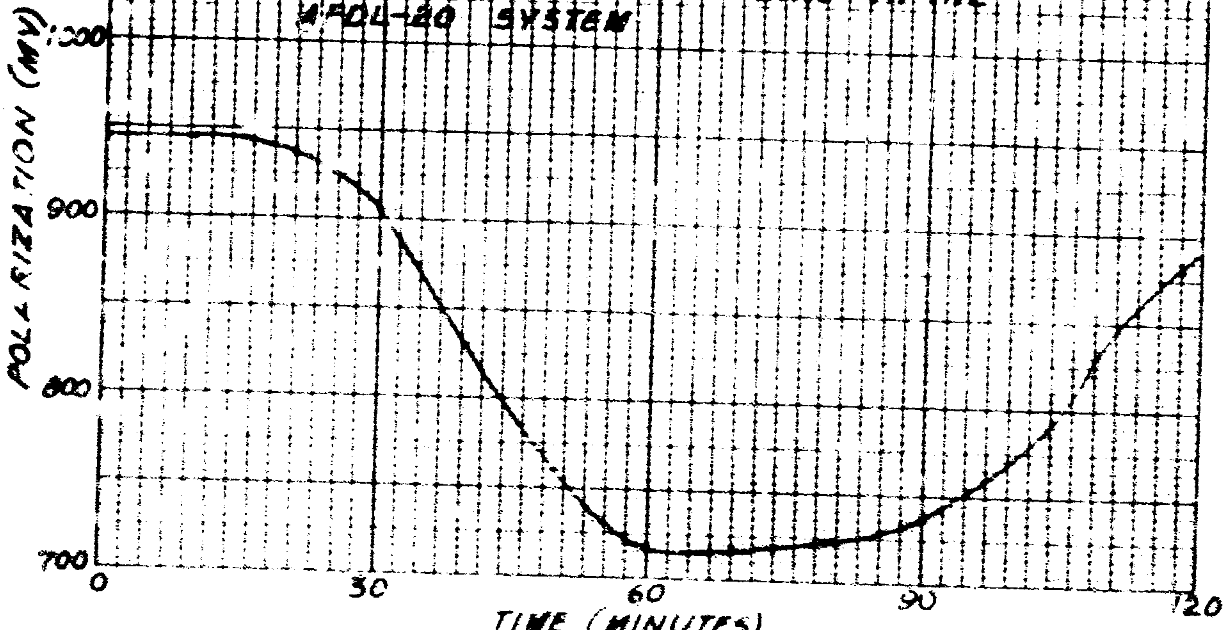
