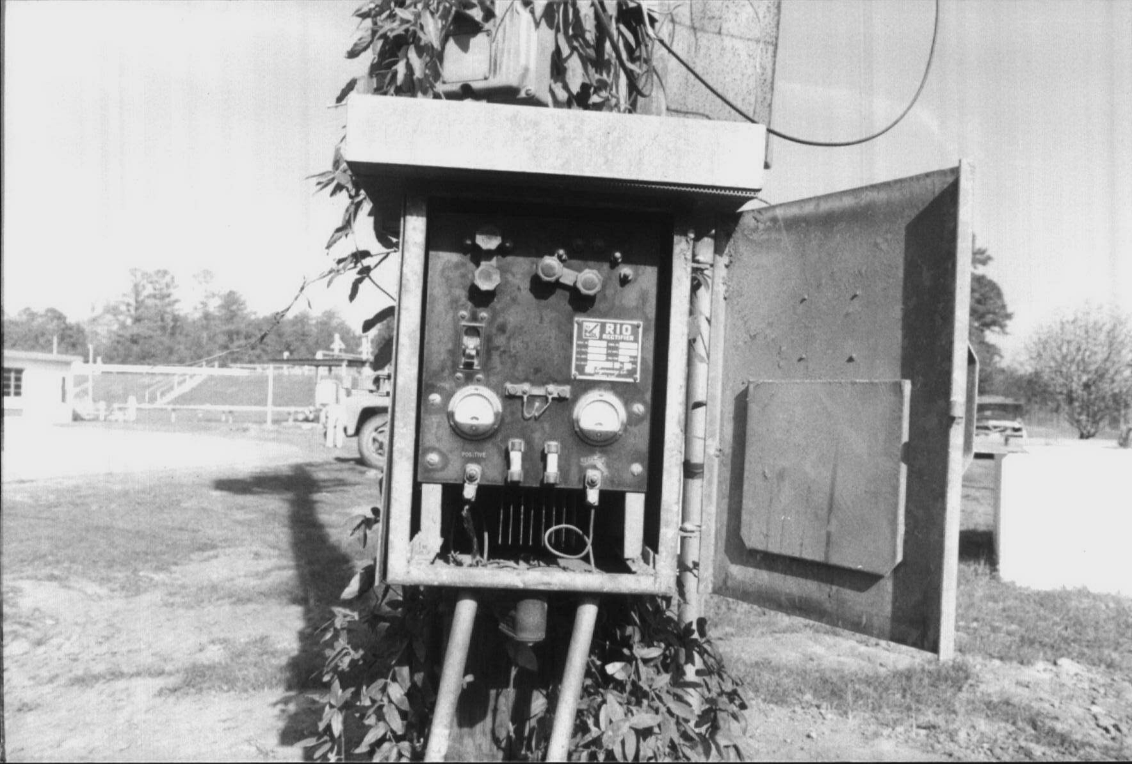
PHOTO NO. 2

TANK FARM AREA
LOOKING NORTH-EAST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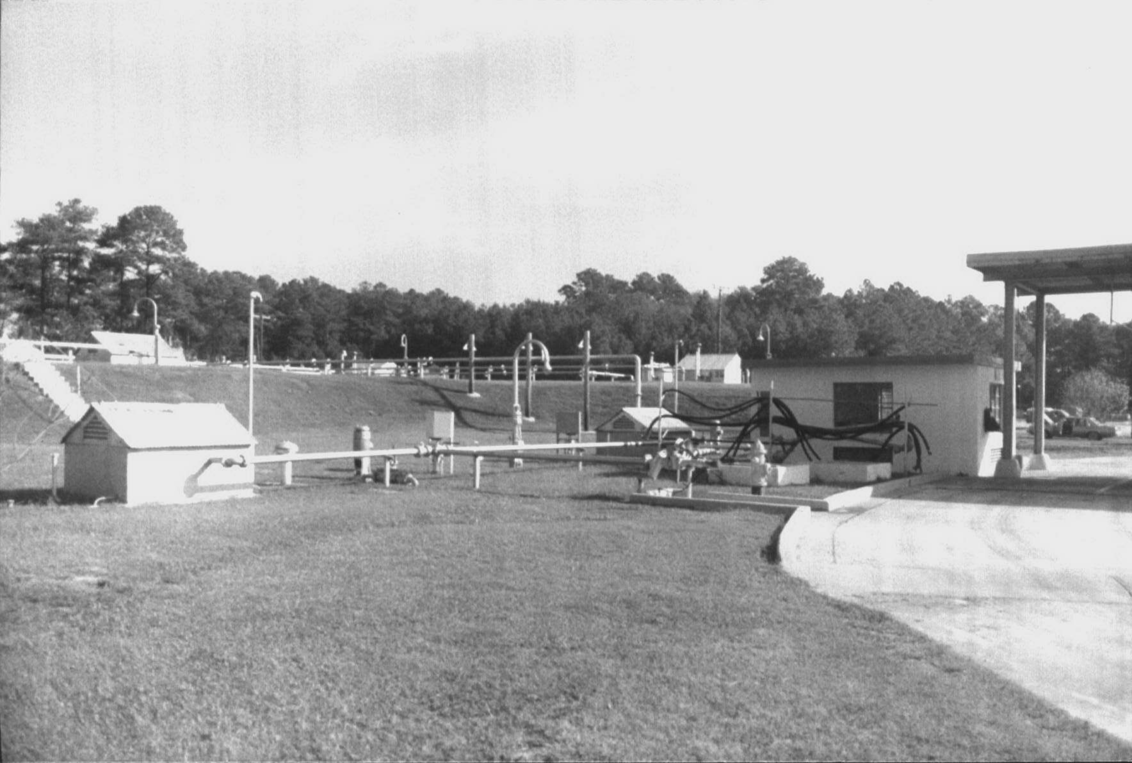

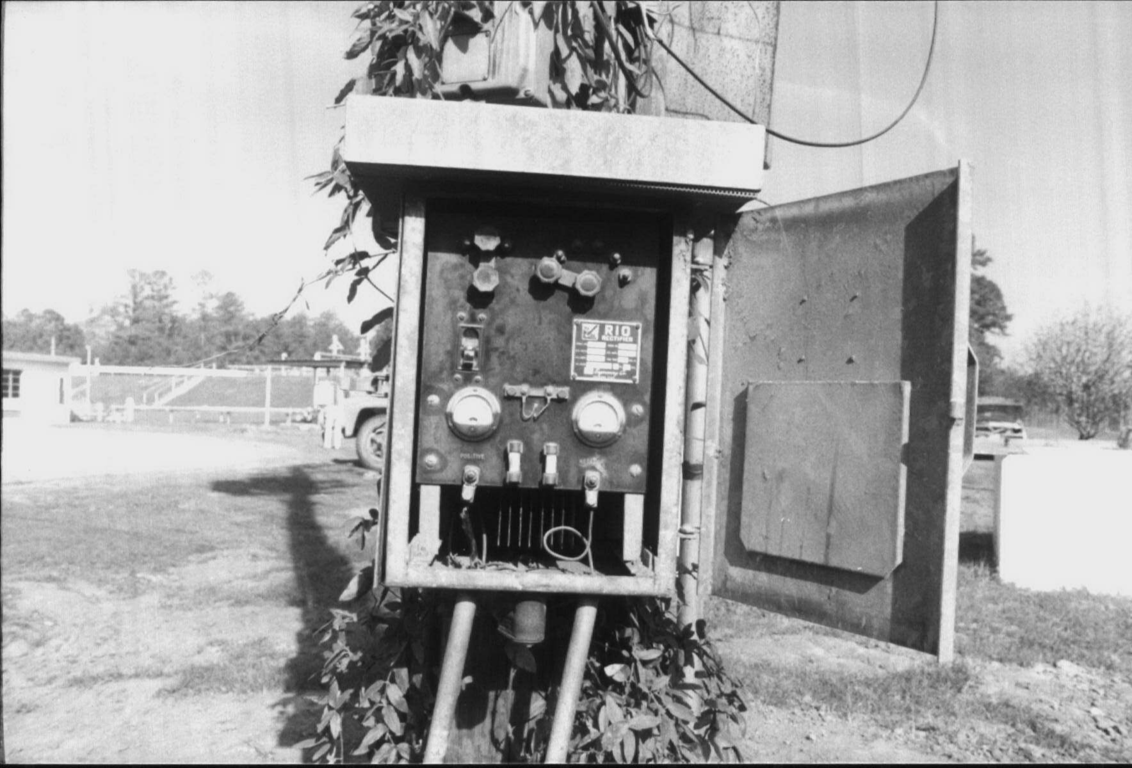
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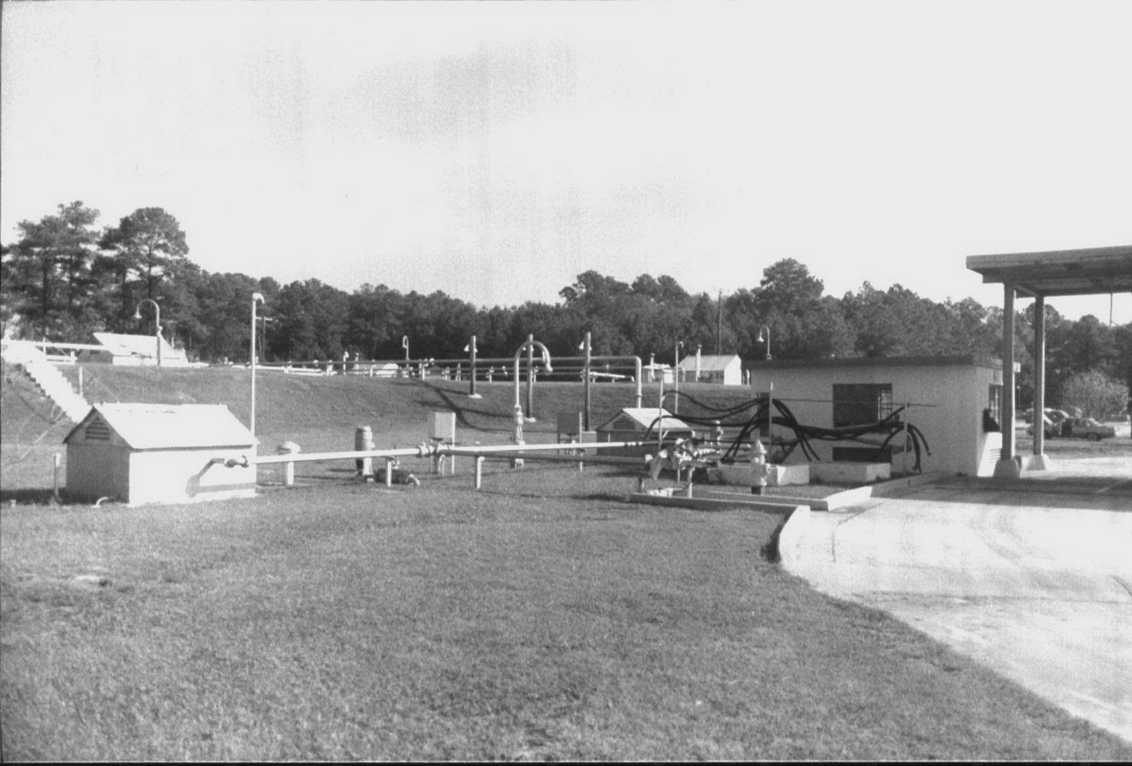

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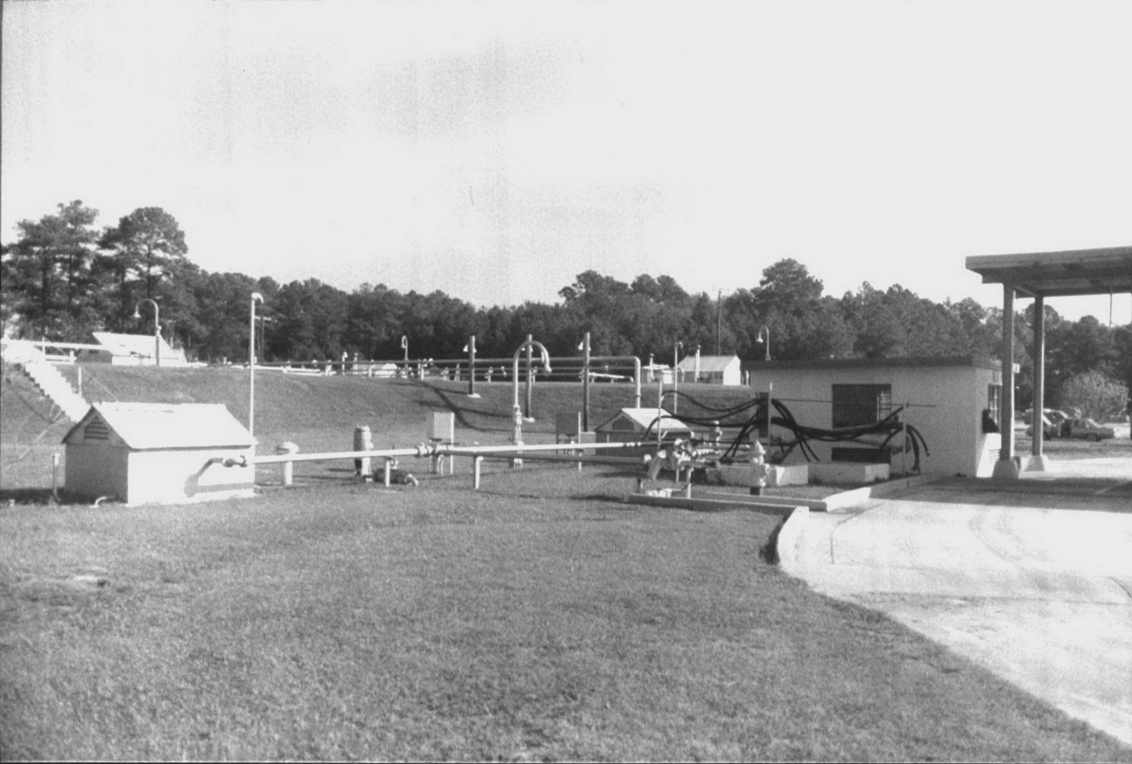
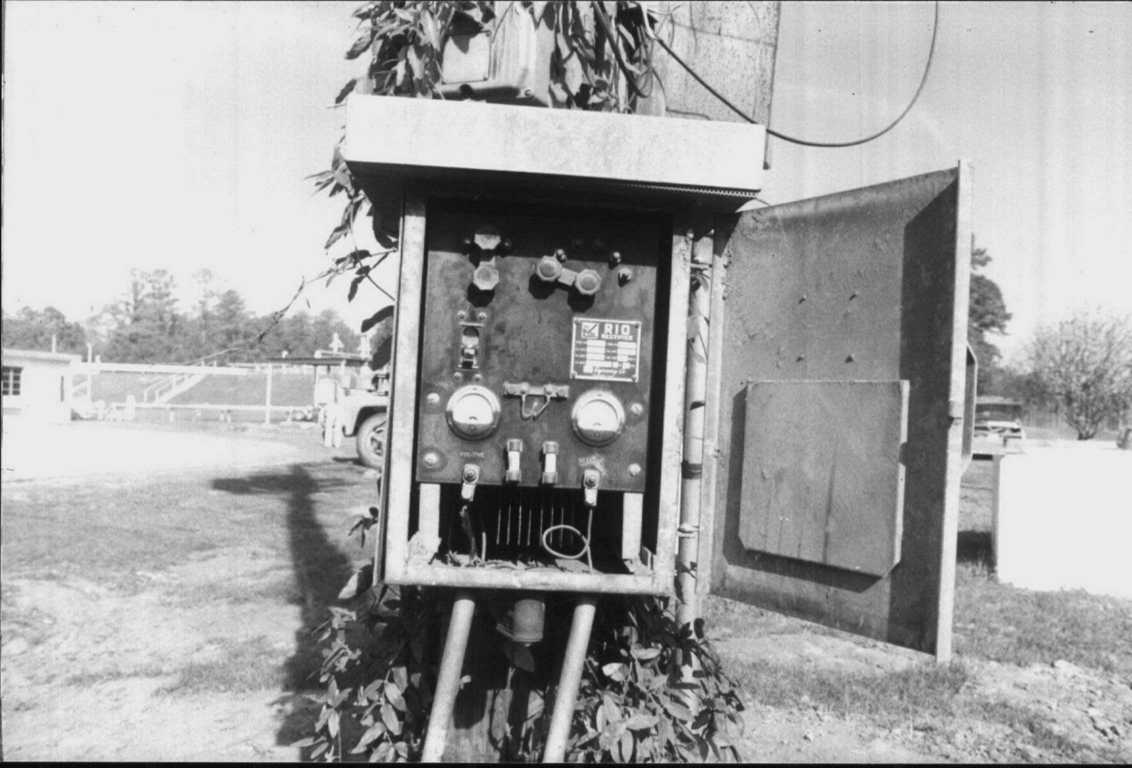
PHOTO NO. 3 ELEVATED WATER STORAGE TANK NO. 4130

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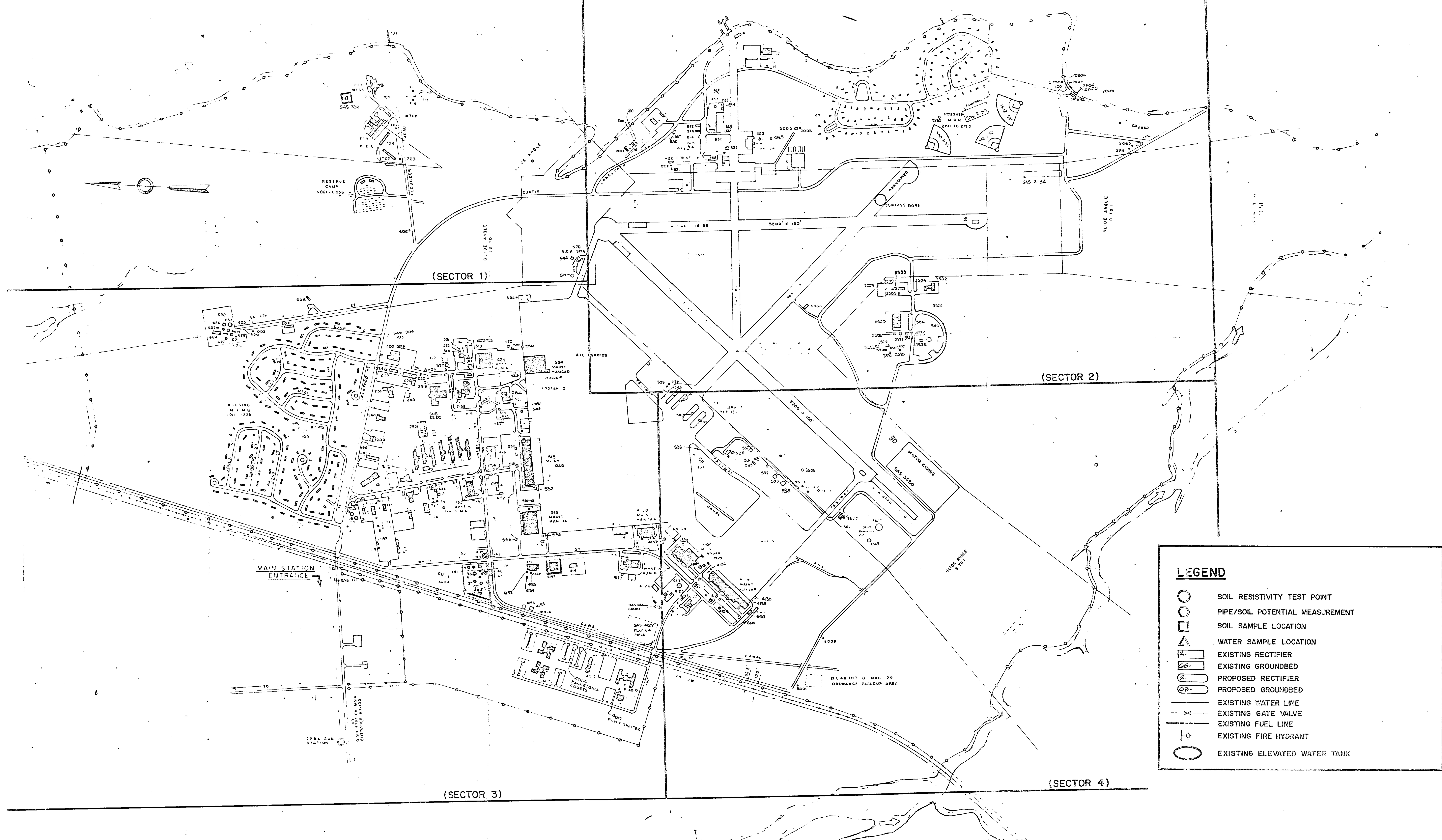


GRAPHIC SCALE

500 0 500 1000 1500 2000 2500

SCALE 1" = 500'-0"

MDA MENENDEZ-DONNELL & ASSOCIATES, INC.
GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.

ATLANTIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
NORFOLK, VIRGINIA

CATHODIC PROTECTION SURVEY

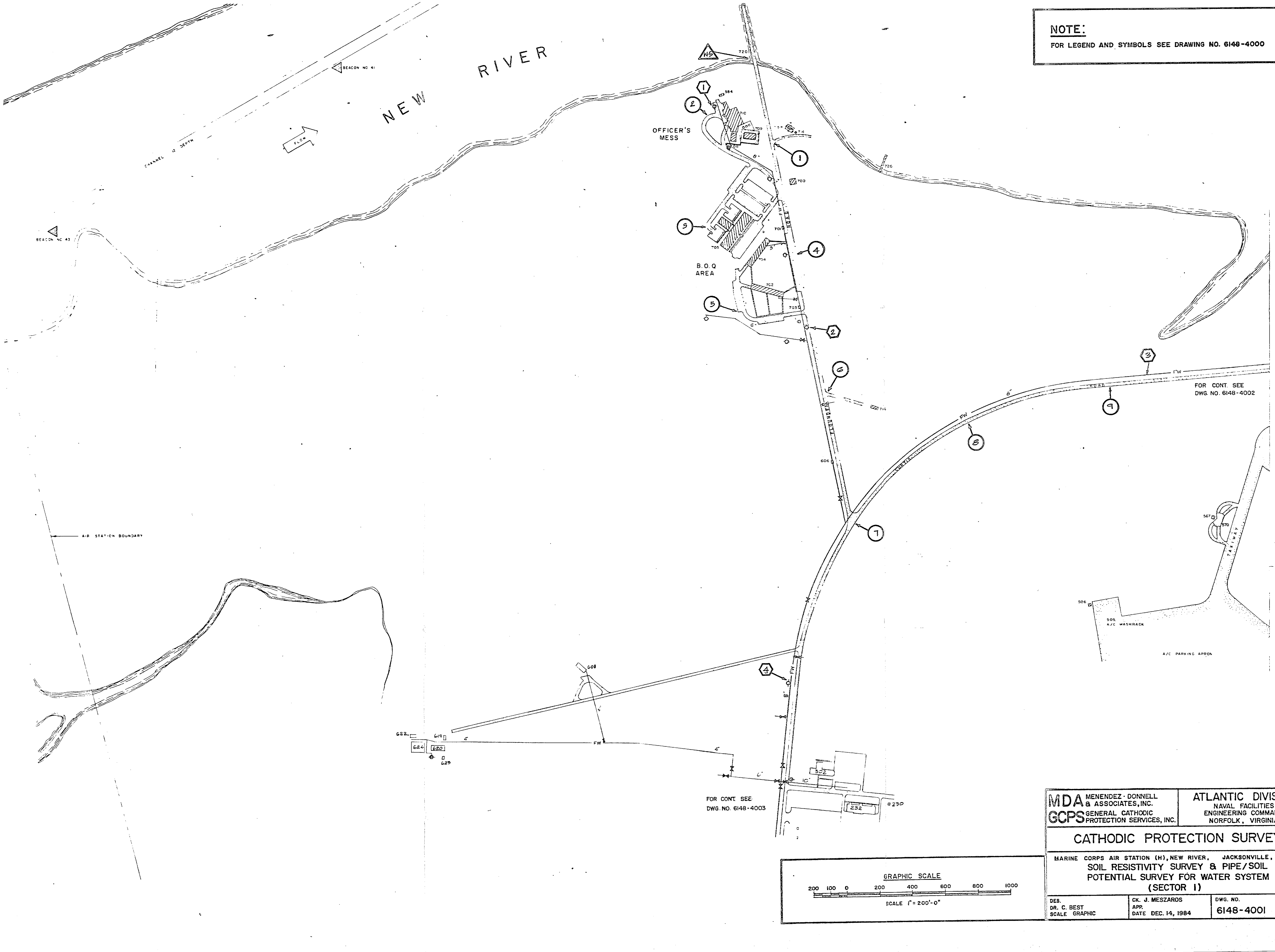
MARINE CORPS AIR STATION (H), NEW RIVER, JACKSONVILLE, N.C.

STATION MAP

DES. DR. J. CRUZ SCALE GRAPHIC	CK. J. MESZAROS APP. DATE DEC. 14, 1984	DWG. NO. 6148-4000	REV.

NOTE:

FOR LEGEND AND SYMBOLS SEE DRAWING NO. 6148-4000



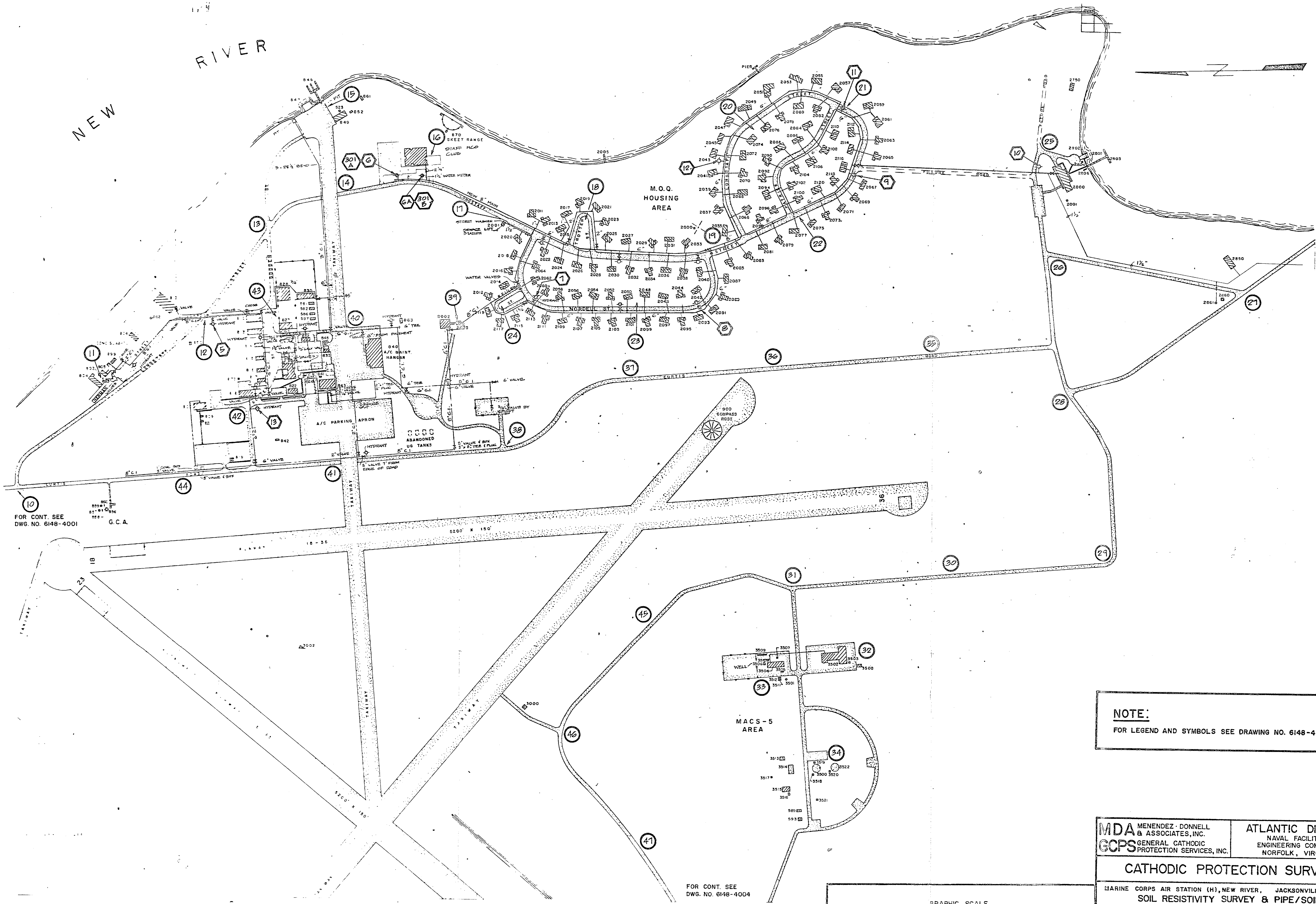
MDA MENENDEZ-DONNELL & ASSOCIATES, INC.
GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.

ATLANTIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
NORFOLK, VIRGINIA

CATHODIC PROTECTION SURVEY

MARINE CORPS AIR STATION (H), NEW RIVER, JACKSONVILLE, N.C.
SOIL RESISTIVITY SURVEY & PIPE/SOIL POTENTIAL SURVEY FOR WATER SYSTEM
(SECTOR 1)

DES. DR. C. BEST SCALE GRAPHIC	CK. J. MESZAROS APP. DATE DEC. 14, 1984	DWG. NO. 6148-4001 REV.



NOTE:

FOR LEGEND AND SYMBOLS SEE DRAWING NO. 6148-4000

GRAPHIC SCALE

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SCALE 1" = 200'-0"

MDA MENENDEZ-DONNELL & ASSOCIATES, INC. GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.	ATLANTIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND NORFOLK, VIRGINIA

CATHODIC PROTECTION SURVEY

MARINE CORPS AIR STATION (H), NEW RIVER, JACKSONVILLE, N.C.

SOIL RESISTIVITY SURVEY & PIPE/SOIL POTENTIAL SURVEY FOR WATER SYSTEM (SECTOR 2)

DGS. DR. J. CRUZ SCALE GRAPHIC	CK. J. MESZAROS APP. DATE DEC. 14, 1984	DWG. NO. 6148-4002 REV.

NOTE:
FOR LEGEND AND SYMBOLS SEE DRAWING NO. 6148-4000

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GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.

ATLANTIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
NORFOLK, VIRGINIA

CATHODIC PROTECTION SURVEY

MARINE CORPS AIR STATION (H), NEW RIVER, JACKSONVILLE, N.C.
SOIL RESISTIVITY SURVEY & PIPE/SOIL POTENTIAL SURVEY FOR WATER SYSTEM
(SECTOR 3)

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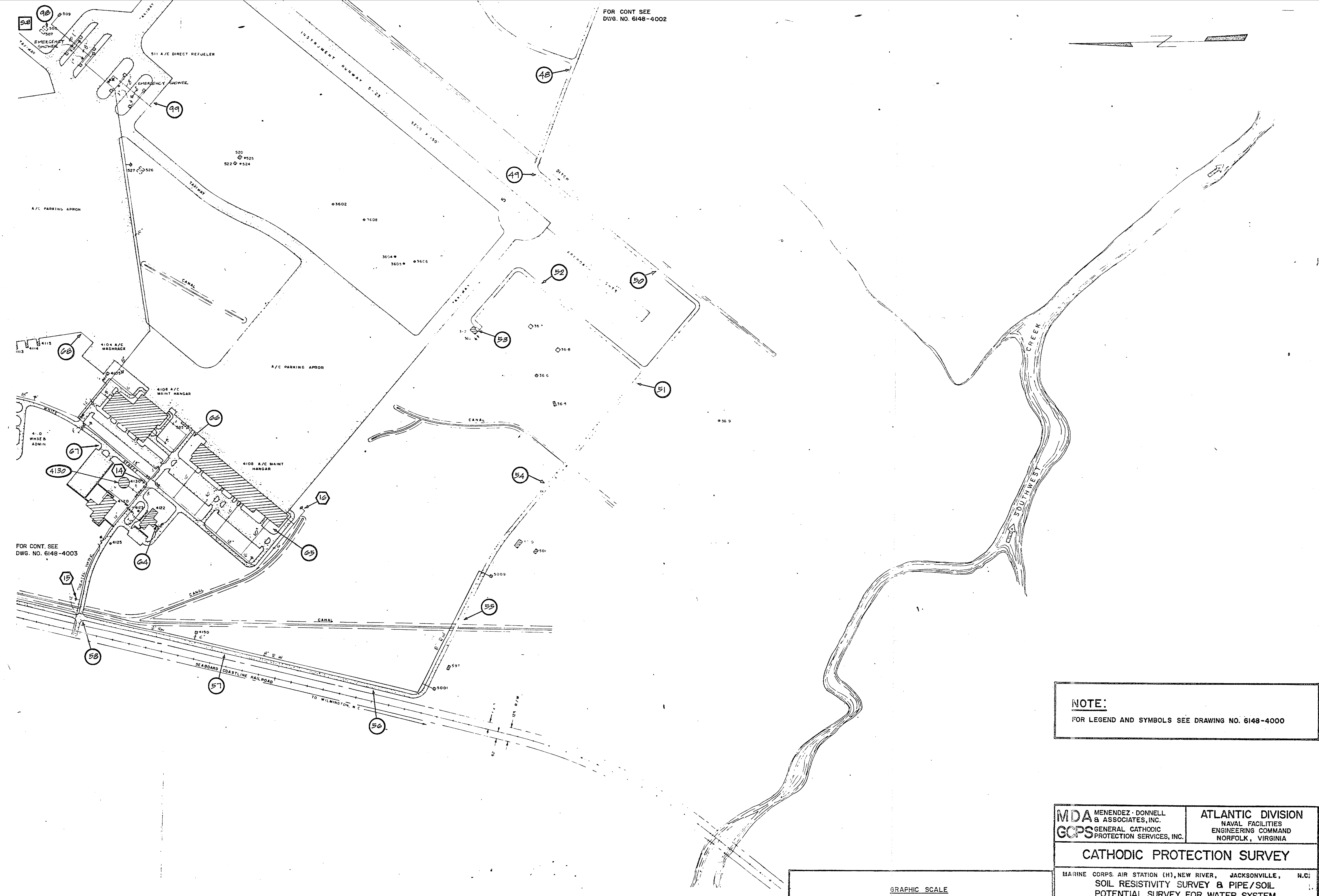

NOTE:

FOR LEGEND AND SYMBOLS SEE DRAWING NO. 6148-4000

GRAPHIC SCALE

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SCALE 1" = 200'-0"

MDA MENENDEZ-DONNELL & ASSOCIATES, INC. GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.	ATLANTIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND NORFOLK, VIRGINIA

CATHODIC PROTECTION SURVEY

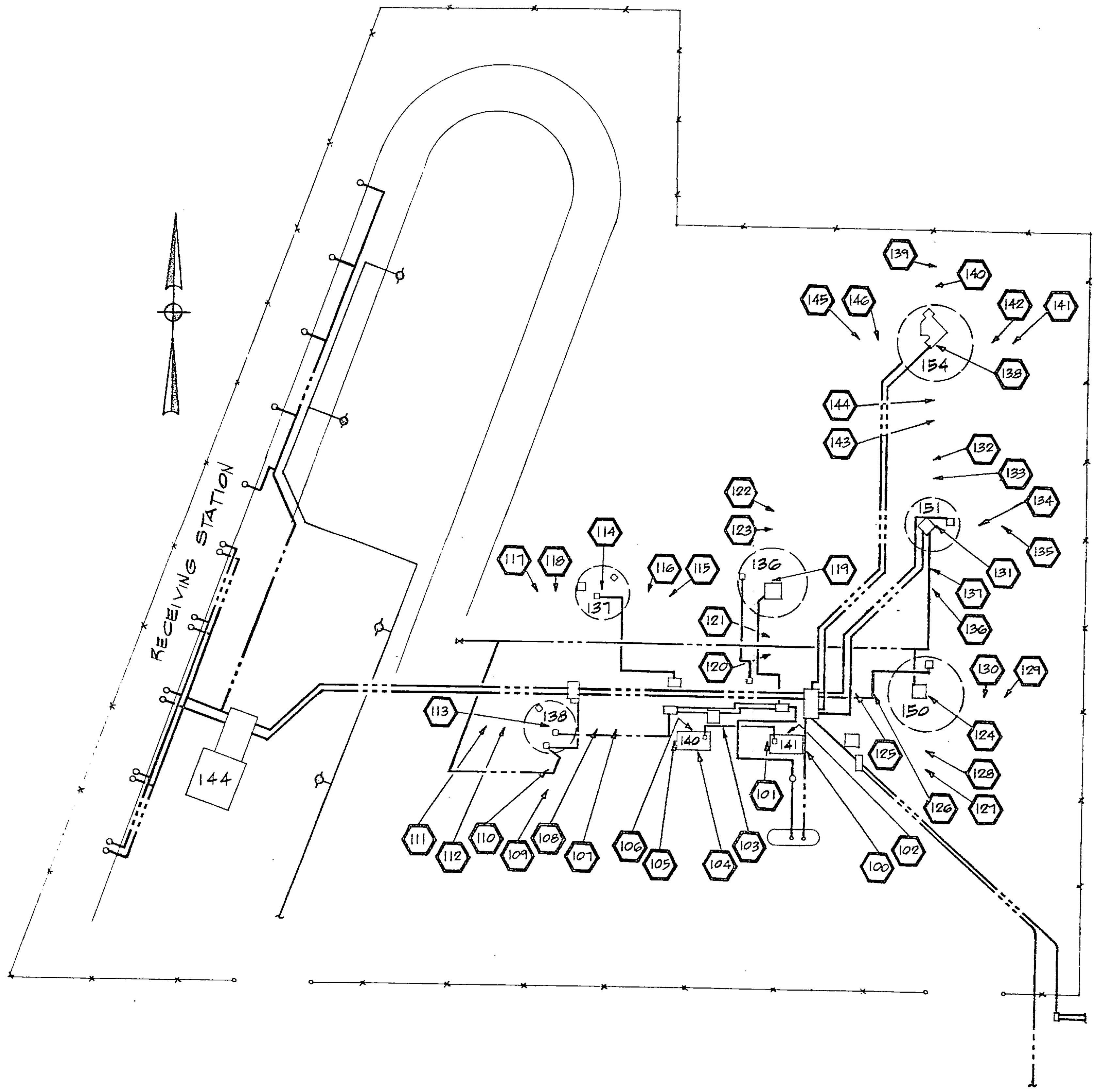
MARINE CORPS AIR STATION (H), NEW RIVER, JACKSONVILLE, N.C.

SOIL RESISTIVITY SURVEY & PIPE/SOIL POTENTIAL SURVEY FOR WATER SYSTEM (SECTOR 4)

DES. DR. C. BEST SCALE GRAPHIC	CK. J. MESZAROS APP. DATE DEC. 14, 1984	DWG. NO. 6148-4004	REV.

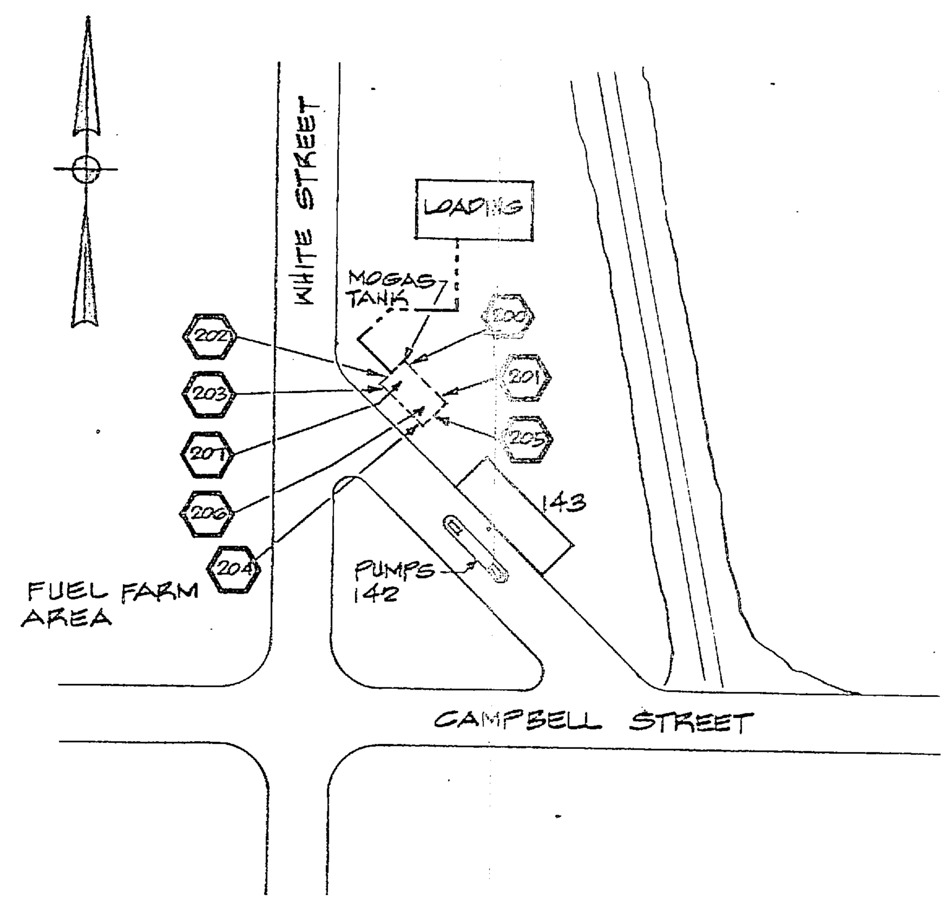
NOTE:

FOR LEGEND AND SYMBOLS SEE DRAWING NO. 6148-4000



PIPING PLAN AT FUEL FARM AREA

SCALE 1" = 40'-0"



UNDERGROUND MOGAS TANK AT BLDG. 143

NOT TO SCALE

GRAPHIC SCALE

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SCALE 1" = 40'-0"

MDA MENENDEZ · DONNELL & ASSOCIATES, INC. GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.	ATLANTIC DIVISION NAVAL FACILITIES ENGINEERING COMMAND NORFOLK, VIRGINIA	
CATHODIC PROTECTION SURVEY		
MARINE CORPS AIR STATION (H), NEW RIVER, JACKSONVILLE, N.C. POTENTIAL SURVEY FOR POL SYSTEMS		
DES. DR. J. CRUZ SCALE GRAPHIC	CK. J. MESZAROS APP. DATE DEC. 14, 1984	DWG. NO. 6148-4005 REV.

