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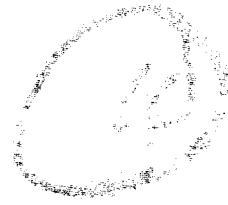
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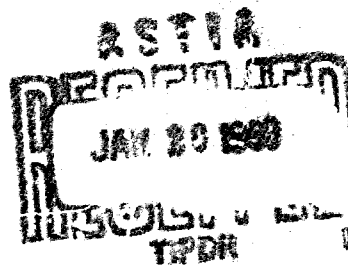
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**Report of Corrosion Survey
on Waterfront Bulkheads at
U.S. Coast Guard Depot
Key West, Florida, and
U. S. Coast Guard Air Station
St. Petersburg, Florida
Contract No. 32664 (CG-32,659-A)
Our Job No. 654-314**

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Report of
Corrosion Survey on
Newly Constructed Waterfront Bulkheads at
U.S. Coast Guard Depot
Key West, Florida
and
U.S. Coast Guard Air Station
St. Petersburg, Florida

United States Coast Guard
Headquarters
Washington 25, D.C.
Contract No. Tcg-39664 (CG-32, 659-A) new

Our Job. No. 654-314
August 3, 1954

The Hinchman Corporation
Engineers
Francis Palms Building
Detroit 1, Michigan

Summary

An investigation was made to determine the corrosion conditions at the new waterfront bulkhead at the U.S. Coast Guard Depot, Key West, Florida and the waterfront bulkhead and seaplane ramp at the U.S. Coast Guard Air Station, St. Petersburg, Florida. An analysis of the present designs for cathodic protection of these structures is included together with recommended modifications of the present designs and recommendations for future construction practices.

At Key West cathodic protection tests were made on the sea water and earth sides of the steel bulkhead. As a result of these tests cathodic protection was found to be feasible, and is recommended for both sides of the Key West bulkhead. The total cost of construction is estimated to be \$5180.00. Other recommendations concerning the mooring of ships and adjacent utilities are included.

The front range light structure south of Key West island was inspected and a resume of three types of corrosion control systems are included for consideration.

At St. Petersburg tests were made on the quay wall and seaplane ramp pilings and as a result cathodic protection by means of an impressed current system using a rectifier and graphite anodes is recommended. The cost of construction for this system is estimated to be \$3600.00.

Cost comparisons are made in the report as well as recommendations for future construction practices.

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1. PURPOSE OF THE SURVEY

The purpose of the corrosion survey at the U. S. Coast Guard Depot, Key West, Florida and U. S. Coast Guard Air Station, St. Petersburg, Florida was to investigate the corrosion problems on the waterfront bulkheads at both stations and the seaplane ramp at St. Petersburg and submit a report of recommendations for cathodic protection of water front structures, both future and existing. Also an analysis of the existing plans for cathodic protection for the bulkheads and seaplane ramp was to be made and recommendations or modifications as required submitted. Included are the cost estimates for recommended cathodic protection, economic justification for the installation of cathodic protection and design suggestions for possible future cathodic protection installations.

Part A

Seawater Bulkhead at Key West, Florida

2. SOIL ELECTRICAL RESISTIVITY SURVEY

Underground utilities and structures are subject to deterioration by soil corrosion. The corrosive soils are usually low in electrical resistivity, and other factors may contribute to corrosivity such as soil texture, moisture content, aeration and compactness. At the two Coast Guard Stations in Florida, the soil resistivity is the most reliable index of corrosivity.

The electrical resistivity of the soil was checked by two methods, the 4-pin or Wenner Method and by the use of a probe Vibroground. The 4-pin method was used to obtain a soil profile of the resistivity characteristics to a particular depth, and these readings were taken in two foot steps to a depth of 12 feet below grade. The probe Vibroground method was used to obtain the soil resistivity in excavations next to the bulkhead and also to make a large number of checks in the fill area back of the bulkhead to a depth of 4 feet.

The 4-pin method measures the flow of current between two current electrodes spaced 3D feet apart and the voltage drop is measured between two voltage electrodes spaced D feet apart between the current electrodes. The resulting values give the soil resistivity in ohms per cubic centimeter (called ohm-cm) to a depth of A feet taken as $191 AE/I$ when E is the voltage across the two center electrodes and I is the current flow between the two end electrodes. The particular spacing of the electrodes on the surface of the ground produces the average soil resistivity to the depth below grade corresponding to the surface spacing.

The location of the 4-pin soil resistivity test is given in Table 1 and is shown on the map at the rear of the report.

The probe vibroground soil resistivity tests were made with an instrument developed to measure directly the resistance between the point and tube of the probe and is calibrated in ohm-cms. The location of the probe tests are also shown in Table 1 and on the map at the rear of the report.

The soil found in the area consists of coral sand or marl hydraulic fill and the resistivity varies from 140 to 4000 ohm-cms at various locations in the fill area. Low values of soil electrical resistivity make it possible for galvanic currents to flow easily from one section of a buried structure to another section of the same structure through the soil, resulting in structure corrosion. The low soil resistivity on the other hand aids in making possible economical cathodic protection ground beds for corrosion control. The low soil electrical resistivities shown in Table 1 indicate that the soil will be corrosive to the inside of the waterfront bulkhead and to the tie rods supporting the bulkhead.

The sea water electrical resistivity was checked by means of the probe vibroground method and showed a resistivity of 40 ohm-cms which is normal.

3. EXPERIMENTAL CATHODIC PROTECTION TESTS

The corrosion of underground or underwater metallic structures is caused by small electric currents flowing from anodic (plus) to cathodic (negative) areas. Cathodic protection stops the flow of current in these local "corrosion cells" by furnishing an auxiliary current of magnitude sufficient to nullify the local corrosion currents from anodes buried underground or immersed in sea water in the form of ground beds. The auxiliary current is supplied by means of rectifiers or galvanic anodes. Since there are several variables in the design of a cathodic protection system it is good practice to perform a temporary cathodic protection test on the structure to be protected, if the structure is available.

(a) Seawater Side of the Waterfront Bulkhead - It was not possible to examine the steel quay wall piling below the mud line; however, the steel area below the mud line should be in the same general good condition as that above the mud. For the relatively short time that the bulkhead has been in the water the future corrosion pitting is indeterminant. However, the steel structures of this type at the Naval Station have shown considerable corrosion activity. Usually it is found that the corrosion is a result of the combination of marine growth and mill scale, along with the sea water which promotes the very rapid corrosion.

An experimental cathodic protection test was run on the water side of the waterfront bulkhead using a sheet metal plate approximately 4' x 5' as the temporary anode for the section B (west wall) and the hull of the ARIADNE as the temporary anode for section D (south wall). An electric welding generator was used as the temporary source of power. The negative side of the generator was connected to the bulkhead by means of the #4/0 bare copper cable installed when the bulkhead was built. The current flow

from the anode was adjusted to various values and the bulkhead to water potentials as measured to a copper-copper sulfate half-cell located in the water near the bulkhead were checked. The results of this test are given in Table 2 and Figure 1 for section B and in Table 3 and Figure 2 for Section D of the bulkhead. These results indicate that cathodic protection is feasible for the water side of the bulkhead and that the protection is sound economically. When sufficient protective current flows from the anode to completely nullify the flow of galvanic current from the sheet piling of the bulkhead then corrosion stops. In actual practice, one criterion to stop corrosion is to depress, or make more negative the potential of the structure by .15 to .20 volts as measured between the sheet piling and an electrode immersed in the sea water.

The test setup is shown in the sketch at the top of Table 2 and 3 for the two sections of the bulkhead. The data from Tables 2 and 3 is plotted in Figure 1 and 2 and show the characteristic curve of applied current against structure to water potential as measured to a copper-copper sulfate half-cell. The point where the break in the curve occurs is generally accepted as the current required to suppress the galvanic current developed by the immersion of the structure in an electrolyte, in this case sea water. When the structure is first placed under cathodic protection, the current required to suppress the galvanic current is quite large, on the order of 11.6 milliamperes per square foot of total structure area as shown by the break in the curve of Figure 1 at 120 amperes. The area of the various parts of the bulkhead are shown in Table 5. As the structure polarizes and a calcareous coating is plated out of the water on to the steel of the piling, the current requirement to suppress the galvanic current becomes less and less until the structure stabilizes at some value of impressed current. The high current requirement initially for protection is due to several factors in this

test. First, the single anode used for the test was small in area and only 75 feet from the bulkhead so that the current distribution was not even along the sheet piling. Second, the piling was relatively new and required an excess of current to start to polarize. Third, there was no coating of any kind deposited on the sheet piling during the short period of the test to reduce the protection current requirement.

As can be seen from the curve of Figure 2 for section D, where the much larger area of the hull of the ARIADNE was used as the temporary anode, the current requirement to protect approximately the same area as section B was approximately 70 amperes. This smaller initial current for suppression of the galvanic current from the bulkhead is due to the better current distribution from the much larger anode surface. In this case as for section B the piling will polarize and as the calcareous coating is plated out of the sea water, the current requirement for protection will drop until a stabilization point is reached. The initial current to suppress the galvanic current from the sheet for section D is approximately 6.9 milliamperes per square foot of total area as shown by the break in the curve of Figure 2. For both sections B and D of the bulkhead the current density required for protection will be considerably less for the portions of the piling in the mud and moist concrete than the part exposed directly to the sea water.

(b) Earth Side of Waterfront Bulkhead - An experimental cathodic protection test was also run on the inside of the bulkhead using a buried pipeline as the temporary anode for section B and two steel boats on the fill as the anode for section D. The current flow from the anode was adjusted to various values and the bulkhead to soil potentials as measured to the copper-copper sulfate half-cell located on the soil side of the bulkhead were checked. The results of these tests are shown in Table 4 and Figure 3.

Since the soil electrical resistivity is quite low adjacent to the bulkhead and the tie rods for the bulkhead lie in this area, cathodic protection is recommended for the inside of the bulkhead as well as the water side.

The curve of Figure 3 shows the characteristic break at approximately 50 amperes which corresponds to a current density of 2 ma. per square foot of area in contact with the soil. This curve was plotted from the readings obtained at test point 4 which was fairly close to one of the steel boats used as the anode and the current density is somewhat low. To provide a margin of reserve for the system, 3 ma. per square foot of area is considered a reliable design factor based upon experience with other structures in the type of fill used at the Coast Guard station. Also the various utilities around the shop building are not believed to be bonded to the bulkhead and the additional area involved should be considered for protection. Since the tie rods for the sheet piling lie in very low electrical resistivity soil at this location, the corrosive rate will be almost as rapid as the sea water side of the bulkhead. The area of the tie rods is shown in Table 5. As the rods form a vital part of the sea wall structure, Cathodic protection is recommended to prevent possible failure. In addition to the rapid corrosion from low resistivity environment, steel members under tension will corrode at a more rapid rate than similar structures not under tension. In this case, the tie rods would corrode at a more rapid rate than the inside of the bulkhead steel piling. The tie rods are in contact with the bulkhead steel so that they will come under Cathodic protection from the system recommended for the shore side of the bulkhead. The end through the steel bulkhead will receive protection from the system for the water side of the bulkhead.

A separate anode system for protection of the shore side of the bulkhead is required, as protection current from the water side anodes is shielded from the shore side of the bulkhead by the bulkhead steel. The bulkhead will act as a conductor carrying the current back to the negative side of the rectifier. Consequently none of the current is collected on the shore face of the bulkhead. The resistance of the current path from the water side anodes around the sheet piling is much greater than the resistance of the current path from the anodes directly to the water side of the piling.

In some cases it is practical to use a single rectifier of large enough DC capacity with two separate anode beds to protect both sides of a structure, however, in the case of a bulkhead with low resistivity sea water on one side and higher resistivity soil on the other side a different voltage on the higher resistivity side of the bulkhead is required to overcome the higher ground bed resistance. The difficulty of control of the current drawn by the two sides becomes a factor when heavy continuous DC currents are involved in parallel circuits. Also the cost of the heavy current capacity DC rectifier required to feed both sides of this structure increases very rapidly and two rectifiers of 100 ampere DC capacity can be purchased for approximately the same cost as one 200 ampere unit. The separate units for each side of the bulkhead provide a much better means of control of the protection current without excessive losses through resistors.

The picture on the next page shows the Section D bulkhead sheet piling before the concrete cap was poured. The #4/0 bare copper bonding cable brazed to the top of the piling is visible as is one of the steel boats used as a temporary anode for the cathodic protection test on the shore side of the bulkhead. The piling in the unfinished area was used as Test Point 4.



Bulkhead Construction
USCG Station
Key West, Florida

4. SERVICE UTILITIES AT THE PIER

The service utilities at the pier consist of water and air piping to the West edge of the pier, water and air piping around the shop building and some fiber electrical conduit. The air piping is 1" and 1-1/2" in diameter with approximately three short runs of 10 ft. each from the service pits to the steel bulkhead being underground. The fresh water piping is 2" in diameter and the underground runs are the same as for the air piping. The electrical conduit runs parallel to the steel bulkhead underground, but it is of fiber material and not subject to corrosion.

The underground surface area of these utility lines is relatively small, and it is recommended that the lines be bonded to the steel bulkhead in order that the utilities may be protected by the Cathodic protection system for the inside of the bulkhead. It is not good practice to have unprotected structures adjacent to protected structures as there is a good possibility that interference corrosion will develop on the unprotected items. The air and water service pipes may be bonded to the steel bulkhead, by spot welding at the locations where the piping go through the bulkhead. This will effectively bond the short 10 ft. runs of the piping to the piling if this has not already been inadvertently accomplished during construction. Such bonding is recommended for new construction, however, at Key West 4" diameter sleeves have been used where the piping passes through the concrete pile cap above the metal quay wall. For this location pipe grounding clamps may be used on the piping and #2 type RR wire used to bond between the pipe clamps and welded to the metal quay wall.

There is a #4/0 bare copper ground conductor which runs underground between the three service pits and also in the deck slab to the switch gear located at the West edge of the pier. A detailed discussion of this grounding

conductor will be given in Part 6 later in the report; however, the grounding conductor should be connected to the metal quay wall to prevent cathodic interference corrosion. This may be accomplished at the service pits by bonding to the air and water piping.

There are considerable metal 2-1/2" diameter steel tie rods on the earth side of the quay wall, in addition to the utilities discussed above. The tie rods have been discussed in detail in Part 3, section (b).