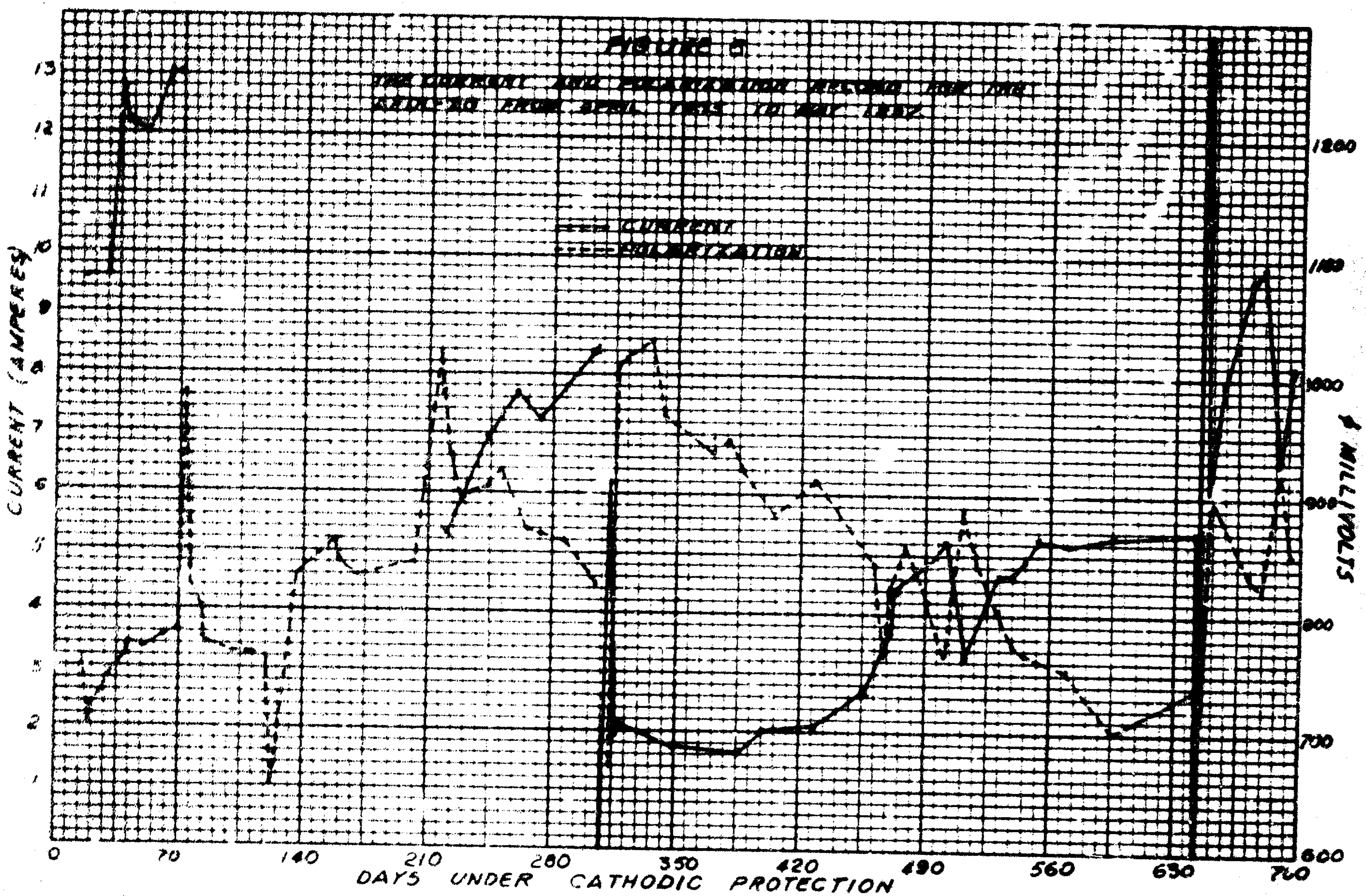