ASSISTANT CHIEF OF STAFF, FACILITIES
HEADQUARTERS, MARINE CORPS BASE

DATE 21 MAR 1985

TO:

BASE MAINT O | DIR, FAMILY HOUSING

PUBLIC WORKS O | DIR, UNACCOMPANIED PERS HSG

COMM-ELECT O | BASE FIRE CHIEF

ATTN: Cmdr Johannesmeyer

1. Attached is forwarded for info/action.

10
04
404
~~403~~

2. Please initial, or c... all papers to this office.

CATHODIC PROTECTION
SURVEY REPORT
MCAS(H) - NEW

3. ...

MENENDEZ-DONNELL
& ASSOCIATES, INC.
11999 Katy Freeway #355
HOUSTON, TEXAS 77079

LET'S THINK OF A FEW REASONS
WHY IT CAN BE DONE!

MCBCL 5216/21 (REV. 2-81)

ASSISTANT CHIEF OF STAFF, FACILITIES
HEADQUARTERS, MARINE CORPS BASE

DATE 21 MAR 1985

TO:

BASE MAINT O	DIR, FAMILY HOUSING
PUBLIC WORKS O	DIR, UNACCOMPANIED PERS HSG
COMM-ELECT O	BASE FIRE CHIEF

ATTN: Cmdr Johannesmeyer

1. Attached is forwarded for info/action.

10
04
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~~403~~

2. Please initial, or comment, and return all papers to this office.

3.

MCBCL 5216/21 (REV. 2-81)

CATHODIC PROTECTION
SURVEY REPORT
MCAS(H) - NEW RIVER, N.C.

DEPARTMENT OF THE NAVY
ATLANTIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
NORFOLK, VIRGINIA 23511-6287

TELEPHONE NO.
(804)444-9521
(AV) 564-9521
IN REPLY REFER TO:

9633
102B4
07 MAR 1985

From: Commander, Atlantic Division, Naval Facilities Engineering Command
To: Commanding General, Marine Corps Base, Camp Lejeune

Subj: CATHODIC PROTECTION SURVEY REPORT FOR THE MARINE CORPS BASE, CAMP LEJEUNE, NC

Ref: (a) NAVFACINST 11014.51 of 19 October 1983
(b) A/E Contract N62470-83-C-6148 "Annual Contract for Engineering Services/Cathodic Protection Surveys at Various Activities"

Encl: (1) Cathodic Protection Survey for MCB Camp Lejeune and MCAS (H) New River
(2) "Cathodic Protection Rectifier Report" NAVFAC 9-11014/75 (5/83)
(3) Recommended Rectifier Settings
(4) NCEL Tech Memo 52-81-03 "Corrosion of Shore Facilities"
(5) NCEL Tech MEMO M-52-81-03S "R&D Proposal for Corrosion Control for Shore Facilities - a Zero Milestone Report"
(6) NCEL Tech Data Sheet 84-10 July 84
(7) NCEL Tech Data Sheet 85-1 January 1985
(8) NCEL Tech Data Sheet 85-2 January 1985
(9) "Common Corrosion Protection for Typical Structures"
(10) Training Courses in Cathodic Protection/Corrosion Control

1. In accordance with reference (a), the subject survey has been accomplished under reference (b) and the resulting report is provided for your information and action as enclosure (1).

2. LANTNAVFACENGCOM supports the recommendations made in this report. The recommendations indicate that new cathodic protection systems are required. If the design of these new systems is accomplished by activity personnel/contract vice LANTNAVFACENGCOM, it is requested that the 90% plans and specifications be forwarded to this Command (Attn: Mr. Karl Liebrich) for technical review/comments prior to final design.

3. It is recommended that all rectifiers be set as indicated in enclosure (3) and all current outputs be maintained at the levels indicated in enclosure (3) in order to provide adequate protection to the systems. These limits should be posted on each rectifier.

4. The discrepancies with the cathodic protection systems should be included in the annual inspection summary (AIS). This should aid in obtaining additional maintenance funding to correct these problem areas.

5. It is recommended that MCB Camp Lejeune continue to maintain and improve its corrosion control program in accordance with reference (a). The corrosion control program should:

a. Establish a point of contact for corrosion control/cathodic protection with LANTNAVFACENGCOM Code 102B4.

[illegible]
(N[illegible] 56[illegible]95[illegible])

[illegible]
[illegible]
0 7 MAR 1985

From: Commander, Atlantic Division, Naval Facilities Engineering Command
To: Commanding General, Marine Corps Base, Camp Lejeune

Subj: CATHODIC PROTECTION SURVEY REPORT FOR THE MARINE CORPS BASE, CAMP LEJEUNE, NC

Ref: (a) NAVFACINST 11014.51 of 19 October 1983
(b) A/E Contract N62470-83-C-6145, Annual Contracts for Engineering Services (Cathodic Protection Surveys at Various Activities)

Encl: (1) Cathodic Protection Survey for MCB Camp Lejeune and MCAS (H) New River
(2) Cathodic Protection Facilities Report NAVFAC 9-11014/75 (5/83)
(3) Recommended Rectifier Settings
(4) NAVFAC MO-[illegible] "Corrosion of Shore Facilities"
(5) NCEL Tech [illegible] Corrosion Control for [illegible] Report
[illegible]
(8) NCEL [illegible] Design Lab [illegible] 1985
(9) [illegible] Protection for Typical Structures"
(10) [illegible] in Cathodic [illegible] Corrosion Control

1. In accordance with reference (a), the cathodic survey has been accomplished under reference (b) and the resulting report is provided for your information and action as enclosure (1).

2. LANTNAVFACENGCOM supports the recommendations made in this report. The [illegible] indicate that new cathodic protection systems are required. [illegible] by activity reconnaissance [illegible] NAVFACENGCOM [illegible] prepared [illegible] and specifications be forwarded to this Command (Attn: Mr. Ken [illegible]) for [illegible].

4. It is recommended that all rectifiers be set as indicated in enclosure (3) and all current outputs be maintained at the level indicated in enclosure (3) to provide adequate protection to the systems. These [illegible] should be [illegible].

5. The [illegible] associated with the cathodic protection systems should be included in the [illegible] (AIM). This should [illegible] problem areas.

6. [illegible]
[illegible] with reference (a). The [illegible]
[illegible]

[illegible]

Subj: CATHODIC PROTECTION SURVEY REPORT FOR THE MARINE CORPS BASE, CAMP LEJEUNE, NC

b. Monitor and maintain existing and new systems on a monthly basis. NAVFAC MO-307 of May 1981 provides basic guidelines for the inspection and maintenance of cathodic protection systems.

c. Submit rectifier readings to LANTNAVFACENGCOM Code 102B4 on a regular basis (i.e., monthly, but not less than quarterly) utilizing enclosure (2) or the "Cathodic Protection Monthly Rectifier Record" card - LANTNAVFACENGCOM 9-1104/2 (Rev 9-80) as appropriate. This submission will allow the LANTNAVFACENGCOM corrosion engineer to monitor the operations of these systems, computer analyze output readings and settings, then provide feedback to the activity point of contact with any necessary rectifier changes, and program surveys of these systems on a periodic basis (every 2 or 3 years). Camp Lejeune presently submits rectifier readings on a monthly basics to LANTNAVFACENGCOM 102B4. However, they should also include tap settings and DC voltage readings in their monthly submittal as indicated in enclosure (2).

d. Train the activity engineers and maintenance personnel in cathodic protection systems.

6. Enclosures (4) thru (9) are provided for your information on cathodic protection systems. Enclosure (10) will provide your activity with a list of the formal training courses which exist in this field for the engineer, technician and electrician. Additional information may be obtained from LANTNAVFACENGCOM Code 102B4 or by contacting the training courses directly.

7. Assistance in establishing a corrosion control program and/or any technical expertise in the cathodic protection field may be received by contacting Mr. Karl D. Liebrich, Code 102B4, telephone (804)444-9521 or AUTOVON 564-9521.

Gordon J. Bosch

GORDON J. BOSCH
By direction

tm no: 52-81-03

Technical Memorandum

title: CORROSION OF SHORE FACILITIES

author: Richard W. Drisko, Ph D

date: July 1981

sponsor: Naval Facilities Engineering Command

program no: YF61.544.091.01.021

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

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ENCLOSURE (4)

Table of Contents

INTRODUCTION

The Naval Shore Establishment has a real property value of $62 billion and an annual construction and maintenance cost associated with it of $3 billion. A large portion of the latter is related to the $0.5 billion of estimated corrosion losses to Navy property investments suffered each year. These losses have also resulted in facilities being downgraded or removed from operation for repair or replacement. The Naval Facilities Engineering Command (NAVFAC) has become increasingly concerned with corrosion-related costs at shore activities as well as the need for continuous availability of support to the fleet and air arms. Consequently, in FY81 the Naval Civil Engineering Laboratory (NCEL) was asked to investigate the nature and extent of the corrosion problem to provide information for initiating an effective program for its control. The short time frame was dictated by the urgency in initiating the program. This report presents the findings of this brief investigation along with a plan of action for Work Unit YF61.544.091.01.021 "Corrosion of Shore Facilities," in the Materials Technology Exploratory Development Program that will support the overall objective of a NAVFAC program to effectively control corrosion of shore facilities.

PROBLEM DEFINITION

Corrosion is an electrochemical reaction of a metal with its environment resulting in loss of both physical properties and material, either in general or localized areas. It is among the chief sources of economic loss to all industrial nations. It occurs so commonly that it is often considered to be an inevitable act of God to return a refined product to its natural state rather than a controllable phenomenon. Major concerns in corrosion of shore facilities are (1) its long term control be accomplished in the most economical manner and (2) vital support to fleet and air arms be available at times of need. Of lesser but important concern are loss of energy (e.g., fuels, steam, etc.) and contamination of the environment from corrosion failure of storage or distribution facilities. Such factors as length of desired service; acceptable lengths of shut down for maintenance; and initial, maintenance, and replacement cost must be considered to obtain the lowest life cycle costs for an acceptable level of corrosion control.

Corrosion of shore facilities actually constitutes a group of problems in that many different types of facilities (e.g., waterfront structures, antenna towers, and underground piping) are involved and that different types and degrees of corrosion occur at Navy activities having different environments and different types of service. Also, the management practices that contributed significantly to the facilities being in their present condition must be considered, because improvements in technology can serve no function unless the procedures are present for their effective implementation. In his memorandum of 7 July 1980 to the Vice Chief of Naval Material, RADM Zobel described a three-pronged approach to corrosion prevention involving research and development in corrosion engineering and corrosion assistance teams to achieve a level of control that is not now being achieved.

Condition of Shore Facilities

The overall condition of shore facilities subject to corrosion was determined from conversations with knowledgable individuals at NAVFAC and selected field divisions and activities. Many of the contacts with field personnel were established when they called for assistance; almost one-third of all requests for field support received by NCEL concern corrosion or corrosion control (e.g., coatings). On-site inspections were conducted at selected activities in Pacific Division (PACDIV) where severe environments exist and unusual conditions occur. The results of these inspections along with photographs of corrosion common to most of the activites visited are presented in Appendix A. Corrosion problems encountered in PACDIV were rather typical of those encountered throughout the Naval Shore Establishment but of a greater magnitude. Those facilities/components having major corrosion problems are listed in Table 1 (not in order of priority), along with techniques for controlling their corrosion (design, coatings, cathodic protection, and water treatment). The ineffective use of these techniques resulted in the conditions described in Appendix A. Although serious corrosion problems were found throughout PACDIV, it was encouraging to also find that the activities were very concerned about them and were taking steps to correct them.

Causes of Present Condition

The state of corrosion of shore facilities has five basic causes:

1. Limitations and nature of funding (including manpower)
2. Limited corrosion control expertise and support equipment
3. Distribution of corrosion control expertise and responsibilities in NAVFAC field division, and field activities
4. Limited published guidance on design, maintenance and repair replacement for corrosion control
5. Lack of a single, coordinated corrosion control program.

Funding is not available to field activities for corrosion control on a uniform, continuous basis. It is usually associated with special construction or maintenance projects or with maintenance funding from major claimants. Recent concern for installation of corrosion control procedures during repair is expressed in OPNAV Instruction 11010.20D (Ref 1), Paragraph 4105.F, "In the repair of piping systems that have deteriorated, cathodic protection shall be incorporated as a repair cost where economically justified." Mooring maintenance money has been provided directly to field activities by NAVFAC, but the amount of annual funding has varied greatly. Thus, in FY81, all the available mooring funds were spent on priority work at Diego Garcia. NCEL studies have shown that lower life-cycle costs and reduced maintenance costs can be achieved with continuing programs of cathodic protection and coatings (Ref 2-4).

The survey of field activities in PACDIV revealed that very few personnel had any corrosion training. At least one individual at each field division contacted and one-half dozen people at NAVFAC have some expertise in corosion. Most of these individuals, however, have specialized (e.g., coatings or cathodic protection) rather than broad knowledge of corrosion control.* NAVFAC Code 10 sponsors a 3-day coatings workshop each year, alternating between the east and west coast. The 1981 workshop in Honolulu, which was expanded to include information on corrosion, was attended by over 50 people (inspectors, coating foremen, specification monitors, etc.). A syllabus (prepared by NCEL) covering the course material was given to each attendee. It is also being expanded to include more information on corrosion. Unfortunately much of the training from this course is lost because of changes in personnel, regulations, technical developments, and management procedures. Personnel responsible for corrosion at three field divisions (Pacific, Western, and Southern Divisions) are looking into corrosion workshops and hope to develop one for activities in their division in the near future. For those personnel with training, there is very limited equipment for monitoring corrosion and its control. Most of the field divisions have a meter and half-cell for measuring pipe-to-soil or steel (water tank or marine piling) to water cathodic potentials, but limited use is made of the equipment or the data received from it.

Because there are many aspects to corrosion control, its responsibility and expertise have been fragmented through several offices and personnel at NAVFAC, its field divisions, and shore activities. Also, because many different technologies are involved in corrosion control few individuals in the NAVFAC organization have a broad working knowledge the subject. Table 2 lists all the NAVFAC documents that will be affected by new developments in corrosion control and the cognizant codes. The responsibilities are divided between Codes 04, 10, and 11. As of 1 October 1981, the overall responsibility for the NAVFAC corrosion control program will be transferred from Code 11 to Code 10 where it will encompass all phases of corrosion control. Table 1 lists the different techniques appropriate for controlling corrosion in a variety of facilities. The best approach is usually a combination of two or more techniques. Thus, in paragraph 2.5.3, of MO-307 (Ref 5), it states that a well-coated pipe will require only 0.1 milliamps of electrical current per square foot for cathodic protection as compared to 3 milliamps per square foot for bare pipe. However, a coatings specialist seldom has expertise in cathodic protection and vice-versa.

Although many NAVFAC documents contain informatiom on specific aspects of corrosion control (see Table 2), there is currently no manual on design for corrosion control, and MO-306 (Ref 6) and MO-307 (Ref 5) on corrosion prevention and control and corrosion control by cathodic

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*California is the only state that certifies professional engineers in the field of corrosion. Four people at NCEL and at least one at a field division and one at a Public Works Center have received such certification.

protection, respectively, are 17 years old and badly out of date. By contrast, MO-110 (Ref 7) on paints and protective coatings is currently receiving its second updating since its original publication in 1969.

The absence of a single, coordinated corrosion control program with continuous, planned funding; a training program for responsible personnel; up-to-date guidance featuring the latest technology for corrosion control; and utilization of all available technologies has resulted in a costly, haphazard approach that has permitted shore facilities to deteriorate. As previously stated, NCEL studies (Ref 2, 3, 4) show that a long range program of deterioration control can greatly reduce costs as compared to immediate, stopgap measures.

Statement of Problem

The problem to be addressed in this report can be simply stated: Corrosion of facilities throughout the Naval Shore Establishment has been permitted to reach to a condition that will be extremely difficult and costly to correct and maintain acceptably utilizing present corrosion control practices, management procedures, and resource personnel and equipment.

COSTS OF CORROSION

In response to a Congressional directive, a study of the annual cost of metallic corrosion in the United States was undertaken by the National Bureau of Standards (NBS). The analysis required in the study was placed under contract to the Battelle-Columbus Laboratories (BCL). The overall study was conducted jointly by BCL and NBS. In addition to the lengthy NBS report (Ref 8), the findings were printed in a series of seven articles (Ref 9) in Materials Performance. The study was designed to provide a reference that would allow the economic impact of corrosion to be compared with other factors affecting the economy. In 1975, the base year for the study, corrosion cost the United States an estimated $70 billion. This was 4.2% of the estimated gross national product (GNP) for that year. Of this total, about 15%, or $10 billion, was avoidable. An uncertainty of about ±30% for the total corrosion cost results from inadequate data in some areas and unsure technical and economic judgments. The uncertainty in the avoidance costs is considerably greater. The total corrosion costs in the Federal Government sector amounted to about $8 billion, or approximately 2% of the Federal Budget. Real property value in the form of buildings and other structures (but not including land) comprises 36% of the total capital owned by the Federal Government. The Department of Defense is the single largest property owner in the Federal Government, with $62 billion of real property value in the Navy. Air Force annual corrosion losses are about $300 million, approximately 50% of which reportedly could be saved by implementing and maintaining a proper corrosion control program. The average Air Force Base loses over $1 million annually to corrosion. The Naval Shore Establishment which has a greater real property value, older facilities, and more facilities exposed to a marine environment has annual corrosion losses of about $500 million. Because there is currently no coordinated corrosion control program for the Navy facilities similar to the Air Force program, the losses which could be prevented using available technology are closer to 75%. One engineer at PWC, Pearl Harbor estimated the annual corrosion losses there to be at least $1 million, and this may be typical of all Naval activities of this size.

The National Association of Corrosion Engineers (NACE) Technical Unit Committee T-3C, Economics of Corrosion, has a scope of accumulation of data, appraisal of methods, development of recommended practices, promotion of knowledge and communication relative to the economic evaluation of corrosion and counter-corrosion measures. It develops and updates such recommended practices as NACE Standard RP-02-72, "Direct Calculation of Economic Appraisals of Corrosion Control Measures." Corrosion cost calculation methods and prediction models have also been studied by the Air Force and Army (Ref 10), Federal Highway Administration (Ref 11), and private industry (Ref 12, 13). The author of this report and Dr. B. R. Appleman of the Federal Highway Administration will co-chair a symposium on "Economics of Corrosion Control with Coatings" at Corrosion/82 (the annual NACE meeting) in Houston in March 1982.

STATE-OF-ART IN FACILITIES CORROSION CONTROL

Air Force Corrosion Control Program

Air Force Regulation 91-27 of 29 January 1981 establishes corrosion control responsibilities, policies and procedures for real property, materials, supplies, and installed equipment on Air Force and Air Force Reserve installations. Its objective is to develop and maintain an effective corrosion control program to sustain a high degree of operational dependability; extend the life of structures, equipment, plants and systems; conserve energy and resources; and reduce costs. It spells out in detail the responsibilities and functions of the Air Force Engineering and Services Center (AFESC), Air Force Regional Engineers, major commands, and bases. A description of AFESC's corrosion control program and the Air Force Corrosion Analysis Team (CAT) which is composed of military personnel that normally surveys six bases each fiscal year and possibly one additional base on a contingency basis, is presented in Appendix B. Team members, who are trained at the Air Force school at Wright-Patterson AFB, have individual expertise in radiography, cathodic protection and water analyses with the team chief trained in all facets of corrosion. Two special vehicles are utilized -- a van outfitted to perform all types of cathodic protection testing, and a mobile laboratory with photographic and water analysis capabilities (Ref 14). Appendix C contains introductory comments made by the CAT team to an Air Force Base as the survey is initiated.

AFESC personnel provided NCEL with the draft of an updated version of AF manual 85-5: Maintenance and Operation of Cathodic Protection Systems. This document is much more complete and current than the Navy's MO-307 (Ref 5) and can be of great assistance in updating the latter. Additional information is available from two handbooks/pamphlets being prepared by NCEL for the Air Force. One (Appendix D) is a guide to initiating and maintaining a base corrosion control program, and the other (Appendix E) is a guide for monitoring and maintaining of a cathodic protection system.

Army Corrosion Control Program

The responsibility for corrosion control of Army facilities resides with the U. S. Army Facilities Engineering Support Agency (FESA), Fort Belvoir, Va. The Army's program is similar to the Air Force's but is not so fully implemented because of limited funding. Their Survey Teams (see Appendix F) are part civilian (from FESA) and part military (from detachments). The military personnel do field investigation, but no report writing. They do not have fully equipped inspection vehicles like the Air Force but send their limited equipment (e.g., ultrasonic but no radiograph equipment) ahead. Contracting corrosion surveys has not proven to be successful because of (1) resentment from outside intrusion, (2) frequent poor quality reports, and (3) relatively high costs. The Army has no formal training program, but utilized the Air Force school at Wright-Patterson AFB, the ARRCO course from Rock Island, the Appalachian Short Course, and the Bureau of Mines Boiler Treatment School. A typical Army corrosion report (Ref 15) is similar to (e.g., has facsimiles of Tables 3 and 4) but smaller than an Air Force corrosion analysis report. DARCOM-R 702-24 (Ref 16) describes the Army program for Material Deterioration Prevention and Control.

Navy Corrosion Control Experience

As previously noted, NAVFAC headquarters and field divisions have had their expertise and responsibilities distributed among several codes. Thus, at NAVFAC, expertise on coatings has centered in Code 04, on maintenance in Code 10, and cathodic protection in Code 11. Such distribution of expertise also occurs at field divisions. Because of personnel changes the expertise is frequently lost. This is especially true for field activities. NAVFAC Code 04 has kept MO-110 (Ref 7) on paints and protective coatings current, while NAVFAC Code 10 has presented a workshop on protective coatings each year. This has not been the case for other technologies for corrosion control.

Technical Societies/Private Industry

NACE is the technical society that covers all aspects of corrosion and has programs for corrosion technicians as well as professionals. It publishes three periodicals as well as special documents. Corrosion and Corrosion Abstracts are directed at people conducting corrosion research, while Materials Performance is a practical journal predominantly for field people. NACE conducts an annual national meeting (e.g., Corrosion/82 in Houston, 22-26 March 1982) and five regional meetings (e.g., 1981 Western Regional Conference in Seattle, 10-12 Nov 1981), as well as several corrosion courses, seminars, and special technical meetings. It also certifies NACE-Accredited Corrosion Technicians, Senior Corrosion Technologists, Corrosion Specialists-in-Training, and Corrosion Specialists (Ref 17)*. NACE also has several technical committees (Ref 18). Some concern technologies (e.g. T-6: Protective Coatings and Linings, and T-10A: Cathodic Protection of Underground Structures), while others

*The author of this report is an Accredited Corrosion Specialist and a member of the accreditation committee.

concern industries (e.g., T-5: Corrosion Problems in the Process Industries and T-8: Refining Industry Corrosion). There is no technical committee on facilities corrosion, but Mr. T. J. Hull, executive secretary of NACE, indicated that such a committee could be established if there was sufficient interest. The technical committees prepare standards (e.g., Cathodic Protection of Steel Water Storage Tanks) and recommended practices for corrosion control.

Other technical societies of interest include the Federation of Societies for Coatings Technology (mostly for researchers) and the Steel Structures Painting Council (mostly concerned with standards and recommended practices) in the coatings area, the American Society for Testing and Materials (ASTM) in the standards area, and American Petroleum Institute (API) and American Water Works Association (AWWA) in the industries area.

Private industry, particularly in the cathodic protection area, is an excellent source of expertise and training. Examples of cathodic protection surveys for WESTDIV are given in References 19-21. It would seem to be cheaper and wiser to have experienced contractors conduct such surveys rather than train Navy personnel for this purpose. Selected research can also be effectively performed by specialized firms. A good example of this is the work that has been performed by Harco Corporation for the Air Force (Ref 22) on evaluation of cathodic protection criteria.

AVAILABLE TRAINING COURSES

Recognizing the importance of training personnel in corrosion technology, NAVFAC requested information on appropriate training facilities. These are described below according to the sources.

Department of Defense Courses

The Air Force has a 2-week (72-hour) "Corrosion Control Course" that is taught twice a year at Wright-Patterson AFB, Ohio. The hours of instruction are distributed on the subjects shown below:

Subject	Hours
Fundamentals of Corrosion	7
Economics	3
Cathodic Protection	24½
Corrosion Management	7½
Protection Coatings	10
Water Treatment	14
Administration	3
Exams and Critiques	3
	72

The students are taught how to design a cathodic protection system and how to conduct laboratory analyses. Air Training Command, Sheppard AFB, Texas, also offers, by demand only, courses in cathodic protection maintenance and in boiler water corrosion control. AFESC distributes corrosion newsletters periodically to keep their personnel informed on new developments. The Army provides upon request a 1-week "Prevention of Material Deterioration" corrosion control course. The printed material (Ref 23) for the course is 14 to 32 years old and, thus, of limited value.

NAVFAC sponsors an annual workshop on protective coatings taught on the east and west coast on alternative years. NCEL has prepared a syllabus and examination for the course and presents several of the lectures. There are current plans to convert it to a 1-week corrosion course covering these areas with approximate times:

Subject	Hours
Fundamentals of Corrosion	2
Corrosion Economics	1
Design for Corrosion Control	1
Cathodic Protection	16
Protective Coatings	16
Water Treatment	1
Corrosion Management at Shore Activities	2
Examination	1
	40

Some of the subjects, particularly cathodic protection, might be taught by a private company. J. F. Jenkins of NCEL also periodically teaches a 1- or 2-week course in applied metallurgy, marine corrosion control, and material selection.

NACE Courses

NACE teaches four 4-1/2-day (34-hour) corrosion education and training courses, each costing $400 for NACE members and $450 for non-members. The price includes textbook, other materials, daily lunches and coffee break refreshments but not accommodations. The four courses are:

Course 1 - Basic Corrosion Course

Course 2 - Corrosion Prevention by Cathodic Protection

Course 5 - Corrosion Prevention by Surface Preparation and Coatings

Course 6 - Corrosion Prevention in Oil and Gas Production

NACE also presents 3-day short courses at several locations each year:

Western States Corrosion Seminar at California State Polytechnic University, Pomona, California.

Appalachian Underground Corrosion Short Course, West Virginia University, Morganstown, West Virginia.

Liberty Bell Corrosion Course, Philadelphia, Pennsylvania.

University of Oklahoma Corrosion Control Short Course, University of Oklahoma, Norman, Oklahoma.

Purdue Corrosion Short Course, Purdue University, West Lafayette, Indiana.

University Courses

Several Universities (e.g., UCLA, Purdue, MIT, etc.) present corrosion courses in their regular programs or special programs for researchers. MIT also offers a self-study video course on corrosion engineering. Others present courses in coatings or similar materials.

University of Missouri at Rolla:

Introductory Short Course on the Composition of Paints and Coatings, 4 days

Paint Short Course, 4 days

Paint Inspectors and Quality Controllers Short Course, 4 days

Short Course on Tinting, Shading and Matching of Colored Paints and Coatings, 5 days

Advanced Chemical Coatings Workshop, 4 days

North Dakota State University, Basic Coatings Science:
Advanced Coatings Science Course

Private Industry Courses

Specialized corrosion and related courses are also available from private industry.

Harco Corporation, Medina, Ohio, has various courses on cathodic protection presented at the requestor's location.

Goodall Electric Inc., Ogallala, Nebraska, has a Cathodic Protection Rectifier Service School.

Heath Consultants Inc., Stoughton, Massachusetts has several corrosion-related courses:

Investigation of Leak Complaints (Distribution) Course, G-102, 2-days. Covers procedures for locating leaks, pinpointing techniques, evaluating effectiveness of repairs, etc.

Operation and Maintenance of Gas Detection Instrumentation, Course G-104, 4 days. Covers theory of operation, on-site capability to maintain, repair and trouble-shoot gas leak detection equipment.

Pinpointing Techniques, Course G-105, 1 day. Covers classroom and field demonstration in methods of pinpointing gas leaks, locating foreign utility lines, placement of cut, etc. Held only at client's site.

Water Conservation and Leak Detection Seminar, Course W-100, 1 day. Covers pipe locating, leak detection and pinpointing.

International Nickel Company, has available educational films and descriptive literature on corrosion.

RECOMMENDED NAVFAC CORROSION CONTROL PROGRAM

NAVFAC field divisions are currently developing their own corrosion control programs. Although these divisions need to identify their own problems, they should not have separate, uncoordinated programs. Thus, it is recommended that:

1. There be developed a single, centrally controlled, uniformly administered corrosion control program for all field divisions. (It would be advantageous to have a Navy-wide facilities corrosion workshop similar to the Air Force-wide workshop at the start of their program.)

2. All field activities determine the corrosion condition of their facilities using contractors where necessary.

3. All data on condition, design, installation and monitoring of facilities be stored in a central data bank for rapid retrieval.

4. New cathodic protection systems be as simple and automatic as possible.

5. Old cathodic protection systems be updated to make them as simple and automatic as possible.

6. Monitoring of corrosion be as simple and automatic as possible.

7. Criteria be developed for satisfactory levels of protection for cathodically protected structures and for actions to be taken when these levels are not achieved.

8. A schedule and plan be developed for surveying all facilities for condition of corrosion on a regular basis.

9. Field activities receive regular and adequate levels of funding for a continuing corrosion control program of scheduled monitoring, maintenance, and replacement of facilities or their components.

10. A 1-week training program on corrosion control be developed for annual presentation to field activities, and more advanced training be taken by corrosion specialists at field divisions.

11. A standard set of monitoring/equipment be specified for use by field activities; e.g., Table 3 plus coating thickness gages (Ref 24), holiday detectors (Ref 25), and surface preparation standards (Ref 26).

12. Published guidance for field divisions and activities be updated to meet present needs.

13. R and D be conducted to develop technology for corrosion control where none exists and modify existing technology to meet the needs at field activities.

Because no NAVFAC corrosion control program exists at the present time, any real effort at preparing and implementing one will of necessity be beneficial. The exact amount of savings at each activity will be related to both the present condition of facilities and the efficiency of the program. It is anticipated that CEL participation in the program would be (1) execution of required R and D, (2) field support (particularly failure analysis) to field activities, (3) technical input on upgrading published guidance, and (4) expertise for workshops.

NCEL APPROACH AND PLAN TO RESOLVE PROBLEM

The most productive approach by NCEL to resolve the defined problem would be a cooperative effort on two fronts: (1) A research and development program coordinated with the Air Force and Army to meet present needs and (2) support of NAVFAC headquarters, field divisions, and field activities, as described in the last paragraph of the previous section. The Army, Navy, and Air Force have a joint agreement on support of corrosion control program and hold a tri-service conference on corrosion bi-annually to exchange technical information. The author of this report attended the 1980 conference held at the Air Force Academy, 5-7 Nov 1980, but found no interest in facilities corrosion there. Papers were directed at corrosion of ships, planes, and vehicles. AFESC and FESA have expressed an interest in a tri-service joint committee on facilities corrosion, and this will be implemented in FY82.

NCEL is currently conducting limited 6.1 basic research in specialized areas of corrosion to provide technical input for exploratory development.

The NCEL 6.2 exploratory development plan that is directed at the problem defined in this report is summarized in Table 5. A combination of the corrosion control techniques listed in Table 1 will be utilized. The program will be modified to meet needs of field activities as data developed by these activities suggest different priorities or as new operational requirements dictate charges. This will later be followed by 6.3 advanced development to actually conduct field testing of materials, equipment, and techniques developed in the 6.2 program. Separate proposals for investigating costs of corrosion and its control and corrosion estimating are being prepared by NCEL for O&M or Director of Navy Laboratory funding.

Develop Design Criteria

About 10% of our corrosion problems at shore facilities are created through poor design. These can be resolved with relative ease. Jenkins and Reinhart (Ref 27-29) have described design for corrosion control of potable water distribution systems, aviation fuel storage and distribution systems, and OTEC plants. Pludek (Ref 30) and Perrigo and Jensen (Ref 31) provide more general information on design factors. The specific steps in the approach are: (1) Review corrosion problems at shore facilities, (2) obtain design criteria for corrosion control from published literature, DOD documents, and technical societies, (3) determine design criteria appropriate for shore facilities, and (4) prepare practical documentation describing the appropriate criteria in detail. Design factors to be considered include (1) geometry, orientation, and siting, (2) compatibility of materials, (3) sharp edges and corners, (4) skip welds and other crevices, (5) configurations that permit water and salt collection, abrasion, or impact, (6) velocity effects, (7) concentration cell effects, (8) erosion and fatigue, (9) cavitation, (10) galvanic effects, (11) high temperatures, (12) attack by corrosive gases, (13) thermal effects, and (14) stray current corrosion.

Cathodic Protection of Underground Structures

Field activities currently have relatively few underground structures (i.e., utility lines) cathodically protected, and those that are protected are seldom monitored to the extent that the protective potentials are kept at the desired level. A program will be developed to standarize (1) cathodic protection equipment for installation and monitoring, (2) training of personnel, (3) reporting procedures for monitoring data, and (4) instructions for actions to be taken when monitoring data indicate deficiencies. Simple and uniform procedures (i.e., automation as far as possible) will be developed so that decisions on actions to be taken be made for them. This includes the recording and analysis of pipe-to-soil potentials. If time permits, a survey into the use of instrumented pigs to determine the condition of pipe interiors of varying diameter will be conducted.

Develop Coating Procedures for Special Problems

During the CEL survey of field activities in the Pacific Division, several common coating problems were encountered. These include loss of organic coatings from galvanized steel surfaces, corrosion of coated cyclone fencing, and loss of coatings and corrosion of stacks, mufflers, and other hot structural components at power and steam plants. These problems are so serious and widespread that a significant improvement in coating performance will result in an immediate significant saving of funds. A variety of coatings are available for these purposes, but none appear to provide the necessary level of protection. The investigation would include (1) contacting suppliers for their experience and recommendations; (2) contacting the NBS, the Steel Structures Painting Council, the Zinc Institute, Lehigh University, (conducting coatings research with ONR support), and other organizations with experience in these areas to obtain basic information; (3) conducting laboratory tests to determine the effects of (a) pretreatment with solutions that convert the zinc or other surface to one more receptive to bonding of primer and/or resistance to corrosion, (b) wash priming to promote primer adhesion, and (c) inhibitors for the control of underfilm corrosion that accelerates coating delamination; and (4) field testing of coating materials and procedures to establish the requirements for obtaining long life from a coating system for the particular application and preparation of recommended procedures for NAVFAC implementation. The use of vapor phase inhibitors (sometimes called volatile corrosion inhibitors) in closed spaces (e.g., doors in vehicles) will also be investigated.

Cathodic Protection of Marine Structures

Relatively few marine structures at shore activities are cathodically protected. Galvanic (sacrificial anode) cathodic protection systems will be developed for moorings, floats, pontoon camels, and other small floating and fixed structures along with criteria for their use. Simple, automatic impressed current cathodic protection systems will be developed for larger marine structures such as piers and quaywalls. The stability of reference half-cells and their calibration will be established, along with determination of the number and locations necessary to assure complete protection of a structure. In some instances, it may be necessary to use a diver-operated portable voltmeter to obtain localized potentials to assure protection in those areas.

Coordinated Corrosion Control Plan

An overall plan will be developed for the implementation with 6.3 support of materials, equipment, or systems found, modified, or developed in each phase of the plan into a NAVFAC corrosion control program. It will present criteria for the selection and use of each of these tools for the most economical utilization in corrosion control of shore facilities.

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3. ____________ Technical Report R-723: Plastic mooring buoys - design and cost criteria, Port Hueneme, Calif., Apr 1971.

4. ____________ Techdata Sheet 79-10: Programmed painting. Port Hueneme, Calif., Dec 1979.

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6. ____________ NAVDOCKS MO-306: Corrosion prevention and control. Washington, D.C., June 1964.

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17. National Association of Corrosion Engineers. 1979 Accreditation Directory, Houston, Tex., 1979.

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28. ________ AFWL-TR-74-31: Design for corrosion control of aviation fuel storage and distribution systems by F. M. Reinhart, Naval Civil Engineering Laboratory. Kirtland AFB, N.M., Jun 1975.

29. Civil Engineering Laboratory. Technical Report R-868: Corrosion and biofouling of OTEC system surfaces - design factors. Port Hueneme, Calif., Nov 1978.

30. Design and corrosion control by V. R. Pludek. The MacMillan Press Ltd., London and Basingstoke. 1977 with corrections and some revisions in 1979.

31. L. D. Perrigo and G. A. Jensen. Fundamentals of corrosion control design. Paper 6. 15th Western States Corrosion Seminar, California State Polytechnic University, Pomona Calif., 1981.