5. PRESENT DESIGN OF CATHODIC PROTECTION SYSTEM

The present design of cathodic protection referred to in this part of the report is shown on the plans - Coast Guard drawing No. 1926, sheet 10 of 11, for Seventh District, Miami, Florida.

(a) Test Connections - The system of cathodic protection shown on the above drawing is a rectifier system, but no provisions are made to measure the structure-to-water or soil electrical potentials by means of a voltmeter. Such a measurement indicates the adequacy of the corrosion prevention system. In order for the metal quay wall to be under good corrosion control, the wall-to-water potential should be $-.85$ volts as measured to a copper-copper sulfate half-cell, or $-.78$ volts as measured to a calomel cell. During the course of the survey it was necessary to install temporary test points by having a diver drive nails in the cracks between sheets of the piling. It is recommended that test leads be welded to the sheet piling at designated locations, shown on drawing sheet 1 at the rear of the report for TP#1 through TP#4. The leads should be terminated under the gratings along section B. For section D they could be terminated in junction boxes along the curb in locations where they would be protected from impact. On future installations it is recommended that the test leads be welded to the top of the piling, embedded in the concrete cap

and terminated in a junction box in the concrete curb. An alternative suggestion offered here for consideration on future construction, would be to bring a length of the bare #4/0 copper wire, used to bond the sheet piling together, to the surface of the concrete pile cap. The wire would be protected from damage by terminating it in a small recessed cavity in the concrete. The voltmeter connection could then be readily made to the test wire for potential measurements.

(b) Designed Capacity - The capacity of the rectifiers specified is sufficient to protect the water side of the new bulkhead, however the old section of sheet piling at the northwest corner of the pier has not been included nor has the land side of the bulkhead and the tie rods. It is believed that the old section of sheet piling will have electrical continuity and may be considered connected to the new sheet piling if the piling were driven as shown on Detail A, Coast Guard Drawing No. 1926, sheet 2 of 11.

The surface areas for the various sections of the Key West bulkhead are given in Table 5. On the basis of these areas the cathodic protection load requirements have been computed and given in the computation sheets, appendix, at the rear of the report. A total of 44.6 amperes are required for the B section sea water side of the bulkhead and an additional 14.7 amperes would be necessary to protect the sea water side of the Old Section bulkhead just north of the B section. A current load of 59.3 amperes would be required to protect the sea water sides of the B section and the Old Section bulkheads. The sea water side of the D section bulkhead requires 44.0 amperes for protection.

On the basis of this analysis it is felt by the engineers that the two 75 ampere, 12 volt rectifiers specified for the B and D sections of the new quay wall are adequate to maintain corrosion control of the sea water side of these sections. From the actual tests described in section 3 of this report it was seen that a current density of 11.6 milliamperes per sq. ft. was required for the B section or a total of

120 amperes for corrosion control. The D section required 6.9 milliamperes per sq. ft. and a total current of 70 amperes. The earth side of the quay wall required 2 milliamperes per sq. ft. and a total current of 74 amperes. These current densities are for the bare steel and consequently are greater than the current requirements would be after a calcareous coating is plated out of the sea water. Also in the case of the B section an inefficient anode was used.

In order to protect the Old Section in addition to the B section of the quay wall it is recommended that the rectifier for the B section be increased to 100 amperes, at 12 volts. The proposed 75 ampere, 12 volt rectifier for the D wall is satisfactory, and provides excess capacity for the purpose of plating out a calcareous coating from the sea water. Cathodic protection is recommended for the earth side of the quay wall, and a 100 ampere, 18 volt rectifier is recommended for this corrosion control load.

(c) Placing and Anchoring of Anodes - The anode placement as shown on C.G. Drawing No. 1926, sheet 10, will provide adequate coverage of the new sections of the bulkhead, however the spread of current to the old section of sheet piling at the northwest corner of the pier will attenuate very rapidly and provide very little if any protection to the west and north side of the old sheet piling. It is recommended that the anode bed for section B be extended around the old section to provide cathodic current for this part of the pier.

Experience has shown that 3" x 60" anodes placed in water subject to turbulence, either natural or caused by ship traffic, move considerably and there is a good possibility of breakage or short circuiting of the anodes. Several methods of anchoring anodes have been used, such as fastening the anode to a piece of angle iron with insulated bolts and a rubber insulating sheet and suspending the assembly from the under side of the deck, suspending the anode in an old automobile tire or using a concrete block to weight the anode.

Another method for this installation would be to fasten the anodes to a length of angle iron in groups of three anodes to each angle with insulated bolts and a rubber strip between the anode and angle. The angle should then be electrically connected to the negative side of the rectifier to protect the angle through a control resistor to limit the current drawn by the angle. The whole assembly is then placed on the bottom approximately 40 feet from the bulkhead. This method of installation would preserve the anode spacing and tend to eliminate breakage due to movement.

Another method of installing the anodes which would reduce the cost of the ground bed considerably and provide adequate current distribution and life is to use 4" x 80" graphite anodes, suitable for salt water immersion in groups of 2 with 7 groups spaced approximately 35' apart along sections B and D of the bulkhead and 2 groups on the west and 1 on the north side of the Old Section of piling. This would be a total of 34 anodes with a life of approximately 21 years. The 4" x 80" anodes are heavy enough so that turbulence would have little effect and the anodes could be placed on the bottom with small possibility of moving and with the greater spacing between groups the possibility of shorting to adjacent anodes is eliminated. The anodes recommended for use on the earth side of the quay wall are 4" x 80" graphite. These also should be treated for salt water immersion since a considerable amount of salt will be in solution in the coral fill used. A total quantity of 22 anodes is considered adequate for the cathodic protection of the earth side of the quay wall. The computations for the anode ground beds for the Key West bulkheads are given on Sheet 3 of the Computations in the rear of the report.

(d) Installation Procedure - During installation of the anodes, every care must be taken to insure watertight splices at all points. For this reason it is recommended that as much as possible of the wiring be pre-assembled on the deck of the pier in a form of wiring harness and then place the anodes in the water after the splices have been carefully waterproofed. The No. 82A Splicing Kit as manufactured by Minnesota Mining and Manufacturing Company or equal is recommended for covering the underwater splices. Special care is necessary for splices, because, once wet, they can become small anodes and corrode out in a short time.

The anode connecting lead shown on C.G. Drawing No. 1926, sheet 10, is specified as #12 type RR wire with a special connection to the anode proper. It is recommended that the standard #8 type RR lead wire with a standard connection to the graphite anode be used for mechanical strength and good insulation properties. The use of standard anode assemblies will simplify the wiring recommended above and reduce the cost and delivery time for the anodes.

The type B junction box in the curb of bulkhead section D nearest the west side of the pier is believed to be inadequate in size to contain a good waterproof splice of #2 type RR cable as called for in the wiring diagram and a larger size of box is recommended for future installation.

Other than the exceptions noted above, it is felt that the conduit runs and junction boxes cast in the concrete are excellent from the standpoint of future planning for possible cathodic protection systems to control corrosion of steel seawalls.

(e) Coating of Negative Cable Leads at Piling -

The design of the cathodic protection system calls for a copper cable bond connecting all sheet piles which is good practice, to insure electrical continuity of the bulkhead. However, when the copper cable is brazed to the steel of the sheet piling, a dissimilar metal cell is established which in the presence of moisture can cause galvanic action, rapid corrosion and failure of the bond. It is recommended for future installations that each brazed or welded connection to the protected structure be thoroughly coated with coal tar enamel after the connection is completed in order to prevent moisture reaching the dissimilar metals.

6. ELECTRICAL GROUNDING

The present cathodic protection system design has no provision for connecting moored vessels along the pier to the system. As stated above, it is not good practice to have unprotected structures adjacent to protected structures as interference corrosion is liable to develop. On steel hull vessels this corrosion will be concentrated at scratches in the paint coating on the steel and can cause possible perforation of the hull in a relatively short period of time. The cathodic interference corrosion can be minimized by providing a heavy flexible electrical connection between the hull of the vessel and the sheet piling bulkhead. This should be furnished with a ground clamp to provide an easy means of connecting to the metal of the hull. This grounding connection provides a low resistance path to drain off the current from the hull to the bulkhead rather than through the water to the bulkhead. This grounding applies particularly to Section D of the pier where the ARIADNE is moored semi-permanently. The hull will be in the field of the anodes between the anodes and the bulkhead of section D and will collect considerable current which should be drained through a desired path rather than through the water to prevent possible damage to the hull.

Vessels moored along section B of the pier will be outside of the current path from the anodes to the bulkhead and consequently will collect little or no current from the cathodic protection system. However, if flammable liquids are handled over this section of the pier, it would be a necessary precaution to provide a grounding lead to the vessel from the utilities lines in the service pits along the edge of section B.

The utilities manholes installed at various locations on the pier are connected together by a #4/0 bare copper ground bus which is connected to a water line at the southwest corner of the shop building. This ground bus should also be connected to the sheet piling bulkhead in order to provide a good low resistance ground connection and further to insure that the various utilities are not left unprotected. Also, it was noted that most of the electrical conduit near the manholes was not connected to the ground bus.

7. SUMMARY OF RECOMMENDATIONS FOR USCG DEPOT,
KEY WEST, FLORIDA

(a) The shore side of the bulkhead and the tie rods should be placed under cathodic protection with a separate system from that used for the water side of the bulkhead. The higher electrical resistance of the fill compared to the sea water makes a higher voltage desirable to overcome the higher anode bed resistance. The separate rectifier for the shore side is also desirable for control of the current to the anodes without introducing the losses inherent in resistor control.

(b) Since the Old Section of sheet piling at the northwest corner of the pier is bonded to the new section of piling for section B of the pier, it is assumed that this section will be electrically continuous and sufficient capacity in the rectifier for section B to provide cathodic protection for the old section of piling is recommended. The Old Section of piling is a continuation of the new section, therefore, a single rectifier to provide protection current for both sections of the west side of the pier is feasible.

(c) The anode bed for section B bulkhead as designed will provide very little if any protection current to the west and north sides of the Old Section of sheet piling. Additional anodes around the old section of piling are recommended to furnish an even distribution of cathodic protection current to this section.

(d) The type NA graphite anodes specified for the installation are 3" x 60" with a special connection system for the #12 lead wire consisting of a soldered joint and a fiber tube filled with compound adjacent to the anode. This size anode weighs only 17 lbs. in water and it is recommended that if this size is used some method of anchorage be provided for the anode to prevent movement. In lieu of the specified type of anode, it is recommended that standard 4" x 80" type NA graphite anodes with the standard connection and #8 lead wire be installed in groups of 2 anodes with approximately 35' spacing between groups. Two group of 2 anodes should be installed along the west side and one group along the north side of the old sheet piling. The recommended anode bed layout would consist of 7 groups of 2 anodes each along section B and D of the bulkhead and 3 groups for the old section of piling or a total of 34 anodes.

The standard method of connecting the #8 type RR lead wire is recommended for strength and to eliminate the long delivery time and extra cost of special anodes.

(e) The most frequent source of trouble in cathodic protection systems installed in sea water is the failure of the insulation on underwater splices. Moisture reaching the copper of the connection between the lead wire on the anode and the feeder causes rapid corrosion and failure of the splice. It is recommended that a sealed splice insulation such as the Scotch cast 82A Unipac Splicing Kit as manufactured by Minnesota Mining and Manufacturing Company or equal be used for all underwater splices. It is also recommended that as much as possible of the wiring be preassembled on the pier in a form of wiring harness to insure proper sealing of the splices.

(f) A heavy flexible grounding lead such as welding lead cable with a clamp type connector is recommended for installation on section D of the bulkhead. The ships moored along this section of the pier will be between the anodes and the bulkhead and a grounding lead to the hull will drain the collected current from the hull at the proper point. This grounding lead is not required along section B of the pier as vessels moored at this location will not be between the anodes and bulkhead B and therefore, will not collect current from the cathodic protection system.

(g) The various utility lines to the pier are specified to be bonded by a #4/0 bare copper bus connecting all of the utilities to the water line at the southwest corner of the shop building. It is recommended that this bonding bus be connected to the sheet piling of the bulkhead to provide protection to the utility lines in the soil. It is not good practice to have unprotected structures adjacent to protected structures as cathodic interference corrosion may develop. The bonding of utility lines and other metal structures should be considered in future designs where cathodic protection systems are to be installed.

(h) Due to the difficulty of obtaining good electrical contact to the sheet piling at this station, it is recommended that test leads be welded to the piling at the north end of section B, the east end of section D and at the intersection of sections B and D. These test leads should then be brought up to a point accessible from the pier deck and protected from damage. For future installations, the test leads should be imbedded in the concrete cap and terminated in junction boxes where they will be protected from damage. The test leads should be located at points on the structure remote from the negative lead connection to the structure.

(1) Recapitulation - The various recommendations over and above the existing design for the cathodic protection system at Key West are recapitulated here for reference. It is recommended that protection be applied to the Old Section of quay wall which is located north of the B section. This increase in load requires that the planned rectifier for the B section be increased from 75 amperes to 100 amperes. Also, cathodic protection is recommended for the earth side of the quay wall, and this will require a 100 ampere, 18 volt rectifier. These recommendations are as follows:

(1) Cost of construction to finish the cathodic protection for the sea water side of the quay wall, using one 75 amp. and one 100 amp. rectifier and 4" x 80" graphite anodes \$3,280.00

(2) Cost of construction for the cathodic protection of the earth side of the quay wall, using one 100 amp. rectifier and 4" x 80" anodes \$1,900.00

Total cost of construction at Key West, Florida \$5,180.00

(3) Preparation of plans and specifications by the Hinchman Corp. @ 6% \$ 310.80

(4) It is contemplated that balancing and adjusting of the two systems, the one at Key West and the one at St. Petersburg can be accomplished with one trip. Therefore, the estimate for this item is made in Section 14 of this report.

(5) Preparation of an Operation and Maintenance Manual for the Key West system \$ 350.00

8. FRONT RANGE LIGHT, KEY WEST, FLORIDA

A visual inspection of the Front Range Light at Key West, Fla. was made on 16 July 1954. The structure was built in the Spring of 1953 and was painted before installation. The supports, which consisted of 12" diameter extra strong pipe with an 8" x 8" x 36# bearing pile grouted inside, showed some marine life and barnacles. When the barnacles were scraped off, corrosion products were found underneath with some bright metal showing, indicating active corrosion. At some points the top coat of paint came off with the barnacle, leaving the light green undercoat intact.