FIGURE 5
THE POTENTIAL CHANGES RECORDED WITH A CHANGE IN DRAFT FROM 7.0 FT. TO 21.5 FT.


CURRENT (AMPERES)
DAYS UNDER CATHODIC PROTECTION
MILLIVOLTS
CURRENT
0 70 140 210 280 350 420 490 560 630 700
1 2 3 4 5 6 7 8 9 10 11 12 13
600 700 800 900 1000 1100 1200

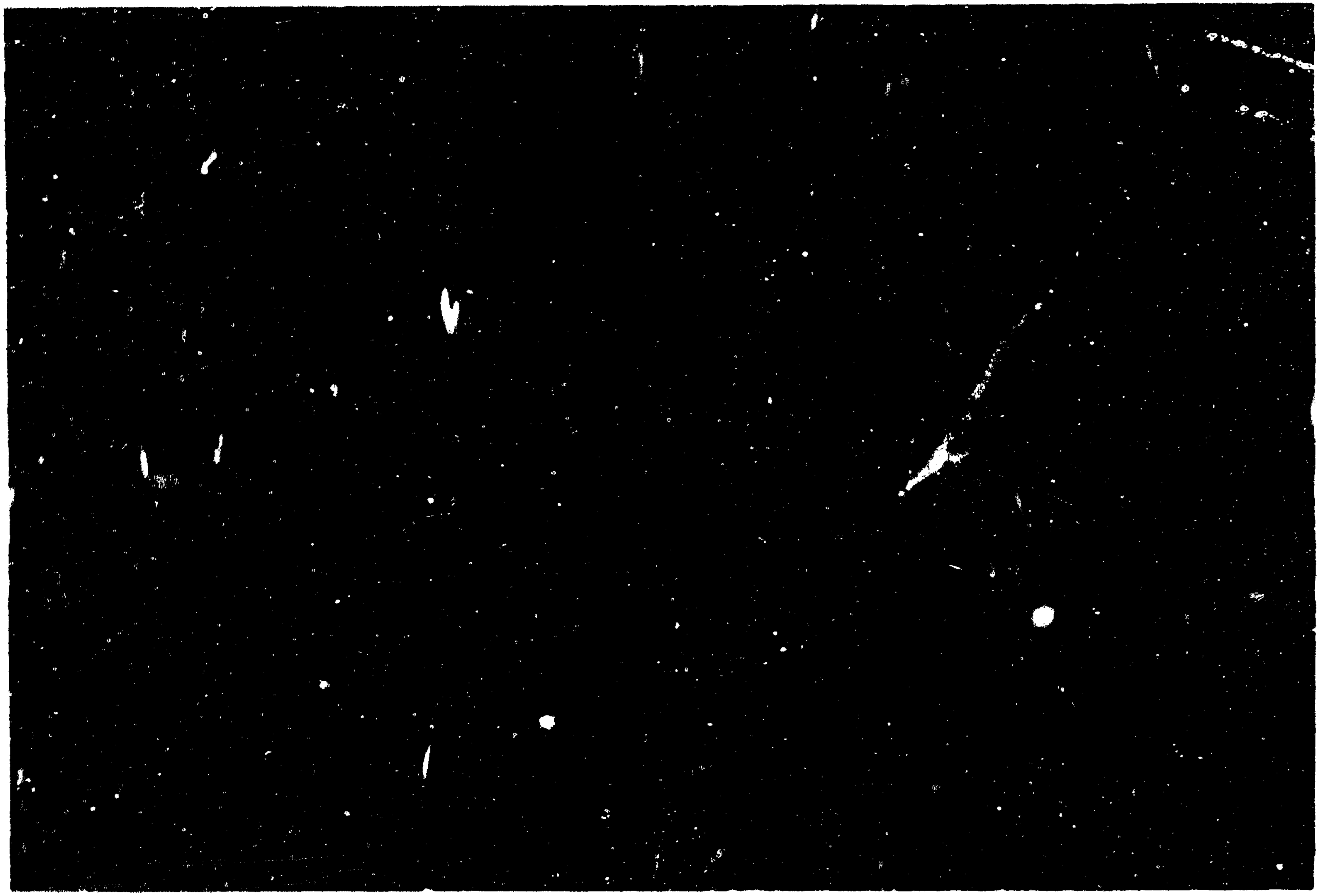


Figure 7. Paint deterioration and fouling in the boot-top area.