Table 1. Techniques for Controlling Corrosion of Facilities/Components at Shore Activities Having Major Corrosion Problems

Facilities/Components	Design	Coatings	Cathodic Protection	Water Treatment
	Corrosion Control Technique			
Fuel Storage Tanks	+	+	(+)	-
Water Storage Tanks	+	+	(+)	(+)
Fuel Distribution Systems	+	+	(+)	-
Water Distribution Systems	+	+	(+)	(+)
Hot Water/Steam Distribution System	+	+	-	(+)
Power/Steam Plants	+	+	-	(+)
Fleet Moorings	+	+	(+)	-
Waterfront Structures	+	+	(+)	-
Vehicles	+	+	-	(+)
Buildings/Housing	+	+	-	-
Air Conditioners	+	+	-	(+)
Antenna Towers	+	+	-	-
Cyclone Fencing	+	+	-	-
Electrical Conduct/Fixtures	+	+	-	-

+ = effective use
(+) = effective use on part of structure (e.g., buried or immersed part)
- = no effective use

Table 2. NAVFAC Documents Affected by New Developments in Corrosion Control

Number	Title	Date of Publication	Cognizant NAVFAC Code
DM-2	Structural Engineering	70-10	0461
DM-2	Mechanical Engineering	72-09	0441
DM-4.6	Electrical Engineering Lighting & Cathodic Protection	79-12	043
DM-4.7	Electrical Engineering Wire Communication & signal Systems	79-12	043
DM-5.6	Civil Engineering -- Trackage	79-10	045
DM-5.7	Civil Engineering -- Water Supply Systems	79-10	045
DM-5.8	Civil Engineering -- Pollution Control Systems	79-10	045
DM-5.12	Civil Engineering -- Fencing, Gates & Guard Towers	79-10	045
DM-22	Liquid Fueling & Dispensing Facilities	72-12	0441
DM-23	Communications, Navigational Aids & Airfield Lighting	71-08	0442
DM-23.2	Navigational and Traffic Aids	79-06	0442
DM-25	Waterfront Operational Facilities	71-10	0453
DM-26	Harbor and Coastal Facilities	68-07	0453
DM-28	Maintenance Facilities	74-12	0461
DM-29	Drydocking Facilities	74-02	0453
DM-25	Family Housing	71-08	0461
MO-103	Maintenance of Trackage (Tri-Service)	74-01	1002
MO-104	Maintenance of Waterfront Facilities	78-06	1002
MO-109A	Maintenance Manual for Antenna Groups	72-11	0044
MO-110	Paints & Protective Coatings (Tri-Service)	69-01	1002
MO-111	Building Maintenance; Structures	63-09	1002
MO-113	Facilities Engineering Maintenance & Repair of Roofs	74-01	1002
MO-114	Building Maintenance; Plumbing, Heating & ventilating	64-04	1002
MO-114	Building Maintenance; Plumbing, Heating & Ventilating, Shop Edition	64-04	1002
MO-115	Building Maintenance; Air Conditioning & Refrigeration	62-12	1002
MO-116	Facilities Engineering; Electrical Interior Facilities	72-03	1002
MO-117	Fire Alarm and Sprinkler Maintenance	68-09	1002
MO-119	Building Maintenance; Galley Equipment	63-09	1002
MO-124	Mooring Maintenance	73-12	100
MO-200	Facilities Engineering-Electrical Exterior Facilities	78-07	111

Number	Title	Date of Publication	Cognizant NAVFAC Code
MO-201	Operation of Electric Power Distribution System	63-11	111
MO-203	(Vol 1) Wire Communications & Signal System Maintenance	63-02	111
MO-203	(Vol 6) Outside Plant Maintenance	63-05	111
MO-205	(Vol 1) Central Heating & Steam Electric Generating Plants 111	64-06	111
MO-209	Maintenance of Steam, Hot Water & Compressed Air Distribution Systems	66-03 66-03	111 111
MO-210	Water Supply Systems	64-06	112
MO-212	Sewage & Industrial Waste Disposal System	62-11	112
MO-215	Mobile Utilities Support Equipment (MUSE)	70-06	100
MO-220	Maintenance & Operation of Gas Systems	70-11	111
MO-230	Maintenance Manual Petroleum Fuel Facilities	77-05	111
MO-306	Corrosion Prevention & Control	64-06	111
MO-307	Corrosion Control by Cathodic Protection	64-06	111
MO-322	(Vol 1) Inspection of Shore Facilities	77-07	1001
MO-322	(Vol 2) Inspection of Shore Facilities	78-05	1001
MO-322	(Vol 3) Inspection of Shore Facilities	77-09	1001
MO-909	Oil Ship Offload Barge (SWOB)	79-08	1123
TS-02312	Prestressed Concrete Piling	77-02	043
TS-02315	Steel H-Piles	76-07	043
TS-02317	Cast-in-Place Concrete Piles, Steel Casing	74-08	043
TS-02441	Underground Sprinkler Systems	79-10	043
TS-02444	Fence, Chain Link	79-11	043
TS-02711	Outside Gas System	79-09	043
TS-05120	Structural Steel with Amendment	79-04	043
TS-05210	Steel Joists	79-10	043
TS-05311	Steel Roof Decking	79-08	043
TS-05321	Steel Floor Decks with Amendment	79-09	043
TS-05420	Metal Framing and Furring	76-01	043
TS-R6	Corrugated Metal Roofing & Siding with Amendment	76-11	043
TS-07600	Flashing and Sheet Metal	78-09	043
TS-8D9	Sliding Hangar Doors	71-03	043
TS-08110	Hollow Metal Doors & Frames with Amendment 1,2	77-03	043
TS-08120	Aluminum Doors and Frames	78-10	043
TS-08301	Steel Sliding Hangar Doors	78-08	043
TS-08310	Fire Doors with Amendment	76-04	043
TS-08320	Metal-Clad (Kalamein) Doors and Frames	79-06	043
TS-08330	Coiling Steel Doors	79-04	043

Number	Title	Date of Publication	Cognizant NAVFAC Code
TS-08360	Overhead and Vertical Lift Steel Doors	78-07	043
TS-08510	Steel Windows	80-01	043
TS-08520	Aluminum Windows	78-10	043
TS-09100	Metal Support Systems	80-04	043
TS-09805	(.1) Coating Systems (Coal-Tar) for Sheet-Steel Piling & Other Steel Waterfront Structures	79-09	043
TS-09805	(.2) Coating Systems (Vinyl and Epoxy) for Sheet-Steel Piling & Other Steel Waterfront Structures	79-09	043
TS-09809	Protection of Buried Steel Piping & Steel Bulkhead Tie Rods	78-09	043
TS-09872	Coating Systems Interior Welded Steel Storage Tanks (for Petroleum Fuel Storage)	79-09	043
TS-09910	Painting of Buildings-Field Painting	76-08	043
TS-11171	Incinerators/Packaged Controlled-Air Type with Amendment	78-10	043
TS-11701	Casework, Metal and Wood	74-04	043
TS-13601	Prefabricated Metal (Straight Walls)	78-06	043
TS-14336	Cranes, Overhead Electric, Overrunning Type	78-01	043
TS-15T8	Steel Tanks with Fixed Roofs Including Change	71-03	043
TS-15057	Coal Tar Coating Systems for Steel Surfaces	74-04	043
TS-15240	Water Storage Tanks with Amendment	79-04	043
TS-15271	Water Distribution System - Exterior	78-11	043
TS-15301	Exterior Sanitary Sewer & Drainage System Piping	78-12	043
TS-15401	Plumbing	77-10	043
TS-15631	Steam Boilers & Equipment (500,000-18,000,000 BTU/Hr.)	76-06	043
TS-15711	Hot Water Heating System	74-09	043
TS-15721	Steam System and Terminal Units	74-12	043
TS-15812	Warm Air Heating Systems	74-06	043
TS-16301	Underground Electrical Work	78-08	043
TS-16302	Overhead Electrical Work	78-08	043
TS-16641	Cathodic Protection by Galvanic Anodes	79-03	043
TS-16642	Cathodic Protection by Impressed Current	79-03	043
TS-20322	Elevator Maintenance	76-09	043

Table 3. Monitoring Equipment for Cathodic Protection (From Ref 14)

*Multimeter Model M3M, FSN 6625-00-051-2786, TA 486, Cost: $620.00

*Test Set Ground Resistance Model 263, (Vibroground) FSN 6625-00-051-2786, TA 479, Cost: $395.00

*Carrying Case, Test Pins, and Cable, for Model 263 Vibroground. FSN 6625, P 18533, TA 486 Cost: $200.00

*Current Interrupter, FSN 6625-00-607-5226, TA 486, Cost: $365.00

Pipe Locater (Pipe Horn), 6695-01-032-5228, TA 486, Cost: $345.00

Thermic-Welding Kit, FSN 3439-00-018-4928, Cost: $150.00

*Copper-sulfate Electrode, 5 inches long. FSN 5935-01-012-9823, Cost: $15.00

*Submersible Adapter, 50 ft lead for copper-sulfate Electrode 5935-01-012-9823. FSN 5935-01-012-9824, Cost: $13.00

*Copper-sulfate Crystals, 12-oz bottle, M. C. Miller Co. Catalog #16906. Cost: $5.50, (MCM) Price list P.4, M.C. Miller Co. Inc., 288 Saddle Road, Upper Saddle River, N. J. 07458, Phone (201) 327-2246

Agra Aluminum Reel, (Hand-Held) 8-ft-diameter capacity approx 150 ft #12 stranded field wire or 250 ft test lead wire. Cost: $35.00. Order from M. C. Miller, Co. Inc., catalog #30501

*Hykon Reel Model, 19 x C (Stand Type). Capacity 500 ft MCM #16 wire 1500 ft MCM #18. Order from M. C. Miller Co. Inc., catalog #30104, p.4, Cost: $33.00

Test Lead Wire, #16 AWG (105 strands #36 tinned copper wire) with PVC insulation. Supplied on 500-ft spools, P.5, M. C. Miller Co. Inc.,

Catalog #30807	Red	$ .07/ft.
#30909	Green	$ .07/ft.
#31006	Orange	$ .07/ft.
#31108	Yellow	$ .07/ft.

Test Lead Wire, #18 AWG (41 strands #34 tinned copper wire) with PVC insulation. Supplied on 1000 & 2500 ft. spools, P.5, M. C. Miller Co. Inc.,

Catalog #31210	Red	$ .04/ft.
#31301	Green	$ .04/ft.
#31403	Orange	$ .04/ft.

*Wire #22 gage, w/16,000 Dienier Nylon core w/bare copper serve shield. PVC jacket, specify 2000-ft continuous length. Berkshire Electric Cable Co. Leeds, Mass (413) 584-3853. Cost $0.12 per foot.

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*Minimum equipment needed.

Table 4. Suppliers of Cathodic Protection Equipment
(From Ref 14)

[This list is not intended to be all inclusive nor does it constitute an indorsement of any one company.]

General Materials, Equipment, and Instruments:

*The Harco Corporation
4600 East 71st. Street
Cleveland, Ohio 44125

*Cathodic Protection Service
4601 Stanford
Houston, Texas 77006

*General Corrosion Services
743 Lambert Dr., N. E.
Atlanta, Georgia 30324

*Farwest Corrosion Control Co.
1000 E. 220th St.
Carson, Calif. 90745

Testing Instruments:

*Agra Engineering Company
1537 East 10th Street
Tulsa, Oklahoma 74120

*M. C. Miller Company
288 East Saddle River Road
Upper Saddle River, N.J. 07458

Tinker and Rasor
P.O. Box 281
San Gabriel, Calif. 91778

Vigroground-Associated Research, Inc.
3758 West Belmont Avenue
Chicago, Illinois 60618

Recifiers:

*Good-All Corrosion Control Co.
201 South Spruce Street
Ogallala, Nebraska 69153

*Petroleum Electronics Mfg, Inc.
Box 2766
Tulsa, Oklahoma 74101

Anodes:

*The Duriron Company, Inc.
Box 1019
Dayton, Ohio 45401

The Dow Chemical Company
Metals Product Department
Midland, Michigan 48640

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*Will provide catalogs upon request.

Table 5. Plan for Exploratory Development on Corrosion of Shore Facilities

Product: Corrosion of Shore Facilities YF61.544.091.021	Program Support ($K)					
	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87
Milestones:						
1. Develop design criteria for corrosion control.	® 40 ©					
2. Develop procedures/criteria for cathodic protection of underground structures.	® 60	60 ©				
3. Develop coating procedures for special problems (e.g., coating of galvanizing).		® 40	50	30 ©		
4. Develop procedures/criteria for cathodic protection of marine structures.			® 50	40 ©		
5. Prepare coordinated corrosion control plan with latest corrosion control technology for shore facilities.				® 30 ©		

Start Date / Expended	User		FY 82	FY 83	FY 84	FY 85	FY 86	FY 87
Start Date: FY Expended: ($K): FY81: 30 Prior to FY81: 0	User: NAVFAC Codes 04, 10, and 11 Naval Shore Facilities	6.2	100	100	100	100		
		Total	100	100	100	100		

Problem: Facilities at shore activities have been permitted to corrode to a costly ($500 million yearly corrosion losses) and unacceptable level. This has been due in large part to (1) funding deficiencies, (2) lack of a coordinated corrosion control program, (3) outdated instructions and manuals, and (4) lack of personnel with corrosion expertise. The problem can only be resolved by field activities implementing a corrosion control plan with new and improved corrosion control techniques that can be simply installed and monitored by trained personnel.

Approach: (1) Identify areas for which technology is currently available for field implementation and those for which new developments or modifications are required, (2) determine nature and extent of field problems so that priorities of different problems can be determined and specific approaches to their solution (particularly those using automation or not requiring technical knowledge for decisions) can best be found, (3) find, modify, or develop appropriate procedures for corrosion control (e.g., cathodic protection, coatings, design, water treatment, materials selection), and (4) prepare procedures for implementation of these procedures by field activities utilizing information or simplified procedures as much as possible.

Deliverables: Designs, criteria, and recommended practices for corrosion control at shore facilities suitable for use in NAVFAC manuals, instructions, and specifications.

Benefits: Control of corrosion at shore activities to permit continuous operational support to fleet and air activities utilizing a coordinated plan that significantly reduces (20% to 40%) maintenance and replacement costs ($100-200 million annually).

6.2 ——— 6.3 ------- 6.4 .... ® Beginning of RDT&E Δ Initiation of Advanced Develop. or O&MN

6.5 →→→→→→→ O&MN ======= Other ======= © Completion of Exploratory Develop. ∇ Completion of Advanced Develop. or O&MN

tm no: M-52-81-03S

Technical Memorandum

title: RESEARCH AND DEVELOPMENT PROPOSAL FOR CORROSION CONTROL FOR SHORE FACILITIES - A ZERO MILESTONE REPORT

author: Richard W. Drisko, Ph D

date: October 1981

sponsor: Naval Facilities Engineering Command

program no: YF61.544.091.01.021

DEPARTMENT OF THE NAVY
NAVAL CIVIL ENGINEERING LABORATORY

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

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ENCLOSURE (5)

CONTENTS

INTRODUCTION

Naval Civil Engineering Laboratory (NCEL) Technical Memorandum M-52-81-03 (Ref 1) described the estimated \$0.5 billion corrosion losses suffered each year in the Naval Shore Establishment and recommended actions to be taken by the Naval Facilities Engineering Command (NAVFAC) in establishing a single, coordinated corrosion control program. Areas of fruitful research, development, test, and evaluation were also mentioned. This report is written to highlight these areas. While all the recommendations are considered necessary to provide field activities with the total criteria and direction necessary for effective control of facilities corrosion, not all are suitable for support under the 6.2 and 6.3 materials program. Each will be considered separately with appropriate sponsorship, and that proposed for 6.2 and 6.3 fundings will be discussed in more detail.

PROBLEM

The problem of corrosion of shore facilities was summarized in Reference 1:

> Corrosion of facilities throughout the Naval Shore Establishment has been permitted to reach a condition that will be extremely difficult and costly to correct and maintain acceptably utilizing present corrosion control technology, management procedures, personnel and equipment resources.

This report is directed at development of corrosion control technology that will alleviate this problem by providing to personnel at shore activities simple, efficient control equipment/techniques to be utilized through manuals, specifications, and techdata sheets.

APPROACHES TO CORROSION CONTROL

Effective corrosion control must include design, construction, maintenance, operation, and repair aspects of a facility. Thus the control approaches of design (including materials selection), coatings, cathodic protection, and water treatment (e.g., inhibitors) must be reflected in new inspection, maintenance, and repair procedures and schedules. Table 1 lists the major corrosion encountered at shore facilities and their components, and shows that the four above approaches are best used in combination with each other. The Appendix describes in a simplified manner these control techniques and the mechanisms of corrosion of shore facilities. It should be understood that although each of the actions recommended in this report is proposed separately and under different support, it is only a part of the overall approach to corrosion control and must be integrated into a coordinated corrosion control program.

PROPOSED ENGINEERING INVESTIGATIONS

Development of Design Criteria

About 10% of corrosion problems at shore facilities are created through poor design. These can be resolved with relative ease in new construction. Reinhart (Ref 2) and Jenkins (Ref 3) have described design for corrosion control of potable water distribution systems, aviation fuel storage and distribution systems, and OTEC plants. Pludek (Ref 4) and Perrigo and Jensen (Ref 5) provide more general information on design factors. The specific steps in the approach are: (1) review corrosion problems at shore facilities; (2) obtain design criteria for corrosion control from published literature, DOD documents, and technical societies; (3) determine design criteria appropriate for shore facilities; and (4) prepare practical documentation describing the appropriate criteria in detail. Design factors to be considered include: (1) geometry, orientation, and siting; (2) compatibility of materials; (3) sharp edges and corners; (4) skip welds and other crevices; (5) configurations that permit water and salt collection, abrasion, or impact; (6) velocity effects; (7) concentration cell effects; (8) erosion and fatigue; (9) cavitation; (10) galvanic effects; (11) high temperatures; (12) attack by corrosive gases; (13) thermal effects; and (14) stray current corrosion.

NAVFAC Code 0451F has assisted NCEL in preparing a Statement of Work for developing design criteria resulting in the preparation of three design manuals: (1) Corrosion Control by Design, (2) Coatings and Their Use in Corrosion Control, and (3) Corrosion Control by Use of Cathodic Protection. The three-year effort would receive Engineering Investigation funding of $60,000 in FY82, $60,000 in FY83, and $30,000 in FY84.

Specialized Coatings for Corrosion Control

During the NCEL survey of field activities in the Pacific Division, several common coating problems were encountered. These include loss of organic coatings from galvanized steel surfaces, corrosion of coated cyclone fencing, and loss of coatings and corrosion of stacks, mufflers, and other hot structural components at power and steam plants. These problems are so serious and widespread that a significant improvement in coating performance will result in an immediate significant saving of funds. NCEL will continue to accumulate information on coating problems and supply immediate assistance to field activities through its Facilities Engineering Support (field assistance) Program. Two investigations that have been identified in field contacts are being proposed to start in FY82.

<u>Coatings for Galvanized Steel</u>. Peeling of topcoating with resultant corrosion of galvanized steel is one of the most commonly encountered corrosion problems at shore activities (Ref 1). Although many organic coatings are recommended by suppliers for galvanized steel, no one preferred system is recommended by the Steel Structures Painting Council (Ref 6) or Zinc Institute (Ref 7). Based upon long-term exposure tests,

zinc dust/zinc oxide primers are reported (Ref 7) to give the best protection. Thus, NAVFAC MO-110 (Ref 8) recommends the use of TT-P-641, a zinc dust/zinc oxide primer, over wash-primed (DOD-P-15328) galvanizing. The Zinc Institute, however, states (Ref 7) that no treatment or washing of new surfaces is necessary, and washing with vinegar, copper sulfate solution, acetic acid, muriatic acid, or other acids is not recommended. Leidheiser of Lehigh University (Ref 9), on the other hand, has found in his laboratory that certain aqueous treatments of zinc inhibit corrosion. Thus, there are a number of differing views on the effects of surface treatment of galvanizing prior to coating and the types of primers and topcoats to be used. More importantly, there is no system of coating galvanized steel that presently can be depended upon to provide long-term protection. It is believed that the observed peeling of coatings from galvanizing at Naval shore activities is related to one or more of the following:

1. Undercutting of the coating by corrosion of zinc

2. Poor adhesion of the coating to the galvanizing

3. Saponification of alkyd primers

Because of the magnitude of this problem, NAVFAC Code 0451F has proposed that Engineering Investigation support be given to the National Bureau of Standards for a study of coating performance on weathered galvanized steel that will largely consist of field exposures of different coating formulations. NCEL will be advised of the progress of the work so that a determination can be made if 6.1 basic research should be proposed in FY83 or 84 to provide needed basic information, or if broad-scale field testing should be conducted in FY84 or 85 under 6.3 materials funding to provide in-service data on recommended methods of cleaning, treating, and coating new and weathered (both coated and uncoated) galvanized steel.

Coatings for Hot Steel Surfaces. Another corrosion problem found to be quite prevalent throughout the Naval Shore Establishment (Ref 1) is the corrosion of hot steel surfaces, such as are found on mufflers and stacks at power plants and vapor control devices for fuel storage tanks. Corrosion of steel in jet engine test facilities was also noted at several locations. NAVFAC MO-110 (Ref 8) specifies TT-P-28 (aluminum paint) and MIL-P-14105 (fritsilicone paint) for hot surfaces. The latter is difficult to procure because of the very limited number of suppliers, and neither has provided long-term protection from corrosion. Stacks of Southern California Edison Company power plants have been effectively protected with special inorganic zinc coatings, and these may also be effective on Navy stacks at temperatures below 800°F. The temperature requirements for the hot surfaces and the temperature limitations of the coatings must be determined to see if they differ appreciably from those of private industry, and thus, if products used by them can be used effectively at Naval activities. Coating thickness limitations must also be determined. Thus, for inorganic zinc coatings, the dry film thickness may be limited to 3 mils to prevent mudcracking. Inorganic ethyl silicate coatings without zinc loading have also been reported to effectively control high-temperature corrosion. Another approach is the use of flamesprayed aluminum, which has been used effectively on corrosive areas (e.g., those exposed to stack exhausts) on Navy ships (Ref 10). Both these and inorganic zinc coatings require a high level of surface preparation (usually abrasive blasting), so the criteria for a coating system for hot metal surfaces must include: (1) formulation requirements, (2) operational temperatures, (3) thickness requirements, and (4) surface preparation requirements. The above described materials, along with others reported to be effective for private industry, can be screened in the laboratory before field testing so that practical performance criteria can be established to NAVFAC MO-110 (Ref 8) and other documents. NAVFAC Code 0451F is assisting NCEL in procuring funding for this investigation.

PROPOSED EXPLORATORY DEVELOPMENT (6.2) INVESTIGATION

Cathodic protection is the corrosion control tool with currently the greatest potential and the least effective use in the Naval Shore Establishment. In the few applications to buried or immersed steel at Naval shore facilities, only limited monitoring and maintenance of these systems occur (Ref 1). On the other hand, several instances of its misuse have been encountered. Thus, a simple system to monitor and maintain cathodic protection systems at desired operational levels has been given number one priority. The proposed investigation will be further restricted to marine applications because (1) they are more Navy-unique, (2) marine environments are more corrosive, (3) marine facilities are in worse condition than others, and (4) buried facilities are more easily cathodically protected with existing technology. It should be remembered that cathodic protection is best used in conjunction with coatings, and that in marine applications, this is especially true because cathodic protection can only protect areas immersed in electrolyte (e.g., seawater), and marine structures have alternately immersed and dry areas due to tidal and wave actions on fixed structures and differences in freeboard from loading variations of floating structures. The proposed work on cathodic protection is scheduled, as shown in Table 2, in four phases: (1) system for diver monitoring cathodic potentials, (2) systems for continuous diver and for remote monitoring of potentials (3) criteria for use of marine coatings on cathodically protected structures, and (4) system for automatic control of cathodic protection for marine structures. Results from this work would be placed in MO-307 (Ref 11) currently due for updating. NAVSEA has also expressed interest (Ref 12) in joint funding of the work so that results might also be utilized in NAVSEA documents.

System for Monitoring Cathodic Potentials

Several years ago, NCEL developed (Ref 13) a remote system for monitoring tank-to-water potentials inside cathodically protected water storage tanks. This technology was subsequently used by private industry to develop automatically controlled systems for regulating cathodic potentials inside freshwater tanks within a desired range. The purpose of measuring cathodic potentials is to (1) insure that complete protection is achieved (e.g., -850 mv with respect to a copper/copper sulfate reference half-cell) without using more electrical energy than necessary, and (2) prevent exposure of interior coatings to excessively high potentials that might damage them.

More recently, NCEL devised (Ref 14) a system of diver inspection of fleet moorings that utilizes a portable underwater voltmeter developed by the Navy. One or more commercial models of differing design are also available. The chief features of the Navy model are a titanium probe, a silver/silver chloride reference half-cell, and a digital readout with an LED display that is accurate to the nearest millivolt. Measurements are given by the diver over a telephone to the engineer on topside who plots the potential profile along the mooring and requests repeat readings where discrepancies are noted or when the potentials fall outside the desired range. The chief cause for erroneous readings is the difficulty in a diver obtaining good electrical contact between the probe and the mooring. Localized measurements are made in this manner rather than moving a reference half-cell along the mooring legs with the other lead attached to the buoy above water (quite an acceptable procedure for water tanks) because of (1) possible electrical discontinuity along the mooring legs, and (2) difficulties in getting the half-cell close to mooring components to detect local variations. Cathodic protection measurements are strongly dependent upon the location of the half-cell (partially for base structures). As a half-cell becomes remote from the protected structure, the readings of steel-to-water potentials become an average reading of a larger area. Thus, diver inspection of cathodic potentials aboard the Queen Mary showed great variations in areas where sea chests and other appurtenances were located. Similarly, significant variations might be expected in various areas of Z-shaped steel sheet piling used on quaywalls to retain soil, particularly if there is poor electrical continuity between adjacent piling. Such variations would also be expected on piers with H and pipe piling with various cross members located underwater. Only by determining the potential profiles of such structures can it be determined if modifications, such as changing current input, bonding structures where discontinuities occur, or adding supplemental anodes, are necessary.

As shown in Table 2, this phase of the work would be a two-year effort. In milestone 1, completed after the first year, a simple, portable system (equipment and criteria for use) for rapidly measuring and reporting of potentials to the surface for a variety of marine structures and data on the variation of potentials along the underwater portions of different structure/configurations would be developed. At the same time, an investigation would be conducted into the feasibility of (1) a system for continuous recording on topside of the potentials received as a probe and half-cell are moved along a cathodically protected structure, and (2) installing permanent half-cells along different portions of immersed marine structures to monitor potentials at selected locations either continuously or as desired. The former system would require continuous electrical contact and transfer of data to a remote recorder topside; the latter system would require very stable reference half-cells protected from structural damage and lines leading to the recorders located topside. In milestone 2, at the end of the second year, criteria and/or equipment for either or both of these systems would be developed based upon the feasibility study. The chance of success in milestone 1 is quite high and in milestone 2 only slightly lower.

Criteria for Coatings on Cathodically Protected Marine Structures

As previously mentioned, coatings are generally used in cathodic protection of marine structures in order to reduce the required level of current and to extend corrosion control into nonimmersed portions of the structure. It was also noted that high cathodic potentials (i.e., well in excess of 1 volt) can damage coatings and thus render them ineffective in corrosion control (Ref 15). In addition, cathodic protection produces an alkaline environment (from hydroxide ions formed in the cathodic reaction) that may reduce adhesion or react with the coating. Thus, in order for a coating to perform effectively on cathodically protected structures, it must be resistant to alkalinity, relatively impermeable to water and ions present in seawater, and resistant to cathodic potentials necessary for protection of steel. A two-year laboratory effort is proposed for long term exposure of cathodically protected and coated steel specimens in flowing seawater. Flowing seawater will dissipate heat and buildup of cathodic reaction products. Two types of coating will receive special emphasis. One is the Formula 150 series of epoxy-polyamide coatings described under MIL-P-24441 and used extensively on Navy ships (Ref 16) and mooring buoys (Ref 17). The other is the amine-cured coal tar epoxy that is especially impermeable to water and resistant to alkali. Both systems will be tested with and without an antifouling coating, such as the vinyl/cuprous oxide system of Formula 121/63 (MIL-P-15931). Criteria will be developed for maximum levels of cathodic potentials at different thicknesses of selected coating systems. Data from this investigation will be placed in NAVFAC MO-110 (Ref 8), NAVFAC MO-307 (Ref 11), and various NAVSEA manuals.

Systems for Automatic Control of Cathodic Protection for Marine Structures

Based upon the results of Milestones 1 and 2 in developing a monitoring system for cathodic potentials on marine structures, an automatic control system will be developed to increase or decrease current output of a cathodic protection system to keep the protective potential in the desired range (e.g. -875 to -975 mv with respect to a copper/copper sulfate reference half-cell). The range will be varied from structure to structure, depending upon individual requirements.

The desired system of automatic control for marine structures will be somewhat similar to that now commercially available for water storage tanks. Thus, one or more reference half-cells, stable over a long period of time and protected from impact, ice, and other physical damage, will be developed to impart to a potential comparator system data on structure-to-water potentials to be utilized by a current control system to maintain potentials in a preselected range. Currently, the automatic systems for water tanks are not receiving widespread use and are in disfavor with Army and Air Force facilities because of maintenance problems. Even more problems are expected from a more complex cathodic protection system for marine structures, so that much more care must be taken to simplify operation and maintenance procedures. It will be necessary to prepare a simple system for troubleshooting and replacement of component parts (e.g., circuit boards and half-cells) in order to keep the overall system at a level for practical and efficient use by field activities. The Port of Long Beach has done some preliminary work in this area. Chances of developing such a system are quite good.

PROPOSED ADVANCED DEVELOPMENT (6.3) INVESTIGATION

Currently, $1.6 million is required annually to maintain 330 fleet moorings in operating condition (one-third are overhauled annually at a cost of up to $25K each). In FY81, all mooring maintenance funds were sent to Diego Garcia for priority work, thus adding to the maintenance backlog that now totals about $4 million. Also, the supply of old steel buoys and other mooring accessories from World War II has been depleted, so that new, costly components for moorings will have to be procured. Clearly there is a requirement for both reduction of mooring maintenance costs for keeping fleet moorings in a safe, operational condition. This need was recognized by NAVFAC Code 10, who requested this proposal be prepared so that MO-124 (Ref 17) could be updated with more simplified, cost effective maintenance procedures.

According to NAVFAC MO-124,

> " Any part of a chain or its components that has had its mean wire diameter reduced to 90 percent of its original diameter must be replaced; the removed chain can be used later in a mooring designed for chain of the next lower standard size. (If chain testing equipment is available, a proof test for the smaller chain size should be run on the used chain.) A chain that has had its original wire diameter reduced to 80 percent of original diameter should be removed from service and disposed of as scrap."

The above criteria of 80% and 90% are not based upon technical data but upon arbitrarily assigned values received from past experience.* Because stocks of components for mooring ground tackle are exhausted, a great deal of additional expense may be required if corroded components are unnecessarily replaced with new ones. Thus, a proposal is presented to establish a relationship between the diameter/corrosion condition of the mooring component and its loading capacity (breaking strength).

The proposed investigation would consist of two parts: (1) relationship of component diameter/condition to breaking strength, and (2) failure analysis of mooring components. The schedule and funding of the work is given in Table 3. This work should be approved as soon as possible using funds available in either the 6.3 materials or 6.3 shore facilities program. The probability of success for this work is high.

Criteria for Estimating Breaking Strength from Component Diameter/Condition

Many old ground tackles from fleet moorings have been downgraded and are being stored for possible use on lower capacity moorings. They are available from a variety of different mooring configurations (e.g., riser and telephone types with different numbers of legs and diameters of components) and from different service environments. The remaining

*MO-124 was prepared by the author of this Technical Memorandum.

cross section of the various components will be determined along with the corrosion condition (e.g., general corrosion, pitting, galvanic corrosion, etc.). Die-lock chain exposed to different environments will be compared to cast steel chain from the same environment, as the former is not recommended for some services (Ref 16). After complete characterization, the components will be pulled in tension to failure. A mathematical model will be developed separately to relate component cross section and condition to breaking strength, and field data will be used to determine the validity of the model.

Loading Criteria from Failure Analysis of Mooring Components

Several failures of mooring components have occurred and, based upon past experience, can be expected to occur again. No analysis of these failures have been made to determine their causes. NAVFAC Code 10 will direct activities encountering failure of mooring components to send them immediately to NCEL for failure analysis using preservative methods that will not affect failure analysis. The failed components will then be examined under light and scanning electron microscopes to determine the mechanism of failure (e.g., fatigue, grain boundary, etc.). The information received from the analyses will be used to verify findings found in the other part of this investigation to determine if actual service failures occur at loads predicted by characterization methods developed in the other phase of this investigation.

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Table 1. Techniques for Controlling Corrosion of Facilities/Components at Shore Activities Having Major Corrosion Problems

Facilities/Components	Corrosion Control Technique			
	Design	Coatings	Cathodic Protection	Water Treatment
Fuel Storage Tanks	+	+	(+)	-
Water Storage Tanks	+	+	(+)	(+)
Fuel Distribution Systems	+	+	(+)	-
Water Distribution Systems	+	+	(+)	(+)
Hot Water/Steam Distribution System	+	+	-	(+)
Power/Steam Plants	+	+	-	(+)
Fleet Moorings	+	+	(+)	-
Waterfront Structures	+	+	(+)	-
Vehicles	+	+	-	(+)
Buildings/Housing	+	+	-	-
Air Conditioners	+	+	-	(+)
Antenna Towers	+	+	-	-
Cyclone Fencing	+	+	-	-
Electrical Conduct/Fixtures	+	+	-	-

\+ = effective use

(+) = effective use on part of structure (e.g., buried or immersed part)

\- = no effective use

...pment of Systems for Monitoring and Controlling
Cathodic Protection on Marine Structures

Product: Monitoring and Controlling System for Cathodic Protection of Marine Structures

Milestones:	Program Support ( ) FY 82	FY 83	FY 84	FY 85	FY 86	FY 87
1. Complete development and field testing of simple, portable system for recording cathodic potentials.	® 50 ©					
2. Complete feasibility determination of continuous diver or remote recording of potentials and development of practical systems.	® 20	70 ©				
3. Complete laboratory determination of criteria for marine coatings on cathodically protected marine structures.	® 30	30 ©				
4. Complete development and field testing of automatic system for controlling cathodic potentials.			® 100	100 ©		

Start Date: FY82
Expended: ($K):
FY81: 0
Prior to FY81: 0

User: NAVFAC Codes 04, 10, and 11
NAVFAC Field Divisions
Shore Activities

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87
6.2	100	100	100	100		
Total	100	100	100	100		

Problem: Corrosion of marine structures providing vital support to the fleet is one of the chief causes of the estimated $0.5 billion annual corrosion losses in the Naval Shore Establishment. Cathodic protection is the corrosion control tool with currently the greatest potential and the least effective use in protecting these structures. Where cathodic protection systems have been installed at shore activities, they have not been properly inspected and maintained by personnel to the extent that continuous, long-term protection has been obtained.

Approach: (1) Improve underwater voltmeter for inspection capability to measure structure-to-water potentials and transmit it to a recorder topside, and obtain data on potential variations on different structural configurations; (2) determine feasibility of (a) continuously recording potentials as probe is moved across a protected surface and (b) a permanently installed system with which potentials could be recorded continuously or as desired; (3) develop equipment for the feasible systems; (4) establish criteria (composition, permeability, thickness, electrical resistance) for coatings for cathodically protected structures; and (5) develop easily maintained automatic system for controlling potentials received remotely by monitoring system.

Deliverables: Recording system (FY82); system for remote monitoring (FY83); criteria for coating use (FY83); system for automatic control (FY85).

Benefits: Simplified systems for cathodically protecting marine structures resulting in significant reduction of corrosion costs (est. $100M annually).

6.2 ——— 6.3 ------- 6.4 .... ® Beginning of RDT&E Δ Initiation of Advanced Develop. or O&MN
6.5 →→→→→→ O&MN ======= Other ======= © Completion of Exploratory Develop. ∇ Completion of Advanced Develop. or O&MN

Table 3. Plan for Developing System for Estimating Capacity of Fleet Moorings

Product: System for Estimating Capacity of Fleet Moorings

Milestones:	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87
1. Complete laboratory investigation relating component diameter/condition to breaking strength.	Δ 50	20 ∇				
2. Complete development of mathematical model.		Δ 30 ∇				
3. Complete laboratory failure analysis of mooring components.	Δ 10	10 ∇				

Program Support ($K)

Start Date: FY82
Expended: ($K):
FY81: 0
Prior to FY81: 0

User: NAVFAC Codes 04 and 10
NAVFAC Field Division
Shore Activities

	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87
6.3	60	60				
Total	60	60				

Problem: $1.6M is required annually to maintain 330 fleet moorings. The supply of old replacement components has been exhausted so that this cost should increase significantly. Present criteria of 90% and 80% of diameter for lowering the classification and discarding the component, respectively, have no technical basis except that they have been used historically. Thus, some components of adequate strength may have been downgraded or discarded unnecessarily. At the same time, failure of mooring components occasionally occurs withoug knowledge of the cause of failure.

Approach: (1) Using old, downgraded or discarded mooring components from differing services and environments, relate chain diameter and condition of metal to breaking strength values obtained using high-capacity testing machines; (2) develop a mathematical model for mooring components and test model with breaking strength data; and (3) perform failure analyses on mooring components when failure occurs to relate actual failure data to testing and modeling data.

Deliverables: Technical criteria for estimating breaking strength and thus criteria for downgrading and discarding mooring components.

Benefits: Reduced failures of moorings and reduced costs in their maintenance (estimated 15%).

6.2 ——— 6.3 ------- 6.4 ······· ® Beginning of RDT&E Δ Initiation of Advanced Devel. or O&MN
6.5 →→→→ O&MN ======= Other ≡≡≡≡≡≡≡ © Completion of Exploratory Develop. ∇ Completion of Advanced Devel. or O&MN

APPENDIX

CORROSION AND ITS CONTROL AT NAVAL SHORE FACILITIES

INTRODUCTION

Corrosion is an electrochemical reaction of a metal with its environment that results in the loss of both physical properties and material, either in general or localized areas. It is among the chief sources of economic loss to all industrial nations. It occurs so commonly that it is often considered to be an inevitable act of God to return a refined product to its natural state. Quite the contrary, the application of modern corrosion control technology can significantly reduce the incidence and severity of such attack.

In 1975, corrosion cost the United States an estimated $70 billion. The total corrosion cost in the Federal Government sector amounted to about $8 billion. The Naval Shore Establishment has annual corrosion losses of about $500 million with the average large activity having more than $1 million in annual losses.

Major concerns in corrosion of shore facilities are that (1) its long-term control be accomplished in the most economical manner and (2) vital support to fleet and air arms be available at times of need. Of lesser but important concern are the loss of energy (e.g., fuels, steam, etc.,) and the contamination of the environment from corrosion failure of storage or distribution facilities.

MECHANISM OF CORROSION

During corrosion, energy (electricity) passes from a negative area (anode) of a piece of metal to a positive area (cathode) through an external conductive media (electrolyte) such as soil or water (Figure A-1). The electrical circuit is completed as electricity is returned to the anode internally through the metal. The driving force of the corrosion cell is determined by the chemistries of the metal and its environment. Loss of metal occurs at the anode area where electricity enters the electrolyte, and protection of metal occurs at the cathode area. Other chemical reactions at the anode area usually cause it to be acidic, while reactions occurring at the cathode usually cause the formation of hydrogen gas and an alkaline environment. The hydrogen gas may passify the surface (i.e., make it more corrosion resistant). Reactions involving oxygen in the electrolyte can also occur at the cathode area. Thus, oxygen may combine with the hydrogen there to form water and thereby remove the hydrogen from the surface, a process known as cathodic depolarization that keeps the corrosion cell active. In many instances, the availability of oxygen can determine the rate of corrosion.

TYPES OF CORROSION AT SHORE FACILITIES

The most common types of corrosion at shore facilities are summarized in Table A-1. Galvanic corrosion will be discussed in some detail because (1) it occurs quite frequently at shore activities, (2) it occurs in many forms, (3) it can be quite rapid and costly, and (4) it is frequently relatively easy to correct.

Galvanic corrosion (sometimes called bimetallic or dissimilar metal corrosion) occurs when two metals or portions of the same metal with dissimilar electrical potentials are connected to each other in an electrolyte. Although all metals and metal alloys in an electrolyte exhibit an electrical potential, some of these potentials are much higher than others. A galvanic series for any environment is a listing of metals and alloys in order of potential. A series listed in decreasing order of electronegativity in seawater is given in Table A-2. Similar to this is the electromotive force or EMF series which is an arrangement of pure metals in order of their potential when exposed to a solution of their salts. In each case, the greater the difference in potential, the greater will be the driving force of the corrosion reaction. In such a galvanic corrosion cell, the higher listed (more active) metal will corrode, while the lower listed (more noble) metal will not.

Potential differences existing on pieces of the same or similar metal can also give rise to galvanic corrosion. Typical examples of galvanic corrosion are shown in Figure A-2 and below:

1. New steel is anodic to old steel.

2. Steel is anodic to its surface mill scale.

3. Brightly cut surfaces (e.g., pipe threads) are anodic to uncut surfaces.

4. Highly stressed areas (e.g., pipe bends) are anodic to less stressed areas.

Galvanic corrosion can usually be avoided by selecting compatible metals that must come into direct contact with each other in an electrolyte. If they cannot have the same composition (i.e., be the same metal or alloy), they should be close to each other in the galvanic series for the particular environment. It may also be possible either to use rubber or plastic insulators to avoid undesirable metallic couples or to isolate the couple from the electrolyte. In addition, wrenches and vises that cut into the metal should be avoided, and stressing should be minimized. In all forms of corrosion, the anode/cathode area relationship is very important. As shown in Figure A-3, much more corrosion occurs when a small anode area is in contact with a large cathode area than in the reverse case.

TECHNIQUES FOR CORROSION CONTROL

Among the several techniques available for corrosion control are design, use of corrosion-resistant meterials, protective coatings, cathodic protection, and inhibitors. Although each will be discussed separately, they are always used in combination in an overall corrosion control program.

Design. About 10% of corrosion problems at shore facilities are created by poor design. Design factors that affect corrosion include (1) geometry, orientation, and siting, (2) compatibility of materials, (3) sharp edges and corners, (4) skip welds and other crevices, (5) configurations that permit water and salt collection, abrasion, or impact, (6) velocity effects, (7) concentration cells, (8) erosion and fatigue, (9) cavitation, (10) galvanic differences, (11) temperature, (12) attack by corrosive gases, and (13) stray current corrosion. Each of these should be considered in designing a new facility.

Corrosion-Resistant Materials. There are many alloys which, if used properly, are quite resistant to corrosion. These alloys exhibit three types of corrosion behavior. Some are essentially immune to corrosion, while some corrode but at rates signficantly slower than steel. Some of these alloys are essentially corrosion free if properly used, but may corrode at extremely rapid rates if used improperly. Table A-3 describes alloys that have been successfully used in marine structures.

There are several plastic or elastomeric corrosion-resistant materials that are effectively used as substitutes for steel at shore facilities. Uses for these materials include water and gas piping and hangers, grating, gutters, and downspouts. Table A-4 describes some plastic and elastomeric materials used in waterfront structures.

Protective Coatings. The chief means by which protective coatings impart protection to steel is by providing a barrier between the metal and the environment (i.e., the electrolyte). To deter corrosion the coating must be relatively impervious to water and salts, free of pinholes or other discontinuities, and of sufficient thickness to prevent the environment from reaching the metal. Certain corrosion inhibitive pigments (e.g., chromate salts and red lead) when properly formulated in a primer pigment can deter corrosion should there be a break in the coating barrier.