The structure to water potential as measured to a copper-copper sulfate half cell was $-.74$ volts and the sea water electrical resistivity was 40 ohm-cms measured with a probe vibroground.

Since the paint coating has started to break down under the marine growth on the structure after approximately one year in the water, cathodic protection is recommended to prevent further corrosion. The estimated current requirements for cathodic protection are .010 amperes per sq. ft. to lay down an initial calcareous coating and .003 amperes per sq. ft. to maintain cathodic protection. The structure has an underwater area of 370 sq. ft. Therefore, the initial current requirement would be $370 \times .01 = 3.7$ amperes, or 5.0 amperes for one week is recommended for the initial period. The current required to maintain cathodic protection is estimated to be $370 \times .003 = 1.11$ amperes.

This front range light is approximately 920 yards off shore from the south west corner of Key West island, and located at 12 to 15 feet of water. From the standpoint of an analysis of possible corrosion prevention systems two types of galvanic anode systems will be described, and also an impressed current system will be analyzed using a wind driven electric generator.

A galvanic anode system using magnesium anodes is described here as a possible type of system to be used for the range light structure. Magnesium dissipates at the rate of approximately 17 lbs. per ampere year. From the above calculations 1.11 amperes of current are required for protection, $17 \times 1.11 = 18.9$ lbs. per year required, and assuming a 70% dissipation factor, $18.9 \times 1.30 = 24.6$ lbs. /year, or designing for a 10 year life, 246 lbs. of magnesium would be required. For reasons of symmetrical design of the anode placement, four anode groups of 62 lbs. each would be recommended. In order to use standard anode sizes, two 50 lb. anodes would be used for each anode group. Computing the theoretical life of the magnesium anode system: $8 \times 50 / 24.6 = 16.25$ years of life. This does not consider the problem of self-dissipation of magnesium alloy as a result of a small percentage of copper, which can cause considerable self-corrosion in such a low resistance electrolyte as salt water. The cost of the magnesium anode system outlined above is estimated to be \$609.00 installed including a magnesium ribbon anode initially to provide heavy current for depositing the calcareous coating.

A source of cathodic protection current which has some advantages over magnesium anodes and a wind generator system is the use of special high purity zinc anodes. The zinc anode has a lower solution potential than the magnesium anodes which will prevent damage to paint films close to the anode from excessive current. The dissipation rate of the zinc is 26 lbs. per ampere per year compared to 17 lbs. per ampere year for magnesium. However, the cost of zinc is much less than magnesium.

A zinc supplied system for the outer range light would consist of two 250 lb. zinc anodes hung by means of a $3/4$ " steel rod from the cross bracing of the structure. The $3/4$ " rod is welded into the $3/4$ " pipe core of the anode and hung from a clevis to allow some movement. A flexible bond is required from the rod to the structure.

The cost of this system including the use of magnesium ribbon initially to deposit the calcareous coating is estimated to be approximately \$250.00. The life of this installation would be approximately 14-1/2 years using a 75% life factor. This life is based on using special zinc castings which have an analysis as follows:

<u>Maximum Impurities</u>	<u>Percent</u>
Lead	.006
Iron	.0015
Cadmium	.004
Aluminum	.000
Zinc	99.99

These anodes can be supplied by the New Jersey Zinc Sales Co., 160 Front St., New York 38, New York.

The third source of cathodic protection current which might be installed at a remote location such as the range light would be to use a wind driven generator as manufactured by the Wincharger Corporation, or equal to maintain the charge on heavy duty storage batteries. The batteries would then be connected to a single 3" x 60" NA treated graphite anode suitable for immersion in salt water. Wind driven generators have been successfully used for a number of years on pipe line cathodic protection systems in various parts of the country as well as for various other installations remote from power lines. The life of the graphite anode, assuming a dissipation rate of 2 lbs. per ampere per year would be $27/2.22 = 12.15$ years for a 3" x 60" graphite anode.

The cost of this method of supplying cathodic protection current is estimated to be \$394.00 installed. The generators are designed for long periods of operation with only nominal maintenance and the cost of a complete unit, if replacement becomes necessary, is listed as \$106.00 including the 10' mounting tower and controls.

A recapitulation is given here for comparison purposes, for the three possible arrangements of cathodic protection for the range light structure.

<u>System</u>	<u>Quantity and Size of Anodes</u>	<u>Expected Life, Yrs.</u>	<u>Cost to Install</u>
1. Magnesium Anodes	8-50 lb.	16.2	\$609.00
2. High Purity Zinc	2-250 lb.	14.5	\$250.00
3. Wind gener- ator and graphite anode	1-3"x60"-27 lb.	12.15	\$394.00

Part B

Seawall and Seaplane Ramp at St. Petersburg, Florida

9. SOIL ELECTRICAL RESISTIVITY SURVEY

Soil electrical resistivity tests were made at the station by the 4-pin or Wenner test as outlined in section 2 of this report. The probe vibroground was used to obtain the resistivity of the sea water and the bottom sand. The results of these tests are shown in Table 6.

10. EXPERIMENTAL CATHODIC PROTECTION TESTS

(a) SSa Water Side of Bulkhead - An experimental cathodic protection test was run on the sea water side of the bulkhead using a sheet metal plate approximately 3' x 3' as a temporary anode. This plate was carried out in the angle between the seaplane ramp and the bulkhead on both sides of the ramp. An electric welding generator was used as the temporary source of power with the negative side of the generator connected to the bulkhead by means of the copper cable terminating in a junction box on the walkway on either

side of the seaplane ramp. The current flow from the anode was adjusted to various values and the bulkhead to water potentials as measured to a copper-copper sulfate half-cell in the water near the bulkhead were checked. The results of these tests are given in Table 7 and Figure 4 for the north end of the bulkhead and Table 8 and Figure 5 for the south end.

It was not possible to visually inspect the bulkhead piling as the concrete cap covers the top of the piling and the bottom of the cap is within approximately 4" of the mud line. The old sheet piling around the bend of the sea wall at the south end of the station has extensive severe corrosion evident, and there is every reason to believe that the new sheet piling would have a comparable rate of corrosion, without cathodic protection.

The test setup is shown in the sketch at the top of Tables 7 and 8 for the north and south sections of the bulkhead. The results of the tests from these tables are plotted on Figures 4 and 5 and show the characteristic break in the curve for the bulkhead to water potential versus applied current curve at approximately 90 amperes for the north end and approximately 80 amperes for the south end. This corresponds to a current density of 6.8 MA per square foot of area for the north end and 6.1 MA per sq. ft. for the south end of the bulkhead and seaplane ramp. The area of the north and south sections are approximately equal, however, the north end has almost six times as much recently installed piling as the south end. This will account for the small variation in the current density for the two sections as the new piling requires more current to start polarization. As in the tests at Key West, the anode was small and fairly close to the bulkhead so that the current distribution was not even along the bulkhead. No coating was deposited on the piling due to the short period of the test. Also, in this location, practically all of the sheet piling was in the mud. All of the above

factors enter into the relatively high current density required initially to suppress the galvanic current developed by the immersion of the piling in the electrolyte. As the cathodic protection current is applied over a period of time and the calcareous coating is built up by plating out from the water, the current density required to protect the bulkhead and ramp will decrease in value. A current density of approximately 3 milliamperes per square foot will then adequately prevent corrosion from occurring. The photograph on the following page shows the experimental cathodic protection setup from the seaplane ramp. The welding generator used for the temporary source of power and the plate used for the temporary anode are visible in the photograph.

(b) Land Side of Bulkhead - An experimental cathodic protection test was run on the land side of the bulkhead using the hose connection on a two inch water line near the hanger building as the temporary anode. The welding generator was used as the temporary source of power with the negative side of the generator connected as above. The current flow from the anode was adjusted to various values and the bulkhead to soil potentials as measured to the copper-copper sulfate half-cell on the ground near the bulkhead were checked. The results of this test are shown in Table 9. The data from Table 9 was plotted in Figure 6 and the curve shows a break at approximately 65 amperes, or a density of 4.1 MA per sq. ft. This is less than the density required on the water side of the bulkhead and was expected from the use of the water pipe grid as temporary anode for a better distribution of current and the higher resistivity of the soil on the shore side of the bulkhead. Since the new sheet piling was driven outside of existing sheet piling cathodic protection of the shore side of the new sheet piling is not possible because of the shielding effect of the old bulkhead.



Cathodic Protection Test
USCG Air Station
St. Petersburg, Fla.

11. PRESENT DESIGN OF CATHODIC PROTECTION SYSTEM

(a) Test Connections - As in the design for the Key West bulkhead, no provisions for test connections to the sheet piling of the bulkhead are included. CG Drawing 1863, sheet 6 of 6, indicated that connection points for the magnesium anode beds were to be placed at several locations along the concrete cap of the bulkhead, however, only the two junction boxes nearest the seaplane ramp were actually installed. The test connection points for a magnesium anode supplied cathodic protection system are even more desirable than for a rectifier supplied system as the test points are the only means of determining the proper functioning of the system. The land side of the bulkhead is not considered in the present design of the cathodic protection system. Also, this is because the soil electrical resistivity is relatively high in value back of the sea wall and consequently is not considered as corrosive as the low resistance coral at Key West. As outlined in Section 10(b) above, protection of this earth face of the new bulkhead is not possible due to the electrical shielding effect of the old piling.

(b) Designed Capacity - Experience with cathodic protection systems in waters similar to that found at St. Petersburg indicates that 3 milliamperes of impressed current per square foot of protected structure will adequately prevent corrosion after the system has been in operation for a long enough period of time for the structure to polarize and build up a calcareous coating. Using this figure as a design criteria for the bulkhead and seaplane ramp, the structure would require a total current of approximately 79 amperes for protection. The magnesium anode system as designed with a total of 126 anodes at 51 lbs. each would contain 6426 lbs. of magnesium. At 17 lbs. of magnesium per ampere year, the theoretical life of the anode would be 4-3/4 years. In actual installations, however, the traces of copper found in the magnesium alloy used for anodes set up local galvanic cells in sea water and the self dissipation

of the magnesium contributes to a shorter period of operation than the theoretical life. The system as designed is sufficiently large to protect the bulkhead and seaplane ramp but would require complete replacement of the magnesium anodes in from 3 to 5 years. The layout of the system as presently designed would provide good current distribution to the various sections of the bulkhead and seaplane ramp. The use of magnesium ribbon to supply a high initial current density in order to deposit a calcareous coating on the piling is excellent practice and is recommended for all magnesium anode installations in sea water to prevent high initial dissipation of the permanent magnesium anodes.

(c) Design Changes Necessary for a Rectifier System - The design changes required to install a rectifier supplied cathodic protection system in lieu of the present magnesium anode system design are as follows: A rectifier unit would be installed on a concrete pad adjacent to the Gear House which is located at the edge of Parking Area #2. The positive and negative leads from the rectifier would be direct buried from the rectifier to the present south junction box at the concrete walkway near the intersection of the ramp and the sea wall. The positive and negative leads would be extended through the existing duct to the north junction box at the north side of the ramp. From each of the junction boxes, both leads would go to the existing connection chambers. The graphite anodes, treated for salt water applications, would be placed in the water in the angle between the ramp and the bulkhead on each side of the ramp. The negative lead from the rectifier would connect to the existing cables from the sheet piling which are terminated in the two connection boxes near the intersection of the ramp and bulkhead.

The primary AC supply from the rectifier would be obtained from the existing supply in the Gear House.

(d) Old Bulkhead at Bend - The bulkhead to water potential tests shown in Table 8 for test point TP7 indicate that the old sheet piling around the bend of the sea wall at the south end of the station has poor electrical continuity. Since the plans call for new piling outside of this old section the lack of continuity is not considered serious as the new piling can be bonded very simply by welding each sheet pile to the next during construction for protection of the water side of the new piling.

(e) Use of Existing Duct Runs - The plans for the new sea wall show two 4" fiber ducts and a 15" split tile duct across the shore end of the seaplane ramp. It has been assumed that sufficient space exists in the ducts for the installation of the positive and negative leads to the north anode bed of the proposed rectifier cathodic protection system.

12. UTILITIES BACK OF BULKHEAD

The main structures immediately in back of the bulkhead consist of four 4500 gallon Avgas storage tanks, the operation of which uses the aqua system, three lead sheathed cables from the operations building to the transmitter building, water line, air line, and conduit to winches. Since the soil resistivity is fairly high as shown in Table 6 and the corrosion rate will be slow, cathodic protection is not recommended for these utilities at this time, and this is the same recommendation for the back of the sea wall.

13. COST COMPARISON OF MAGNESIUM ANODE AND RECTIFIER SYSTEMS

The estimated cost of a magnesium anode system as presently designed for the bulkhead and seaplane ramp at St. Petersburg would be approximately \$7729.00 installed. An additional expenditure of approximately \$6450.00 would be required every 3 to 5 years for replacement of the magnesium anodes.

Based on a 20 year period the total cost of the magnesium anode system would be \$34,808.00 with a strong possibility of an additional \$6,450.00 for anodes at or before the end of the 20 year period. This figure includes a 5% per year renewal charge on the parts of the system other than the anodes.

A rectifier supplied system with sufficient capacity to apply an increased amount of current initially to the bulkhead would cost approximately \$3,600.00 installed, including materials and labor. The increased current density is used initially to form a calcareous coating on the bulkhead and then the current is reduced to maintain the protection. Based on a 20 year period, assuming electric power at \$0.03 per KWH, and a \$1,000.00 renewal charge on the system, the total cost of the rectifier supplied system would be \$12,900.00.

The foregoing comparison indicates that the rectifier supplied system is much more economical than the magnesium anode system for a structure of this size. The rectifier supplied system is therefore recommended for installation at the U.S. Coast Guard Air Station at St. Petersburg in lieu of the magnesium anode system.

14. SUMMARY OF RECOMMENDATIONS FOR USCG AIR STATION,
ST. PETERSBURG, FLA.

(a) The installation of a rectifier supplied Cathodic protection system is recommended in place of the presently designed magnesium anode system for this location. The reasons for this recommendation are: Lower initial cost, lower cost over a period of years, longer anode life (approx. 10 years), and ease of adjustment of the current impressed on the bulkhead.

(b) Test leads should be brazed or welded to the piling at the ends of the bulkhead and brought up to a point accessible from the concrete cap. For future installations, the test leads should be welded to the top of the piling and brought up through the concrete cap where they can be

terminated in a junction box. All welded connections should be coated with coal tar enamel to prevent moisture reaching the dissimilar metals of the lead wire and the piling.