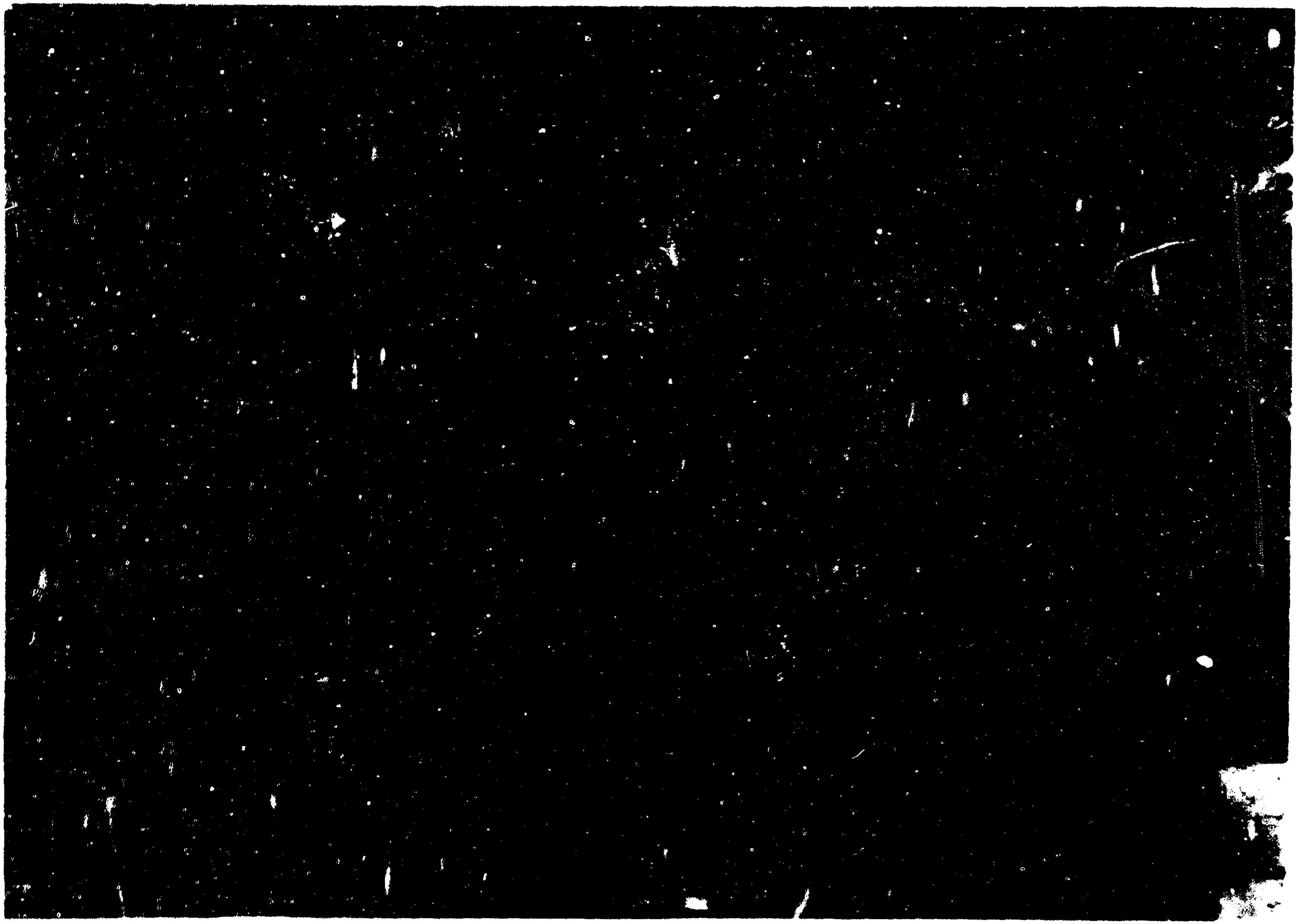


Figure 8. The AFDL-20 hull prior to cleaning on 29 January 1956.

Figure 9. Connection detail for the addition of a new anode.

Figure 10. New and old anode assembled on one cable.

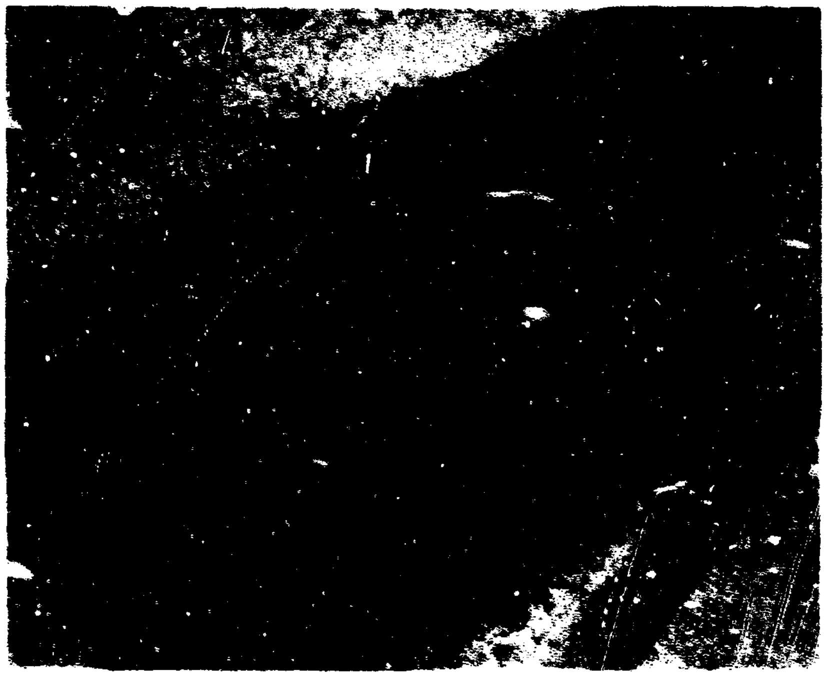


Figure 11. Deteriorated anode partially seperated from iron core.