A third manner in which coatings deter metal corrosion is by a type of cathodic protection provided by zinc-rich coatings applied directly to steel. In addition to conventional paints, coatings, and varnishes, barrier protection may also be imparted by greases, oils, and waxes.

Cathodic Protection. Cathodic protection is a system for controlling corrosion of a metal surface by passing sufficient direct current onto it to make it a cathode, thus eliminating the possibility of anodic loss of metal. The electrolyte for cathodic protection is usually soil or water. It must be remembered that cathodic protection can prevent corrosion of a new structure or stop corrosion on an existing structure, but it cannot replace metal lost by corrosion of an existing structure.

There are two basic systems for supplying the necessary direct current electrical energy to a structure to cause it to become a cathode. The basic differences in these systems are shown in Table A-5. The galvanic anode system requires no external power supply, but incorporates anodes of a special alloy that generate the necessary direct current by virtue of a natural voltage difference from the protected structure (Figure A-4). The galvanic anodes (also known as "sacrifical") are consumed, like the anodes in a typical galvanic corrosion cell, in the process of generating current and, thus, have a limited service life. The galvanic anodes are fabricated from active metals and alloys; three basic materials are used — magnesium, zinc, and aluminum of high purity or other special composition.

The impressed current system utilizes low-voltage, high-amperage, direct current from an external power source (Figure A-5). The positive terminal of the power source must be connected to the anodes, and the negative terminal to the structure to be protected. The relatively stable anodes used to discharge current have much longer service lives than galvanic anodes. These anodes can theoretically be made from any electrically conductive material. However, unless the material is inert in the environment, it will be consumed. High silicon cast iron, graphite, and aluminum are commonly used materials at Navy activities. Scrap iron, special lead alloys, platinum, platinum-palladium alloy, platinized titanium alloy and platinized tantalum alloy are also sometimes used. Normally, rectifiers using available AC shore power supply the DC power to the system.

Coatings are generally used on cathodically protected structures to reduce current requirements. Thus, a well-coated buried pipe (e.g., epoxy primer and polyethylene wrap) may require only 0.01 milliamps per sq ft as compared to 3 milliamps per sq ft for a bare pipe. Previously used bituminous coatings required about 0.1 milliamps per sq ft. Coatings on cathodically protected structures must be resistant to the alkaline environment produced by the system.

Inhibitors. Inhibitors are chemicals added in small amounts, either continuously or intermittently, to acids, cooling waters, steam, or other environments to achieve a less corrosive condition. They may reduce corrosion by forming a very thin film on the metal surface, by causing a passive layer to form on the surface, or by removing aggressive constituents from the environment. The best known corrosion inhibitors are those used in antifreeze and coolant liquids for engine cooling systems.

CONCLUSION

Although corrosion is a complex and costly problem at Naval shore activites, a coordinated corrosion control program utilizing all the available control techniques can result in maintaining important Navy support facilities in proper operating condition in a very cost-effective manner.

REFERENCES FOR FURTHER INFORMATION ON CORROSION

1. Naval Facilities Engineering Command. NAVFAC MO-104: Maintenance of waterfront facilities. Alexandria, Va., Jun 1978.

2. __________. NAVFAC MO-110: Paints and protective coatings. Alexandria, Va., Jan 1969, with amendments.

3. Bureau of Yards and Docks. NAVDOCKS MO-306: Corrosion prevention and control. Washington, D.C., Jun 1964.

4. __________. NAVDOCKS MO-307. Corrosion control by cathodic protection (subsurface metal structures). Washington, D.C., Jun 1964.

5. NACE Basic Corrosion Course. A. deS. Brasunos and N. E. Hamner, editors, National Association of Corrosion Engineers, Houston, Tex., 1970.

6. Proceedings of 1981 Western States Corrosion Seminar, National Association of Corrosion, Houston, Tex., 1981.

7. Corrosion in Action. International Nickel Company, Inc., New York, 1977.

Table A-1. Types of Corrosion Commonly Found at Shore Facilities

Type	Description	Remarks
Galvanic Corrosion	Two dissimilar metals connected to each other electrically in an electrolyte (e.g., seawater). Current flows through the electolyte from the more reactive metal (the anode) to the less reactive metal (the cathode), thereby corroding the anode area while protecting the cathode area from corrosion.	1. New steel is anodic to old steel. 2. Steel is anodic to its surface mill scale. 3. Brightly cut surfaces (e.g., pipe threads) are anodic to uncut surfaces. 4. Highly stressed areas (e.g., pipe bends) are anodic to less stressed areas.
Stray Current	Occurs on metal surfaces wherever stray direct current passes from them to an electrolyte. This current most frequently arises from electric railway and crane systems, improperly grounded welding generators, and adjacent cathodic protection systems.	Stray current corrosion should always be suspected as the cause of accelerated corrosion in areas adjacent to sources of DC current and checked for by detection of current flow.
Differential Environmental	Occurs from differences in composition of the medium. Usually results from different levels of aeration (oxygen content); less frequently from different salinities.	Corrosion occurs in area of lower oxygen content. On steel piling, this is just below the mean low tide level. Also in crevices and corners because less oxygen is there.
Erosion-Corrosion	Scouring action of sand and other abrasives exposes bright metal and keeps the corrosion active.	1. Commonly found at or just above the mud line on steel piling or riser chains of moorings. 2. Wind in sandy areas.
Corrosion Fatigue	The combined action of corrosion and fatigue (cycle stressing) in causing metal fracture.	Occurs mostly in moving parts of mechanical equipment.

continued

Table A-1. Continued

Type	Description	Remarks
Dealloying	The selective corrosion (loss) of a metallic constituent from an alloy.	The leached metal may be aluminum, nickel, molylodenum, or zinc.
Graphitization	Corrosion of gray cast iron in which the metallic constituents are converted to corrosion products, leaving the graphite intact.	Can be considered a type of dealloying.
Hydrogen Embrittlement	Embrittlement of a metal caused by hydrogen.	Sometimes observed in cathodically protected steel, electroplated parts, and pickled steel.
Cavitation Corrosion	Damage resulting from combined effects of corrosion and cavitation (the formation and sudden collapse of gas bubbles in a liquid).	Momentary, localized high pressure can destroy metal, corrosion products, or surface of propellers or pump impellers.
Stress Corrosion	Corrosion which is accelerated by stress and frequently accompanied by metal cracking.	Occurs with metal objects pulled or bent to a desired shape in manufacture or use.

Table A-2. Galvanic Series in Surface Seawater*

Anode-Active-Corroding

Magnesium
Zinc
Galvanized Steel (New)
Aluminum Alloy 7000 Series
Aluminum Alloy 6000 Series
Pure Aluminum (99+%)
Alclad Aluminum
Cadmium
Cadmium coated steel (New)
Aluminum Alloy 3000 Series
Aluminum Alloy 2000 Series
Aluminum Alloy 5000 Series
Mild Steel
Wrought Iron
Alloy Steel
Cast Iron
Ni-Resist Cast Iron
Monel alloy 400 (Active)
Stainless Steel 410 (Active)
Stainless Steel 430 (Active)
Solder (60% Pb - 40% Sn)
Stainless Steel 304 (Active)
Stainless Steel 316 (Active)
Stainless Steel Alloy 20 - Cb (Active)
Lead
Tin
Muntz Metal
Manganese Bronze
Naval Brass
Nickel (Active)
Inconel 600 (Active)
Yellow Brass
Admiralty Brass
Aluminum Bronze
Red Brass
Copper
Silicon Bronze
Nickel Silver
Cupro-Nickel 95-5
Cupro-Nickel 90-10
Cupro-Nickel 80-20
Cupro-Nickel 70-30 low Fe
Cupro-Nickel 70-30 high Fe
G-Bronze
M-Bronze
Nickel (Passive)
Inconel 600 (Passive)

Continued

Silver Solder
Monel (Passive)
Stainless Steel 410 (Passive)
Stainless Steel 430 (Passive)
Stainless Steel 304 (Passive)
Stainless Steel 316 (Passive)
Stainless Steel Alloy 20 - Cb (Passive)
Silver
Inconel 625
Hastelloy C
Titanium
Graphite
Gold
Platinum

Cathode-Passive-Noble-Protected

*If two of the listed materials are in contact in surface seawater, the higher one is the anode (active, corroding) and the lower one the cathode (passive, noble, protected).

Table A-3. Alloys Successfully Used in Marine Structures

Alloy	Properties
Aluminum	Aluminum alloys subject to marine pitting and crevice corrosion, especially in seawater; successfully used if pitting can be tolerated and crevices eliminated; lightweight.
Stainless Steel	Normally corrodes without special protection; marine grades of stainless steel (300 series) usually corrode by crevice corrosion unless crevices avoided or cathodically protected. Grades 304 and 316 most widely used. Grades 303 and other series such as 400 should be avoided.
Copper	Copper, cupro-nickle 90-10, cupro-nickel 70-30, arsenical admiralty brass, and most true bronzes corrode uniformly at low rates in low velocity marine waters.
Titanium	Essentially corrosion free except for stress-corrosion in some alloys; chemically pure grades and heat-treatable alloy 6Al-4V annealed (100-ksi yield) immune to corrosion in seawater and marine atmosphere; costly and difficult to fabricate, but strong and lightweight.
Nickel	Inconel alloy 625 and Hastelloy alloy C immune to marine corrosion; Monel alloy 400 usually immune if cathodically protected.

Table A-4. Plastic and Elastomeric Materials in Waterfront Structures

Type of Material	Composition/Construction	Properties	Waterfront Use
Fiberglass Reinforced	Lay-up of layers of fiberglass cloth (woven roving) or mat and polyester or epoxy resin.	Strong, abrasion resistant	Buoys, floats, brows
Plastic	Spray-up of polyester or epoxy resin and chopped glass fibers.	Strong; cheaply fabricated	Buoys
	Polyester or epoxy wetted glass filament wound around a mandrel at a desired angle.	Expensive but very strong	Buoys, floats, piping
Foam	Urethane material foamed in place.	Easy to use; yellows and degrades in sunlight	Buoy and pontoon flotation
	Polystyrene (styrofoam) cut to desired length.	Relatively inexpensive; weathers well	Buoy and float flotation
	Syntactic foams of hollow glass or plastic balloons bonded together with epoxy resin.	Very strong; water resistant	Deep Submergence Vehicles
Plastic Wrap	Flexible poly (vinyl chloride) sheets.	Water resistant; damaged by impact	Protective barriers for wooden piling from marine borers
Rubber	Natural or synthetic rubber molded to desired shape.	Good impact resistance	Fenders for piers, wharves, landing floats, mooring buoys, and piling
Splash-Zone Compound	Two-component epoxy-polyamide putty.	Can be applied to underwater surfaces	Patching coating or other damage between tides or underwater

Table A-5. Basic Differences in Galvanic and Impressed Current Cathodic Protection Systems

Galvanic	Impressed Current
No external power supply required	Requires an external power source
Low maintenance costs	Voltage can be easily varied
Interference to foreign structures is usually nonexistent	Current can be easily varied
Installation costs are low	Suitable for high resistivity electrolytes
Usually does not require additional right-of-way	Protects larger, more extensive structures
Adjusts output as structure potential varies	Can cause interference problems
Severely limited current output	Requires higher installation and maintenance costs
Useful only in low resistivity electrolytes	Usually results in a monthly power bill

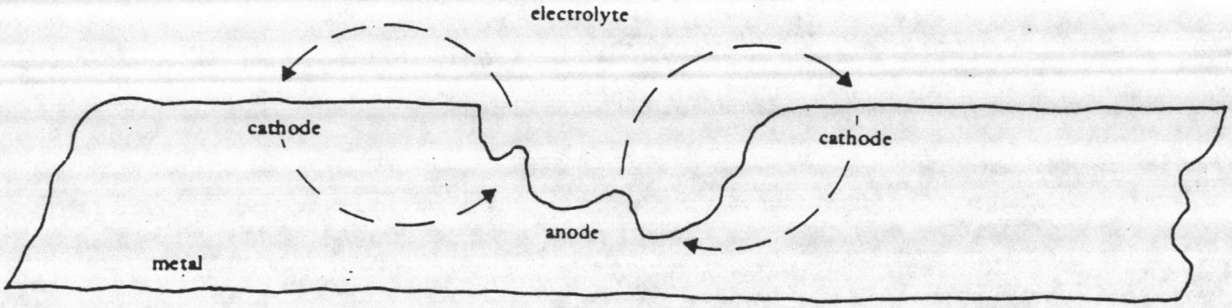

Figure A-1. Corrosion cell.

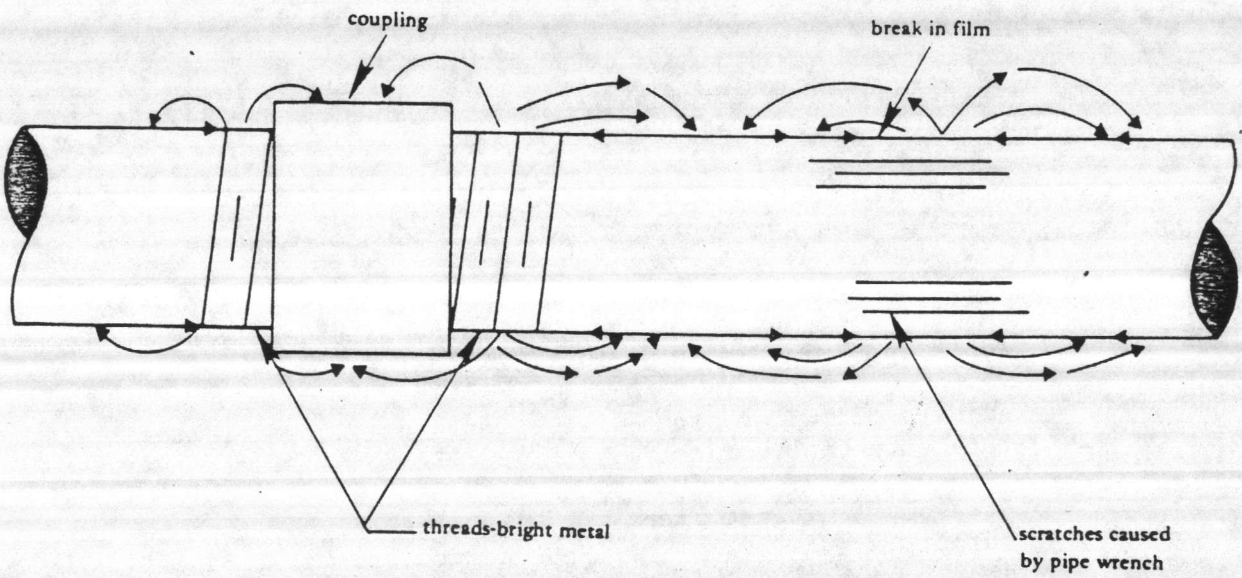

Figure A-2. Corrosion caused by dissimilar surface conditions.

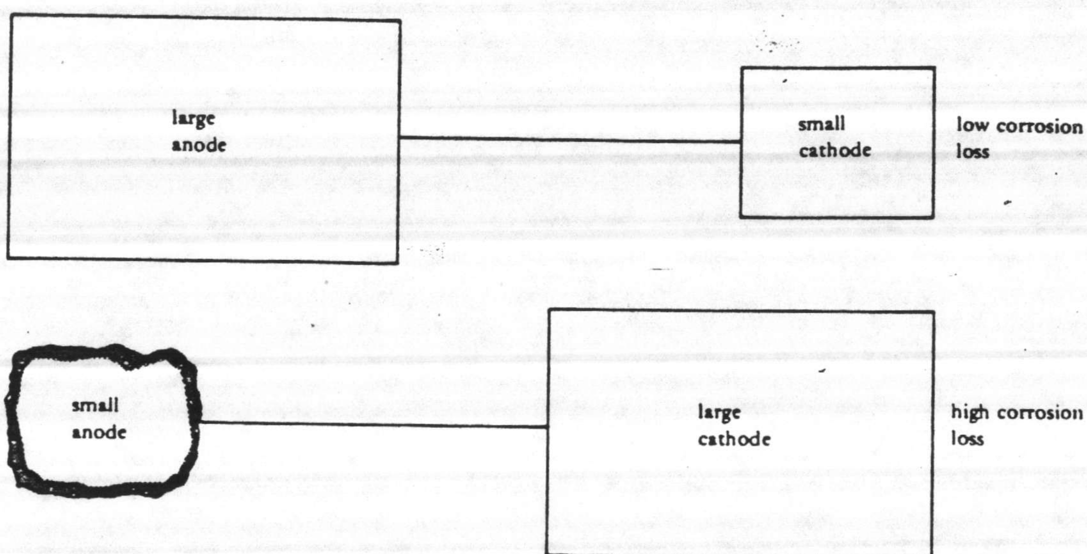

Figure A-3. Effect of relative anode/cathode areas on corrosion.

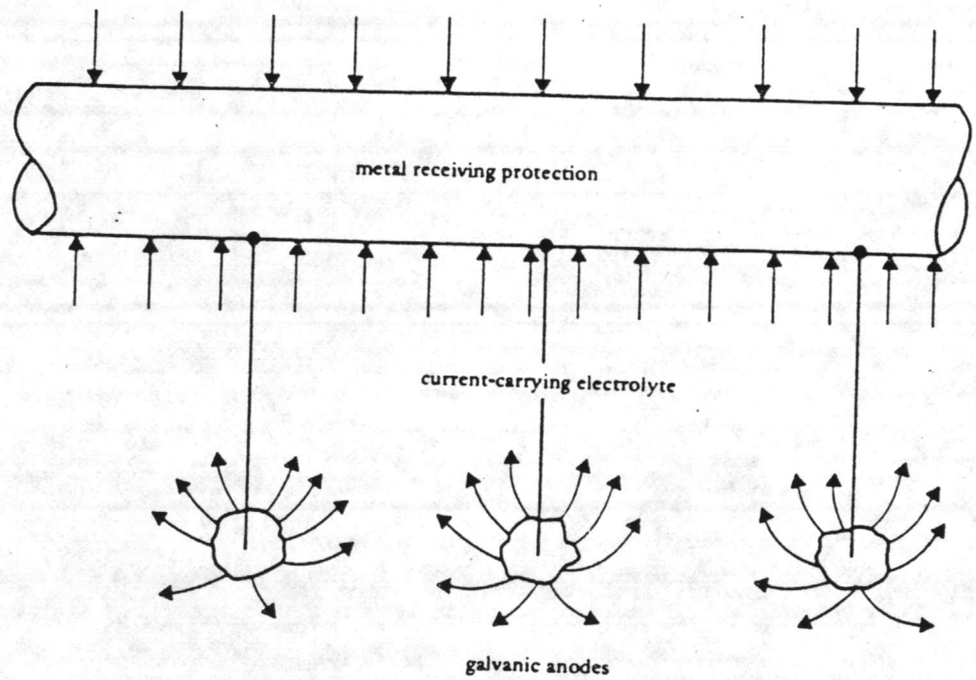

Figure A-4. Galvanic system of cathodic protection.

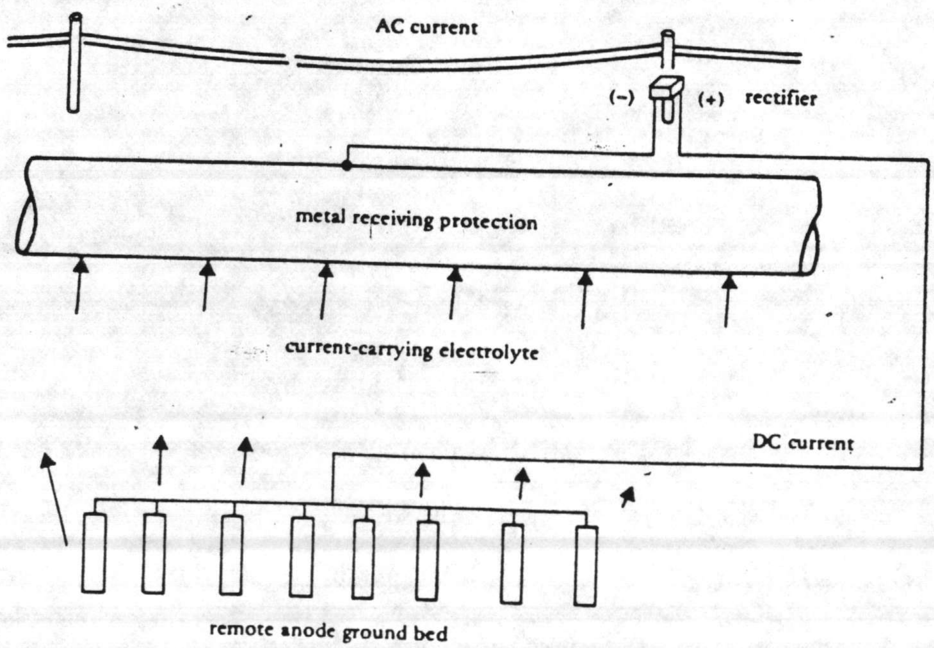

Figure A-5. Impressed current system of cathodic protection.

Techdata Sheet
Jul 1984 84-10

NAVFAC'S CORROSION MANAGEMENT PROGRAM

This Techdata Sheet is first in a series that outlines the forms and causes of corrosion and the methods that can be used to control corrosion at shore facilities. Increased emphasis on corrosion control at shore facilities is a means for reducing maintenance and repair costs and increasing the life of facilities.

Due to an increased awareness of the impact of corrosion damage not only on the cost of maintaining a Naval Shore Establishment but on the readiness of the Shore Establishment to provide continuous fleet support, the Naval Facilities Engineering Command has placed increased emphasis on corrosion control. NAVFAC's Corrosion Control Program has three main parts:

- Inspection to identify opportunities for the application of corrosion control.
- Application of appropriate corrosion control techniques.
- Continued maintenance and operation of corrosion control systems.

NAVFAC FUNCTIONS

NAVFAC Headquarters is responsible for the establishment of policy, guidelines and criteria for the corrosion control program, and overall coordination of the program.

EFD FUNCTIONS

Designated personnel at the Engineering Field Divisions are responsible for providing technical assistance to the activities in establishing and maintaining an effective corrosion control program and for monitoring the effectiveness of the activity's corrosion control programs.

ACTIVITY FUNCTIONS

Each activity is responsible for analyzing facilities, structures, and systems for signs of corrosion and for inspecting and maintaining corrosion control systems. Each activity is required to designate in writing a person responsible for the activity's corrosion control program. This person functions as a single point of contact for corrosion control and is responsible for activity corrosion control reviews, training in corrosion control for all activity personnel, maintenance and operation of cathodic protection systems, and other duties associated with improvements to the activity's corrosion control program.

NCEL FUNCTIONS

The Naval Civil Engineering Laboratory is responsible for research in support of the Program as well as direct support to activities in the investigation of corrosion problems.

ORGANIZATIONAL STRUCTURE OF CORROSION MANAGEMENT PROGRAM

The organizational structure and the personnel assigned to the various positions in the corrosion management program at the time this Techdata Sheet was written are given below:

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NAVFAC's policy regarding corrosion control at shore facilities has recently been updated by the issuance of NAVFACINST 11014.51. This instruction details the responsibilities of the various organizations involved in the program and outlines specific requirements for the application of corrosion control techniques. For example, application of coatings and cathodic protection to natural gas and POL pipelines and storage facilities is required by the instruction and by Public Law.

Technical guidance for the implementation of an effective corrosion control program is contained in several NAVFAC design and maintenance and operations manuals as listed below. These documents are being periodically updated to reflect the most current corrosion control technology. Technical guidance for specific corrosion problems is available from NAVFAC Headquarters, the local EFD, and NCEL.

NAVFAC TECHNICAL GUIDANCE FOR CORROSION CONTROL

Design Manuals

DM-3: Mechanical Engineering
DM-4.6: Electrical Engineering – Lightning and Cathodic Protection
DM-22: Petroleum Fuel Facilities
DM-25.6: General Criteria for Waterfront Construction

Operation and Maintenance Manuals

MO-104: Maintenance of Waterfront Facilities
MO-110: Paints and Protective Coatings
MO-230: Maintenance Manual – Petroleum Fuel Facilities
MO-306: Corrosion Prevention and Control
MO-307: Cathodic Protection System Maintenance (Pocket Manual)

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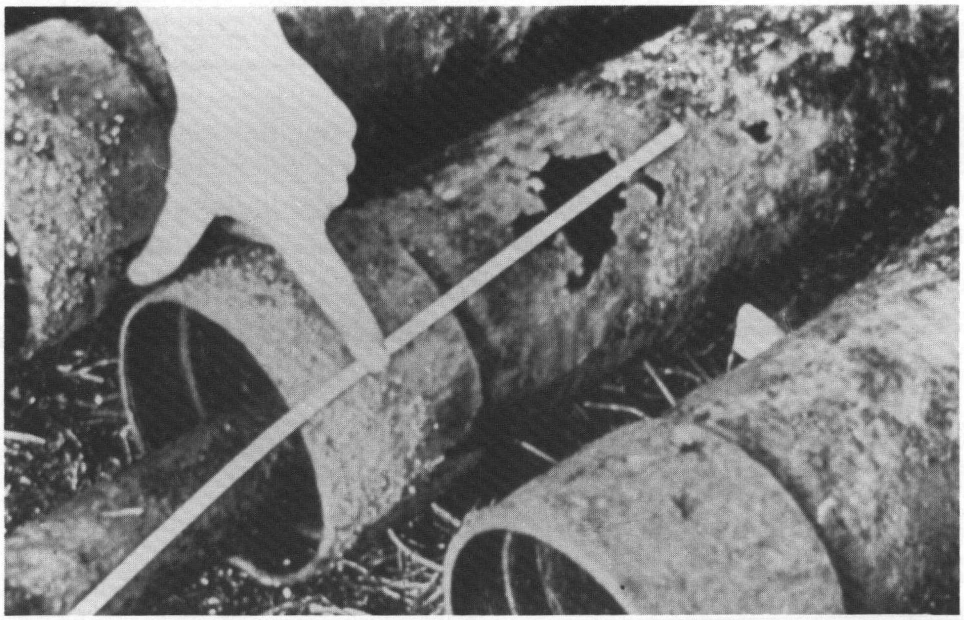
DOD-316

Techdata Sheet
Jan 1985 85-01

CORROSION CONTROL ASHORE

This Techdata Sheet is second in a series that outlines the forms and causes of corrosion and the methods that can be used to control corrosion at shore activities.



85% of the corrosion losses at Naval Shore Activities could be prevented by the application of currently available corrosion control technology. Corrosion is not only costly, but it can result in nonavailability of facilities required for critical Fleet Support.

Why is corrosion control important? An effective corrosion control program can save an activity both money and manpower as well as improving the reliability and safety of facilities as well as their appearance. Through effective corrosion control, environmental contamination and loss of fuel can also be reduced. An effective corrosion control program is not only beneficial, it is required. As outlined in NAVFACINST 11014.51, activities are required to perform specific functions related to corrosion control.

Why is knowledge of the forms, causes, and control of corrosion important to activity personnel? This knowledge will enable field personnel to better recognize corrosion problems and to better describe the problems so that corrective measures can be effectively applied. Personnel with a working knowledge of corrosion and corrosion control will be able to more effectively implement an improved corrosion control program.

Thirteen forms of corrosion attack and six forms of corrosion control will be described in the series. All of the forms of corrosion attack encountered at shore activities occur through electrochemical action. The corrosion process can be best understood in terms of the electrochemical cell.

The electrochemical cell, as shown in Figure 1, has four components: an anode, a cathode, an electrolyte, and an electron path.

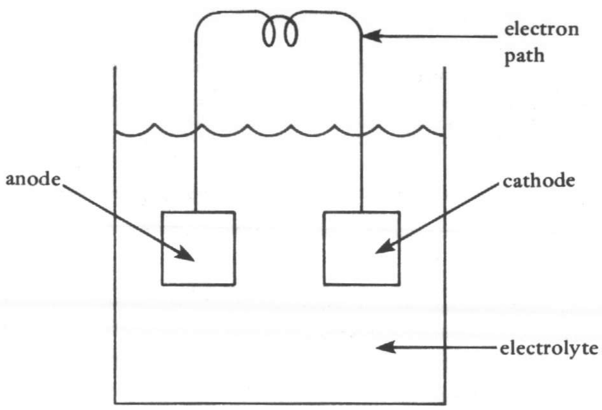


Figure 1. The electrochemical cell.

At the anode, a chemical reaction occurs where metal atoms give up electrons and enter the electrolyte (usually soil or water) as ions. Thus, the metal anode loses atoms and is said to "corrode."

The electrons from the corrosion of the anode flow through the electron path to the cathode (usually metal).

At the cathode, another chemical reaction occurs that uses up the electrons which were produced at the anode. Thus, there is no loss of metal (i.e., no corrosion) at the cathode.

The electrolyte serves both as a source of chemicals for the reactions and as a medium in which the flow of electrical current between the anode and the cathode can occur.

The electrochemical cell can either be destructive as in the case of corrosion or it can be made useful in the form of a battery. An ordinary dry cell battery is a common example of an electrochemical cell. As shown in Figure 2, a dry cell consists of a zinc case which serves as an anode; a carbon rod which serves as a cathode; and a solution of ammonium chloride that is absorbed on a powder to prevent spillage and serves as the electrolyte. The electron path is furnished by the external load, such as a lamp. Until the lamp is switched on completing the circuit no current flows and no electrochemical action occurs. When the lamp is switched on, the zinc corrodes, and the electrons flow through the lamp to the cathode where they are consumed in the cathodic reaction. Thus, in a dry cell, the corrosion of zinc is harnessed to provide energy.

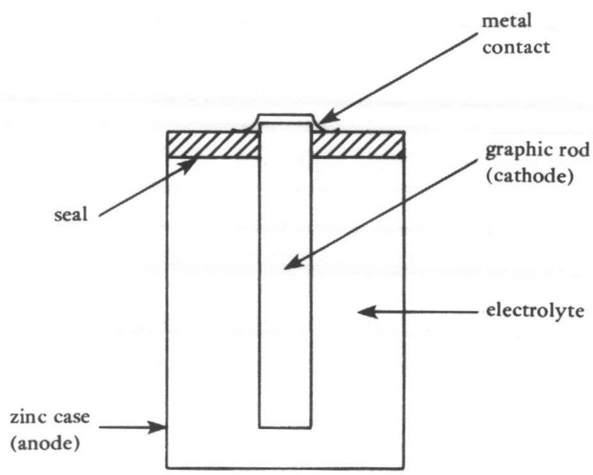


Figure 2. The dry cell battery.

In each of the forms of corrosive attack that will be described in this series of Techdata Sheets, an electrochemical cell will be identified, and the components described in detail. The forms of corrosion are:

- No Attack
- Uniform Corrosion
- Galvanic Corrosion
- Pitting
- Crevice Corrosion
- Dealloying
- Intergranular Corrosion
- Stress Corrosion Cracking

- Hydrogen Embrittlement
- Erosion Corrosion
- Cavitation Corrosion
- Corrosion Fatigue
- Fretting Corrosion

Corrosion control methods rely on the elimination of one or more of the components of an electrochemical cell to prevent corrosion. Just as in the dry cell when the external circuit is open, elimination of just one of the components of the electrochemical cell is sufficient to stop corrosion from occurring. The forms of corrosion control are:

- Protective Coatings
- Materials Selection
- Cathodic Protection
- Control of Environment
- Corrosion Allowance
- Design

CONTACT

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Techdata Sheet
Jan 1985 85-02

FORMS OF CORROSION I: UNIFORM CORROSION/NO ATTACK

This Techdata Sheet is third in a series that outlines the forms and causes of corrosion and the methods that can be used to control corrosion at shore activities.

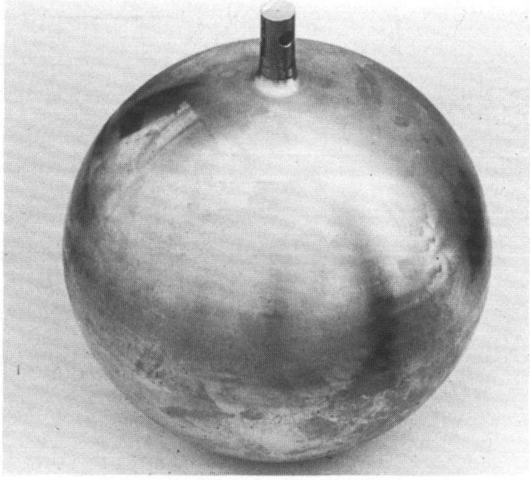

Figure 1.

Uniform corrosion and no corrosion are a matter of degree.

Two forms of corrosion are described in this Techdata Sheet: uniform corrosion and no corrosion. Uniform corrosion is defined as corrosion that occurs at substantially the same rate over the entire exposed surface of a metal. Rusting of steel in the atmosphere is usually uniform corrosion. Other examples of materials that normally corrode uniformly are the copper alloys and cast iron. When uniform corrosion occurs, very small electrochemical cells are established on the surface of the metal due to small differences in metal composition or the nonuniform nature of corrosion product layers that form on the surfaces. They are called local action cells, and because they depend on only very small local differences, they shift from place to place periodically. Thus, the corrosion that is occurring at only a few small sites at any given time is uniformly distributed over the entire surface, and a uniform reduction in cross section results.

This form of attack can be evaluated in terms of loss of thickness, usually expressed in mils (0.001 inch) per year. This value is often determined experimentally by measuring the weight loss of exposed specimens and calculating an equivalent uniform loss of thickness. While this is useful in evaluating uniform attack, it may not be applicable for evaluating other forms of attack.

The rate of attack experienced in a given environment varies greatly among various metals. The differences in corrosion rate may be due to a basic difference in chemical activity or they may be due to the formation of corrosion product layers which give some protection to the surface. The patina that forms on copper and the protective rust that forms on weathering steels are examples of the lowering of corrosion rates due to the formation of semi-protective corrosion product films. The films that protect materials such as stainless steels are much more protective in some cases and will be discussed in a subsequent techdata sheet in this series.

No corrosion is defined as a total lack of measureable interaction of a metal with its environment. It is essentially uniform attack with a zero rate. There are two basic reasons for this lack of interaction. The first is that the metal does not have a chemical tendency to react with the chemicals in its environment. Any possible reaction would result in an increase in chemical energy and, therefore, does not occur. (A chemical reaction that results in a gain of energy would be as surprising as a ball rolling uphill by itself.) Examples of metals that do not have a tendency to react because of energy considerations are gold and platinum.

The second reason that a metal may not interact with its environment is that some metals and alloys form very tightly adherent oxide films on their surfaces that are stable in particular environments. These films are invisible and are generally formed naturally during the manufacture of the metals. These films isolate the metal from its environment in the manner of a paint except, in this case, the coating is more stable and can repair itself if damaged. Examples of metals that have these protective films are the stainless steels, aluminum alloys, and titanium alloys. As shown in Figure 1, these metals can retain their original surface finish even after years of exposure. It is important to remember, however, that the films formed on each of the metals in this group may be unstable in certain environments. Where the films are unstable, they can break down, and localized attack will occur as will be described in a subsequent Techdata Sheet in this series.

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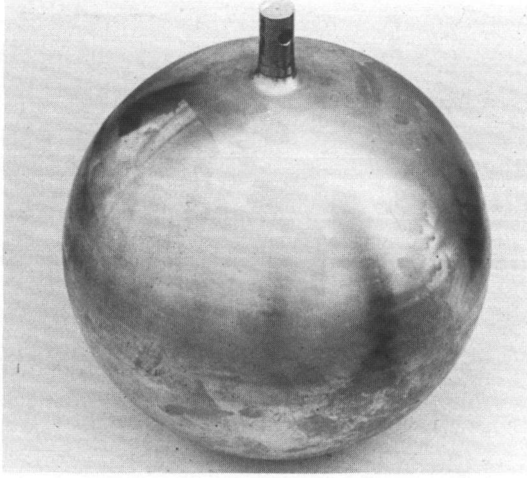

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This form of attack can be evaluated in terms of loss of thickness, usually expressed in mils (0.001 inch) per year. This value is often determined experimentally by measuring the weight loss of exposed specimens and calculating an equivalent uniform loss of thickness. While this is useful in evaluating uniform attack, it may not be applicable for evaluating other forms of attack.

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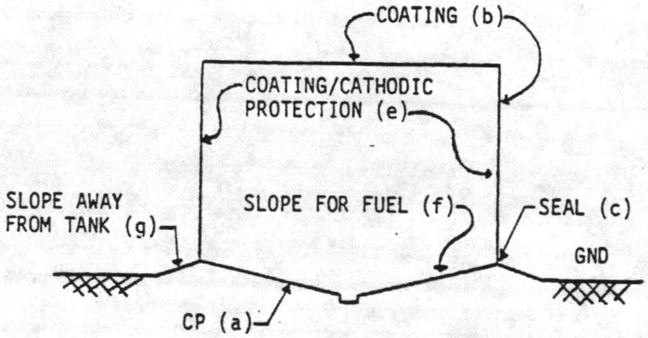
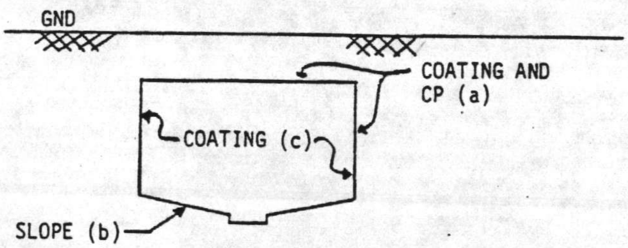
COMMON CORROSION PROTECTION FOR TYPICAL STRUCTURES

ABOVE GROUND TANKS



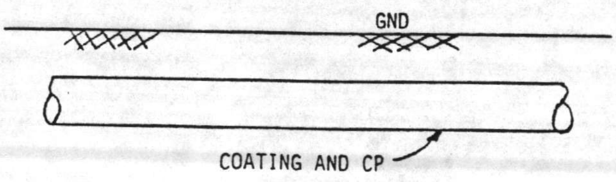
(a) PROTECT EXTERIOR BOTTOM WITH CATHODIC PROTECTION (CP)
(b) COAT EXTERIOR SIDES AND TOP
(c) SEAL JOINT BETWEEN TANK AND BASE
(d) COAT FUEL TANK INTERIOR AT LEAST UP TO 5' LINE
(e) COAT WATER TANK INTERIOR AND PROVIDE CATHODIC PROTECTION (CP)
(f) PROVIDE SUMP AND SLOPE BOTTOM OF FUEL TANK
(g) SLOPE TANK BASE AWAY FROM TANK

BURIED FUEL TANKS



(a) PROVIDE COATING AND CATHODIC PROTECTION FOR ALL EXTERIOR SURFACES
(b) SLOPE BOTTOM OF TANK
(c) COAT INTERIOR AT LEAST TO 5' LINE

UNDERGROUND DISTRIBUTION LINES

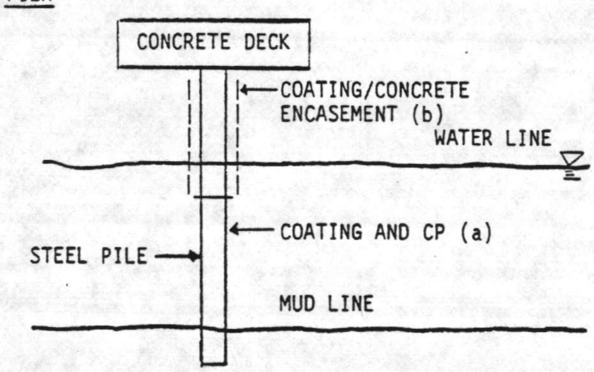


(a) PROVIDE COATING AND CATHODIC PROTECTION FOR EXTERIOR SURFACES (MANDATORY FOR FUEL LINES)

COMMON CORROSION PROTECTION FOR TYPICAL STRUCTURES

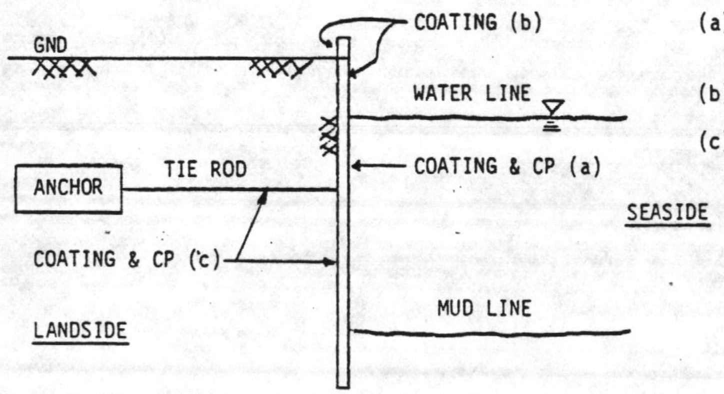
WATERFRONT STRUCTURE

PIER



(a) PROTECT STEEL BELOW WATER LINE WITH COATING AND CATHODIC PROTECTION (CP)
(b) PROTECT STEEL ABOVE WATER LINE WITH COATING AND/OR CONCRETE ENCASEMENT

SHEETPILE



(a) PROTECT SEASIDE STEEL BELOW WATER LINE WITH COATING AND CATHODIC PROTECTION (CP)
(b) PROTECT STEEL ABOVE WATER LINE WITH COATING
(c) PROTECT LANDSIDE STEEL WITH COATING AND CATHODIC PROTECTION (CP)

Table 1. Techniques for Controlling Corrosion of Facilities/Components at Shore Activities Having Major Corrosion Problems

Facilities/Components	Design	Coatings	Cathodic Protection	Water Treatment
	Corrosion Control Technique			
Fuel Storage Tanks	+	+	(+)	-
Water Storage Tanks	+	+	(+)	(+)
Fuel Distribution Systems	+	+	(+)	-
Water Distribution Systems	+	+	(+)	(+)
Hot Water/Steam Distribution System	+	+	-	(+)
Power/Steam Plants	+	+	-	(+)
Fleet Moorings	+	+	(+)	-
Waterfront Structures	+	+	(+)	-
Vehicles	+	+	-	(+)
Buildings/Housing	+	+	-	-
Air Conditioners	+	+	-	(+)
Antenna Towers	+	+	-	-
Cyclone Fencing	+	+	-	-
Electrical Conduct/Fixtures	+	+	-	-

\+ = effective use
(+) = effective use on part of structure (e.g., buried or immersed part)
\- = no effective use

TRAINING COURSES IN
CATHODIC PROTECTION/CORROSION CONTROL

1. U.S. Air Force courses

   a. "Corrosion Control Course"
      Air Force Institute of Technology
      Wright Paterson AFB
      Dayton, Ohio

      1. 2-week course
      2. Covers Cathodic Protection, coating and water treatment
      3. Contact MAJ. Mike Kaminskas telephone AV 785-4552

   b. "Cathodic Protection Maintenance"
      Sheppard AFB
      Wichita Falls, Texas

      1. 1-week, 3-day course
      2. Designed for technicians and maintenance electricians
      3. Contact Tom Lewicki (Kendall AFB) telephone AV 970-6352

2. National Association of Corrosion Engineers (NACE) Courses

   a. "Basic Corrosion Course"
   b. "Corrosion Prevention by Cathodic Protection"
   c. "Corrosion Prevention by Coatings"

3. University Courses

   a. "Appalachian Underground Corrosion Short Course"
      West Virginia University
      Morgantown, West Virginia 26506

      1. "Basic Corrosion Course"
      2. "Intermediate Corrosion Course" (Cathodic Protection)
      3. "Advanced Corrosion Course" (Cathodic Protection)
      4. Each course is 2 1/2 days
      5. Tuition: $60 per course
      6. Contact Ms. Lynne Thomas telephone (304)293-4211

   b. Perdue University
      Division of Conferences
      Stuart Center
      West Lafayette, Indiana 47907

      1. Two day Basic/Intermediate/Advanced program
      2. Contact (317)749-2533

Enclosure (10)

4. Industry Courses

a. Good-All Electric Company

1. "Cathodic Protection Rectifier Service School"

a. Three day course for technicians and electricians

2. Contact Mr. Forest French telephone (303)484-3080

b. M.C. Miller Company

1. "Short Course on Corrosion Testing"
2. Designed for engineers and technicians

5. Naval Civil Engineering Lab

a. "Corrosion Control Course"

1. Five day course given three times per year at selected EFD's is oriented towards public work personnel.

2. Course is expected to be given at LANTNAVFACENGCOM during FY-85/86 timeframe. Activities will be notified when scheduled.