(c) All sheet piling should be bonded for electrical continuity by welding adjacent piles together or by installing a bonding bus brazed to each pile. If the bonding cable is used, all connections should be coated with coal tar enamel to seal out moisture.

(d) Recapitulation - The various recommendations made above are recapitulated here on the basis of cost estimates. These are as follows:

- (1) Cost of construction to provide cathodic protection for the seawater side of the quay wall and ramp using one 100 amp. 12 volt rectifier and 4" x 80" graphite anodes \$3600.00
- (a) Cost of electric power @ \$.03 /KWH for 20 yrs. - \$8300.00
- (b) Replacement and maintenance costs for 20 yrs.- \$1000.00
- (2) Preparation of plans and specifications by the Hinchman Corp. @ 6% \$ 216.00
- (3) Balancing and adjusting of the two systems, one at St. Petersburg and one at Key West would be accomplished with one trip - 2 engineers for 6 days including travel and subsistence in accordance with Government regulations \$1528.78
- (4) Preparation of an Operation and Maintenance Manual for the St. Petersburg system \$ 350.00

15. RECOMMENDATIONS FOR FUTURE CONSTRUCTION

The following recommendations for future construction projects are submitted as design factors to be considered where cathodic protection is indicated as a probability.

(1) The necessary action should be taken to insure electrical continuity of bulkhead piling by either welding adjacent piles together or the installation of a bonding bus. This feature was considered most satisfactory at Key West and St. Petersburg. Where other structures, such as water lines, air lines, metallic conduit, etc. are in the vicinity of the main structure to be protected, these utilities should be electrically bonded to the main structure.

(2) All bonds or other connections to underground or underwater structures should be coated with moisture proof sealing materials.

(3) Where the protected structures will be inaccessible after completion of the construction project, test leads should be installed at points on the structures remote from the rectifier negative connections. The test leads should be terminated at accessible locations and protected from damage.

(4) The installation of conduit runs for the cathodic protection system wiring during the construction phase of the project will aid materially in reducing the cost of installation of the protection system after the project is completed. This was considered satisfactory at both Stations.

(5) Coating and wrapping of underground structures such as piping and tanks will reduce the current required for cathodic protection and reduce the cost of a possible future cathodic protection system.

- (6) Where possible, space for anode beds at shore installations should be provided in the planning stage.
- (7) Backfill for underground structures should be of clean sand in accordance with good construction practice.
- (8) The use of cinders either as backfill or road surfacing is to be avoided as the chemicals leached out of this material is extremely corrosive to underground structures.
- (9) In the planning stage of the project, space should be provided for installation of rectifiers, if required, and sufficient capacity in the AC wiring to accommodate the requirements of the protection system should be included. This was considered to be satisfactorily handled at Key West.
- (10) Where possible, the alternately wet and dry zone of metal structures should be eliminated as cathodic protection is not possible unless the environment of the structure is continuous. This was well handled by use of concrete pile caps with whalers which were at all times below the water line at both stations.
- (11) If graphite anodes are used, the standard type with lead wires installed by the manufacturer should be specified. Special care should be given to the proper method of specifying all underwater splices. If light weight anodes are used some means of anchoring the anodes should be provided.
- (12) If steel hull ships are to be tied to piers so that the hull is in the current field of the cathodic protection anodes special bonding should be provided to prevent cathodic interference corrosion of the ship hull.

(13) Recapitulation of proposed construction and engineering costs for both Coast Guard Stations:

(a) Cost of construction

Key West	\$ 5180.00
St. Petersburg	<u>3600.00</u>
Total cost of construction	\$ 8780.00

(b) Preparation of Plans and Specifications:

Key West	\$ 310.80
St. Petersburg	<u>216.00</u>
Total	\$ 526.80

(c) Balancing and adjusting of the two stations with one trip \$ 1528.78

(d) Preparation of Operation and Maintenance Manuals:

Key West	\$ 350.00
St. Petersburg	<u>350.00</u>
Total	\$ 700.00

Total cost of construction	\$ 8780.00
Total engineering	<u>2755.58</u>

Total	\$11535.58
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(16) APPRECIATION

The assistance of the U.S. Coast Guard, 7th District, Engineering office under Captain Creedon and the assistance of Mr. George DeVier, Electrical Engineer for the 7th District office, was very much appreciated by the survey team.

The plans, information and cooperation of Lt. Smith, Public Works Officer at the U.S. Coast Guard Air Station, St. Petersburg, Fla. and Mr. Frank Thompson, U.S. Coast Guard Construction Inspector at the U.S. Coast Guard Depot, Key West, Fla. were most helpful in the successful completion of the survey and were very much appreciated.

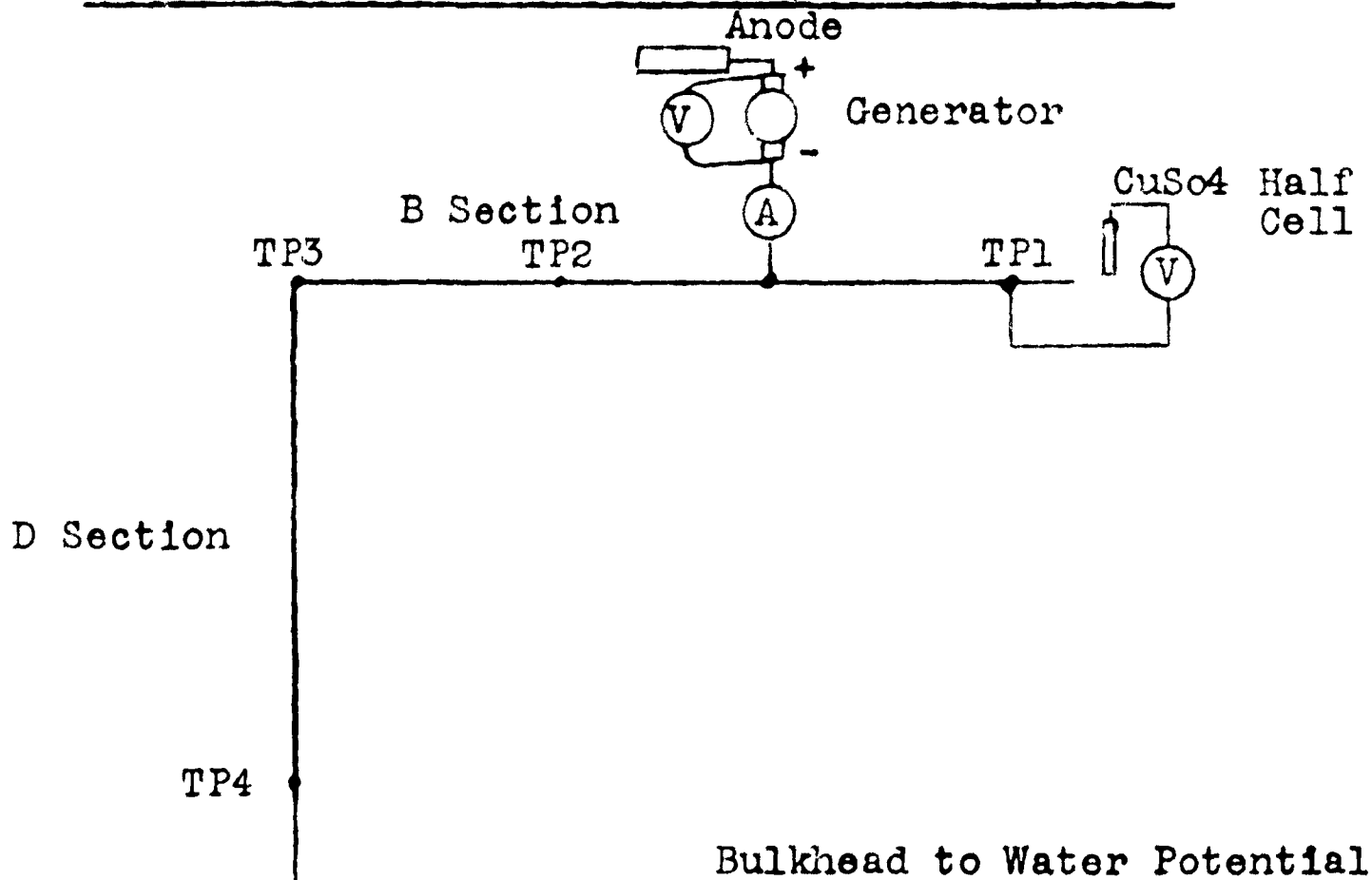
TABLE 1

LOCATION AND RESULTS OF SOIL AND WATER RESISTIVITY TESTS
U.S. COAST GUARD DEPOT
KEY WEST, FLORIDA

These locations are shown on the map at the rear of the report.

Test Station	Location	Depth	Resistivity (OHM-CMS)
4-Pin	Center of new fill area approximately 50' south of shop building	2'	382
		4'	460
		6'	460
		8'	520
		10'	535
		12'	575
<u>Probe</u>			
A	60' from intersection of B & D bulkhead Sections, 10' from D Bulkhead	4'	140
B	At southwest corner of shop building	4'	820
C	5' from south side of shop building, 50' from SW corner	4'	2100
D	At southeast corner of shop building near transformer stand	4'	2750
E	75' south of trans- former stand	4'	190
F	5' from D Bulkhead, 30' from shore end of bulkhead	4'	100
G	Center of D Bulkhead, 15' from bulkhead	4'	380
H	5' from intersection B & D Bulkhead	4'	4000

TABLE 2
CATHODIC PROTECTION TEST ON
SECTION B BULKHEAD WATER SIDE, KEY WEST, FLA.



Impressed Current		Bulkhead to Water Potential Measured to Half Cell			
Voltage	Amperes (Momentary)	TP1	TP2	TP3	TP4
0	0	-.70	-.70	-.71	-.73
3.85	45.0	-.72	-.725	-.725	-.73
7.0	80.0	-.735	-.75	-.75	-.73
14.0	180.0	-.775	-.79	-.775	-.74

Retest with Current Applied for 3 Minutes at Each Value

2.35	30	-.72
3.25	40	-.725
4.10	50	-.725
5.00	60	-.735
5.80	70	-.74
6.65	80	-.745
7.50	90	-.748
8.40	100	-.75
9.30	110	-.751
9.50	120	-.752
10.00	130	-.76
12.00	140	-.77
13.50	150	-.775

FIGURE 1
CATHODIC PROTECTION TEST
WATER SIDE BULKHEAD B
U.S. COAST GUARD DEPOT
KEY WEST, FLA.