6. Informal technical training by EFD personnel will be available to the activity upon request.

CATHODIC PROTECTION RECTIFIER REPORT

ACTIVITY	PERIOD ENDING

RECT. IDENT.	DATE	INSPECTOR INITIALS	TAP SETTING		A.C.		1ST D.C. OUTPUT		2ND D.C. OUTPUT		3RD D.C. OUTPUT		REMARKS
			COARSE	FINE	VOLT	AMP	VOLT	AMP	VOLT	AMP	VOLT	AMP	

ENCL (2) - (10)

GENERAL REMARKS

ENCL (2)

NAVFAC 9-11014/75 (5/83)

CATHODIC PROTECTION
RECTIFIER REPORT

ACTIVITY

PERIOD ENDING

RECT. IDENT.	DATE	INSPECTOR INITIALS	TAP SETTING		A.C.		1ST D.C. OUTPUT		2ND D.C. OUTPUT		3RD D.C. OUTPUT		REMARKS
			COARSE	FINE	VOLT	AMP	VOLT	AMP	VOLT	AMP	VOLT	AMP	

GENERAL REMARKS

ENCL (2)

RECTIFIER SETTINGS FOR MCB CAMP LEJEUNE

RECTIFIER ID	TANK BOWL CURRENT AVERAGE	TANK BOWL CURRENT MAX	RISER CURRENT AVERAGE	RISER CURRENT MAX
MCB CAMP LEJEUNE				
Tank # S-1000	1.0	1.25A	.4	.5
S-29	.65	.75	.015	.02
S-5	.6	.75	.12	.15
S-2323	.45	.55	.2	.25
S-830	1.0	1.2	.2	.25
SMP-4004	.58	.75	.18	.25
SST-40	.4	.5	.06	.07
SM-624	1.0	1.2	.6	.7
STC-606	3.0	3.6	1.8	2.2
STC-1070	4.4	5.3	1.7	2.0
SRR-44	.8	1.0	.32	.40
SBB-25	.75	.9	.3	.40
SBA-108	1.1	1.3	.6	.7
SFC-314	.75	.9	.35	.45
MCAS (H) NEW RIVER				
4130	4.1	5.0	.36	.45
AS-310	3.5	4.2	.29	.40

ENCLOSURE (3)

MCB CAMP LEJEUNE

ENGINEERING	EE - 1	LUTHER WORRIS
	ME - 1	TOM HAWKINS
	PWO - 1	CDR JOHANNISMINE
UTILITIES	- 1	(JR. JOHNSON)
FUEL DIVISION	- 1	
SUPPLY OFFICER	- 1	

Send all To

PUBLIC WORK DESIGN
BLDG 1005
MCB CAMP LEJEUNE
28542

ATTN: MR. LUTHER WORRIS

DEPARTMENT OF THE NAVY
ATLANTIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
NORFOLK, VIRGINIA

CONTRACT N62470-83-C-6148

CATHODIC PROTECTION SURVEY

at the

MARINE CORPS AIR STATION (HELICOPTER) NEW RIVER, NORTH CAROLINA

FINAL SUBMITTAL
December 14, 1984

prepared by

MENENDEZ-DONNELL & ASSOCIATES, INC.
Houston, Texas

in association with

GENERAL CATHODIC PROTECTION SERVICES, INC.
Houston, Texas

STATE OF TEXAS
CARLOS R. MENENDEZ
38755
REGISTERED PROFESSIONAL ENGINEER

Submitted by ______________________
Carlos R. Menendez, PE

REGISTERED PROFESSIONAL ENGINEER
RALPH W. STEPHENS
NO. CR723
CORROSION
STATE OF CALIFORNIA

Submitted by ______________________
Ralph W. Stephens, PE

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Table of Contents, continued.

SUMMARY

MENENDEZ-DONNELL & ASSOCIATES, INC., in association with its consultant, GENERAL CATHODIC PROTECTION SERVICES, INC., conducted a corrosion control survey of underground POL systems, water distribution system, elevated water tanks, and underground fuel tanks at the U.S. Marine Corps Air Station (Helicopter), New River, North Carolina, during October and November, 1984.

The corrosion survey included inspection and evaluation of any existing Cathodic Protection Systems, inspection and testing of underground steel structures, and recommendations for cathodic protection systems for proposed new construction.

Neither one of the two existing rectifier-groundbed installations on the POL Systems is in operation, and none of the POL facilities has cathodic protection.

The underground water distribution system has no cathodic protection, and it would be the most difficult and expensive of all base piping systems to protect since it consists primarily of bare or poorly coated cast iron pipe and it is not electrically continuous.

The two elevated water tanks were found to be under complete cathodic protection and with the internal coating in very good condition.

The soil resistivity tests showed a wide variation ranging from 2200 ohm-cm to 76,000 ohm-cm, however the low resistivity corrosive soils below 5,000 ohm-cm constitute only about 10% of the totals. Laboratory tests of soil samples showed the pH to be essentially neutral, but with a relatively high concentration of sulfates in some areas.

The two existing POL system rectifiers are not in use at the present time.

A new impressed current cathodic protection system should be provided for the tanks and existing steel piping at the Fuel Farm.

New sacrificial cathodic protection systems should be provided for the 20,000 gallon MOGAS Storage Tank at Building No. 142, and at Tanks A and B at the airfield.

Cathodic protection with sacrificial galvanic anodes is recommend for the underground water piping system in soils with resistivities of 5000 ohm-cm or less.

Cost estimates for the recommended work are:

1. Install 3 new rectifiers and groundbeds on tanks and piping at the Fuel Farm $76,670.00

2. Install magnesium anodes on three underground Fuel Storage Tanks $14,847.00

1.0 INTRODUCTION AND PURPOSE

This report contains all data acquired and conclusions reached as a result of the corrosion survey of underground POL system, utility systems, water distribution systems, elevated water tanks and underground fuel storage tanks at MCAS(H), New River, North Carolina.

Field work was started on October 1, 1984, and was completed by November 14, 1984. It consisted of collecting data and studying all existing cathodic protection systems, obtaining soil resistivity measurements, obtaining soil and water samples at selective locations, conducting continuity tests, obtaining structure-to-electrolyte potential measurements, and performing current requirement tests on line sections and selected underground storage tanks.

There are two existing abandoned impressed current cathodic protection systems on the POL facilities and two operational systems on the elevated water tanks. The two abandoned systems were installed to protect the original 5-inch diameter fuel line which has recently been replaced with a new fiberglass pipeline.

No cathodic protection exists for the following facilities:

1. The underground water distribution system.
2. Tanks and Piping at the Fuel Farm.

3. Day Tanks A & B (Jet Fuel).

4. MOGAS tank at Building No. 142.

5. Isolated underground fuel storage tanks.

All data obtained during this survey is included in the tables of Appendix B. Results and analysis of the data are included in Sections 2.1.4 and 2.2.3. The test procedures used during this survey are described in Section 2.1.3 and 2.2.2 of this report. The layouts of recommended cathodic protection systems and test points used during this survey are shown on Drawings enclosed in Appendix H of this report.

Photographs were taken of underground piping systems, rectifiers and various miscellaneous structures. These may be found in Appendix G.

The purposes of this survey were to evaluate the effectiveness of the existing cathodic protection systems; to determine any additional corrosion control requirements and to establish the most feasible type of additional cathodic protection systems, where required. In addition, supportive information, such as drawings, photographs, cost estimates and specific recommendations are supplied.

2.0 CORROSION CONTROL SURVEY

2.1 POL System

2.1.1 System Description

The POL system consists of fifteen tank car and truck unloading stations located West of the Fuel Farm, a truck loading station, thirteen storage tanks, refueling facilities and the connecting underground piping.

JP-5 Fuel is received at ten tank car stations and piped through a 6-inch pipeline to four underground storage tanks located at the Fuel Farm. One storage tank has a capacity of 120,000 gallons, a second tank has a capacity of 105,000 gallons, and each of the remaining two tanks has a capacity of 50,000 gallons.

AVGAS Fuel is received at five tank truck stations and stored in one 100,000 gallon underground steel tank, in one 50,000 gallon underground steel tank, and in two 10,000 gallon day tanks. All AVGAS storage tanks are located at the Fuel Farm.

MOGAS Fuel is stored in a 20,000 gallon underground tank located at Building No. 142.

JP-5 Fuel is transported in a 5-inch diameter underground pipeline to day tanks located near the airfield. All other fuels are transported by tank trucks.

2.1.2 Description and Evaluation of Existing Cathodic Protection Systems

Two existing impressed current cathodic protection systems, installed for cathodic protection of the underground POL piping at the station, were found to be out of service.

Rectifier No. 1, located at the Fuel Farm, is an air cooled unit manufactured by RIO Engineering Company, with a rated DC output of 36 volts and 20 amps. Information on the associated groundbed was not available. Field testing of this groundbed indicated that it has been depleted.

Rectifier No. 2, located at Building No. 4102 near the airfield, is an air cooled unit manufactured by GOODALL Electric Company, with a rated DC output of 40 volt and 20 amperes.

Rectifier No. 1 was tested with a temporary groundbed and seemed to be in good condition. Rectifier No. 2 was locked inside Building No. 4102 and unaccessible for inspection. It was originally installed to protect the 5-inch fuel pipeline between the Fuel Farm and the flight line, which has recently been replaced with a fiberglass pipeline. Therefore, this rectifier, if found to be in good working order, could be available for reuse at the Fuel Farm.

2.1.3 Test Procedures

Test procedures on the POL Systems included inspection of rectifiers; taking soil resistivity and structure to electrolyte potential measurements; conducting current requirement tests to determine design criteria for unprotected structures; and collecting soil and water samples for laboratory analysis.

2.1.3.1 Soil Resistivity Survey

Soil resistivity measurements were acquired at approximately 1000 ft. intervals along underground piping systems throughout the base to five feet average depths, using a Nilsson Model 400 soil resistivity meter and the "Wenner" four pin method. Measurements were also acquired to 10 ft., 15 ft., and 20 ft. depths near and around all

underground tanks within the POL system. The location of individual resistivity measurements are shown in Drawings No. 4001 through 4004, of Appendix H, and the soil resistivity data are presented in Table I, Appendix B.

2.1.3.2 Structure-to-Electrolyte Potential Survey

Structure-to-electrolyte potential measurements were taken on the POL system facilities, using a high impedance digital Beckman Model 3010 volt-ohm meter with reference to a saturated copper-copper sulfate half cell.

Potential measurements were taken at representative location including piping at pumphouses, and around storage tanks. For each measurement the reference electrode was placed directly over or as near as possible to the structure subject to test. All acquired potential measurement data are presented in Table III Appendix B. Test point locations are shown in drawing No. 4005.

2.1.3.3 Current Requirement Tests

Current requirement tests were conducted on various underground tanks to aid in determining the design criteria for POL structures not cathodically protected.

This procedure consisted of applying direct current to the structure under test using a 12-volt automobile battery as a temporary power source and 5/8-inch diameter by 5 ft. long steel rods driven into the ground for anodes. Whenever it was necessary, abandoned lines and metal post fences were used as temporary groundbeds to satisfy the high current demand.

Structure-to-electrolyte potential measurements were taken both before and during the application of the test current. The current output was determined by measuring the voltage drop across a calibrated 100mV-100A shunt. The current requirement was determined by the magnitude of potential shift between the native potential and the measured potential with current applied.

Generally accepted criteria for cathodic protection (NACE and DOT) used for this project, is a structure to electrolyte potential of minus 0.85 volts referred to a copper-copper sulfate half cell at all test points on the structure under test, or to achieve a minimum 300 millivolt negative potential shift with temporary current applied. Current requirements test data are shown in Tables III and IV, Appendix B.

2.1.3.4 Soil and Water Analysis

Soil samples were gathered from three distributed locations along the POL and water distribution systems. These samples were taken at depths from 18-inches to approximately 3 ft. A potable water sample was taken at the elevated water storage tank S-TC-606, located in Camp Geiger, which is connected to the water distribution system at the New River Air Station. Riverwater samples were gathered at the shoreline.

The soil samples were sealed in sterile Zip Lock plastic bags and the water samples were stored in sterile glass jars. They were submitted to SGS Control Services, Inc., Houston, Texas, for chemical analysis. Specific tests were for:

1. Electrical conductance
2. pH
3. Chlorides
4. Sulfates
5. Sodium
6. Phosphate
7. Carbonate

The locations from which the samples were acquired are shown on Drawings No. 4001, 4003 and 4004, and the chemical analysis data is presented in Appendix C.

2.1.3.5 Rectifier and Groundbed Investigation

The two rectifiers were visually inspected. Direct current and voltage outputs were measured with accurate portable test meters.

Rectifier No. 1 is located at the Fuel Farm and no information was available concerning its associated groundbed which appears to be depleted.

Rectifier No. 2 and its associated groundbed were installed to protect the original 5-inch underground steel pipeline between the Fuel Farm and the airfield. This pipeline has recently been replaced with a fiberglass pipeline.

All acquired test data are presented in Table VII, Appendix B, and in the discussion in Section 2.1.4.5.

2.1.4 Results and Analysis

2.1.4.1 Soil Resistivity Measurements

Soil resistivity is the reciprocal of soil conductance, and is usually expressed in ohm-cm. It is the most commonly used criterion for estimating the corrosivity of a given soil.

Soil resistivity is one of the primary factors affecting the flow of electrical currents associated with corrosion. A scale often used by corrosion engineers to classify the corrosivity of soil is as follows:

Soil Resistivity	Classification
Below 1000 ohm-cm	Extremely corrosive
1000 to 5000 ohm-cm	Very corrosive
5000 to 10,000 ohm-cm	Mildly corrosive
Above 10,000 ohm-cm	Progressively less corrosive

As shown on the data sheets in Table I, Appendix B, soil resistivity measurements near the POL facilities are generally above 5,000 ohm-cm, except in the area of Day Tanks A & B.

Serious corrosion can occur in higher resistivity soils where large variations in soil resistivity exist. These diverse resistivities indicate the existance of varying soil compositions, and such variations are conducive to concentration cell corrosion activity on the underground pipeline as it extends through the boundaries of the dissimilar soils. Corrosion is often encountered at such boundaries in the lower resistivity soils.

2.1.4.2 Structure to Electrolyte Potential Measurements

The level of cathodic protection of a given structure is evaluated by structure-to-electrolyte potential measurements. The most generally accepted criteria for cathodic protection of steel and cast iron structures buried or submerged in an electrolyte is a structure to electrolyte potential measurement of at least 0.85 volt negative to a saturated copper-copper sulfate half-cell, with DC current applied.

This is also one of the criteria established by NACE in its Recommended Practice R.P 01-69 (1983 REV); and it is one of the criteria specified by the U.S. Department of Transportation Office of Pipeline Safety Regulations for natural gas and hazardous liquid pipelines.

Analysis of the POL system structure-to-soil potential data in Table III, Appendix B, shows that none of the POL underground steel structures meet or exceed this criterion for cathodic protection.

A summary of structures not currently under the influence of cathodic protection is as follows:

1. Underground tanks and associated piping at the Fuel Farm.
2. Underground steel Day Tanks A and B.
3. Underground fuel tank at Building No. 142.
4. Miscellaneous underground tanks throughout the station.

2.1.4.3 Current Requirement Tests

Current requirement test data are presented in Tables III and IV, Appendix B. Impressed current testing of underground fuel storage tanks and associated piping at the Fuel Farm indicate that a minimum of 78 amperes, or a current density of approximately 0.0031 ampere per square foot of exterior tank wall, will be required for adequate protection.

This current requirement is somewhat higher than normal, however since it is a result of actual field test, it should be considered correct. Contributing factors to the high current requirement may be sulfate reducing bacteria, as indicated by the high (973 ppm) sulfate content of the soil or by electrical contacts with other structures, abandoned underground steel piping. See Sample S-6, Appendix C.

Another impressed current requirement test was conducted on the MOGAS Tank No. 143 located at the gas station Building No. 142. A current drain of 0.30 amperes, or a current density of 0.000222 amperes per square foot, was required to provide cathodic protection.

Calculations of tank surface areas and current densities can be found in Appendix D of the report. These calculations are based on tank dimensions and sizes provided us by station personnel. These current density values were used in the design calculations to estimate current requirements for other underground steel tanks of similar type and environment.

2.1.4.4 Soil and Water Analysis

Generally speaking, the three soil sample analyses appear

to be normal for this area except for relatively high concentrations of sulfates for Samples S-6 and S-8. These levels can be indicative of the presence of sulfate reducing bacteria which would result in higher current requirement for protecting underground steel structures.

The pH values of the soil samples range from a low of 5.8 for Sample S-7, up to a high of 6.9 for Sample S-8 which is essentially neutral. A pH of 5.8 is moderately acidic but presents no major problems for steel pipe or tanks.

Water sample W-5 taken from the New River shoreline has a high chloride content and a calculated resistivity of 65 ohm-cm. This is typical of brackish river water near the seacoast.

This water is very corrosive to any steel bulkheads that may be present. Impressed current cathodic protection would be effective in stopping much of this corrosion.

2.1.4.5 Rectifier and Groundbed Investigation

Inspection of Rectifier No. 1 at the Fuel Farm revealed that the rectifier is still in good working order. Testing revealed that the groundbed associated with this rectifier is already depleted. The rectifier was used as a supplemental DC current source during the impressed current

requirement testing of the Fuel Farm.

Access to Rectifier No. 2 was not possible because it was locked inside Building No. 4102. This rectifier is fairly new, installed in 1982, and should be found in good condition.

All rectifier test data are presented in Table VII, Appendix B.

2.2 Water Distribution System

2.2.1 System Description

The water distribution system consists of the treatment and filtration of raw water for domestic and industrial use and fire protection. Water wells scattered throughout the base constitute the primary source of raw water.

Raw water is piped to the water reservoir located at the filtration plant. The water is treated and filtered before being discharged to two elevated water tanks. The water is then piped from the individual storage facilities to station facilities.

2.2.2 Test Procedures

Test procedures on the water distribution system included soil resistivity measurements, pipe-to-soil potential measurements, electrical continuity tests, internal investigation of elevated water tanks, rectifier and anode inspection and electrolyte chemical analysis.

2.2.2.1 Soil Resistivity Survey

Soil resistivity measurements were obtained at approximately 1000 foot intervals along the right-of-way to 5 foot average depths. A Nilsson Model 400 soil resistivity meter and the Wenner four-pin method were utilized to obtain the measurements. This procedure involved driving four steel pins into the earth in a straight line, equally spaced, with the pin spacing equal to the depth to which the average soil resistivity was desired. The average soil resistivity measurement is a function of the voltage drop between the center pair of pins with current flowing between the two outside pins. Soil resistivity measurements obtained in the vicinity of the water distribution system are listed in Table I, of Appendix B.

All test locations are shown on drawings No. 4001 to 4004, Appendix H.

2.2.2.2 Structure-to-Soil Potential Survey

Structure-to-soil potential measurements were obtained on the firewater hydrants at representative locations throughout the station including the residential areas.

All potential measurements were obtained using a high input impedence voltmeter Beckman Model 3010 in conjunction with a copper-copper sulfate reference electrode placed directly over or as near as possible to the structure subject to test.

Potential measurements obtained on the water distribution system are listed in Table II of Appendix B.

All test point locations and their respective reference numbers are shown on Drawings No. 4001 to 4004, in Appendix H of this report.

2.2.2.3 Continuity Tests

Continuity tests were conducted at various locations throughout the station. A temporary groundbed consisting

of four 5 ft. long ground rods and an automobile battery were utilized. The test was performed by measuring pipe-to-soil potentials at one test point, then moving the negative connection to the next test point location with the reference electrode kept stationary. Electrical continuity between test points is indicated when both potential measurements are of the same magnitude. Electrical discontinuity between test points is indicated when potential measurements are of different magnitude.

Continuity test results are shown in Table V, Appendix B, and on Drawings No. 4001 thru 4004.

2.2.2.4 Elevated Water Storage Tank Inspection

Visual inspection of anode array, handhole inspection plates, conduits, wiring, rectifier unit and coating integrity was performed at two elevated water tanks. All observations were recorded in the field. Please refer to section 2.2.3 for Results and Analysis of this report.

2.2.2.5 Elevated Water Storage Tanks Potential Profile Survey

A potential profile of the submerged portion of each tank was conducted utilizing a standard copper-copper sulfate

reference electrode in conjunction with a high impedance Beckman voltmeter (Model 3010). The reference electrode was lowered to the bottom of each tank, and tank to water potentials were measured and recorded at 3 ft. intervals to the top. Data acquired are presented in Table VI, Appendix B of this report.

2.2.2.6 Tank Rectifiers and Anode Strings Investigations

Each rectifier was visually inspected and adjusted to provide optimum output in accordance with potential measurements taken inside the tank.

All rectifier meters were checked and calibrated as needed, using accurate portable test meters. All meters were left operating properly with no further repairs needed. Voltage measurements were taken directly off the DC stacks. Direct current outputs were determined by connecting the Beckman Voltmeter across the calibrated shunts. The meters were then adjusted to reflect the findings as accurately as possible.

Individual anode strings were inspected at each tank. Anode string current drains were measured and recorded using an SWAIN Model CP-3/4 inductive clip meter.

This data is presented in Table VI, Appendix B.

2.2.2.7 Water and Soil Analysis

A water sample was taken from one of the elevated water tanks at Camp Geiger, which are connected to the water system at the New River Air Station. This sample was placed in a sterile glass jar and submitted to SGS Control Services, Inc., Houston, Texas for analysis. Results are discussed in Section 2.2.3.5. Procedures for soil analysis are discussed in Section 2.1.3.4. Results of the analysis are presented in Appendix C.

2.2.3 Results and Analysis

2.2.3.1 Soil Resistivity Measurements

Soil resistivity is the reciprocal of soil conductance, and is usually expressed in ohm-cm. It is the most commonly used criterion for estimating the corrosivity of a given soil. The resistivity of a given soil is one of the primary factors affecting the flow of electrical currents associated with corrosion. A scale often used by corrosion engineers to classify the corrosivity of soil is as follows:

Soil Resistivity	Classification
Below 1000 ohm-cm	Extremely corrosive
1000 to 5000 ohm-cm	Very corrosive
5000 to 10,000 ohm-cm	Mildly corrosive
Above 10,000 ohm-cm	Progressively less corrosive

As shown on the data sheets in Table I, Appendix B, soil resistivity measurements are generally above 10,000 ohm-cm, with only 10% below 5,000 ohm-cm and 21% between 5,000 and 10,000 ohm-cm.

Serious corrosion can occur in higher resistivity soils where large variations in soil resistivity exist. These diverse resistivities indicate the existance of varying soil compositions, and such variations are conducive to concentration cell corrosion activity on the underground pipeline as it extends through the boundaries of the dissimilar soils. Corrosion is often encountered at such boundaries in the lower resistivity soils.

2.2.3.2 Structure to Soil Potential Measurements

The discussion of cathodic protection criteria presented in Section 2.1.4.2 is also applicable to the water distribution system.

Potential measurements obtained throughout the station's water lines were well below the negative 0.85 volt criteria, showing a lack of cathodic protection.

Structure to soil potentials taken along a bare underground pipeline undergoing active corrosion can range from a low of -0.1 to -0.3 volts in the most cathodic areas to a high approaching -0.8 volts in the most anodic areas.

Generally speaking, older pipelines that have developed a uniform rust film will have lower average potentials than newer lines that have not developed as much rust film and consequently have more bare steel in contact with the electrolyte. Potentials measured along the water system ranged from a low of -0.214 volts to a high of -0.566 volts indicating the probability of corrosion activity in some areas.

2.2.3.3 Continuity Tests

The data acquired from continuity tests at two locations (Table V, Appendix B) shows a lack of electrical continuity between joints on these sections of the water distribution system.

This is typical of mechanically coupled piping, and each joint must be electrically bonded before the system can be cathodically protected with an impressed current system. Sacrificial anodes could be installed on each joint without bonding.

2.2.3.4 Elevated Water Tanks

Normally a standard inspection of a cathodic protection system installed in a water tank encompasses an electrical potential profile on three foot intervals, a visual inspection of the anodes and associated hardware, and a calibration of the rectifier to provide optimum levels of protection to the interior submerged portions of the tank. In some cases where provisions have been made by providing access covers at designated cardinal points, additional electrical potential profiles are taken to correlate readings in order to assure proper current distribution.

Visual inspection of the coating is usually noted as an aid in the over-all analysis of the performance of the corrosion mitigation measures. Assuming anode array integrity, the quality of the coating will be the single greatest factor determining current distribution to the tank surfaces.

Analysis of current drain data from individual anode strings is helpful in verifying a functional anode array and to some extent, coating integrity. Since the anodes are wired in a series-parallel configuration with the same number and size of anodes in each string of a specific "ring", current drains should be essentially uniform if all anodes are intact and coating quality is uniform.

The findings of this report as they relate to the total current requirement to obtain effective protective levels of cathodic protection correlate coating integrity better than any other measurement used. Since in almost all cases we found that very little current was required to achieve adequate protective levels on the tank interiors, one can be reasonably assured that very little metal is exposed and the coatings are in fairly good condition.

Data acquired on elevated water tanks are presented in Table VI, Appendix B. Results and analysis on each tank are discussed in the following paragraphs.

Tank No. 4130

This rectifier (unit 9339) rated at 60 volts and 28 amperes was found operating on transformer tap setting A-2. The potential profile indicated adequate levels of protection, and anode current drains confirmed anode array integrity. The interior coating looked good, however, the manway was detached from its hinges and should be repaired. The anodes looked good and should last at least five more years. All associated hardware also looked in good condition.

Tank No. 310

This rectifier (unit 81C1216) rated at 40 volts and 12 amperes was found to be operating on tap setting A-2 providing 1.41 amps to the bowl and 0.29 amps to the riser at 3.5 volts. The potential profile indicated adequate levels of protection and anode current drains confirmed anode array integrity. The anodes appeared to be about 50% depleted and should not be expected to last more than three more years. The access handhole covers have missing bolts and bars in their square cover assemblies. The interior coating appeared to be in good condition.

2.2.3.5 Water Samples Analysis

The analysis of the treated water sample W-12 may be found in Appendix C, with the analysis of all other samples tested.

The calculated resistivity of this sample is 1355 ohm-cm which is considered low. This sample has a moderate chloride and low sulfate content; a slightly basic (alkaline) pH of 8.6; and should be considered corrosive.

Based on this analysis, cathodic protection for the internal surfaces of the water storage tanks is needed to mitigate corrosion.

2.3 Evaluation of Activity Corrosion Control Program

2.3.1 Operating and Maintenance Practices

As part of the corrosion study, station corrosion control maintenance practices were investigated. Information gathered from station personnel indicated that limited maintenance of the cathodic protection systems had been conducted.

Personnel involved with the fuel system were aware of the use of cathodic protection on the POL facilities, however, their knowledge of monitoring and field testing was limited.

A monthly inspection of the elevated water tank rectifiers is being performed by the Maintenance Department. It consists of a visual inspection, and reading and recording the DC output levels of each rectifier.

We believe that the present station personnel are very capable of incorporating a successful corrosion control maintenance program with the aid of corrosion control short courses, in-field supervised training and proper cathodic protection testing equipment.

3.0 RECOMMENDATIONS

3.1 POL System

Based on the results of this survey, we recommend the following:

1. Utilize the existing 36 volt, 20 ampere rectifier located at the Fuel Farm in conjunction with a new distributed groundbed consisting of at least twenty 3-inch diameter by 60 inches long, specially treated, graphite anodes, or equal.

2. Relocate Rectifier No. 2, rated at 40 volt, 20 ampere to the Fuel Farm and install it in conjunction with a new distributed groundbed containing a minimum of twenty 3-inch diameter by 60 inches long specially treated graphite anodes, or equal.

3. Install an 80 volt, 50 ampere rectifier and a new distributed groundbed consisting of a minimum of forty 3-inch by 60 inches specially treated graphite anodes, to supplement above mentioned groundbeds, for cathodic protection of the Fuel Farm.

4. Because of the existing high soil resistivities, it is recommended that all new anodes be installed in 12-inch diameter by 15-foot deep augered holes containing at least ten feet of low resistivity calcined fluid petroleum coke.

5. Install nine GALVOMAG Type 20D2 prepackaged magnesium anodes and one Flush Fink test station for cathodic protection of the MOGAS tank at Building No. 142

6. Install eight GALVOMAG Type 32D3 prepackaged magnesium anodes and two Flush Fink test stations for cathodic protection of Tanks A & B at the airfield.

3.2 Water Distribution System

Recommendations for the water distribution system are as follows:

1. Inspect elevated water tanks and rectifiers on a monthly basis in order to insure uninterrupted protection. Maintain current outputs as listed on Table VI, Appendix B unless a change in current requirements is indicated by subsequent cathodic protection surveys.

2. Install sacrificial high potential magnesium anodes on individual underground pipe joints in all areas where soil resistivities are below 5000 ohm-cm as described in Appendix D.

   As an alternate, all pipe joints falling within, and adjacent to areas with soils below 5000 ohm-cm could be electrically bonded and cathodically protected with impressed current systems. However, both initial costs and maintenance costs will exceed the cost of sacrificial anode systems and chances of stray current corrosion will be greatly increased.

3. In areas where cathodic protection is to be considered, electrically bond all cast iron pipe joints exposed by maintenance or construction activities. Bonds should be minimum No. 8 AWG copper wire or equivalent copper straps. Electrical continuity of underground piping cathodically protected with sacrificial anodes is desirable since it equalizes structure-to-soil potentials and permits monitoring the effectiveness of the system without the need to contact each pipe joint.

4. Install two-wire potential test stations at preselected locations to monitor the level of cathodic protection and anode outputs.

3.3 Activity Corrosion Control Program

3.3.1 Recommendations for Maintenance Practices

The following recommendations are aimed towards aiding base personnel in developing a total corrosion control preventive maintenance program.

It is recommended that the responsibility for monitoring and maintaining of cathodic protection systems, once they are installed, be assigned to competent permanent personnel with either experience in cathodic protection or with technical backgrounds to facilitate their training as described in Section 3.3.2.

The present policy of monthly rectifier inspections should be continued. These inspections should include as a minimum, reading and recording the D.C. output levels as indicated by the panel meters, and a visual inspection of all major rectifier components. Output levels should be promptly compared with those recorded from previous inspections and any significant changes investigated. In

addition, other system components should be observed and repairs effected whenever needed.

It is further recommended that a comprehensive system-wide corrosion control survey be conducted on an annual basis by an experienced corrosion engineer. The corrosion engineer accomplishing this survey should be accompanied by the station personnel responsible for corrosion control monitoring since this would constitute valuable field experience.

Drawings provided in this report showing the location of structure-to-electrolyte potential measurements should be used as a guide in the annual survey.

It is recommended that all data pertaining to the corrosion control program be recorded for future reference. The corrosion control records program should include investigating and recording all leaks that occur. Bell hole inspections should be made and a leak report form completed, detailing the type of leak, repairs made, and their locations.

For further details in establishing a corrosion control program and for additional information on maintenance programs, refer to NAVFAC INST 11014.51 of 19 October

1983 and MO-307 of May 1981; "Cathodic Protection Systems Maintenance".

Additional assistance in establishing a corrosion control program may be obtained from the Atlantic Division, Naval Facilities Engineering Command corrosion engineer.

3.3.2 Recommendations For Training Program

The routine monitoring of cathodic protection systems is essential to maintaining adequate protection against corrosion attack in soil and water electrolytes. It is recommended that a training program involving station personnel be instituted. This program would involve the training of personnel, in both theory of cathodic protection and field training.

The following corrosion control courses are recommended for base personnel.

National Association of Corrosion Engineers (NACE) Courses:

a. "Basic Corrosion Course".

b. "Corrosion Prevention by Cathodic Protection".

c. "Corrosion Prevention by Coatings".

We recommend these courses for learning the basic theory of corrosion and methods and practices used in cathodic protection. These courses can be taken by "Home Study" with personnel working at their own pace. The courses are designed for people with no prior knowledge of cathodic protection. Further information can be obtained by writing to NACE Education Department, P. O. Box 218340, Houston, Texas 77218; or by telephoning (713) 492-0535.

Another excellent training course is the "Cathodic Protection Rectifier School" offered by Good-All Electric, Inc.

This short three-day course is designed to familiarize students with cathodic protection rectifiers. Basic theory is discussed as well as field troubleshooting. Additional information can be obtained by writing to Good-All Electric, Inc., Box 508, Ogallala, Nebraska 69153, or by calling (308) 284-4081.

A number of corrosion control short courses are offered every year by several universities and sections of NACE throughout the United States.

One of the better ones is held each May in Morgantown, West Virginia; and another excellent course is offered

each September at the University of Oklahoma, Norman, Oklahoma. These three-day seminars are taught by professional instructors and include practical field demonstrations. Details of these courses can be obtained by contacting the University of West Virginia or the University of Oklahoma, respectively.

It is also recommended that an experienced corrosion engineer accredited by NACE as corrosion specialist conduct an on-site training seminar with station personnel. By this seminar, station personnel can obtain practical training on the testing procedures used for conducting routine maintenance of cathodic protection systems. This training would include taking structure-to-electrolyte potentials, soil resistivity measurements and the basics of rectifier inspection techniques.

Additional details on training courses offered by the Atlantic Division, Naval Facilities Engineering Command, the Naval Civil Engineering Laboratory, the U.S. Air Force Institute of Technology and commercial firms may be obtained by contacting the Atlantic Division, Naval Facilities Engineering Command corrosion engineer.

4.0 ECONOMIC EVALUATIONS

4.1 Fuel Farm

1. Based on detailed Cost Estimates shown on Appendix E the initial cathodic protection investment = $59,390.

2. Investment = Initial Cost x Capital Recovery Factor thus on the basis of 12 % for 20 years, the annual cost to own becomes:

$59,390 x 0.1175 = $6,978.

Maximum Power Cost:

$$\text{AC Watts} = \frac{\text{DC Watts}}{\text{conversion efficiency}}$$

Recommended Rectifiers (80 V-50A), (36V-20A), (40V-20A)

$$\text{AC KW} = \frac{(80x50)+(36x20)+(40x20)}{.68} x \frac{1KW}{1000W} = 11.47KW$$

Annual Power Bill:

$$11.47 \text{ KW} \times \frac{8760 \text{ hr}}{\text{yr}} \times \frac{0.06}{\text{KW-h}} = \$ 6,029.00$$

Estimated Annual Cost=6,029 + 6978 = $13,007.

3. Repairs and replacements on the POL system have been made in the past, but exact cost were not available.

4. The investment involved in the tanks and associated equipment, along with their importance to operations, justify the recommended cathodic protection system.

5. DOT Standards require all underground fuel gas storage and piping to be provided with cathodic protection.

4.2 Underground Fuel Storage Tanks

1. Based on detailed Cost Estimates shown on Appendix E, the initial Cathodic Protection Investment = $14,847

2. Investment = Initial Cost x Capital Recovery Factor. Thus on ths basis of 12% for 20 years, the annual cost to own becomes:

   $14,847 x .1175 = $1,759.

3. Leaks have been reported, repairs and replacements on several storage tanks have been made. Day Tanks A and B were replaced once. Day Tanks C and D were replaced with 2 new fiberglass units. The 5"

pipeline between the Fuel Farm and above tanks is being replaced with a new fiberglass pipeline.

4. Replacement and maintenance cost have been high enough to justify cathodic protection of the tanks.

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Appendices

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APPENDIX A

INVENTORY

APPENDIX A

NEW RIVER, NORTH CAROLINA

POL SYSTEM INVENTORY OF PRODUCT STORAGE FACILITIES

Product	Tank No.	Capacity	Type
JP-5	137	50,000 gal	Underground steel
JP-5	150	105,000 gal	Underground steel
JP-5	151	50,000 gal	Underground steel
JP-5	154	120,000 gal	Underground steel
JP-5	Day Tank A	20,000 gal	Underground steel
JP-5	Day Tank B	20,000 gal	Underground steel
JP-5	Day Tank C	20,000 gal	Underground fiberglass
JP-5	Day Tank D	20,000 gal	Underground fiberglass
Avgas	136	100,000 gal	Underground steel
Avgas	137	50,000 gal	Underground steel
Avgas	138	50,000 gal	Underground steel
Avgas	140	20,000 gal	Underground steel
Avgas	141	20,000 gal	Underground steel

POL PIPING OF INVENTORY

Product	Description	Type
Avgas	Piping at Fuel Farm	Underground steel
JP-5	Piping at Fuel Farm	Underground steel
JP-5	5" pipeline between fuel farm and airfield	Underground fiberglass

WATER DISTRIBUTION INVENTORY OF STORAGE FACILITIES

Description	Capacity	Type
Tank No. 4130	350,000 gal.	Elevated steel
Tank No. 310	350,000 gal.	Elevated steel

APPENDIX B

DATA SHEETS

M D A MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

SOIL RESISTIVITY MEASUREMENTS

STRUCTURE:

DATE 10/26/84 ENGINEER J.A.M. TABLE I PAGE 1 OF 7

TEST NO.	TEST LOCATION	AVERAGE DEPTH	READING	MULTI.	* FACTOR	OHM-CM
1	FLOUNDER RD.	5'-3"	6.0	1.0	1000	6000
	↓	10'-6"	3.0	↓	2000	6000
	↓	15'-9"	2.8	↓	3000	8400
	↓	21'-0"	1.2	↓	4000	4800
2	FLOUNDER RD., AT BLDG. 710	5'-3"	5.4	↓	1000	5400
3	AT BLDG. 705	↓	2.4	↓	↓	2400
4	FLOUNDER RD.	↓	6.8	↓	↓	6800
5	PARKING AT BLDG. 702	↓	6.0	10.0	↓	60,000
6	FLOUNDER RD.	↓	2.5	↓	↓	25,000
7	CURTISS RD.	↓	3.5	↓	↓	35,000
	↓	10'-6"	7.3	1.0	2000	14,600
	↓	15'-9"	4.2	↓	3000	12,600
	↓	21'-0"	3.0	↓	4000	12,000
8	↓	5'-3"	4.3	↓	1000	4300
9	↓	↓	2.3	10.0	↓	23,000
10	↓	↓	1.6	10.0	↓	16,000
	↓	10'-6"	6.8	1.0	2000	13,600
	↓	15'-9"	5.9	↓	3000	17,700
	↓	21'-0"	3.4	↓	4000	13,600
11	AT BLDG. 804	5'-3"	6.6	↓	1000	6600

NOTES : Nilsson 400 meter & the 4Pin method were used to obtain soil resistivity measurements.