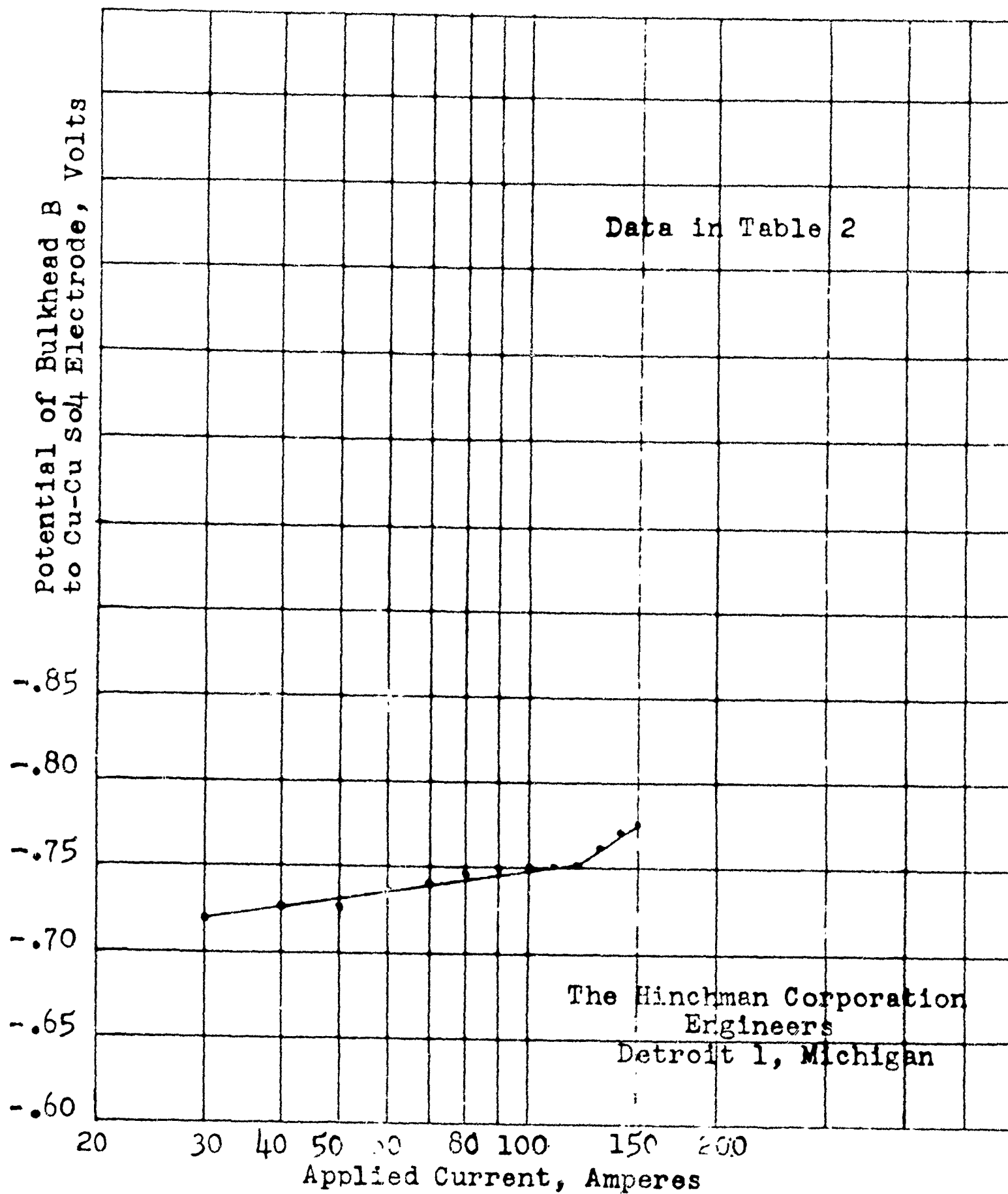


TABLE 3

CATHODIC PROTECTION TEST ON
SECTION D BULKHEAD WATER SIDE
KEY WEST, FLORIDA

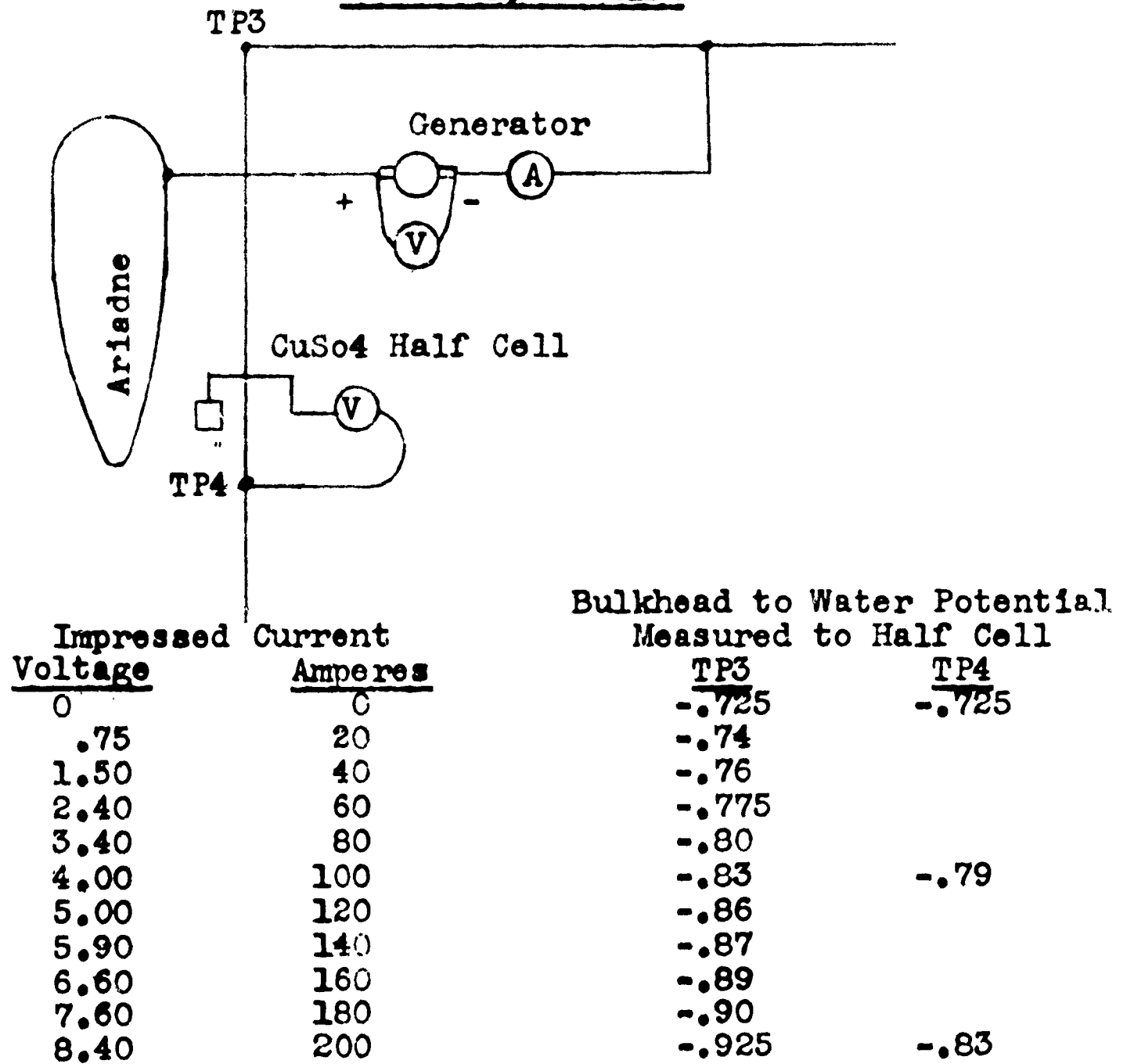


FIGURE 2
CATHODIC PROTECTION TEST
WATER SIDE BULKHEAD D
U.S. COAST GUARD DEPOT
KEY WEST, FLA.

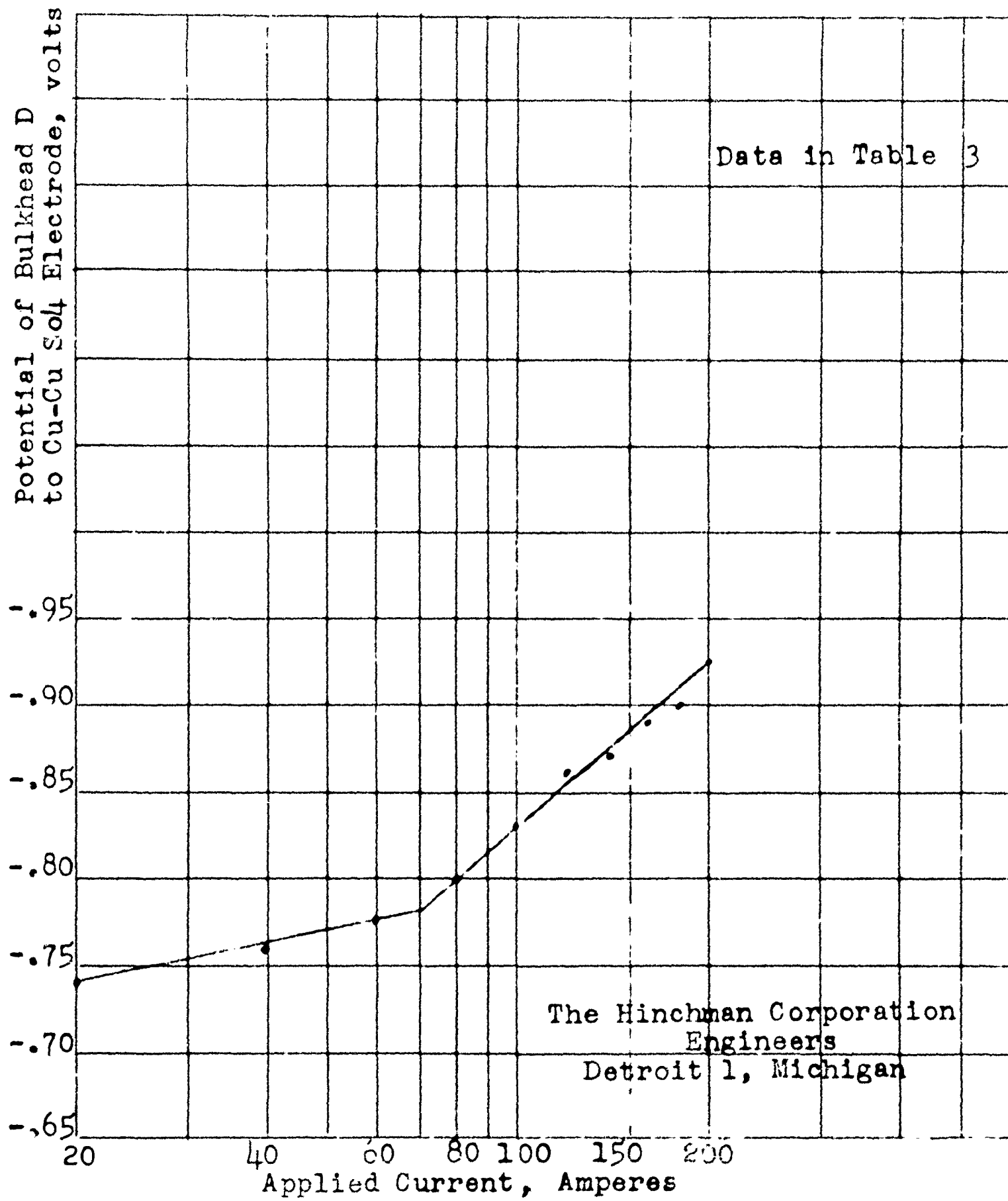
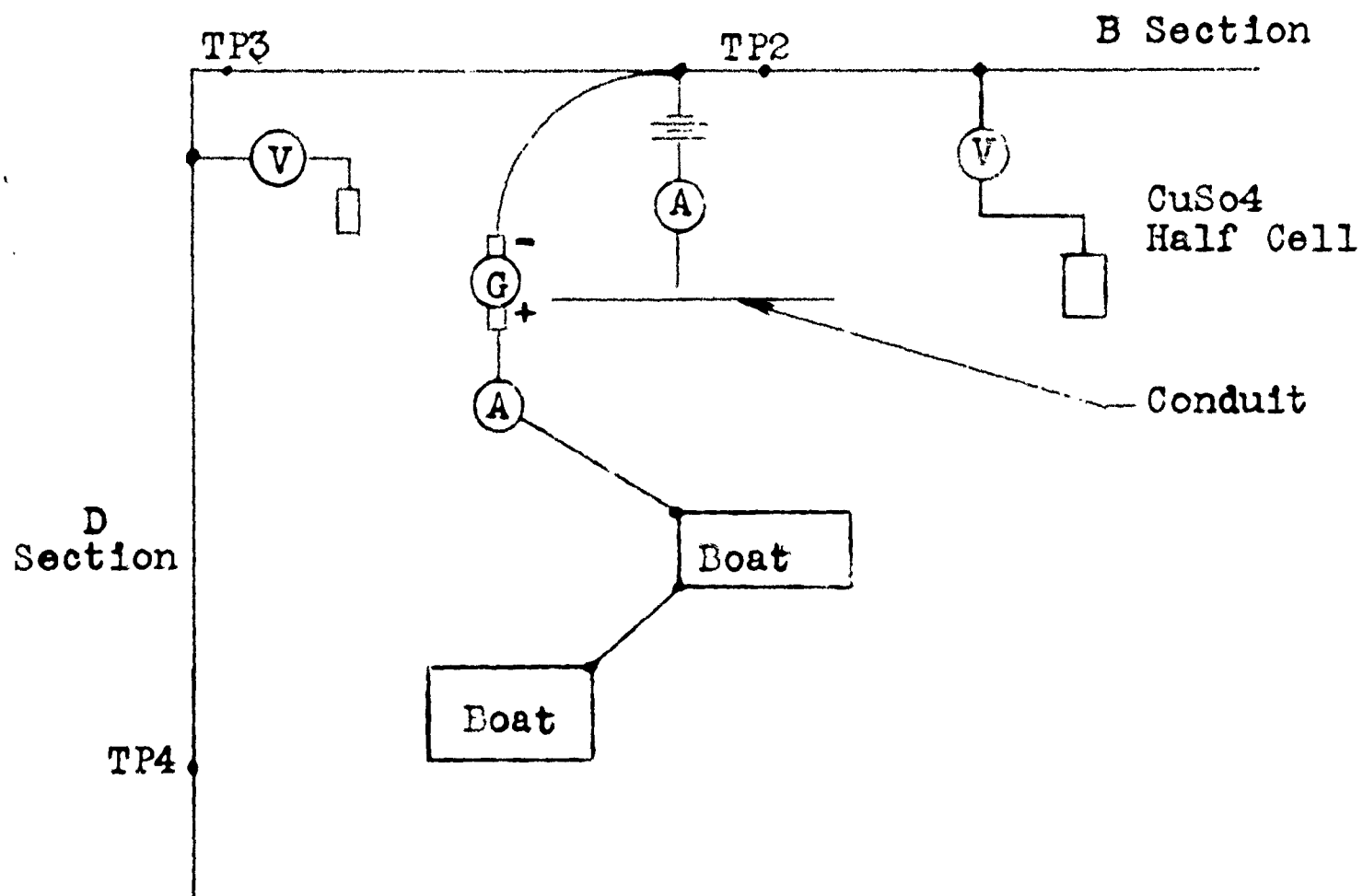


TABLE 4
CATHODIC PROTECTION TEST ON
SHORE SIDE OF B AND D SECTION OF BULKHEAD



The first test was run using storage batteries as the source of power and buried conduit as the temporary anode.

Impressed Current Amperes	Bulkhead to Soil Potential Measured to Half Cell	
	TP2	TP3
0	-.52	-.57
36	-.525	-.58

The second test used a generator for the source of power and two steel work boats lying in the fill area for anodes.

Impressed Current	TP4
0	-.71
20	-.73
40	-.75
60	-.775
80	-.80
100	-.825
120	-.85

FIGURE 3

CATHODIC PROTECTION TEST
SHORE SIDE OF BULKHEAD D
U.S. COAST GUARD DEPOT
KEY WEST, FLA.