* The "K" factor is the Average depth or pin spacing in feet X a meter constant of 191.5

MDA MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N. C.

SOIL RESISTIVITY MEASUREMENTS

STRUCTURE:

DATE 10/26/84 ENGINEER J.A.M. TABLE I PAGE 2 OF 7

TEST NO.	TEST LOCATION	AVERAGE DEPTH	READING	MULTI.	FACTOR	OHM-CM
12	LONGSTAFF ST.	5'-3"	1.7	10.0	1000	17,000
	↓	10'-6"	2.4	↓	2000	48,000
	↓	15'-9"	3.9	↓	3000	117,000
	↓	21'-0"	5.7	↓	4000	228,000
13	↓	5'-3"	7.0	1.0	1000	7000
14	↓	↓	7.7	↓	↓	7700
15	AT BLDG. 849	↓	2.2	↓	↓	2200
16	STAFF NCO CLUB BLDG.	↓	1.1	10.0	↓	11,000
17	LONGSTAFF ST.	↓	6.4	1.0	↓	6400
	↓	10'-6"	4.9	↓	2000	9800
	↓	15'-9"	3.4	↓	3000	10,200
	↓	21'-0"	2.3	↓	4000	9200
18	TROTTER ST.	5'-3"	1.2	10.0	1000	12,000
19	LONGSTAFF ST.	↓	6.6	↓	↓	66,000
20	↓	↓	6.5	↓	↓	65,000
21	↓	↓	2.7	↓	↓	27,000
	↓	10'-6"	1.5	↓	2000	30,000
	↓	15'-9"	1.1	↓	3000	33,000
	↓	21'-0"	5.5	1.0	4000	22,000
22	↓	5'-3"	2.6	1.0	1000	2600
23	NORDELL ST.	↓	2.3	10.0	↓	23,000
24	KELLEY ST.	↓	1.5	100.0	↓	150,000
25	AT BLDG. 2800	↓	4.7	10.0	↓	47,000
26	SAND ST.	↓	3.7	10.0	↓	37,000

M D A MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N. C.

SOIL RESISTIVITY MEASUREMENTS

STRUCTURE:

DATE 10/26/84 ENGINEER J.A.M. TABLE I PAGE 3 OF 7

TEST NO.	TEST LOCATION	AVERAGE DEPTH	READING	MULTI.	FACTOR	OHM-CM
26	SAND ST.	10'-6"	1.3	10.0	2000	26,000
	↓	15'-9"	1.0	10.0	3000	30,000
	↓	21'-0"	6.9	1.0	4000	27,600
27	AT BLDG. 2860	5'-3"	2.1	10.0	1000	21,000
28	PERIMETER ROAD	5'-3"	2.0	↓	1000	20,000
	↓	10'-6"	1.2	↓	2000	24,000
	↓	15'-9"	7.5	1.0	3000	22,500
	↓	21'-0"	7.5	1.0	4000	30,000
29	↓	5'-3"	3.5	10.0	1000	35,000
30	↓	↓	4.4	↓	↓	44,000
31	↓	↓	1.8	↓	↓	18,000
	↓	10'-6"	1.0	↓	2000	20,000
	↓	15'-9"	5.1	1.0	3000	15,300
	↓	21'-0"	3.8	1.0	4000	15,200
32	AT BLDG. 3502	5'-3"	1.5	10.0	1000	15,000
33	AT BLDG. 3504	↓	9.2	1.0	↓	9200
34	AT TANK 3500 & 3522	↓	4.7	10.0	↓	47,000
	↓	10'-6"	1.6	↓	2000	32,000
	↓	15'-9"	1.3	↓	3000	39,000
	↓	21'-0"	8.3	1.0	4000	33,200
35	CURTISS RD.	5'-3"	2.7	10.0	1000	27,000
36	↓	↓	5.0	↓	↓	50,000
37	↓	↓	2.5	↓	↓	25,000
38	↓	↓	3.5	↓	↓	35,000

M D A MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N. C.

SOIL RESISTIVITY MEASUREMENTS

STRUCTURE:

DATE 10/26/84 ENGINEER J.A.M. TABLE I PAGE 4 OF 7

TEST NO.	TEST LOCATION	AVERAGE DEPTH	READING	MULTI.	FACTOR	OHM-CM
39	AT BLDG. 2002	5'-3"	9.9	1.0	1000	9900
40	AT BLDG. 840		7.8	1.0		7800
41	CURTISS RD.		1.4	10.0		14,000
42	GOODEN ST.		1.1			11,000
43	AT BLDG. 827		1.2			12,000
44	CURTISS RD		1.2			12,000
45	GRAVEL RD.		2.9			29,000
46			2.6			26,000
47			4.8			48,000
48			2.7			27,000
49			1.3			13,000
50			2.9			29,000
51			2.0			20,000
52			10.0			100,000
53	, AT BLDG.3620		5.9			59,000
54	ASPHALT RD.		4.7			47,000
55			1.8			18,000
56			8.8			88,000
57			8.4	1.0		8400
58			1.8	10.0		18,000
59			4.8			48,000
60	PARKING AREA		2.1			21,000
61			5.7	1.0		5700
62			1.6	10.0		16,000

M D A MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N. C.

SOIL RESISTIVITY MEASUREMENTS

STRUCTURE:

DATE 10/26/84 ENGINEER J.A.M. TABLE I PAGE 5 OF 7

TEST NO.	TEST LOCATION	AVERAGE DEPTH	READING	MULTI.	FACTOR	OHM-CM
63	PARKING AREA	5'-3"	1.0	10.0	1000	10,000
64	AT BLDG. 4122		2.9	10.0		29,000
65	AT BLDG. 4108		8.1	1.0		8100
66	↓		1.4	1.0		1400
67	WHITE ST.		3.6	10.0		36,000
68	AT BLDG. 4100		1.0			10,000
69	AT BLDG. 4110		2.1			21,000
70	PARKING APRON		1.0	↓		10,000
71	WHITE ST.		5.1	1.0		5100
72	CAMPBELL, AT BLDG. 143		1.4	10.0		14,000
73	AT BLDG. 518		1.1			11,000
74	AT BLDG. 130		2.4			24,000
75	WHITE ST.		1.2			12,000
76	AT BLDG. 414		1.1			11,000
77	CAMPBELL ST.		1.4	↓		14,000
78	PARKING APRON		5.6	1.0		5600
79	AT BLDG. 425		1.3	10.0		13,000
80	Mc AVOY, AT BLDG. 230		6.6			66,000
81	CURTISS RD.		2.8			28,000
82	AGAN ST.		3.6			36,000
83			3.1			31,000
84	↓		1.7			17,000
85	SUMNER ST.		1.1	↓		11,000
86	Mc AVOY ST.	↓	4.9	1.0	↓	4900

M D A MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N. C.

SOIL RESISTIVITY MEASUREMENTS

STRUCTURE:

DATE 10/27/84 **ENGINEER** J.A.M. **TABLE** I **PAGE** 6 **OF** 7

TEST NO.	TEST LOCATION	AVERAGE DEPTH	READING	MULTI.	FACTOR	OHM-CM
87	McAVOY ST.	5'-3"	8.9	10.0	1000	89,000
88			4.8			48,000
89	↓		6.5			65,000
90	GRIER ST.		3.4			34,000
91	CRAWFORD ST.		2.0			20,000
92	COMPTON ST.		3.7			37,000
93	BAXTER ST.		1.7			17,000
94			2.3	↓		23,000
95	↓		2.7	1.0		2700
96	JONES ST.		2.6	1.0		2600
97	HARDIN ST.		1.4	10.0		14,000
98	AT TANK A & B	↓	8.6	1.0	↓	8600
		10'-6"	4.9	0.1	2000	980
	↓	15'-9"	5.0	0.1	3000	1500
99	AT TANK C & D	5'-3"	3.6	10.0	1000	36,000
		10'-6"	4.9	1.0	2000	9800
	↓	15'-9"	4.9	1.0	3000	14,700
100	CURTISS RD. & WHITE ST.	5'-3"	2.1	10.0	1000	21,000
		10'-6"	1.1	10.0	2000	22,000
	↓	15'-9"	7.0	1.0	3000	21,000
101	WHITE RD.	5'-3"	1.1	10.0	1000	11,000
102			6.1	1.0		6100
103	↓		1.7	10.0		17,000
104	AT BLDG. 124	↓	1.7	10.0	↓	17,000

MDA MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

SOIL RESISTIVITY MEASUREMENTS

STRUCTURE:

DATE 10/27/84 ENGINEER J.A.M. TABLE I

TEST NO.	TEST LOCATION	AVERAGE DEPTH	READING	MULTI.	FACTOR	OHM-CM
105	AT BLDG. 209	5'-3"	1.2	10.0	1000	12,000
106	AT BLDG. 205	↓	1.1	↓	↓	11,000
107	AT BLDG. 240		1.0			10,000
108	AT BLDG. 236		1.7			17,000
	↓	10'-6"	4.9	1.0	2000	9800
		15'-9"	4.9	1.0	3000	14,700
109	AT BLDG. 213	5'-3"	1.4	10.0	1000	14,000
110	WHITE RD.	↓	1.2	10.0	↓	12,000
111	FUEL FARM, AT TANKS 154 & 136		3.1	1.0		3100
	↓	10'-6"	4.8	↓	2000	9600
		15'-9"	4.7		3000	14,100
112	FUEL FARM, AT TANK 138	5'-3"	7.7		1000	7700
	↓	10'-6"	1.3	10.0	2000	26,000
		15'-9"	1.1	1.0	3000	3300
113	CANAL ST., AT BLDG. 4155	5'-3"	3.8	1.0	1000	3800
114	CANAL ST.	↓	1.0	10.0	↓	10,000
115	BANCROFT ST.		2.0	10.0		20,000

M D A MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

STRUCTURE - TO - ELECTROLYTE POTENTIAL MEASUREMENT

STRUCTURE: WATER DISTRIBUTION SYSTEM

DATE 10/27/84 **ENGINEER** N.E. **TABLE** II **PAGE** 1 **OF** 2

REF NO.	LOCATION	POTENTIAL MEASUREMENT (VOLT)	REMARKS
1	OFFICER'S MESS, FH	-.420	FH ⇒ FIRE HYDRANT
2	FLOUNDER RD, FH	-.422	
3	8" F.W. LINE EXPOSED AT CREEK	-.490	
4	CURTISS RD., FH	-.506	
5	AT BLDG. 812, FH	-.523	
6	NCO CLUB, FH	-.413	CONTINUITY TEST BETWEEN
6A	↓	-.420	POINTS 6 & 6A WAS PERFORMED
7	NORDELL ST. AT HOUSE #2113	-.361	
8	NORDELL ST. AT HOUSE #2093	-.214	
9	LONGSTAFF ST. AT HOUSE #2118	-.362	NOT SHOWN ON DWG.
10	MARINA OFFICE, FH	-.330	
11	LONGSTAFF & PATRICK, FH	-.329	NOT SHOWN ON DWG.
12	LONGSTAFF ST. AT HOUSE #2043	-.334	↓
13	GOODEN ST. AT BLDG. 818, FH	-.502	
14	AT TANK 4130, FH	-.406	
15	PERIMETER RD. & SCHMIDT, FH	-.566	
16	AC MAINT. HANGAR 4108, FH	-.301	
17	WHITE ST., FH	-.503	
18	WHITE & CAMPBELL ST., FH	-.451	
19	BANCROFT & CAMPBELL ST., FH	-.436	
20	CAMPBELL ST. AT BLDG. 224, FH	-.402	
21	McAVOY ST. AT BLDG. 302, FH	-.460	
22	SUMNER ST. AT HOUSE #1268, FH	-.470	
23	McAVOY ST. AT HOUSE #1208, FH	-.390	

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GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

STRUCTURE - TO - ELECTROLYTE POTENTIAL MEASUREMENT

STRUCTURE: WATER DISTRIBUTION SYSTEM

DATE 10/27/84 ENGINEER N.E. TABLE II PAGE 2 OF 2

REF NO.	LOCATION	POTENTIAL MEASUREMENT (VOLT)	REMARKS
24	MC AVOY ST. AT HOUSE #1100, FH	-.421	
25	CURTISS RD. AT BLDG. 205, FH	-.487	
26	JONES & LANGTRY ST., FH	-.496	
27	BAXTER ST AT HOUSE #1040, FH	-.501	
28	COMPTON & BAXTER	-.483	
29	BANCROFT AT BLDG. 210, FH	-.391	CONTINUITY TEST BETWEEN
30	BANCROFT AT BLDG. 208, FH	-.411	POINTS 29 & 30 WAS PERFORMED
31	FUEL FARM, FH	-.457	

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GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

CURRENT REQUIREMENT TEST

STRUCTURE: FUEL FARM

DATE 10/26/84 ENGINEER N.E. TABLE III PAGE 1 OF 3

REF. NO.	LOCATION	POTENTIAL MEASUREMENTS			REMARKS
		STATIC	CURRENT APPLIED		
		VOLTS	VOLTS	VOLTS	
			64 AMPS	78 AMPS	
100	4" LINE AT BOOSTER	-.507	-.870	-.988	
	PUMP TO PUMP HOUSE				
101	TANK 141, EAST	-.523	-.605	-.681	
102	↓ , NORTH	-.485	-.565	-.638	
103	4" P/L AT BOOSTER	-.476	-.566	-.643	
	TO PUMP HOUSE				
104	TANK 140, SOUTH	-.445	-.580	-.698	
105	, EAST	-.460	-.585	-.701	
106	↓ , NORTH	-.424	-.569	-.690	
	TANK 138				
107	EAST - 20'	-.440	-.680	-.743	
108	↓ 10'	-.412	-.663	-.726	
109	SOUTH - 20'	-.413	-.632	-.701	
110	↓ 10'	-.313	-.526	-.608	
111	WEST - 20'	-.382	-.544	-.632	
112	↓ 10'	-.376	-.536	-.626	
113	TOP OF TANK	-.352	-.493	-.566	
	TANK 137				
114	TOP OF TANK	-.330	-.483	-.545	
115	EAST - 20'	-.461	-.886	-1.044	
116	↓ 10'	-.426	-.802	.960	
117	WEST - 20'	-.386	-.756	-.835	
118	↓ 10'	-.390	-.684	-.762	

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GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

CURRENT REQUIREMENT TEST

STRUCTURE: FUEL FARM

DATE 10/26/84 ENGINEER N.E. TABLE III PAGE 2 OF 3

REF. NO.	LOCATION	POTENTIAL MEASUREMENTS STATIC VOLTS	CURRENT APPLIED VOLTS	VOLTS	REMARKS
	TANK 136		64 AMPS	78 AMPS	
119	TOP OF TANK	-.307	-.438	-.501	
120	SOUTH -20'	-.459	-.684	-.780	
121	↓ 10'	-.457	-.680	-.777	
122	NORTH -20'	-.434	-.663	-.756	
123	↓ 10'	-.443	-.682	-.781	
	TANK 150				
124	TOP OF TANK	-.361	-.464	-.512	
125	WEST -20'	-.470	—	—	
126	↓ 10'	-.452	—	—	
127	SOUTH -20'	-.501	-.733	-.818	
128	↓ 10'	-.465	-.663	-.771	
129	EAST -20'	-.505	-.804	-.988	
130	↓ 10'	-.494	-.780	-.880	
	TANK 151				
131	TOP OF TANK	-.301	-.387	-.424	
132	NORTH -20'	-.422	-.677	-.774	
133	↓ 10'	-.432	-.681	-.782	
134	EAST -20'	-.446	-.691	-.786	
135	↓ 10'	-.430	-.643	-.732	
136	SOUTH -20'	-.346	-.695	-.806	
137	↓ 10'	-.318	-.688	-.790	

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GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

CURRENT REQUIREMENT TEST

STRUCTURE: FUEL FARM

DATE 10/26/84 ENGINEER N.E. TABLE III PAGE 3 OF 3

REF. NO.	LOCATION	POTENTIAL MEASUREMENTS			REMARKS
		STATIC	CURRENT APPLIED		
		VOLTS	VOLTS	VOLTS	
	TANK 154		64 AMPS	78 AMPS	
138	TOP OF TANK	-.404	-.536	-.605	
139	NORTH - 20'	-.495	-.793	-.894	
140	↓ 10'	-.505	-.789	-.880	
141	EAST - 20'	-.500	-.839	-.916	
142	↓ 10'	-.505	-.792	-.887	
143	SOUTH - 20'	-.496	-.742	-.846	
144	↓ 10'	-.483	-.692	-.788	
145	WEST - 20'	-.481	-.784	-.883	
146	↓ 10'	-.490	-.767	-.854	

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GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

CURRENT REQUIREMENT TEST

STRUCTURE: UNDERGROUND MOGAS TANK AT BLDG. 143

DATE 10/27/84 ENGINEER N.E. TABLE IV PAGE 1 OF 1

REF. NO.	LOCATION	POTENTIAL MEASUREMENTS			REMARKS
		STATIC	CURRENT APPLIED		
		VOLTS	VOLTS	VOLTS	
			1.3 AMPS	.30 AMPS	
200	MOGAS TANK	-.526	-.218	-1.221	
201	↓	-.557	-2.81	-1.142	
202		-.595	-2.51	-1.186	
203		-.542	-2.72	-1.209	
204		-.535	-2.55	-1.152	
205		-.560	-2.58	-1.051	
206		-.554	-1.81	-.943	
207	↓	-.558	-1.92	-.964	

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GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

CONTINUITY TEST DATA

STRUCTURE: WATER DISTRIBUTION SYSTEM

DATE 10/27/84 ENGINEER N.E. TABLE V PAGE 1 OF 1

TEST NO.	SECTION OF LINE TESTED	STRUCT.-TO-SOIL POTENTIAL (VOLTS)				REF. LOCAT.	REMARKS
		CLOSE		REMOTE			
		I-ON	I-OFF	I-ON	I-OFF		
	LINE SECTION AT NCO CLUB, BETWEEN REF. POINTS 6 & 6A						
301A	TEMPORARY	-.613	-.413	-.384	-.169	FH-6	NOT CONTINUOUS
301B	GROUNDBED AT REF. 6			-.420	-.420	FH-6A	NOT CONTINUOUS
	LINE SECTION BETWEEN BLDGS. 208 & 210, REF. POINTS 29 & 30						
302A	TEMPORARY	-.688	-.391	-.372	-.293	FH-29	NOT CONTINUOUS
302B	GROUNBED AT REF. 29			-.411	-.411	FH-30	NOT CONTINUOUS

NOTES: SEE DWG. No. SK-6148-A FOR TEST PROCEDURES

RECTIFIER DATA

MFGR. HARCO SERIAL NO. 9339

DC RATING 60 VOLTS. 28 AMPS.

SHUNT RATING: ______ mV. ______ AMPS.

		AS FOUND	AS LEFT
TAP SETTINGS	COURSE	A	A
	FINE	2	2
DC OUTPUT		4.06V	4.06V
BOWL CURRENT		1.70A.	1.70A.
RISER CURRENT		0.36A.	0.36A.

COMMENTS:

HATCH CAME OFF WHEN OPENED - HINGES NOT MATED - NEEDS REPAIR.

ANODES ~ 5YRS. LIFE

HARDWARE OK INTERIOR COATING LOOKED GOOD

SURVEY DATA

POTENTIAL PROFILE

WET AREA AT SURVEY 75% FULL TANK

BOTTOM	1.24V.	+15	1.33V.	+30	
+3	1.29V.	+18	1.33V.	+33	
+6	1.31V.	+21	1.28V.	+36	
+9	1.32V.	+24	SURFACE	+39	
+12	1.33V.	+27			

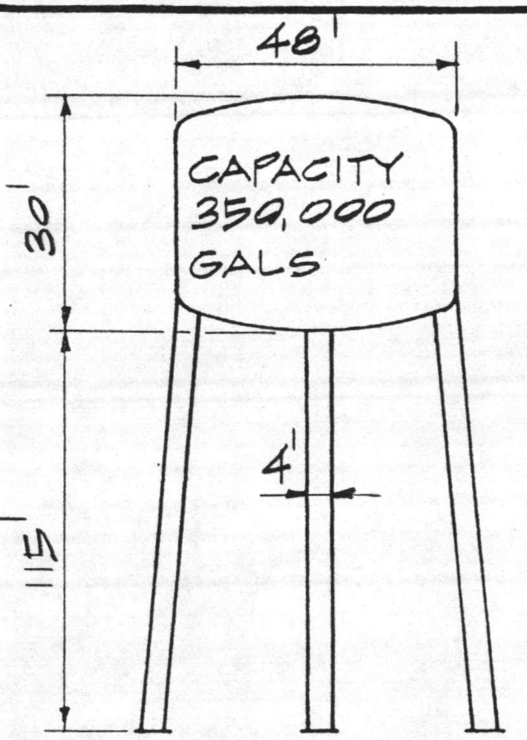
OFF POTENTIAL 1.16 V. I.R. DROP 100 MV.

ANODE STRING CURRENT DRAINS (going counterclockwise from ladder)

OUTER RING		INNER RING	
1	0.18A	1	0.04A
2	0.18A	2	.038A
3	0.18A	3	.035A
4	0.18A	4	.038A
5	0.18A	5	
6	0.18A		
7	0.18A		
8	0.18A	RISER	0.32A
9			
10			

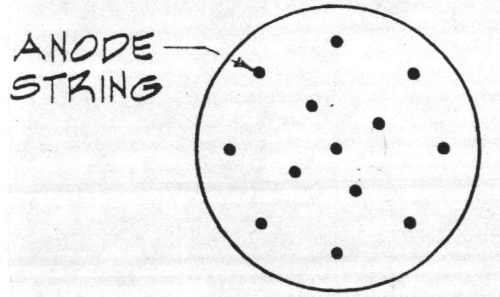
DATE OF SURVEY - NOV. 11, 1984

TANK DATA



ELEVATION

ANODE GEOMETRY



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GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.

ELEVATED WATER STORAGE TANK CATHODIC PROTECTION DATA (TANK 4130)

DES. C.R.M.	CK. R.S.	DWG. NO. REV
DR. J.CRUZ	APP.	TABLE VI-A
SCALE NONE	DATE 12-14-84	

RECTIFIER DATA

MFGR. GOOD-ALL SERIAL NO. 81L1216

DC RATING 40 VOLTS. 12 AMPS.

SHUNT RATING: ______ mV. ______ AMPS. ______

		AS FOUND	AS LEFT
TAP SETTINGS	COURSE	A	A
	FINE	2	2
DC OUTPUT		3.5V	3.5V.
BOWL CURRENT		1.41A.	1.41A.
RISER CURRENT		0.29A.	0.29A

COMMENTS:

SQUARE HANDHOLE COVERS OVER ROUND ACCESS HOLES DO NOT FIT WELL

ANODES ~ 3 YRS. LIFE

CONDUIT & WIRING OK

INTERIOR COATING OK

SURVEY DATA

POTENTIAL PROFILE
WET AREA AT SURVEY FULL TANK

BOTTOM	1.10V.	+15	1.16V.	+30	
+3	1.13V.	+18	1.16V.	+33	
+6	1.15V.	+21	1.16V.	+36	
+9	1.15V.	+24	1.16V.	+39	
+12	1.15V.	+27	1.16V. SURFACE		

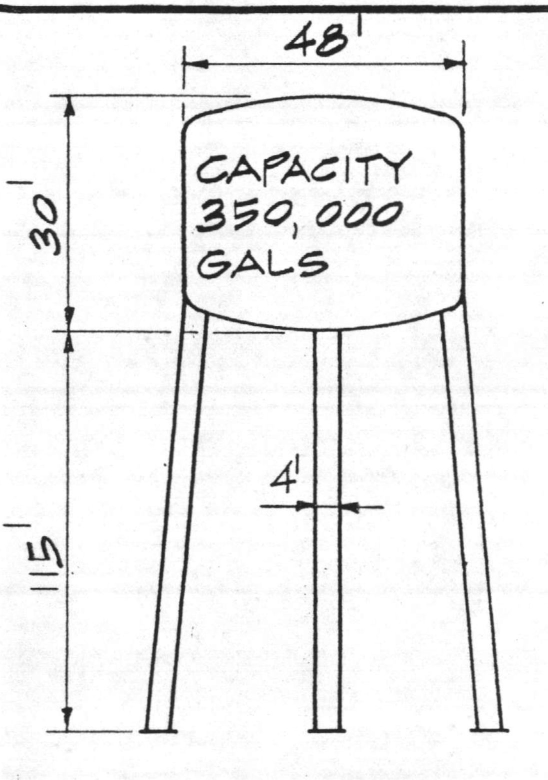
OFF POTENTIAL 1.06 V. I.R. DROP 50 MV

ANODE STRING CURRENT DRAINS
(going counterclockwise from ladder)

OUTER RING		INNER RING	
1	0.10A.	1	.023A.
2	0.12A.	2	.019A.
3	0.10A.	3	.018A.
4	0.13A.	4	.018A.
5	0.11A.	5	
6	0.10A.		
7	0.12A.		
8	0.12A.	RISER	.25A.
9			
10			

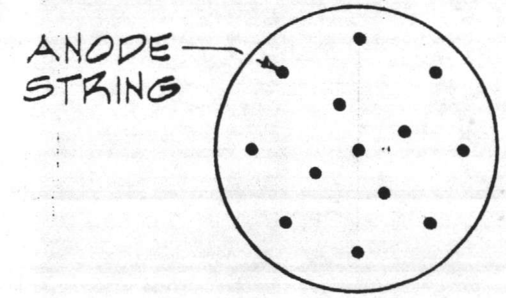
DATE OF SURVEY - NOV. 12, 1984

TANK DATA



ELEVATION

ANODE GEOMETRY



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GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.

ELEVATED WATER STORAGE TANK CATHODIC PROTECTION DATA (TANK AS-310)

DES. C.R.M.	CK. R.S.	DWG. NO.	REV
DR. J.CRUZ	APP.	TABLE VI-B	
SCALE NONE	DATE 12-14-84		

MDA MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

RECTIFIER INSPECTION

SYSTEM FUEL FARM RECTIFIER LOCATION IN FUEL FARM

DATE 10/27/84 ENGINEER N.E. TABLE VII RECTIFIER NO. 1

MFGR. RIO SERIAL NO. 40742 DC RATING: 36 VOLTS 20 AMPS

SHUNT RATING: 30 mV 50 AMPS TAP RANGE: 3 COURSE 6 FINE

RECTIFIER INSPECTION

POWER SWITCH O.K.? ✓ GND. CONNECTION TO CASE? ✓ ROD CONNECTION? ✓

CONDITION OF CASE? O.K. CASE SUPPORTS? ✓ CABLE CLAMPS? ✓ A.C. CONDUIT & FITTINGS? ✓

AIR COOLED UNIT: AIR CIRCULATION HINDERED? NO CONDITION OF PANEL? O.K.

CONDITION OF TRANSFORMER? O.K. OVERHEATED PLATES ? NO

CALIBRATION AND ADJUSTMENT

AS FOUND	DC VOLTS	DC AMPS	AC VOLTS
RECTIFIER METER	0	0	0
CALIBRATION METER	0	0	0

AS LEFT	DC VOLTS	DC AMPS	AC VOLTS
RECTIFIER METER	0	0	
CALIBRATION METER	0	0	

TAP SETTINGS

AS FOUND 2 COURSE 1 FINE

AS LEFT 2 COURSE 1 FINE

GROUND BED INVESTIGATION

JCT. BOX NO.		JCT. BOX NO.		JCT. BOX NO.		JCT. BOX NO.	
ANODE NO.	AMPS	ANODE NO.	AMPS	ANODE NO.	AMPS	ANODE NO.	AMPS
1							
2							
3							
4							
5							

REMARKS GROUNDBED IS DEPLETED, RECTIFIER WAS FOUND "OFF", IT IS IN GOOD CONDITION, IT WAS USED AS A POWER SOURCE FOR A TEMPORARY GROUNDBED

M D A MENENDEZ-DONNELL & ASSOCIATES, INC. HOUSTON, TEXAS

GCPS GENERAL CATHODIC PROTECTION SERVICES INC.

TITLE: CATHODIC PROTECTION SURVEY, MARINE CORPS AIR STATION (H), NEW RIVER, N.C.

RECTIFIER INSPECTION

SYSTEM RECTIFIER LOCATION IN BLDG. 4102

DATE 10/27/84 ENGINEER ______ TABLE VII RECTIFIER NO. 2

MFGR. GOODALL SERIAL NO. — DC RATING: 40 VOLTS 20 AMPS ______

SHUNT RATING: — mV — AMPS TAP RANGE: — COURSE — FINE

RECTIFIER INSPECTION

POWER SWITCH O.K.? ____ GND. CONNECTION TO CASE? ____ ROD CONNECTION? ____

CONDITION OF CASE? ____ CASE SUPPORTS? ____ CABLE CLAMPS? ____ A.C.CONDUIT & FITTINGS? ____

AIR COOLED UNIT: AIR CIRCULATION HINDERED? ____ CONDITION OF PANEL? ____

CONDITION OF TRANSFORMER? ____ OVERHEATED PLATES ? ____

CALIBRATION AND ADJUSTMENT

AS FOUND	DC VOLTS	DC AMPS	AC VOLTS
RECTIFIER METER	0	0	
CALIBRATION METER			

AS LEFT	DC VOLTS	DC AMPS	AC VOLTS
RECTIFIER METER	0	0	
CALIBRATION METER			

TAP SETTINGS

AS FOUND ____ COURSE ____ FINE

AS LEFT ____ COURSE ____ FINE

GROUND BED INVESTIGATION

JCT. BOX NO. ____		JCT. BOX NO. ____		JCT. BOX NO. ____		JCT. BOX NO. ____	
ANODE NO.	AMPS	ANODE NO.	AMPS	ANODE NO.	AMPS	ANODE NO.	AMPS
1							
2							
3							
4							
5							

REMARKS BUILDING 4102 WAS LOCKED, OPERATOR INDICATED THAT THE RECTIFIER IS IN GOOD WORKING CONDITION

APPENDIX C

SOIL AND WATER ANALYSIS

LOCATION OF SAMPLES

SOIL SAMPLES

"S-6" Fuel Farm.

"S-7" Fuel farm, between Tanks No. 136 and 137.

"S-8" At Airfield underground steel Tanks A and B.

WATER SAMPLES

"W-5" At New River shoreline.

"W-12" Potable water from Tank No. S-TC-606.

SGS Control Services Inc.

1201 W. 8th Street
P.O. Box 550
Deer Park, Texas 77536
Tel: (713) 479-7170
TWX: 910 881 1681
TLX: 795065 SUPERCO DERK

November 21, 1984

MENENDEZ-DONNELL & ASSOCIATES
11999 Katy Freeway, #355
Houston, TX 77079

Analytical Report No. #97414

LAB REFERENCE NO.: L/3134/84 SAMPLE DESCRIPTION: Water / Soil

SAMPLE MARKED: SUBMITTED SAMPLES AS MARKED BELOW / RECEIVED 11-5-84

SUBMITTED BY: Menendez-Donnell & Associates

RESULTS OF ANALYSIS

Based upon samples, submitted to us, tested in our laboratory, reported to you as follows:

"SOIL"

Method	Tests
ASTM D-2976	pH
Gravimetric	Sulfate, ppm
Potentiometric	Chlorides, %
Conductimeter*	Conductivity, μmhos/cm
A. A. S.	Sodium, ppm
U. V.	Phosphate, ppm
Carbon Dioxide Apparatus	Carbonate, %

	"S-6"	"S-7"	"S-8"
pH	6.7	5.8	6.9
Sulfate, ppm	973	177	591
Chlorides, %	<0.005	<0.005	<0.005
Conductivity, μmhos/cm	390	53	61
Sodium, ppm	159	176	201
Phosphate, ppm	94	81	52
Carbonate, %	1.77	0.31	2.33

*Soil sample mixed with Deionized Water 1:1 ratio

continued. . . . . .

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LAB REFERENCE NO.: L/3134/84

SAMPLE DESCRIPTION: Water / Soil

SAMPLE MARKED: SUBMITTED SAMPLES AS MARKED BELOW / RECEIVED 11-5-84

SUBMITTED BY: Menendez-Donnell & Associates

RESULTS OF ANALYSIS

Based upon samples, submitted to us, tested in our laboratory, reported to you as follows:

"WATER"

[Standard Methods 15th Edition]

Method	Tests	"W-12"	"W-5"
423	pH	8.6	6.9
209C	Total Dissolved Solids, mg/L	397	8998
426B	Sulfate, mg/L	21.8	664
407C'	Chlorides, mg/L	82	4538
205	Conductivity, µmhos/cm	738	15343

SGS CONTROL SERVICES INC.

By: Hugh L. Mayo

Hugh L. Mayo,
Laboratory Manager

HLM/bj

APPENDIX D

DESIGN CALCULATIONS

I. POL SYSTEM

A. Fuel Farm

1. Current requirement test data indicated that a current of 80 amperes will be required to achieve protective potentials on underground tanks and associated piping at the Fuel Farm.

Underground tanks Surface Area:

50,000 gal. tanks:	$2816 \frac{\text{sq.ft.}}{\text{tank}} \times 3$ tanks	= 8,448 sq.ft.
100,000 gal. tank:		= 3,940 sq.ft.
105,000 gal. tank:		= 3,940 sq.ft.
120,000 gal. tank:		= 4,272 sq.ft.
10,000 gal. tank:	$779 \frac{\text{sq.ft}}{\text{tank}} \times 2$ tanks	= 1,558 sq.ft.
	Total Surface Area	=22,158 sq.ft.
Allow 15% for piping		= 3,324 sq.ft.

Total exposed surface area of underground tanks and piping =25,482 sq.ft.

$$\text{Current density} = \frac{80 \text{ amperes}}{25{,}482 \text{ sq.ft.}} = 0.0031 \frac{\text{Amp}}{\text{sq.ft.}}$$

The current requirement is relatively high, but it is a result of an actual field test and should be considered correct.

2. An impressed current system utilizing distributed type anodes is recommended for proper current distribution around the Fuel Farm.

3. Utilize the two existing abandoned 20 ampere rectifiers and an one additional new rectifier.

4. Weight of anode materials:

Fully treated graphite anodes with calcined petroleum coke backfill are recommended for this installation:

$$\text{Weight} = 20 \text{ years} \times \frac{1\text{-lb}}{\text{amp-yr.}} \times 80 \text{ amperes} =$$

= 1,600 lbs. of anode material

5. Number of anodes required for a 20 years life:

a. Use 3" x 60" specially treated graphite anodes, fitted with epoxy and heat shrink caps.

b. Number = 1600 lbs. x 1-anode/27-bls = 59.2 anodes

59.2 anodes/0.75 = 79 anodes.
.75 is the utilization factor for the graphite anode, meaning when the anode is 75% consumed it will require replacement.

6. Groundbed design:

a. The two existing rectifiers, have a rated DC output as follows:
   36V - 20 amperes.
   40V - 20 amperes.

Two 20 amperes groundbeds can therefore be utilized by the above rectifiers, the following calculations are made to insure that the rated voltage of each rectifier is sufficient:

Resistance of groundbed to earth:

$$R = \frac{.00521\rho}{NM}\left[\ln \frac{8L}{D} - 1 + 2\frac{L}{S}\ln .656(N)\right]$$

L = Length of anode and coke column = 10'
D = Diameter in ft. = 1'
S = Spacing in ft. = 20
ρ = Soil resistivity in ohm-cm = 7,400
N = No. of anodes = 20

$$R = \frac{.00521(7400)}{20(10)}\left[\ln\frac{8(10)}{1} - 1 + \frac{2(10)}{20}\ln .656(20)\right]$$
= 1.15 ohms

Anode Resistance to Backfill:

$$R = \frac{0.0052\rho}{L}\left(\ln\frac{8L}{D} - 1\right)$$

L = Length of anode = 5'
D = Diameter of anode = 0.25
ρ = Resistivity pf Backfill

$$R = \frac{.00521(50)}{5}\left(\ln\frac{8(5)}{.25} - 1\right)$$
= 0.212 ohm for 1 anode

R for 20 anodes = $\frac{.212}{20}$ = 0.0106 ohms.

Total Groundbed resistance=1.15 + 0.0106 = 1.16 ohms.

Cable Resistance:

Maximum conductor length for this installation should not exceed 800 feet.
Use No. 1/0 AWG, resistance = .102 ohm/1000 ft.
Cable Resistance = 800 ft. x $\frac{.102 \text{ ohm}}{1000 \text{ ft.}}$ = .082 ohm

Total Resistance = 1.16 + .082 = 1.24 ohm.

Rectifier Voltage $V_r = \frac{IR+2V \text{ (Back EMF)}}{.08 \text{ reserve factor}}$

$$V_r = \frac{20(1.24) + 2V}{.08} = 33.5 \text{ volts}$$

Therefore, the two existing rectifiers can be utilized in conjunction with 20 anodes groundbed each.

7. New Rectifier Groundbed.

Resistance of Groundbed to earth:

$$R = \frac{.00521\rho}{NL}\left[\ln\frac{8L}{D} - 1 + \frac{2L}{S}\ln .656\ N\right]$$

$$R = \frac{.00521(7400)}{40\ (10)}\left[\ln\frac{8(10)}{1} - 1 + \frac{2(10)}{20}\ln .656\ (40)\right]$$

= 0.64 ohms.

Groundbed resistance to backfill= $\frac{.212}{40}$ = 0.0053ohms.

Total Groundbed resistance = .64+.0053 = 0.645 ohms.

Cable Resistance:
Maximum conductor length for this installation should not exceed 1500 feet.

Use No. 1/0 AWG, resistance = .102 ohm/1000 ft.

Cable Resistance = 1500 ft. x $\frac{.102 \text{ ohm}}{1000 \text{ ft.}}$ = 0.153 ohm

Total resistance = 0.645 + 0.153 = 0.8 ohm.

Rectifier Voltage $V_r = \frac{IR+2V\text{(Back EMF)}}{0.8 \text{ reserve factor}}$

I = 40 Amper + 25% = 50 amp.
$V_r = \frac{(50)\ (.8) + 2V}{0.8} = 52.5$ volts

Use a rectifier with minimum rating = 60 volts.

II. MOGAS Tank at Building 142

1. Current requirement test data indicated that a current of 0.35 amperes will be required to achieve protective potentials on the 20,000 gallon underground MOGAS Tank at building 142.

Tank surface area = 1,350 sq. ft.

$$\text{Current density} = \frac{.30 \text{ amp.}}{1350 \text{ sq. ft.}} = .000222 \frac{\text{amp}}{\text{sq.ft.}} = 0.222 \frac{\text{ma}}{\text{sq.ft.}}$$

The low current density requirement of $0.26 \frac{\text{ma}}{\text{sq.ft.}}$ is quite reasonable for a coated tank. The coating was visually verified during the field inspection.

2. Weight of anode materials required:

Prepackage magnesium anodes will be used having an estimated deterioration rate of 1-lb. per 500 amp.-hr and an estimated life of 20 years.

$$\text{Weight} = 20 \text{ yrs.} \times \frac{1\text{-lb}}{500 \text{ amp-yr.}} \times \frac{8760\text{hr}}{\text{year}} \times 0.30 \text{ amp.}$$
$$= 105\text{-lbs. of anode material.}$$

3. Number of anodes required for 20 years life:

a. Use prepackaged 20 lb longated magnesium anode.

b. $\text{Number} = 105.6 \text{ lb} \times \frac{1\text{-anode}}{20 \text{ lb.}} = 5.25 \text{ anodes}$

$5.25 \text{ anodes} \times \frac{1}{.75} = 7.0 \text{ anodes}$

.75 is the utilization factor meaning when the anode is 75% consumed it will require replacement.

Use 8 anodes.

c. To achieve the desired current distribution the following calculations are made:

$$R = \frac{.00521\rho}{L}\left(\ln \frac{8L}{D} - 1\right)$$

ρ = Soil resistivity
L = Anode length = 5'
D = Anode Diameter = 0.266

$$R = \frac{.00521(6200)}{5}\left(\ln \frac{8(5)}{.266} - 1\right) = 25.9 \text{ ohm.}$$

$I = \frac{E}{R}$ E = Driving potential

= Solution potential of anode-protected potential

$$I = \frac{0.9}{25.9} = 0.0347 \text{ amp/anode}$$

Number of anodes:

$$0.30 \text{ amperes} \times \frac{\text{anode}}{0.0347 \text{ amp.}} = 8.64 \text{ anodes}$$

III. Day Tanks A & B at Airfield

1. The underground Day Tanks A and B have an exposed surface area of 2700 square feet. Based on the current density of .000222 amper per square foot calculated previously, total current requirement will be 0.6 amperes.

2. The low current requirement and soil resistivity of (1500 ohm cm) are suitable for a sacrificial magnesium anode installation.

3. Weight of anode material prepackage of magnesium anodes will be used having an estimated deterioration rate of 1-lb per 500 amp-hr. and an estimated life of 20 years.

$$\text{Weight} = 20 \text{ years} \times \frac{1\text{-lb}}{500 \text{ amp.}} \times \frac{8760\text{-hr.}}{\text{-yr.year}} \times .60 \text{ amps.}$$

$$= 210 \text{ lbs of anode material}$$

4. Number of anodes required for 20 years life:

a. Use prepackaged 32-3D (32 lbs) magnesium anodes.

b. $\text{Number} = 210\text{-lbs} \times \frac{\text{anode}}{32 \text{ lb}} = 6.56 \text{ anodes.}$

$$6.56 \times \frac{1}{.75} = 8.75 \text{ anodes}$$

.75 is the utilization factor.

c. Calculated current drain for a 32-D3 Galvopack anode with a driving potential of 0.9 volts.

$$R = \frac{.00521(1500)}{5} \left(\ln \frac{8(5)}{.3125} - 1\right)$$

$$= 6.0 \text{ ohms.}$$

$$I = \frac{E}{R} = \frac{0.9}{6.0} = 0.15 \text{ ampere/anode}$$

To achieve the desired current drain and a 20 years life for the system, eight 32-D3 Galvopack magnesium anodes will be scheduled for installation.

IV. WATER DISTRIBUTION SYSTEM

1. Based on a current density of 0.0015 ampere per square foot, current requirement for different standard pipe joints will be as follows:

Dimension	Current requirement
4" x 20'	0.032 A
6" x 20'	0.047 A
8" x 20'	0.063 A
10" x 20'	0.078 A
12" x 20'	0.094 A
14" x 20'	0.109 A
20" x 20'	0.157 A

2. Because of soil resistivity variations and the lack of electrical continuity, anodes are sized for each individual joint.

3. Weight of anode materials required for a 6" x 20' joint.

a. Anode life = 20 years

$$\text{weight} = 20 \text{ yrs} \times \frac{8760 \text{ hr}}{\text{yr}} \times \frac{1 \text{lb}}{500 \text{ amp-hr}} \times .047\text{A} \times \frac{1}{.85} = 19.37 \text{lbs}$$

b. Select (1) 20-D2 Galvopack magnesium anode for installation on each 6" x 20' joint

c. Anode Resistance:

$$R = \frac{.00521(\rho)}{L}\left(\ln \frac{8L}{D} - 1\right)$$

$$= \frac{.00521(\rho)}{5}\left(\ln \frac{8(5)}{.266} - 1\right) = 0.004 \text{ ohm}$$

Maximum current drain depends on soil resistivity.

$$I = \frac{\text{Driving Potential}}{R} = \frac{0.09\text{V}}{.004 \text{ ohm}}$$

For ρ = 1000 ohm-cm
I = .225 amperes

Therefore (1) 20-D2 anode can be used on 1 joint of 6" x 20' pipe in soil resistivities up to 5000 ohm/cm.

4. Following the above procedure the following tables were prepared:

4" x 20'

Maximum Soil Resistivity ohm-cm	No. of magnesium Anodes Re.	Maximum Current Ouput "Amperes"
1000	1-20D2	0.215
2000	1-20D2	0.1076
3000	1-20D2	0.072
4000	1-20D2	0.054
5000	1-20D2	0.043

6" x 20'

1000	1-20D2	0.215
2000	1-20D2	0.1076
3000	1-20D2	0.072
4000	1-20D2	0.054
5000	1-20D2	0.043

8" x 20'

1000	1-32-D3	0.192
2000	1-32-D3	0.096
3000	2-20D2	0.144
4000	2-20D2	0.108
5000	2-20D2	0.086

10" x 20'

1000	1-40D3	0.2432
2000	1-40D3	0.122
3000	1-40D3	0.081
4000	2-20D2	0.108
5000	2-20D2	0.086

12" x 20'

1000	1-48D5	0.152
2000	2-20D2	0.215
3000	2-20D2	0.144
4000	2-20D2	0.108
5000	2-20D2	0.086

14" x 20'

1000	1-48D5	0.152
2000	1-40D3	0.121
3000	2-20D2	0.144
4000	2-20D2	0.108
5000	3-20D2	0.135

	20" x 20'	
1000	2-40D3	0.484
2000	2-40D3	0.242
3000	2-40D3	0.161
4000	2-40D3	0.112
5000	2-40D3	0.090

APPENDIX E

COST ESTIMATES

NAVFAC 11013/7 (1-78)
Supersedes NAVDOCKS 2417 and 2417A

COST ESTIMATE

DATE PREPARED: DEC. 14, 1984

SHEET 1 OF 3

ACTIVITY AND LOCATION: MCAS, (HELICOPTER) NEW RIVER, N.C.

CONSTRUCTION CONTRACT NO.:

IDENTIFICATION NUMBER:

PROJECT TITLE: CATHODIC PROTECTION SURVEY

ESTIMATED BY: MENENDEZ-DONNELL & ASSOC.

CATEGORY CODE NUMBER:

STATUS OF DESIGN: ☐ PED ☐ 30% ☐ 100% ☐ FINAL ☒ Other (Specify) STUDY

JOB ORDER NUMBER:

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
FUEL FARM								
1. 3"x60" TREADED GRAPHITE ANODES W/ EPOXY & HEAT SHRINK CAPS & 5' OF #8 HMWPE LEADWIRE	80	EACH	78	6,240	120	9,600		15840
2. CALCINED PETROLEUM COKE	56,000	LB	.275	15,400		1,600		17,000
3. 80 VOLTS, 50 AMPS, OIL INMERSED RECTIFIER	1	EACH	2,070	2,070	700	700		2,770
4. #1/0 HMWPE CABLE	3,000	FT.	.95	2,850	1	3,000		5,850
5. EPOXY RESIN SPLICE KITS & PRESSURE CONNECTION	80	EACH	14	1,120	22	1,760		2,880
6. MISCELLANEOUS	1	LOT	400	400	800	800		1,200
7. POWER CONNECTION	3	EACH	250	750	750	2,250		3,000
8. FIELD ENGINEERING & SUPERVISION								7,650
9. OFFICE ENGINEERING & REPORT								2,000
10. DRAFTING & SECRETARIAL								1,200
TOTAL				28,830		19,710		59,390

S/N 0105-LF-010-1535

★U.S. Government Printing Office: 1982—606-104/6911 2-1

NAVFAC 11013/7 (1-78)
Supersedes NAVDOCKS 2417 and 2417A

COST ESTIMATE

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	DATE PREPARED	SHEET
MCAS, (HELICOPTER) NEW RIVER, N.C.		DEC. 14, 1984	2 OF 3
PROJECT TITLE	ESTIMATED BY	IDENTIFICATION NUMBER	
CATHODIC PROTECTION SURVEY	MENENDEZ-DONNELL & ASSOC.	CATEGORY CODE NUMBER	
	STATUS OF DESIGN: ☐ PED ☐ 30% ☐ 100% ☐ FINAL ☒ Other (Specify) STUDY	JOB ORDER NUMBER	

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
MOGAS TANK AT 142								
1. 20-D2 PREPACKED MAGNESIUM ANODE W/ 15' OF #12 AWG LEADWIRE	9	EACH	63	567	220	1,980		2,547
2. FLUSH FINK TEST STATION	1	EACH	66	66	120	120		186
3. #8 AWG-HMWPE CABLE	100	FT	.32	32	1.5	150		182
4. MISCELLANEOUS	1	LOT	150	150	300	300		450
5. FIELD ENGINEERING & SUPERVISION								1,425
6. OFFICE ENGINEERING & REPORT								800
7. DRAFTING & SECRETARIAL								600
TOTAL				815		2,550		6,190

S/N 0105-LF-010-1335

U.S. Government Printing Office: 1982—

NAVFAC 11013/7 (1-78)
Supersedes NAVDOCKS 2417 and 2417A

COST ESTIMATE

DATE PREPARED: DEC. 14, 1984

SHEET 3 OF 3

ACTIVITY AND LOCATION: MCAS, (HELICOPTER) NEW RIVER, N.C.

CONSTRUCTION CONTRACT NO.:

IDENTIFICATION NUMBER:

PROJECT TITLE: CATHODIC PROTECTION SURVEY

ESTIMATED BY: MENENDEZ-DONNELL & ASSOC.

CATEGORY CODE NUMBER:

STATUS OF DESIGN: ☐ PED ☐ 30% ☐ 100% ☐ FINAL ☒ Other (Specify) STUDY

JOB ORDER NUMBER:

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
DAY TANKS A & B								
1. 32 LB. PREPACKAGED MAGNESIUM ANODE W/ 15' #12 AWG LEADWIRE	8	EACH	102	816	260	2,080		2,896
2. FLUSH FINK TEST STATION	2	EACH	66	132	120	240		372
3. #8 AWG-HMWPE CABLE	200	FT.	.32	64	1.5	300		364
4. MISCELLANEOUS	1	LOT	250	250	500	500		750
5. FIELD ENGINEERING & SUPERVISION								2,375
6. OFFICE ENGINEERING & REPORT								1,200
7. DRAFTING & SECRETARIAL								700
TOTAL				1,262		3,120		8,657

S/N 0105-LF-010-1335

U.S. Government Printing Office: 1982—606-106/6011 3-1

APPENDIX F

CORROSION AND CATHODIC PROTECTION

CORROSION AND CATHODIC PROTECTION THEORY

Corrosion is an electro-chemical process or transformation of energy resulting in the metal of a structure in contact with an electrolyte going into solution, or reverting to its natural status as an oxide form. There is a great deal of stored energy in a piece of metal and it is not at all in accordance with the laws of nature for that piece of metal to remain intact--in fact, it cannot exist without some type or degree of maintenance by man.

There are, generally speaking, two main forms of corrosion--electrolytic and galvanic. Electrolysis is usually construed to mean the process of a stray electrical current being impressed upon a buried structure from an external and metallically unconnected source such as an electric railway (Figure 1). The current, usually relatively great in magnitude, supposedly confined to the rail as a return encounters high resistant joints, takes the path of least resistance to nearby piping, follows the pipe line back to the proximity of the source, at which point the current is discharged from the line carrying iron particles into solution with it. Due to the quantity of current usually involved, this type of corrosion is usually manifested in severe metal loss in the area of current discharge. Any uncontrolled current from a D.C. current source can result in detrimental interference effects on foreign structures within the area of influence of the D.C. source.

Galvanic corrosion is the result of the formation of galvanic cells upon the structure itself and independent of external power sources. Basic forms of galvanic cells exist as: (a) dissimilar connected metals in a common electrolyte, (b) a continuous metal structure exposed to dissimilar electrolytes, and (c) a combination of the above conditions. It is this form of corrosion which plays the major role in deterioration of underground structures in most areas.

The galvanic cell involving dissimilar metals can perhaps best be illustrated by referring to these examples taken from the Electromotive Force Series of Metals Table (Figure 2). This table is a comparative index of the solution potential or activity level of various metals ranging from potassium which has the highest relative potential to the noble metals of silver and gold which are very stable and thus reflect the lowest solution potentials. For practical purposes, the most common metals for underground construction and cathodic protection are shown. Magnesium, with a potential of -2.34, is anodic to zinc, with a

potential of -0.762. Zinc, in turn is anodic to iron, with a potential of -0.044. Iron, with a potential of -0.044, is anodic to copper, with a potential of +0.345. The term anodic is of Greek derivation meaning "up way" and indicates that the metal which has the higher potential will give up current (thus dissipating itself) to the lower potential metal which is termed cathodic or the cathode.

The common flashlight battery is a galvanic cell composed of a zinc outer case, an electrolyte, a carbon rod, and an external circuit (Fig. 3). In this case, the zinc has the higher potential and acts as the anode with the carbon rod being the cathode. When the external circuit is closed through the metallic case of a flashlight, current flows from the zinc outer case, through the electrolyte to the carbon rod, and thence through the light bulb filament. As the metallic ions go into solution, water in the electrolyte is disassociated, the zinc combining with the hydroxyl ion to form an oxide, and the atomic hydrogen released to migrate to the cathode.

Common examples of this type of galvanic cell encountered in everyday construction of underground structures are a brass fitting between steel section (Fig. 4), steel connected to cast iron, steel pipe in contact with cinders (Fig. 5), bright metal from wrench or tong from scratches (Fig. 6), mill scale patches on pipe (Fig. 7), and new pipe installed as replacement between old sections of pipe.

The other basic galvanic cell is one consisting of a common metal in dissimilar electrolytes (Fig. 8). In this case, the electrolyte surrounding the metal determines which portion of the metal is anodic and which is cathodic. The current flow is from the metal in contact with the lower resistivity electrolyte to the portion of metal in a higher resistivity environment. This case is, of course, similar to our underground pipe lines composed of the same metal, but traversing a heterogeneous mixture of soils such as sand, sandy loam, clay, loam, rock, gypsum beds, salt beds, etc. The oxygen content and moisture conditions will also vary radically for different soil types encountered. Each change of soil characteristic such as the frequency, and the degree of change of resistivity, has a great role in determining the severity and extent of corrosion.

Examples of these conditions are dramatized in Figure 9, which illustrates a continuous metal pipe in contact with a moisture retentative (thus relatively low resistivity), clay electrolyte, and also a well-drained (thus higher resistivity) sandy loam electrolyte. Current discharge is

initiated in the lower resistivity soil area with the adjacent pipe surfaces receiving the current, and the pipe wall serving as the external circuit back to the source of the galvanic cell at the corroding area. Figures 10 and 11 illustrate the dissimilarity of soil conditions which can result from normal excavation and backfill procedures of buried structures; also, the dissimilarity of electrolyte conditions encountered due to oxygen availability and presence as a result of normal construction practices.

A typical example of numerical soil resistivity value relationships over an extent of pipe line right-of-way is shown in Figure 12. Although a large percentage of detrimetnal corrosion is normally associated with the low soil resistivity ranges, severe corrosion does occur in the medium and high range categories. Thus, the frequency and magnitude of electrolyte change must be considered rather than relying solely on categorized numerical ranges.

Corrosion results are apparent in several forms--the most common being scaling, pitting, patching, graphitization, and oxide films. Some less common forms are failure within the crystaline structure itself and stress corrosion. Uniform scaling, or exfoliation, is usually associated with some of the older laminated types of pipe construction. The severity of metal loss depends essentially on the ratio of anodic area to cathodic area. In other words, if there is a small anodic area between two large cathodic areas, the small anodic area will be discharging current in quantities large enough to protect the two large cathodic areas. Since the area of current discharge is small, it follows that the metal will be removed in this area at an accelerated rate. However, if the anodic area was relatively large in comparison with the cathodic area, the penetration process would proceed much slower as it would be taking place over a much larger area. When it is realized that one ampere of D.C. current flowing continuously for a period of one year can drive 20 pounds of steel into solution, it can be ascertained that very small quantities of uncontrolled current discharge can cause failure of a thin wall metallic structure within a relatively short time.

Corrosion prevention is normally accomplished by the following procedures:

1. Judicious choice of construction materials and procedures with respect to corrosion mitigation for new construction.

2. Protective coatings.

3. Cathodic protection.

On new construction, many corrosion problems of the future can be prevented during the design stage of proposed faciliites. The type of metal most suitable for handling a given product, the type of surface treatment for the metallic structure, provisions for electrical isolation of new systems from old or foreign systems, and minimizing or avoiding coupling of dissimilar metals are but a few of the decisions which merit consideration during the project planning phase.

Protective coatings are recognized as a basic weapon in the battle against underground corrosion. It is known that if the metal of a structure does not contact an electrolyte, no corrosion will take place. Thus, the use of coatings is widespread, the desire being a coating material which is an impervious, inert substance, unaffected by temperature variance, mechanically sturdy enough to withstand soil and cyclic stress to which it is subjected underground, as well as potential damage from handling during transportation and construction. Commonly used coating materials consist of asphalt and coal tar enamels, asphalt and coal tar mastics, polyethylene and polyvinyl chloride tape applications, micro-crytaline wax compounds, and extruded plastic jackets or sleeves. Coating efficiences of the pipe line coatings in place are dependent not only on the material used, but also the care with which it was applied and the care exercised during structure installation. It is virtually a physical impossibility for any coated structure in place and backfilled to be without minute faults or "holidays", with small bare metal surfaces thus exposed and in direct contact with the surrounding soil or electrolyte. This situation is a classic example of the condition previously discussed concerning ratios of anodic and cathodic areas. Since the exposed metallic area at any coating fault will be relatively small compared to coated or cathodic areas surrounding it, corrosion activity will be concentrated on the small bare metallic area and early metal loss and penetration may be reasonably anticipated unless further protective steps are taken. In addition, all coating materials are subject to deterioration with time, thus exposing more metal surface to the corrosion process.

The accepted supplement to coating procedures is that of applying cathodic protection to the coated structure. In general, cathodic protection is a process whereby adequate quantities of D.C. current are impressed upon a given

structure to overcome the quantities of galvanic current generated and being discharged from the structure. This procedure is accomplished through the use of external current sources; either, galvanic anodes or impressed current systems. Galvanic anodes normally consist of zinc or magnesium alloys of varying shapes and weights to accommodate differing soil resistivity values, current outputs, and design life. In both cases, the anode metal is more active or higher in the electromotive series than the steel structure to which it is attached. Thus, (Fig. 13) a large galvanic cell has been deliberately created with the metal from the sacrificial galvanic anode being dissipated to prolong the life of the structure to which it is attached. The current flow, electrically speaking, is from the sacrificial anode through the earth onto the structure and is returned to the source through the leadwire connected to the structure and the anode.

The same principle holds true for impressed current systems (Fig. 14), except that in this case power is being derived from some external source such as rectifier units which convert A.C. electrical power to D.C. current, or possibly thermoeletric units which convert heat to electric power. The D.C. current is then routed through a groundbed composed of graphite rods, cast iron rods, or junk steel, and thence through the earth to the structure to be protected. Once again, a low resistant return path is provided between the structure and the power source to complete the circuit and to provide controlled current drainage from the structure.

Cathodic protection in various forms and to varying degrees can be applied to old existing structures as well as new construction.

Naturally, the cost of providing complete overall protection to bare structures involves a much greater expenditure than for similar coated structures due to the greater exposed surface area involved on the bare structures. Thus, partial or spot protection at areas subject to deterioration, as indicated by past history or investigative procedures, is often the course followed to reduce maintenance cost and commodity loss, and to prolong useful life of the structure or system.

In any case, whether on new construction or existing facilities, the use of cathodic protection must be justified economically. Since both the initial investment and projected operating costs of cathodic protection are directly dependent upon the design and effectiveness of the installation, it is of great importance that the type of

protective system utilized, amount of current required, and location of the protective current systems must be determined by thorough preliminary field investigation conducted by experienced personnel. Many survey techniques, interpretation standards, and an array of specialized instrumentation are utilized in determining the most economical and practical protective design for providing cathodic protection to a given system or structure. Upon completion of any protective installation, the system must be adjusted and a thorough checkout conducted to determine that adequate protection is being realized over the entirety of the pertinent structure; further, that any detrimental interference effects on foreign or isolated structures are detected and removed.

In as much as electrical grounding systems frequently complicate cathodic protection efforts and contribute to corrosion of other underground structures, possible improvement of grounding procedures and effect of stray current on underground electrical structures merit the following brief discussion.

In general, electrical grounding systems must be comprised of materials that are good electrical conductors with sufficient area in contact with the soil to provide resistance of the current path within the allowable limits, and to be resistant to the corrosion process. The major material utilized for grounding systems in the past has been copper due to its excellent conductance characteristics, reasonable cost, and corrosion resistant properties. As long as overhead power transimission lines utilizing wooden supports were used, very little corrosion damage was apparent from this procedure. However, with the advent of lead sheath cable, armored cable, and galvanized conduit for underground installation, this situation has changed considerably. Potential differences, due to galvanic couples of some of the most commonly used metals for underground electrical construction, are presented in Figure 15. As indicated, the commonly used metals are all anodic to copper, i.e., when coupled with copper in a common electrolyte, the metals will be dissipated to provide current to the copper to which they are attached. Probably the most serious situation here is the couple between lead and copper where even though the potential difference is not as great as indicated for the other couples, the dissipation rate of lead, approximately 75 pounds per ampere year of current, becomes an important factor.

Conditions being what they are today, considerable thought for grounding procedures should be given to utilization of

other metals for grounding materials, the two most common substitutes being zinc and high silicon cast iron anodes. Zinc anodes are generally considered more attractive because they not only provide a degree of protection to metals to which they are attached due to being higher on the electromotive series of metals, but also they exhibit relatively long effective life in most environments. Of interest is a comparison of grounding rod resistance values between standard copper and zinc grounding rods in varying soil resistivity ranges. This comparison, as presented in Figure 16, indicates the effectivness of the zinc anode, particularly when surrounded by a prepared backfill material. Number, spacing, and configuration of grounding rods to provide a specified resistance can be readily determined in most cases when the resistivity of an electrolyte has been acquired through measurements, based upon design data for zinc anodes. High silicon content cast iron anodes are less attractive due to the galvanic couple between the cast iron alloy and steel. Although the potential difference between the two is not great, being in the neighborhood of 0.10 volt, the steel pipe is nevertheless anodic to the cast iron anode.

Another important aspect of choice of grounding system materials involves the application of cathodic protection to underground facilities within the area. In case of a copper grounding system in contact with piping or conduit to be cathodically protected, it is not uncommon to encounter current requirements 40 to 50 times as great to provide protection for both the copper grounding system and the piping as would be required to protect the piping alone if the copper grounding system was not connected to it. On the other hand, zinc grounding system under the same circumstances would actually supplement the cathodic protection system. In many areas, involving both plant piping and grounding systems, the proper choice of grounding materials thus becomes a decision of major economical importance.

Often a piping system also serves as part of a grounding system. Once again, the coupling of a copper grounding system with steel piping results in dissipation of the steel and should be avoided. In addition, today's standard acceptance of high resistance coatings for pipe line construction actually provides, in many cases, a very poor grounding device.

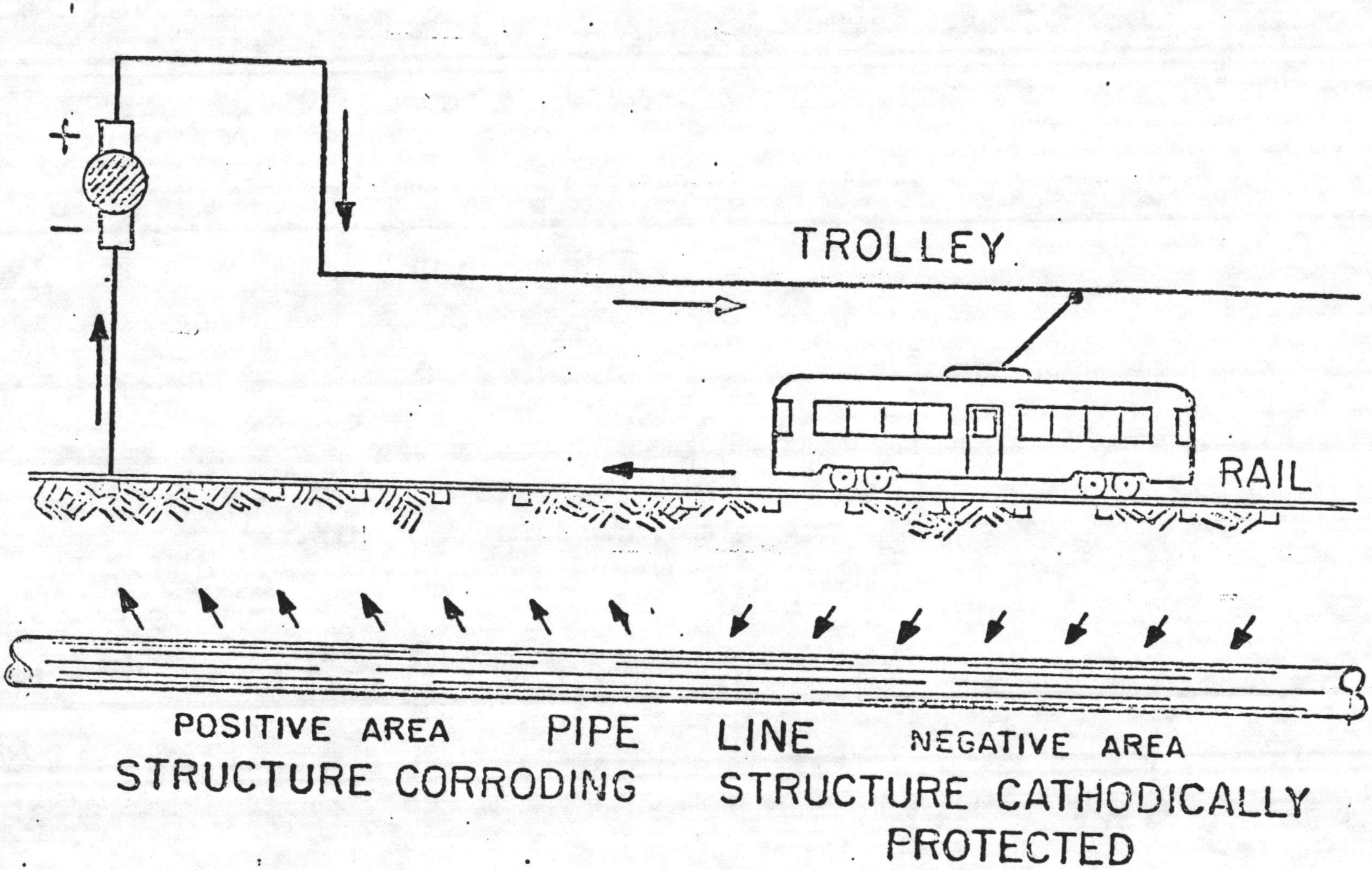
Neutral conductors for underground electrical distribution systems often consist of bare copper cables with the neutrals of transformers and electrical apparatus housings frequently grounded to the neutral conductor. Water piping

for water-cooled transformers and lead-sheath cables is also often grounded to the neutral conductor cable. Once again, the galvanic couples and resulting potential differences between copper and steel and copper and lead is encountered and deterioration of both the steel water piping and lead sheath cable may be reasonably anticipated. The answer to this problem appears to be a neutral conductor provided with a polyethylene or polyvinyl direct burial jacket which will provide insulation between the copper conductor and the earth, and also provide additional self-contained grounding rods.

Any underground power cable equipped with an adequate polyvinyl or plyethylene jacket will not be influenced by stray current from cathodic protection systems or other stray current sources. Certainly, the lead sheath cable, which parallels a cathodically-protected structure or lays within the area of influence of cathodic protection installations, is receptive to pickup and uncontrolled discharge of stray current resulting in metal deterioration. Interference testing and adequate bonding procedures are the answers to this problem. Lead sheath cable installed in metallic or non-metallic duct systems is not subject to stray current influence, but may be subject to galvanic corrosion action at points within the ducts at which moisture may collect.

Any metallic objects such as pole anchors, grounding rods, cables, or grids which fall within the area of influence of a D.C. current source are exposed to varying degrees of deterioration depending largely upon the metals involved, size of structure, and their proximity to the D.C. current source. In cathodic protection installations, judicious placement of current sources, consistent with design requirements of the structure or system to be protected, is taken into consideration to minimize the possibility of interference on foreign structures. Prior to adjustment and checkout of a protective system, native state potential values on all foreign structures within the area of influence of the current source should be acquired. Upon energizing and adjusting the protective system, potential measurements on the foreign structures involved are again acquired to determine any effects being experience from stray current. In the event that detrimental interference effects on a foreign structure are detected, the situation is relieved by either providing a controlled resistance bond from the affected structure to the current source or providing the affected structure with a small protetive system of its own, normally in the form of self-contained sacrificial anodes. The problems involved, particularly in congested areas involving a number of utilities with the

effects of stray current or interference can be complex in nature and costly in results, unless corrected. As in the case of design, installation, and checkout of protective systems, the detection and correction of interference problems can best be solved by personnel experienced in the specialized field of corrosion mitigation.



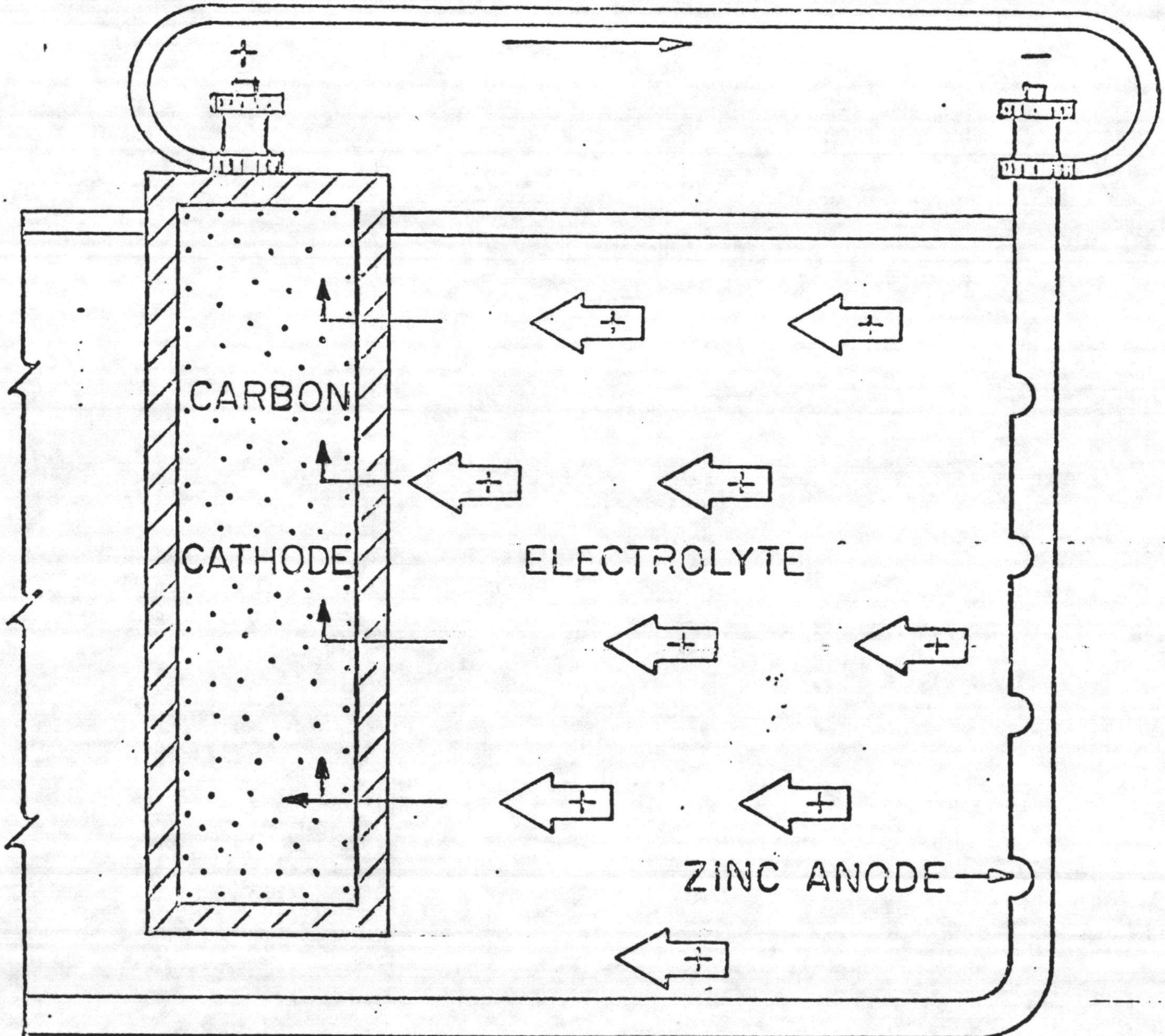
ELECTROLYSIS CORROSION

FIGURE 1

ELECTROMOTIVE FORCE SERIES

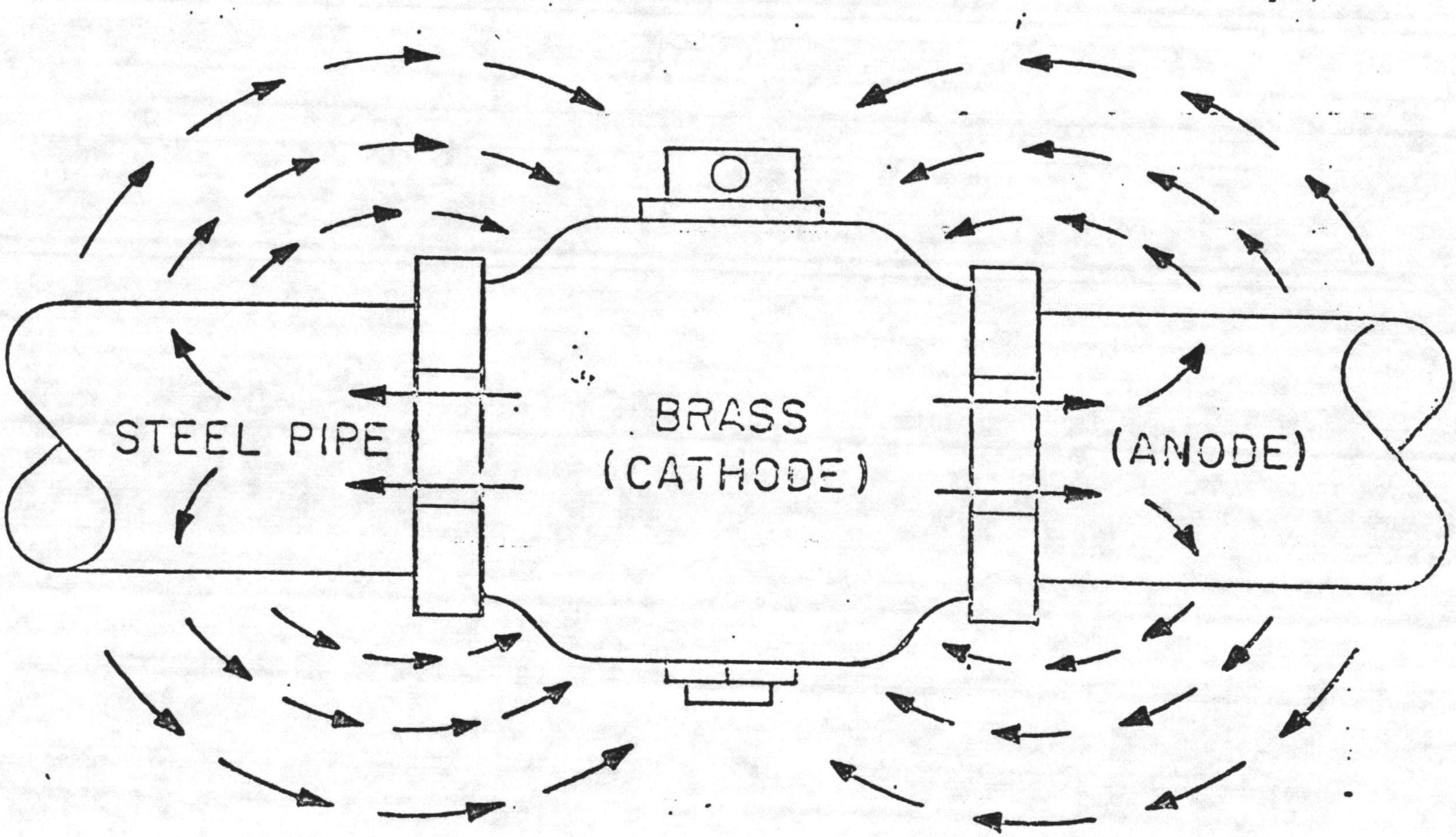
Electrode Reaction		Standard Electrode Potential E^0 (Volts), 25^0 C
Magnesium -	Mg^{++} +2e$^-$	-2.34
Zinc	Zn^{++} +2e$^-$	-0.762
Iron	Fe^{++} +2e$^-$	-0.440
Lead	Pb^{++} +2e$^-$	-0.126
Hydrogen	$2H^+$ +2e$^-$	-0.00
Copper	Cu^+ _e$^-$	+0.522