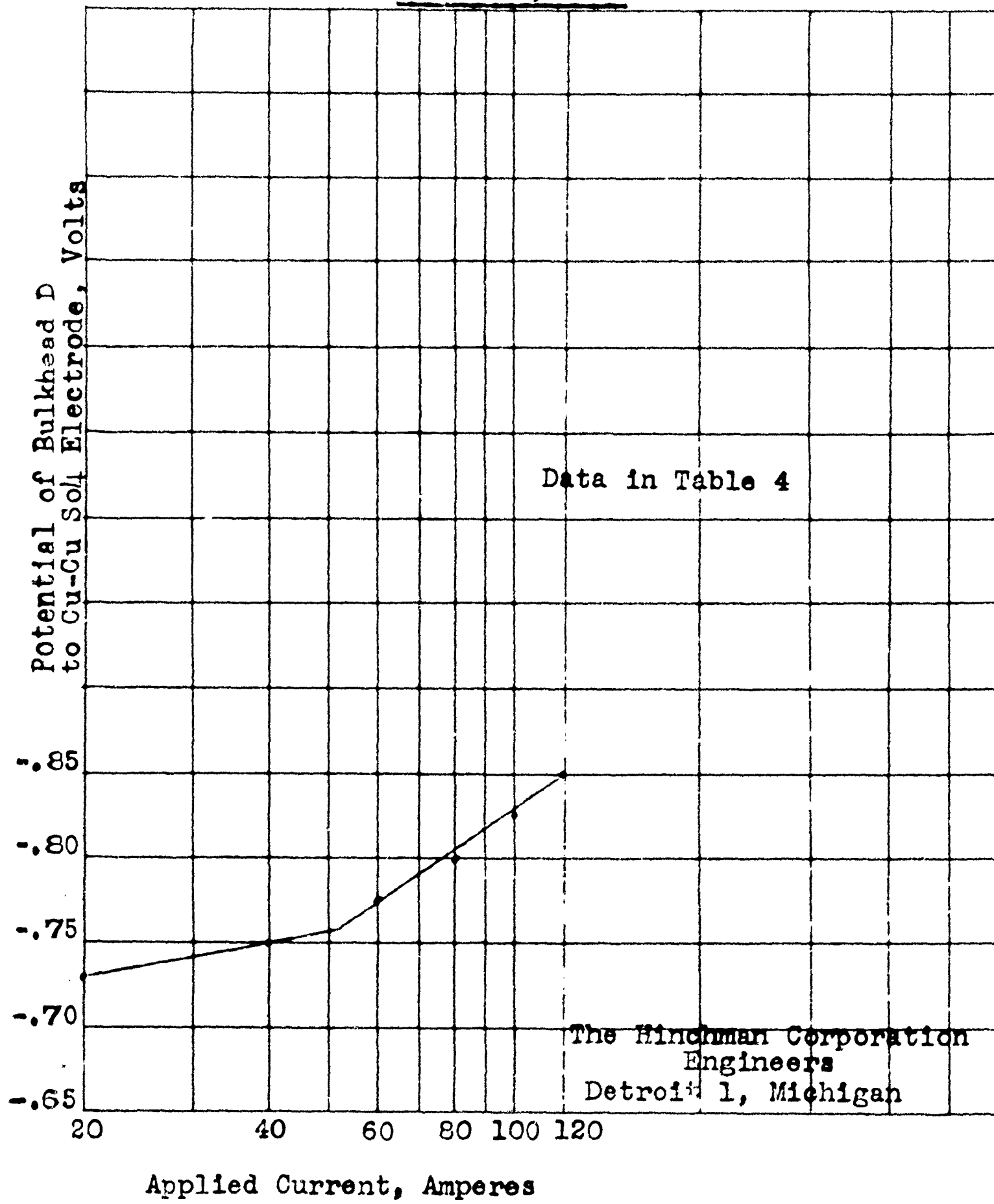


TABLE 5

AREA OF KEY WEST COAST GUARD STATION BULKHEAD

Section B 210 lineal feet Piling section = 1.48 ft.
Water Side per lineal ft.

Area in water = 3419 sq. ft.
Area in mud = 5439 sq. ft.
Area in concrete = 621 sq. ft.
Area of whaler = 840 sq. ft.
Total area = 10319 sq. ft. to be
protected

Section D 207 lineal feet Piling section = 1.48 ft.
Water Side per lineal ft.

Area in water = 3370 sq. ft.
Area in mud = 5362 sq. ft.
Area in concrete = 613 sq. ft.
Area of whaler = 828 sq. ft.
Total area = 10173 sq. ft.

Old Section 140 lineal feet Piling section = 1 ft.
at NW Corner per lineal ft.

Total area = 4900 sq. ft. one side

Tie Rods - Key West Bulkhead - New Sections Only

Type	Quan.	Dia.(in.)	Length	Area Each (sq. ft.)	Total Area (sq. ft.)
A	20	2-1/8	47'-0"	26.1	525
B	3	2-1/2	51'-4"	33.5	100.5
C	1	2-1/2	41'-2"	26.8	26.8
D	1	2-1/2	42'-11"	28.0	28
E	4	2-1/2	42'-4"	27.7	111
F	8	2-1/8	40'-0"	22.2	178
					<u>976.3</u>

TABLE 6

LOCATION AND RESULTS OF SOIL RESISTIVITY TESTS
AT U.S. COAST GUARD AIR STATION
ST. PETERSBURG, FLORIDA

The locations of these tests are shown on the map at the rear of the report.

4-Pin Tests

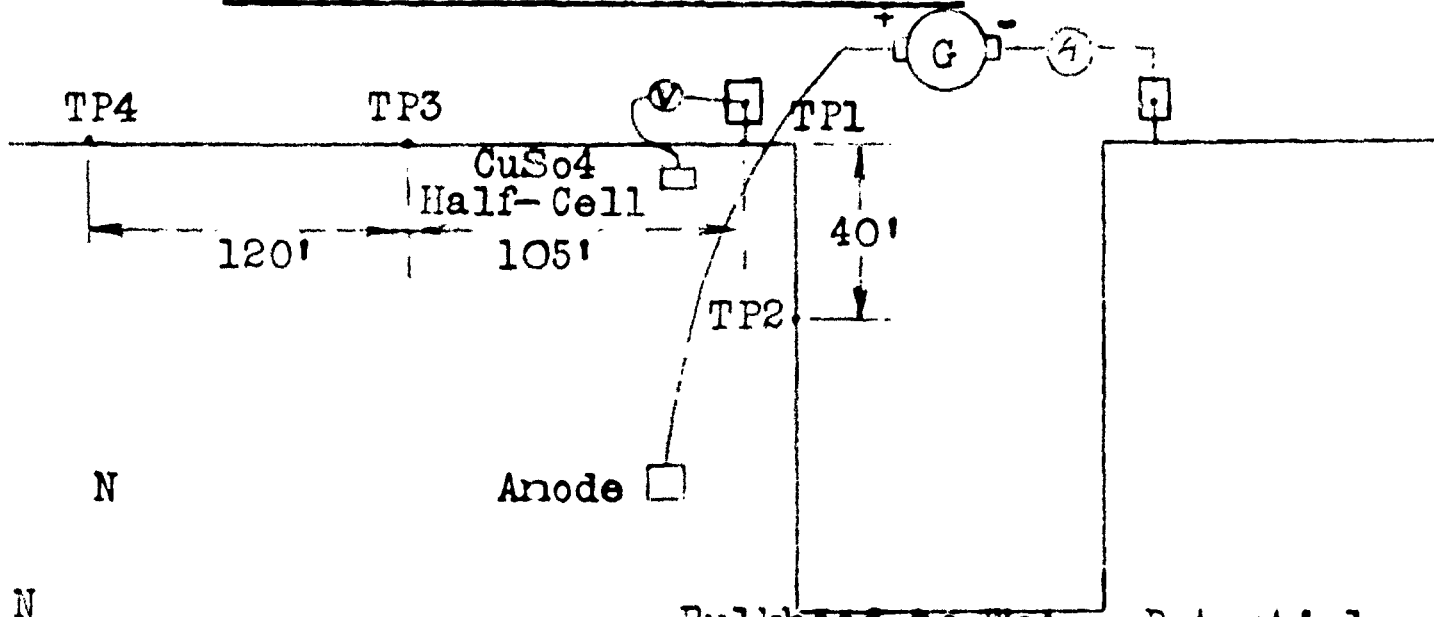
<u>Station</u>	<u>Location</u>	<u>Resistivity at</u> <u>Depth Shown</u>	
A	20' back of bulkhead, midway between ramp and boathouse	2'	11700 Ohm Cms
		4'	13000
		6'	8900
		8'	5400
		10'	3260
		12'	1030
B	10' back of bulkhead between bulkhead and gear house	2'	9800
		4'	3750
		6'	3560
		8'	4150
		10'	4760
		12'	2540

Probe Vibraground Test

<u>Probe</u>	<u>Location</u>	<u>Resistivity</u>	<u>Water</u>	<u>Bottom</u> <u>Sand</u>
	Midway between ramp and boathouse		50 Ohm Cms	320 Ohm Cms

TABLE 7

CATHODIC PROTECTION TEST ON NORTH END
OF BULKHEAD AND SEAPLANE RAMP



Impressed Current Amperes	Bulkhead to Water Potential Measured to Half Cell			
	TP1	TP2	TP3	TP4
0	-.675	-.69	-.725	-.69
20	-.69	-.71		-.71
40	-.72	-.73	-.775	-.74
60	-.75	-.74		-.75
80	-.775	-.765	-.85	-.78
100	-.79	-.78		-.81
120	-.82	-.80	-.93	-.85
140	-.85	-.82		-.88
160	-.87	-.84	-1.02	-.92
180	-.89	-.86		-.96
200	-.91	-.88	-1.10	-1.00

FIGURE 4

CATHODIC PROTECTION TEST
NORTH END OF BULKHEAD AND SEAPLANE RAMP
U.S. COAST GUARD AIR STATION
ST. PETERSBURG, FLA.

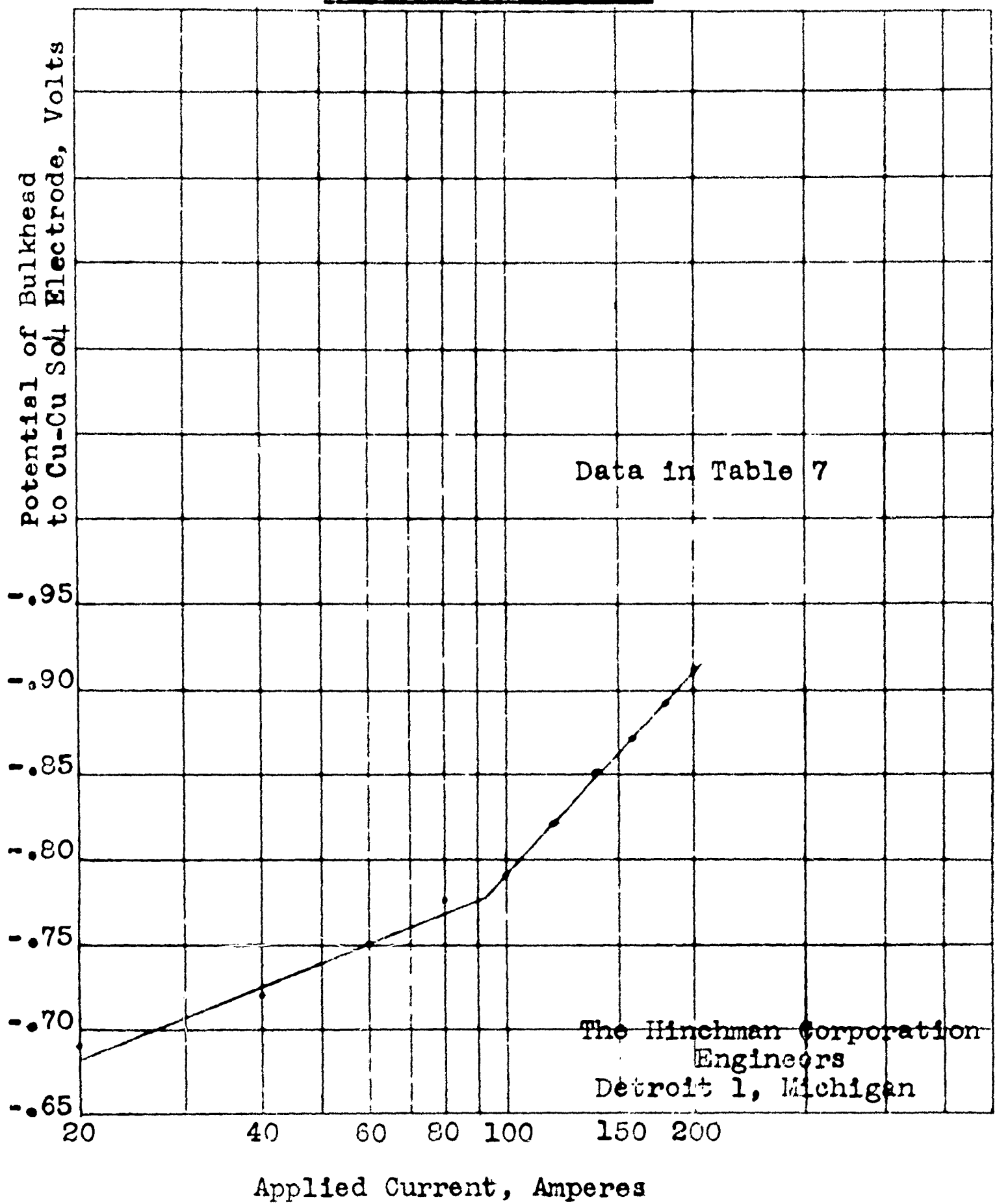
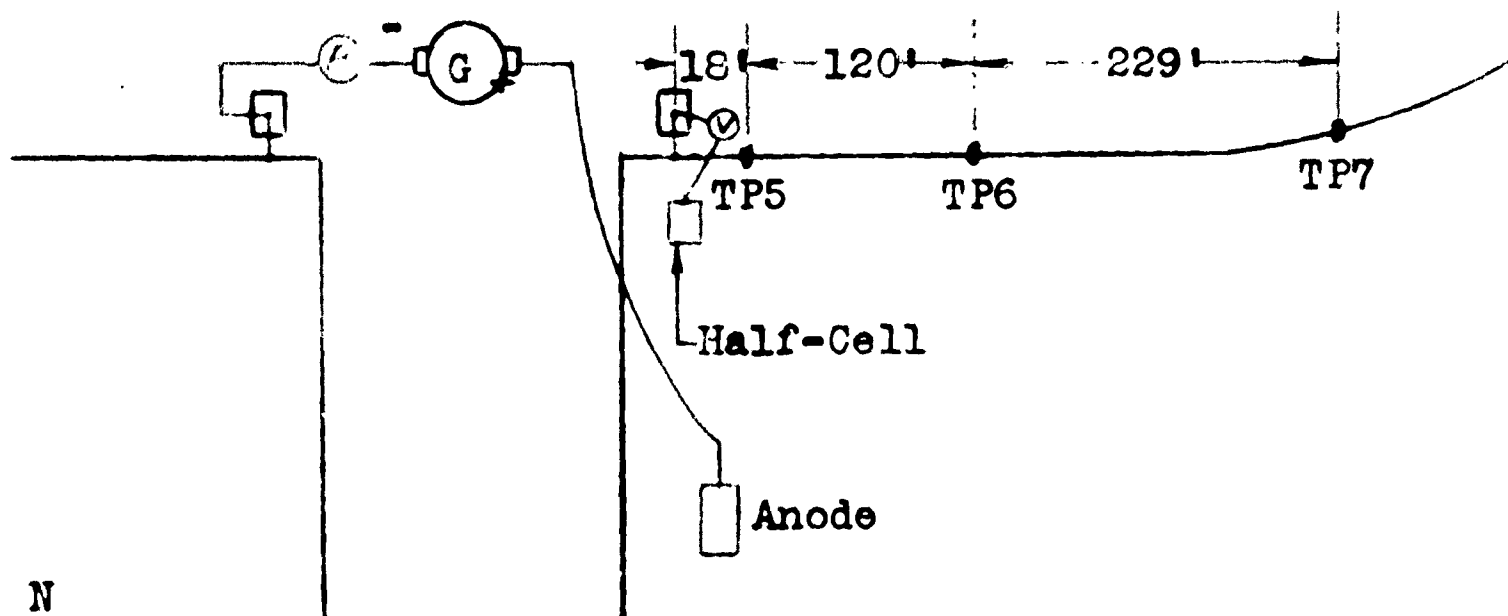


TABLE 8

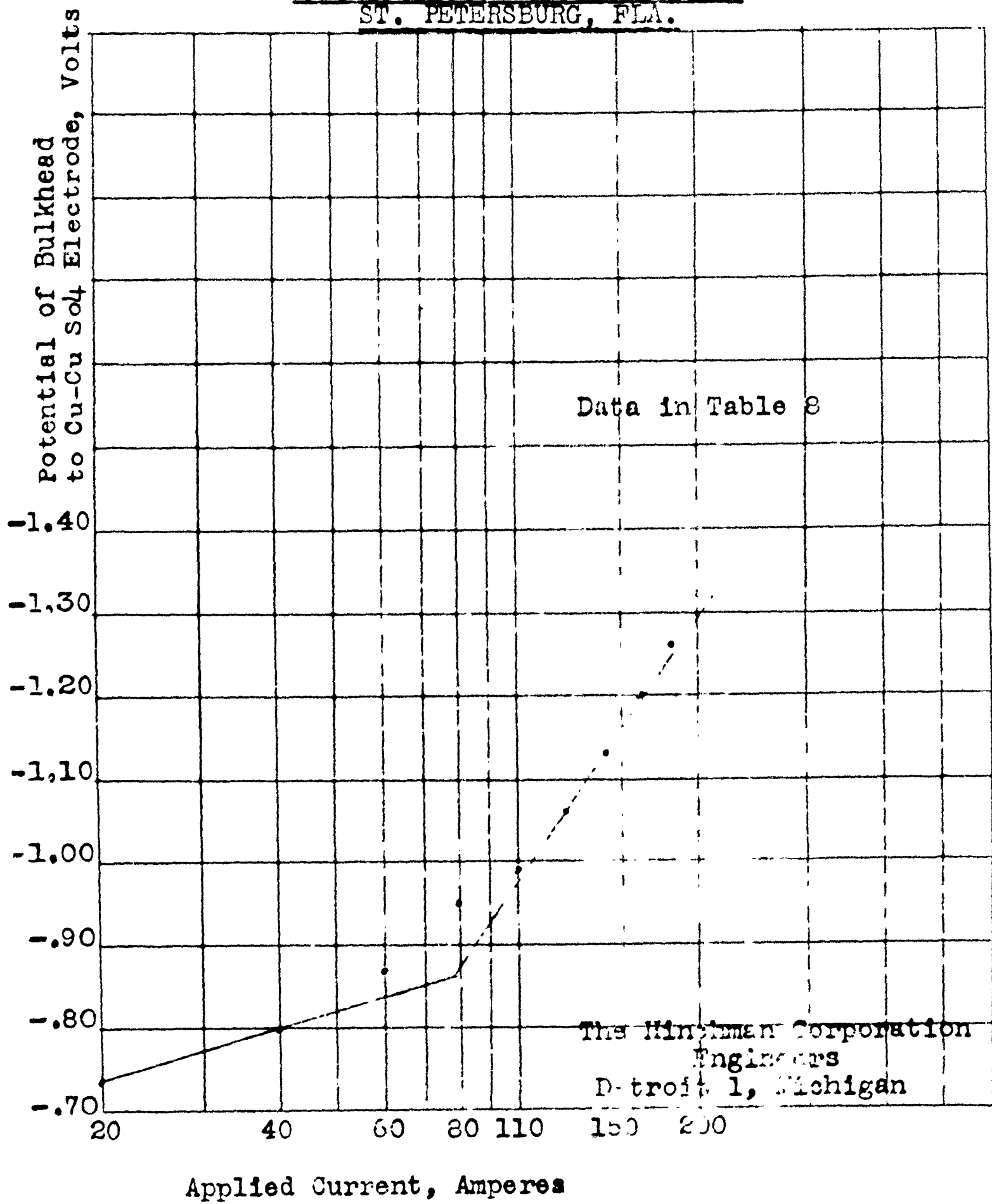
CATHODIC PROTECTION TEST ON SOUTH END
OF BULKHEAD AND SEAPLANE RAMP

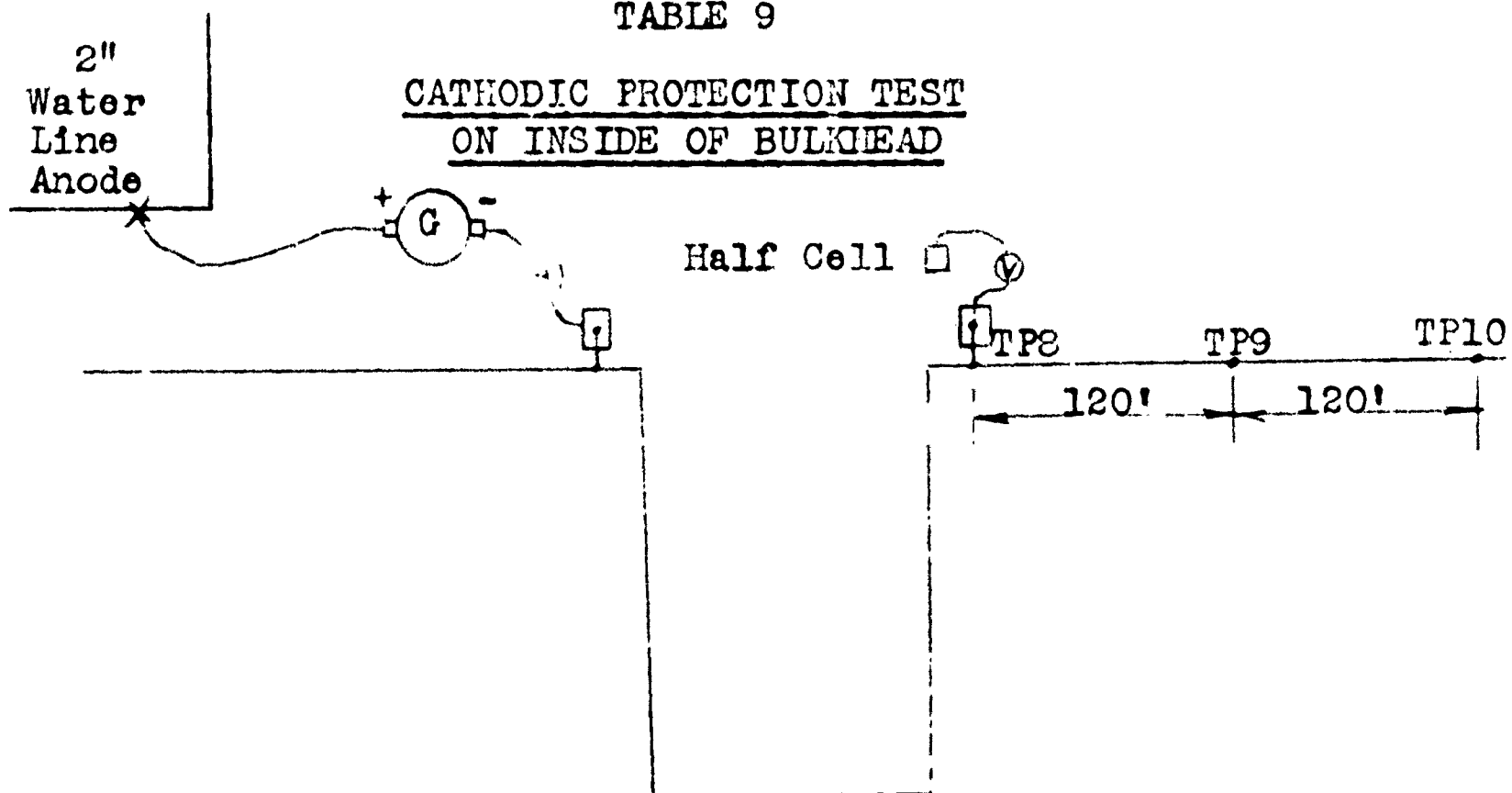


Impressed Current Amperes	Bulkhead to Water Potential Measured to Half Cell		
	TP5	TP6	TP7
0	-.69	-.69	-.625
20	-.74		
40	-.80	-.71	
60	-.87		
80	-.95	-.725	
100	-.99		
120	-1.06	-.74	
140	-1.13		
160	-1.20	-.76	
180	-1.26		
200	-1.32	-.78	-.64

FIGURE 5

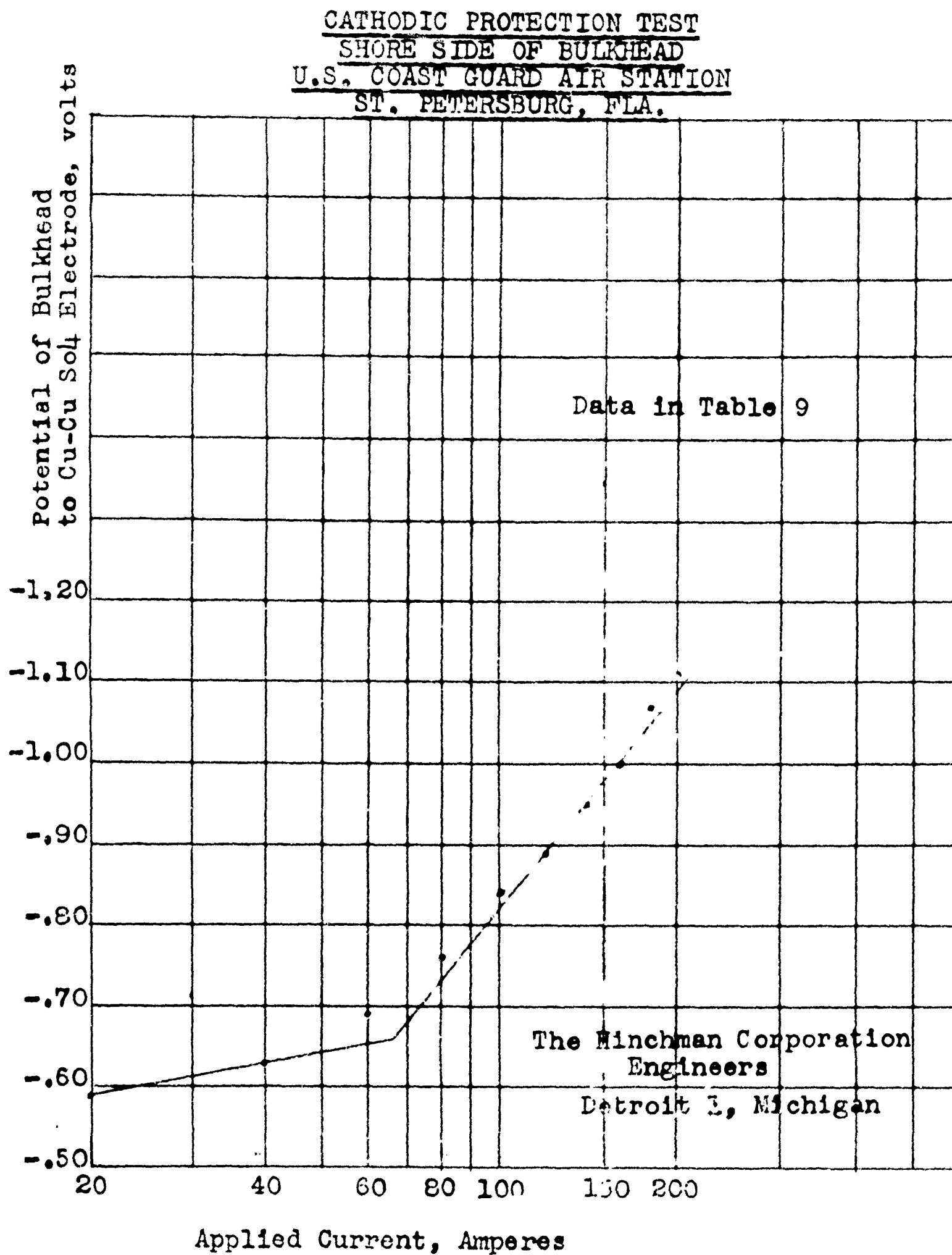
CATHODIC PROTECTION TEST
SOUTH END OF BULKHEAD AND SEAPLANE RAMP
U.S. COAST GUARD AIR STATION
ST. PETERSBURG, FLA.