FIGURE 2



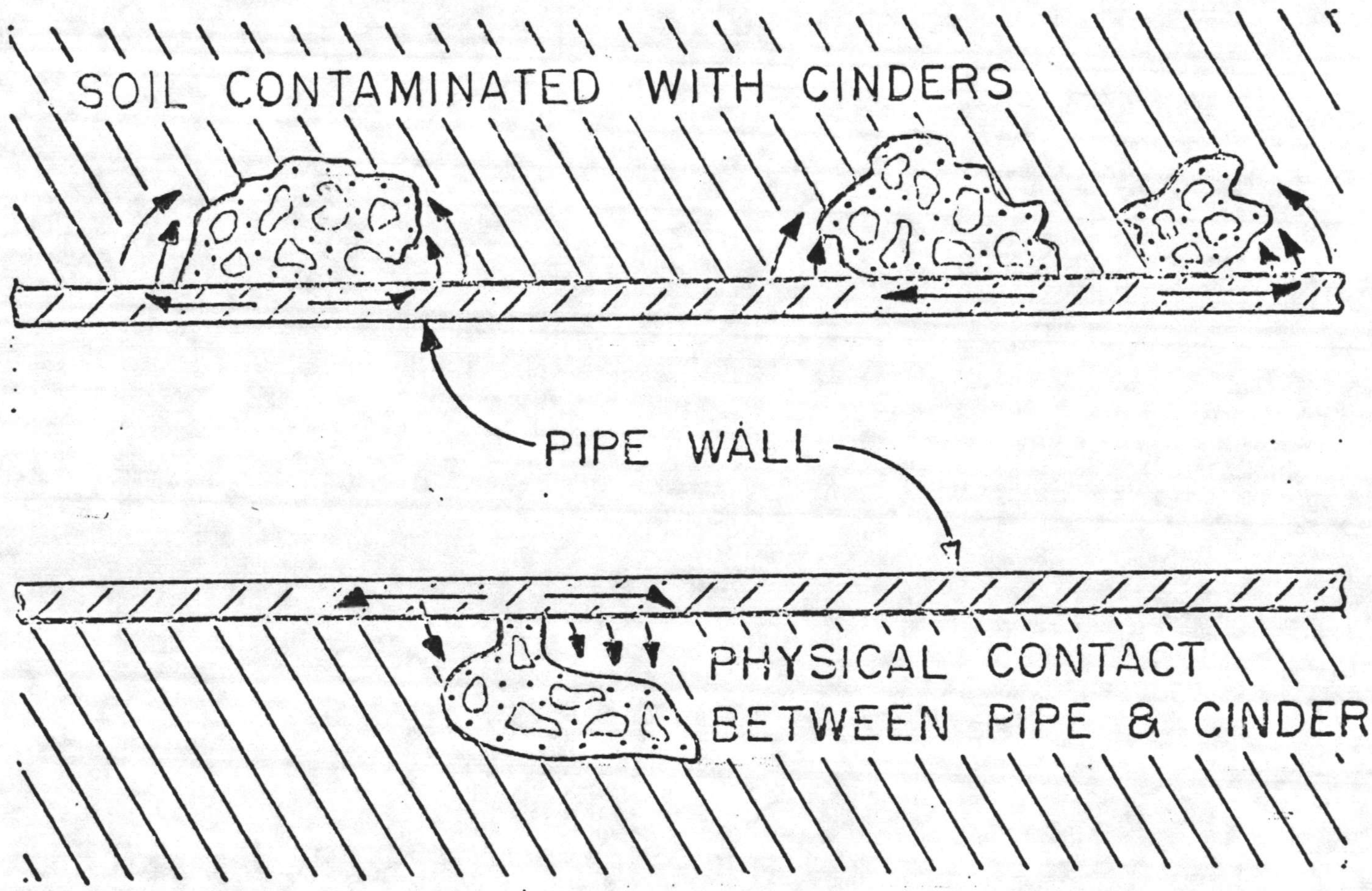
GALVANIC CELL – DISSIMILAR METALS

FIGURE 3



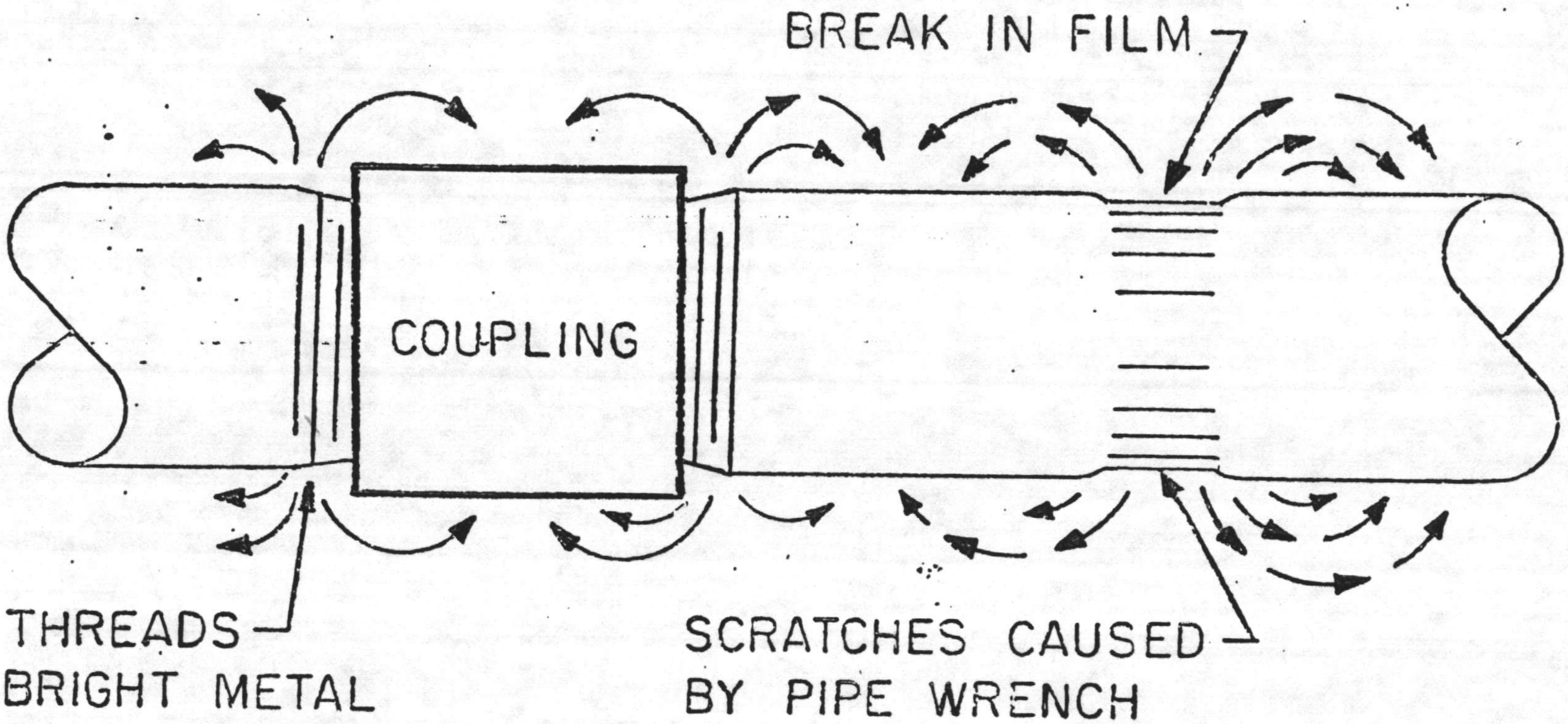
CORROSION CAUSED BY DISSIMILAR METALS

FIGURE 4



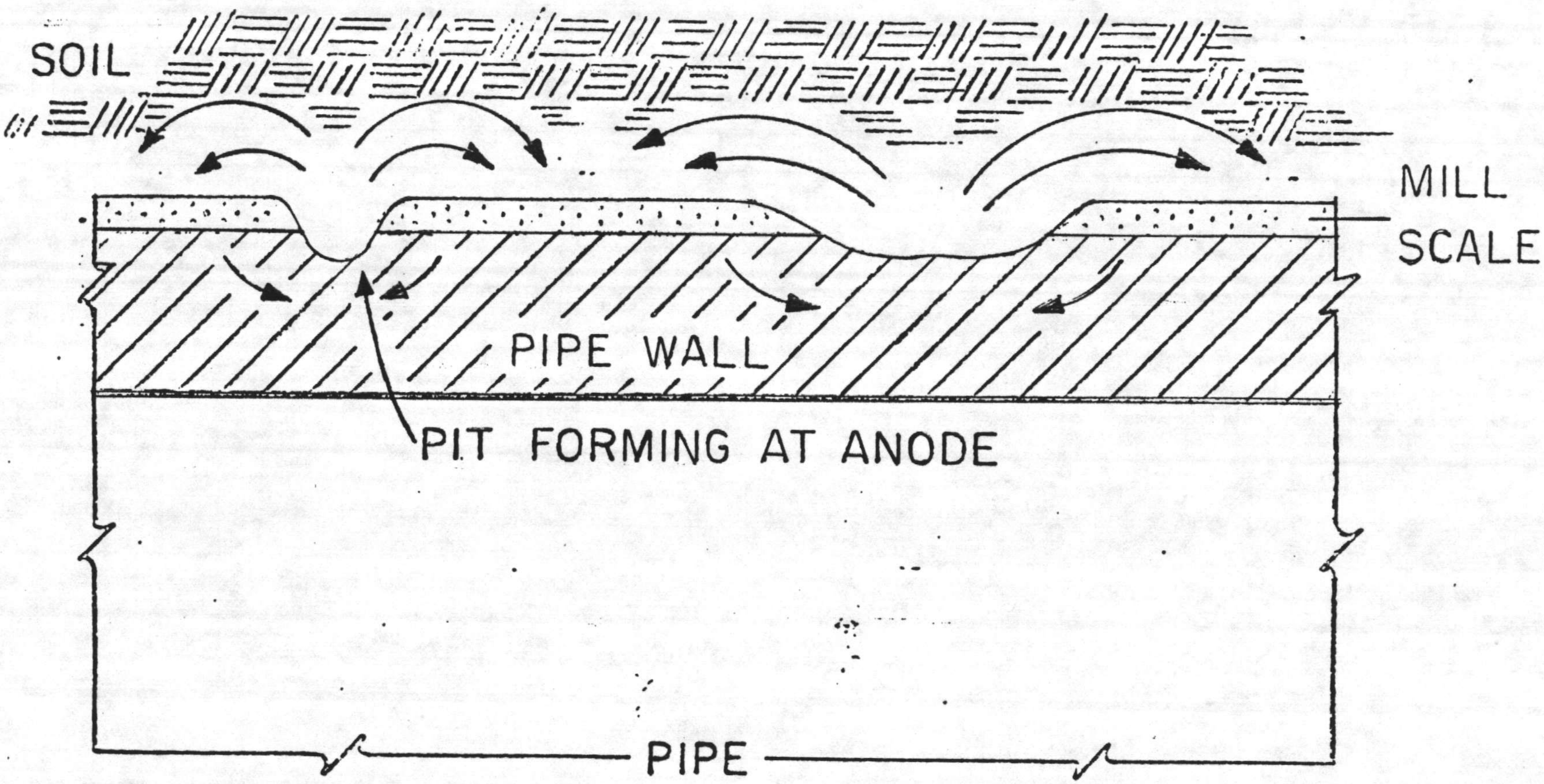
CORROSION DUE TO CINDERS

FIGURE 5



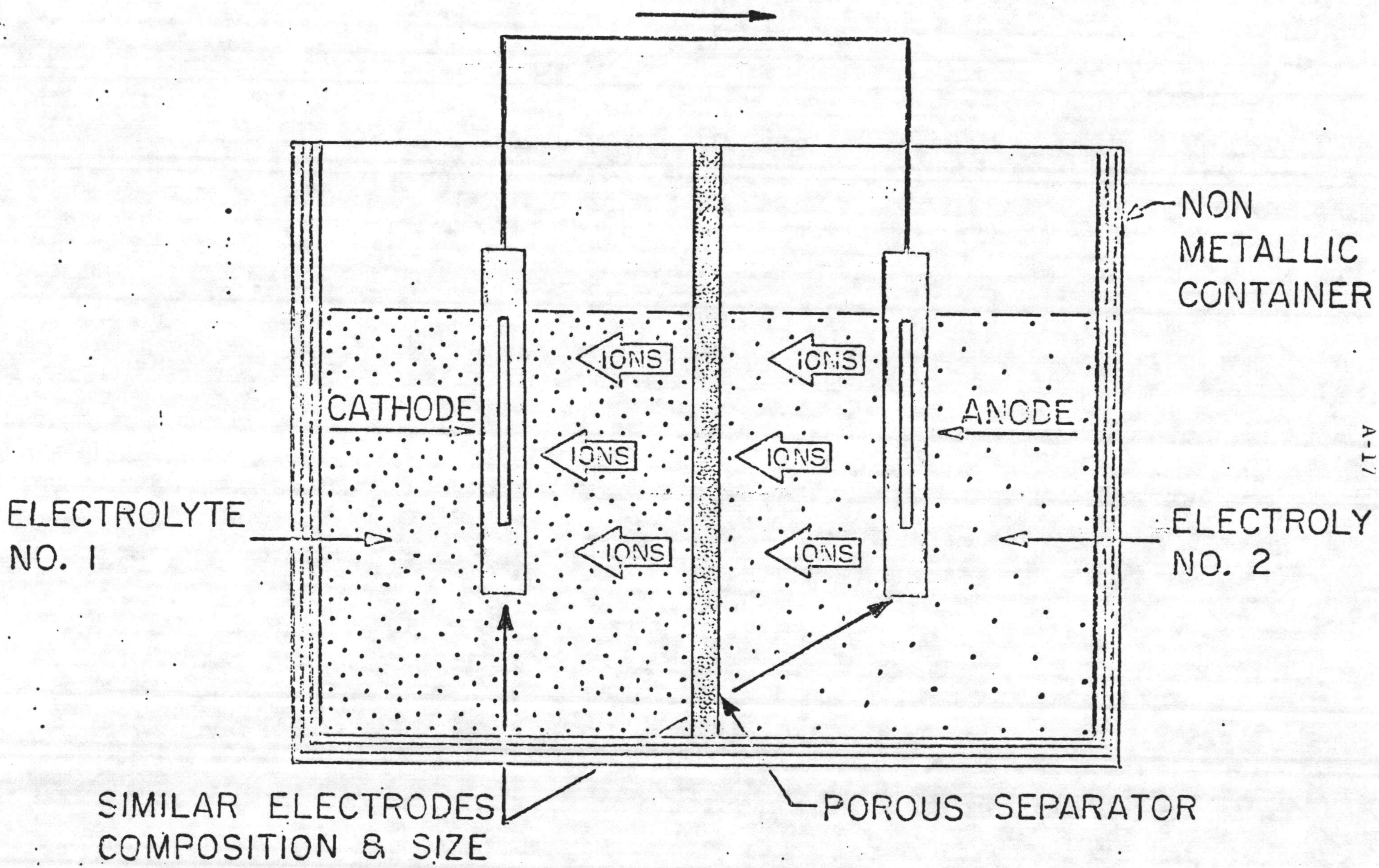
CORROSION CAUSED BY DISSIMILARITY OF SUR-
FACE CONDITIONS

FIGURE 6



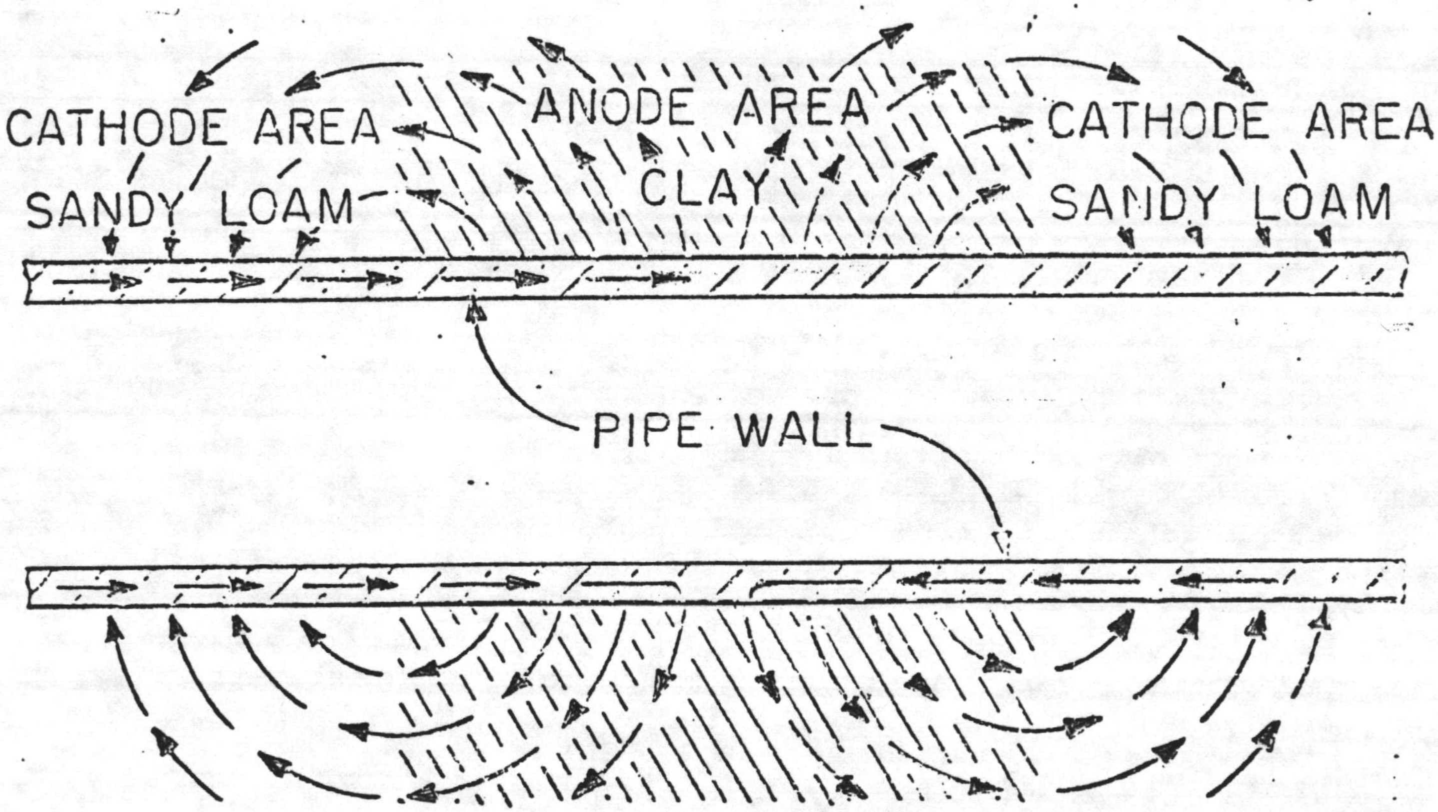
PITTING DUE TO MILL SCALE

FIGURE 7



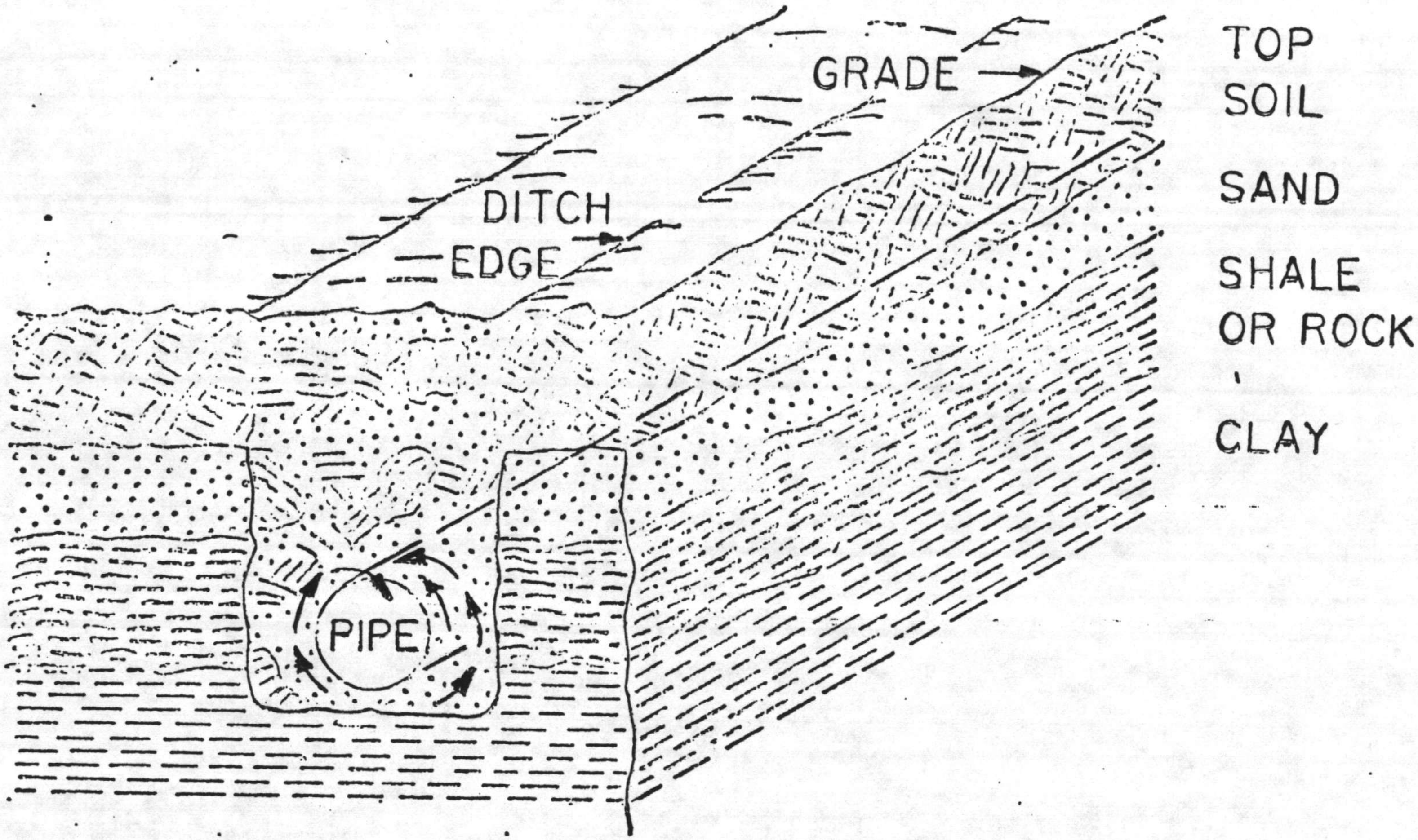
GALVANIC CELL - DISSIMILAR ELECTROLYTE

FIGURE 8



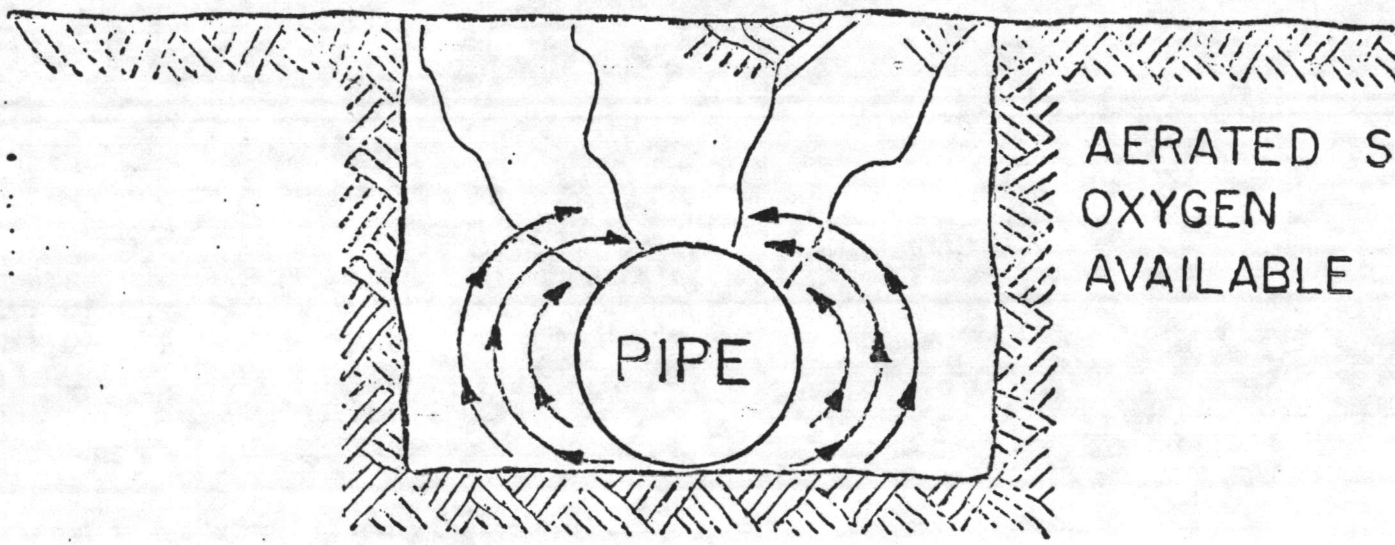
CORROSION CAUSED BY DISSIMILAR SOILS

FIGURE 9



CORROSION CAUSED BY MIXTURE OF DIFFERENT SOILS

FIGURE 10



CORROSION CAUSED BY DIFFERENTIAL
AERATION OF SOIL

FIGURE 11

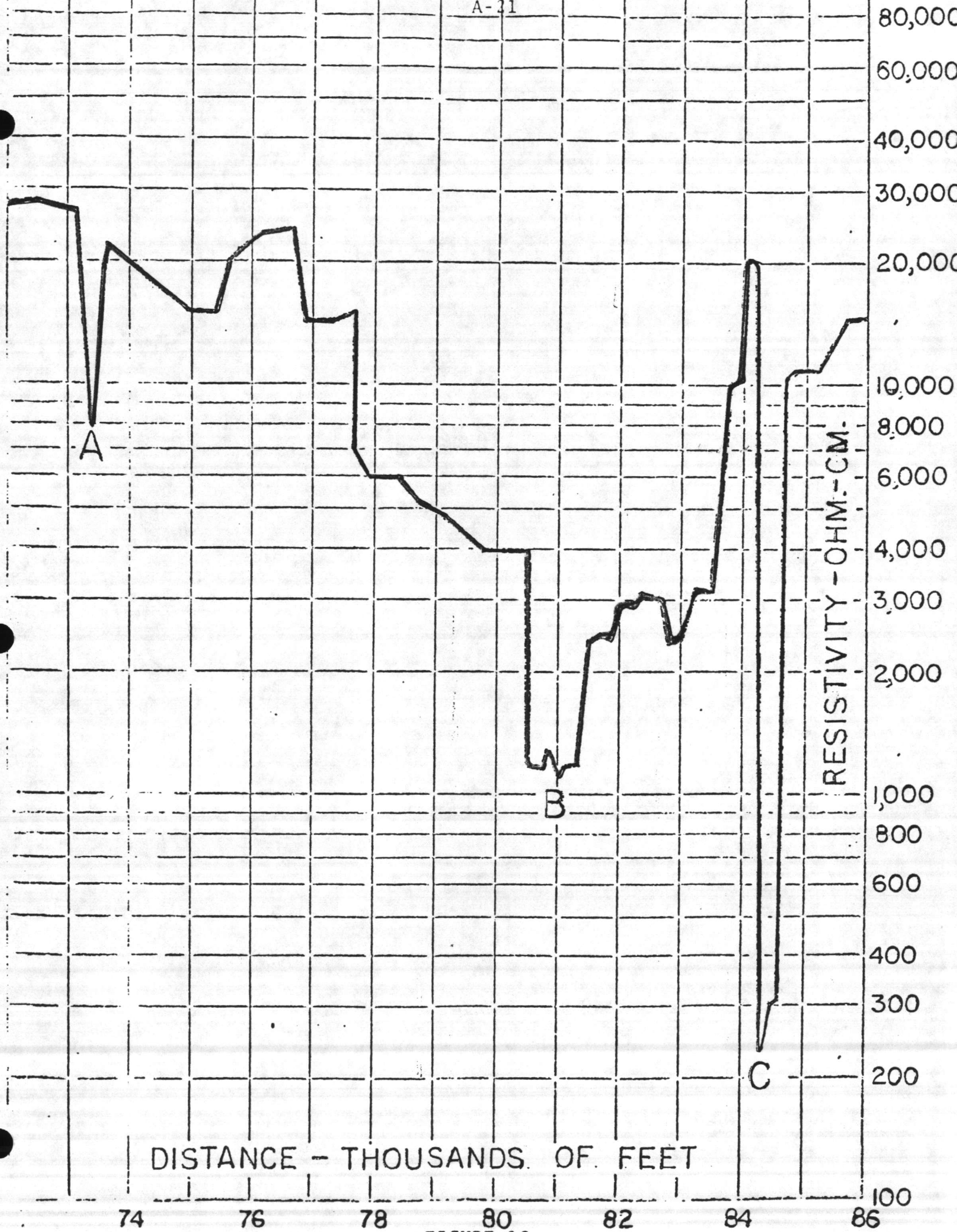
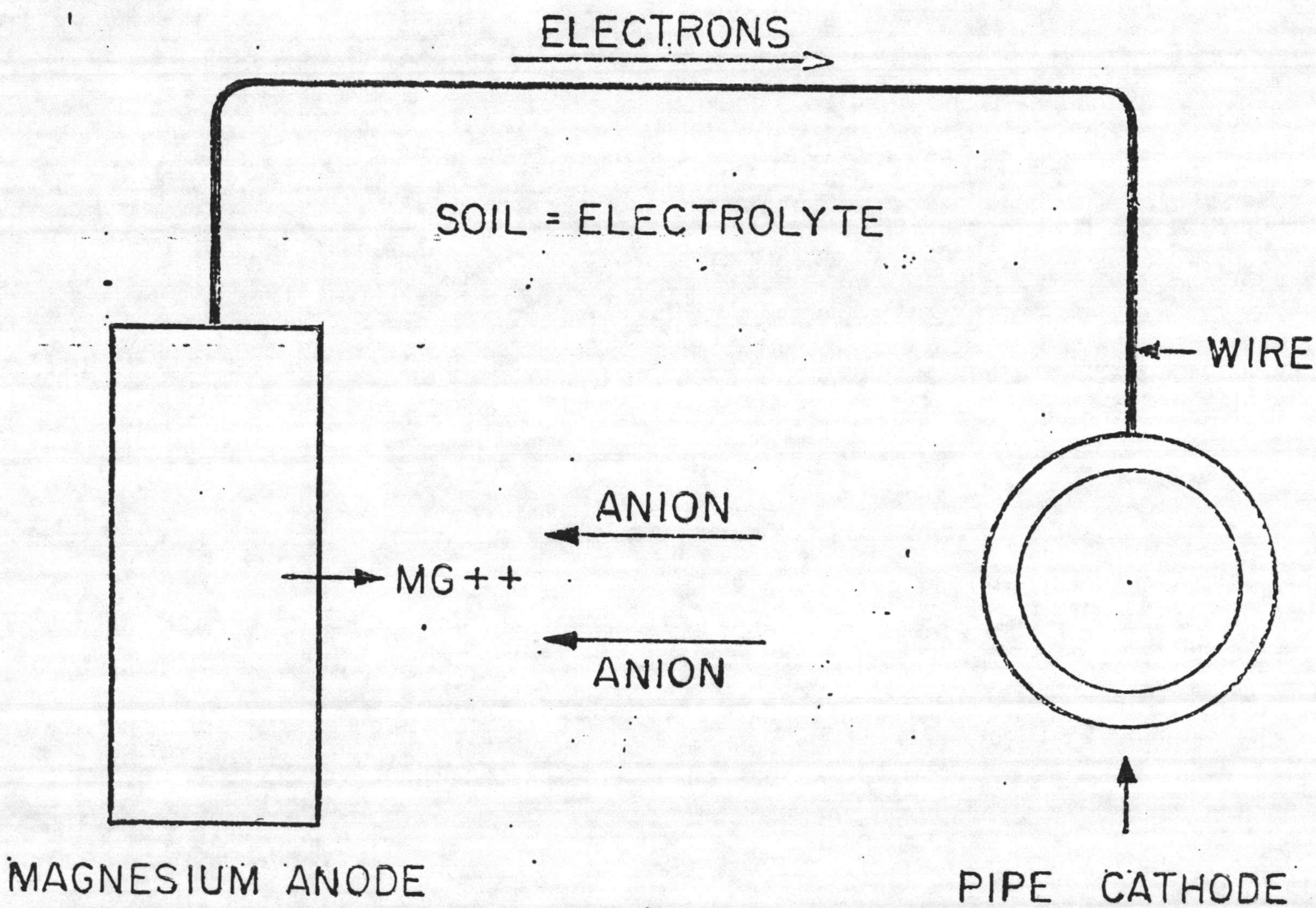
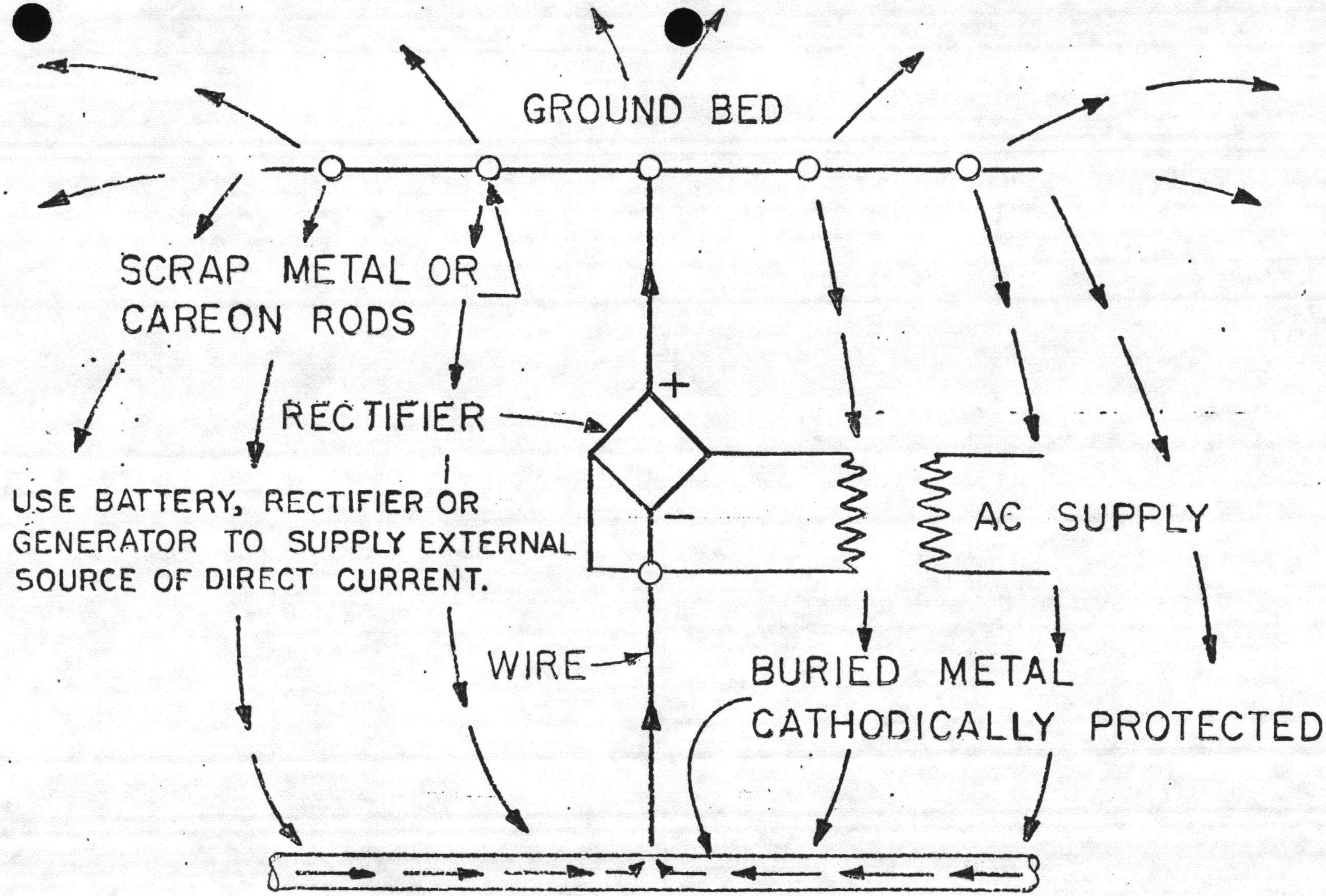

80,000
60,000
40,000
30,000
20,000
10,000
8,000
6,000
4,000
3,000
2,000
1,000
800
600
400
300
200
100
RESISTIVITY - OHM.-CM.
A
B
C
DISTANCE - THOUSANDS OF FEET
74
76
78
80
82
84
86

FIGURE 12



THE CATHODIC PROTECTION BATTERY

FIGURE 13



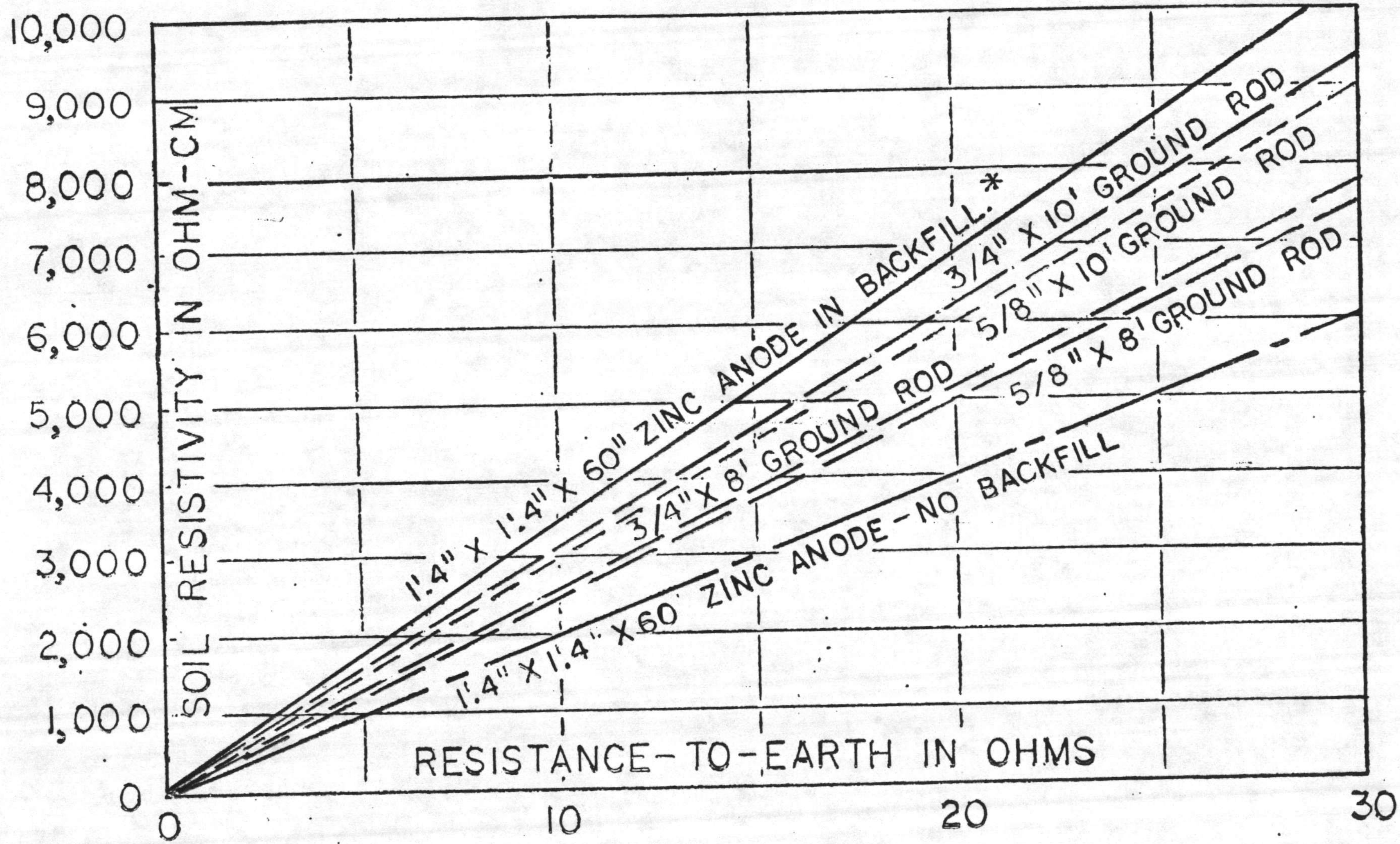
SCHEMATIC DIAGRAM OF CATHODIC PROTECTION OF BURIED METALS

FIGURE 14

GALVANIC COUPLE POTENTIALS

Galvanic Couple	Voltage Difference Volt
Iron-copper	0.55
Aluminum-copper	1.55
Lead-copper	0.45
Zinc (galvanizing)-copper	0.99

FIGURE 15



RESISTANCE OF ZINC ANODE VS COPPER CLAD GROUND RODS

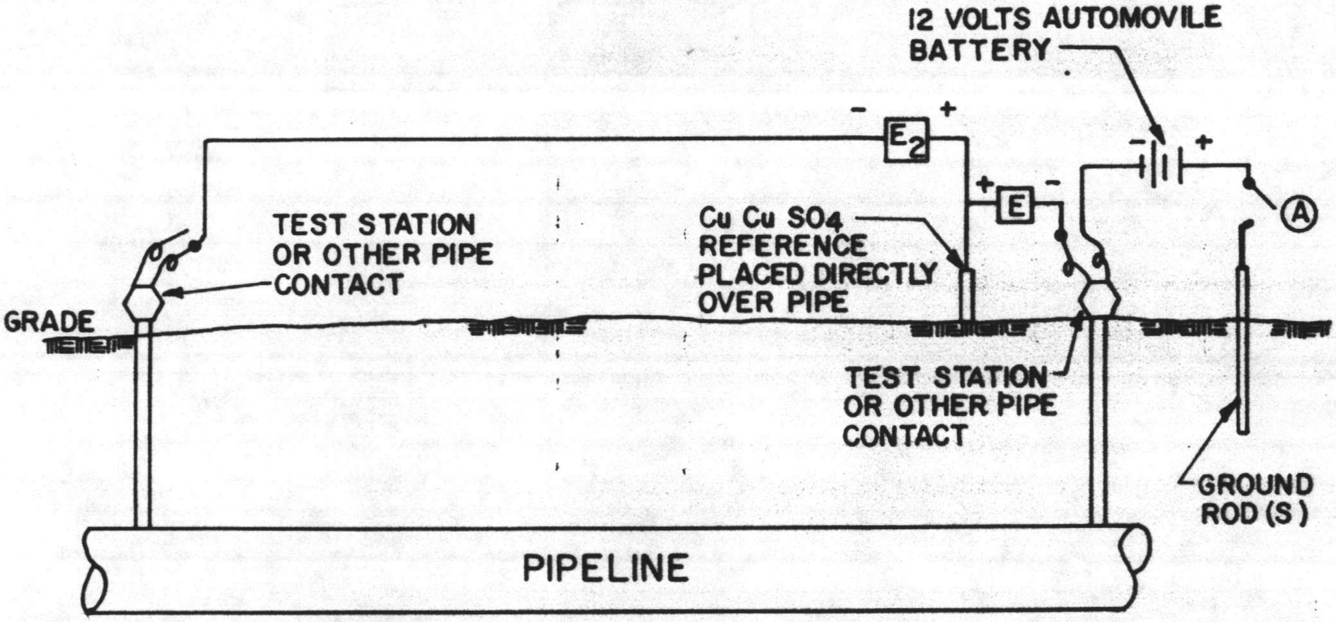
FIGURE 16

APPENDIX G

PHOTOGRAPHS

APPENDIX H

DRAWINGS



TEST PROCEDURE

1. ESTABLISH POSITIVE ELECTRICAL CONTACT TO THE PIPE AT EACH EXTREMITY OF SECTION TO BE TESTED.
2. WITH THE SWITCH AT (A) OPEN AND CLOSED, ELECTRICAL CONTINUITY FROM TEST STATION IS INDICATED WHEN E_1 AND E_2 ARE THE SAME MAGNITUDES.
3. WITH THE SWITCH AT (A) OPEN AND CLOSED, ELECTRICAL DISCONTINUITY FROM TEST STATION TO TEST STATION IS INDICATED WHEN E_1 AND E_2 ARE DIFFERENT MAGNITUDES.

MDA MENENDEZ-DONNELL & ASSOCIATES, INC.
GCPS GENERAL CATHODIC PROTECTION SERVICES, INC.

ELECTRICAL CONTINUITY TEST UNDERGROUND PIPELINE

NO.	REVISION	DATE	DES / DR H.D.V. / SCALE NONE	CK / APP / DATE 10-15-84	DWG NO. SK-6148-A	REV