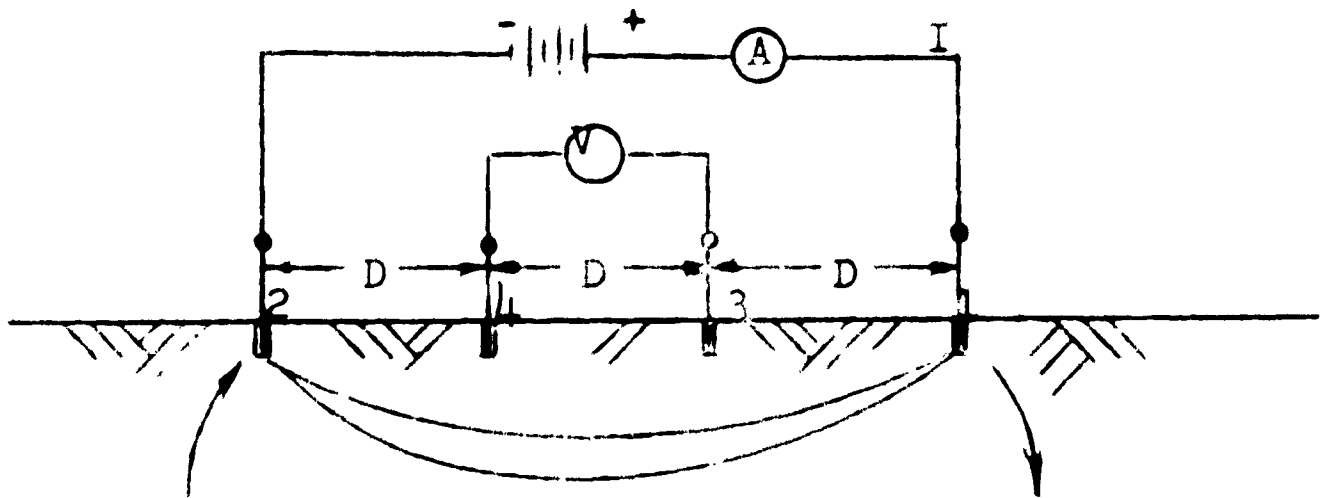
Impressed Current Amperes	Bulkhead to Soil Potential Measured to Half Cell		
	TP8	TP9	TP10
0	-.53	-.46	-.47
20	-.59		
40	-.63	-.59	-.64
60	-.69		
80	-.76	-.74	-.77
100	-.84		
120	-.89	-.92	-.96
140	-.95		
160	-1.00	-1.08	-1.11
180	-1.07		
200	-1.11	-1.25	-1.25

FIGURE 6



APPENDIX A

FOUR ELECTRODE METHOD OF SOIL RESISTIVITY MEASUREMENT



Let current I enter the ground at the point electrode #1 whose radius is s : area = $2\pi s^2$

radial current density: $J = I / 2\pi s^2$

let ρ = soil resistivity

then electrical intensity $E(s)$ is

$$E(s) = \rho I / 2\pi s^2$$

and the potential between the distance s and an infinite point

$$V = \int_s^\infty E(s) ds = I / 2\rho s$$

the resistance of electrode #1 and an infinite point

$$R(s) = V / I = \rho / 2\pi s$$

the resistance of a circuit between 1 and 2 with a circuit between 3 and 4 is

$$\begin{aligned} R &= R_{13} - R_{23} - (R_{14} - R_{24}) \\ &= \rho / 2\pi (1/D - 1/2D - 1/2D + 1/D) \\ &= \rho / 2\pi D \end{aligned}$$

$$\rho = 2\pi DR \quad \text{where } R = V / I$$

for D in feet and ρ = soil resistivity in ohm-cm

$$\begin{aligned} \rho &= 2\pi 30.6 D V / I \\ &= 191 D V / I \end{aligned}$$

THE HINCHMAN CORPORATION
ENGINEERS
FRANCIS PALMS BUILDING
DETROIT, MICHIGAN

COMPUTATION SHEET

SUBJECT Cathodic Protection,
New Sea Water Bulkhead
LOCATION U.S.C.G. Depot
Key West, Florida

JOB NO. 654-314
SHEET NO 1 OF 3
BY D.H. DATE
C.K'D BY DATE

A. Computation of Current Requirements:

Section B - 210 lineal ft. Piling Section = 1.48 ft. per lineal ft.
Section D - 207 lineal ft. Water = 4 sq. ft. per lineal ft.
Old Section - 140 lineal ft. Piling Section = 1.0 ft. per lineal ft.

1) Area Section B

11 X 210 X 1.48 = 3419 ft.² in water
17.5 X 210 X 1.48 = 5439 ft.² in mud
8 X 210 X 1.48 = 621 ft.² in concrete
4 X 210 = 840 ft.² Water in concrete

2) Current Criteria

- Assume a design criterion of .003 amperes per sq. ft. of surface for the areas of the bulkhead in concrete and below the mud line.
- Assume the design criterion of .007 amperes per sq. ft. of surface for the areas exposed to the sea water.

3) Current Required - Section B

Total area in mud and at whaler: 5439 + 621 + 840 = 6900 sq. ft.
Current @ .003 amp./sq. ft. = 6900 X .003 = 20.7 amperes,

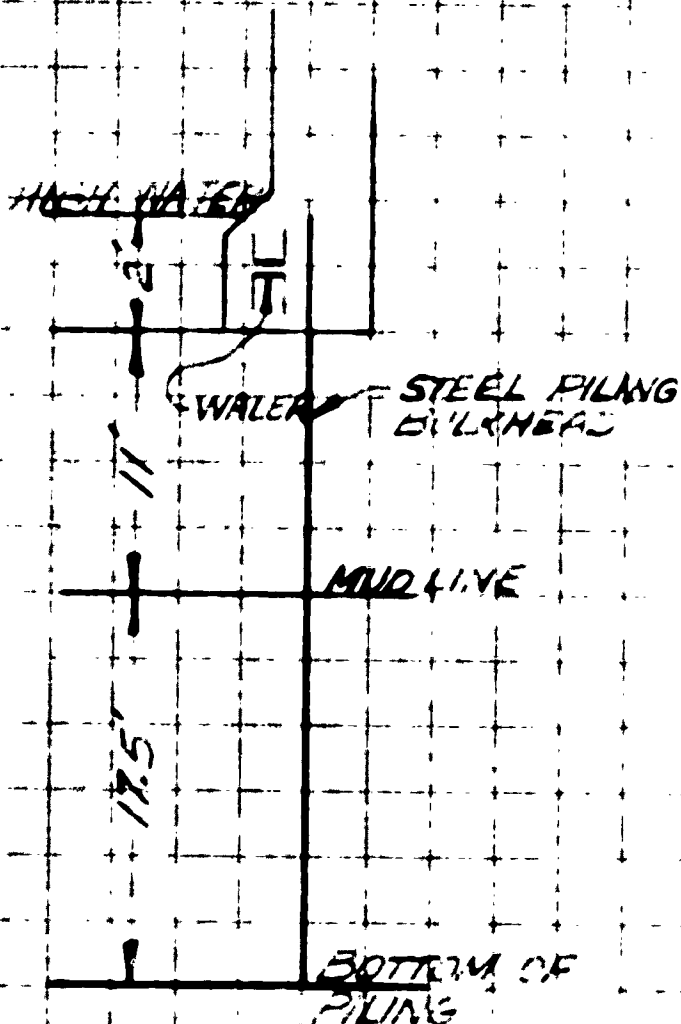
Total area in sea water: 3419 sq. ft.
Current @ .007 amp./sq. ft. = 3419 X .007 = 23.9 amperes,

4) Old Section - Current Required

Area of section: 140 X 35 = 4900 sq. ft.
Current @ .003 amp./sq. ft. = 4900 X .003 = 14.7 amperes,

5) Total Current Required for Section B and the Old Section:

Amperes: 23.9 + 20.7 + 14.7 = 59.3 amperes.



THE HINCHMAN CORPORATION
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DETROIT, MICHIGAN

COMPUTATION SHEET

SUBJECT Cathodic Protection,
New Sea Water Bulkhead
LOCATION U.S.C.G. Depot
Key West, Florida

JOB NO 654-314
SHEET NO 2 OF 3
BY D.H. DATE
CHECK'D BY *PH* DATE *7/56*

6) Area Section D

$11 \times 207 \times 1.48 = 3370 \text{ ft.}^2$ in water

$17.5 \times 207 \times 1.48 = 5362 \text{ ft.}^2$ in mud

$2 \times 207 \times 1.48 = 613 \text{ ft.}^2$ in concrete

$207 \times 4 = 828 \text{ ft.}^2$ water in concrete

7) Current Required - Section D

Total area in mud and at whaler: $5362 + 613 + 828 = 6803 \text{ sq. ft.}$
Current @ .003 amp./sq. ft. $= 6803 \times .003 = 20.4 \text{ amperes}$

Total area in sea water: 3370 sq. ft.
Current @ .007 amp./sq. ft. $= 3370 \times .007 = 23.6 \text{ amperes.}$

8) Total Current Required for Section D

Amperes: $23.6 + 20.4 = 44 \text{ amperes.}$

9) Area of Earth Side of Bulkhead

Section C: $3419 + 5430 + 621 = 9479 \text{ sq. ft.}$

Section D: $3370 + 5362 + 613 = 9345 \text{ sq. ft.}$

Tie Rods: 967 sq. ft.

Old Section: 4900 sq. ft.

Total area $= 9479 + 9345 + 967 + 4900 = 24,691 \text{ sq. ft.}$
Current @ .003 amp./sq. ft. $= 24691 \times .003 = 74.1 \text{ amperes.}$

B. Graphite Anode Life

Graphite dissipation $= 2 \text{ lbs. per ampere year}$

Anode weight $3" \times 60" = 27 \text{ lbs.}$

$4" \times 80" = 68 \text{ lbs.}$

Current required to protect Section B $= 44.6 \text{ amp.}$

Old Section $= 14.7 \text{ amp.}$

Total 59.3 amp.

THE HINCHMAN CORPORATION
ENGINEERS
FRANCIS PALMS BUILDING
DETROIT, MICHIGAN

COMPUTATION SHEET

SUBJECT Cathodic Protection,
New Sea Water Bulkhead
LOCATION U.S.C.G. Depot
Key West, Florida

JOB NO 654-314

SHEET NO 3 OF 3

BY D.H. DATE

CHECK'D BY W.S. DATE 8/6/54

Present design 20 anodes 3" X 60" for Section B

$\frac{44.6}{20} = 2.23$ amp. per anode, anode dissipation is 2 lbs./amp./yr.,
estimated wgt. loss per year = $2 \times 2.23 = 4.46$ lbs.

$\frac{27}{1.46} = 6.08$ years est. life

Recommended design 20 anodes 4" X 80" for Section B Old Section

$\frac{59.3}{20} = 2.96$ amp. per anode, estimated wgt. loss per yr. =
 $2 \times 2.96 = 5.91$

$\frac{68}{5.91} = 11.4$ years est. life

Current required to protect Section D = 44 amperes

Present design 21 anodes 3" X 60" for Section D

$\frac{44}{21} = 2.09$ amperes per anode, anode dissipation @ 2 lb./amp./yr. =
 $2 \times 2.09 = 4.18$

$\frac{27}{4.18} = 6.45$ years estimated life

Recommended design

14 anodes 4" X 80"

$\frac{44}{14} = 3.14$ amp. per anode, estimated wt. loss = $2 \times 3.14 = 6.28$ lbs.

$\frac{68}{6.28} = 10.8$ years

Current required to protect shore side of bulkhead and tie rods =
74.1 amp.

Recommended design = 22 anodes 4" X 80"

$\frac{74.1}{22} = 3.36$ amperes per anode, estimated wt. = $2 \times 3.36 = 6.72$

$\frac{68}{6.72} = 10.1$ years est. life

THE HINCHMAN CORPORATION
ENGINEERS
FRANCIS PALMS BUILDING
DETROIT, MICHIGAN

COMPUTATION SHEET

SUBJECT Cathodic Protection,
Bulkhead and Seaplane Ramp
LOCATION U.S.C.G. Air Station
St. Petersburg, Florida

JOB NO. 654-314
SHEET NO. 4 OF
BY D.H. DATE
C'K'D BY LV DATE 8/6/54

A. Computation of Current Requirements:

Bulkhead - 880 lineal feet
Seaplane Ramp 151 lineal ft. X 61 lineal ft.
Piling Section = 1.48 ft. per lineal foot approx.
Length of Bulkhead Pile 12' Average Length of Ramp Pile 21.9'

1) Area of Bulkhead

$$12 \times 820 \times 1.48 = 14563 \text{ sq. ft.}$$

Area of Ramp

$$21.9 \times 363 \times 1.48 = 11766 \text{ sq. ft.}$$

Total = 26329 sq. ft. to be protected

2) Assume a Design Criteria of .005 Amperes per Sq. Ft. of Surface

3) Current Required

$$26329 \times .005 = 78.99 \text{ amperes}$$

Graphite Anode Life

Graphite dissipation = 2 lbs. per ampere year

Anode weight = 68 lbs.

Current required to protect bulkhead and ramp = 79 amperes

Recommended design

24 anodes 4" X 80"

$$\frac{79}{24} = 3.29 \text{ amperes per anode, estimated wt. loss =}$$

$$2 \times 3.29 = 6.58$$

$$\frac{68}{6.58} = 10.3 \text{ years}$$

FOR CONTINUATION SEE INSERT NO.

AREA A
PIEF-A

EXISTING AREA

AREA-E
1 1/2" CONC. LAR

15" FLAT

TR #2

EXISTING WALL

POWER UNITS MTC IN BLOS.

CONCRETE LAR

TYPICAL AREA

#4.0 EMBE
STEELING - 1/2" DIA. OF 1/2"

1

AREA-C
8" CONC. SLAB

PIER

EXISTING WALL

2

AREA-A
PIER-A

AREA-C
8" CONC SLAB

3

EXISTING WALL

AREA-A
PIER-A

TIE-EDGE



4 PIN TEST

4

NEW AREA

AREA 1, 2

TR #4

F

E

C

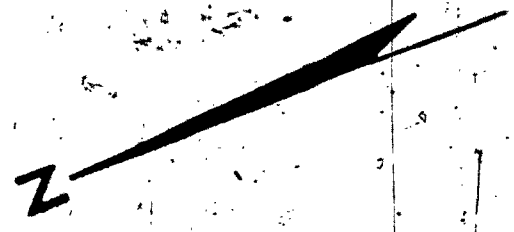
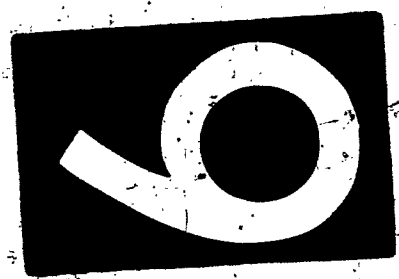
WATER & AIR OUTLET

FACE OF CONCRETE

5

WATER & AIR OUTLET

FACE OF CONCRETE



INSERT N21

TP#4 ▲

F ●

E ●

●

PLOT P AN
SUA : 2 32-10

7

8

LEGEND

- ▲ - STRUCTURE TO SOIL OR WATER TEST POINT
- - PULSE VIBRATION NO TEST POINT

REVISION	DATE	APPD.
U. S. COAST GUARD		
DESIGNED -	CIVIL	
DRAWN -	J.S.C	
TRACED -	L.G.H.	
CHECKED -		
CHIEF OF SECTION	APPROVED	
THE ENGINEER	U.S.	
EXHIBIT	MIC	

—INSERT NO. 1.

▲ = STRUCTURE TO S, L OR WATER TEST POINT
● = PIERCE VIEWPOINT TO TEST POINT

NO. 10-11-12

PAINING AREA 10.2

1

4

11.11.11

2



BARN

3

Efficient D

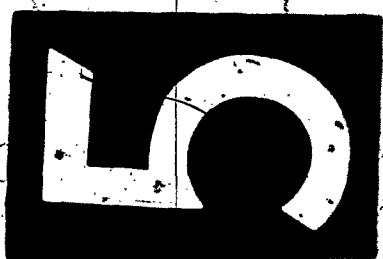
TEN

ED

4

CONCRETE SEAPLANE

NEAR WHEEL



6

● = 4
● = 20
▲ = 100

7

