

# HAWAII DEEP WATER CABLE PROGRAM

## PHASE II-A

### TASK 3

## DEEP WATER ELECTRICAL CABLE CORROSION TESTING

Department of Planning and Economic Development

TK3351  
H35  
PIIA  
T3

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**DEEP WATER ELECTRICAL CABLE  
CORROSION TESTING**

Prepared by

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TABLE OF CONTENTS

	Page
Abstract . . . . .	1
Introduction . . . . .	2
A. Long-Term Corrosion Tests . . . . .	3
Background . . . . .	3
Experimental . . . . .	4
Results. . . . .	5
Discussion . . . . .	6
B. Corrosion and Biofouling of Cupro-Nickel . . . . .	6
Background . . . . .	6
Experimental . . . . .	7
Results. . . . .	7
Discussion . . . . .	7
C. Crevice Corrosion of Stainless Steels. . . . .	7
Background . . . . .	7
Experimental . . . . .	9
Results and Discussion . . . . .	10
D. Abrasiveness of Hawaiian Rocks . . . . .	11
Background . . . . .	11
Experimental . . . . .	12
Results. . . . .	12
References . . . . .	13
Table 1. Typical warm water Conditions at NRELH . . . . .	15
Table 2. Nominal Compositions of Alloys Tested. . . . .	16
Table 3. Results of First Series of Crevice Corrosion Tests . . . . .	17
Illustrations	
Figure 1. Map of Test Site. . . . .	18
Figure 2. Detailed Map of Sample Rack Location. . . . .	19
Figure 3. Overall Arrangement of Warm and Cold Water Test Troughs . . . . .	20
Figure 4. Details of a Test Trough. . . . .	21
Figure 5. Crevice Corrosion Sample with Partially Disassembled Multiple Washer Assembly . . . . .	22
Personnel. . . . .	23

## ABSTRACT

Initial results from a study of the behavior of some typical and some candidate deep sea cable materials under Hawaiian conditions are presented. The effort is aimed at the development of a database on the corrosion, fatigue, and abrasion of materials in Hawaiian waters. Four components of the study have been initiated

-a long-term comparison study of the rates of metallic corrosion in Hawaiian surface waters with rates measured in a wide variety of test sites around the world; six month data show that aluminum alloy 5086 does not pit and that sulfate reducing bacteria are active in the corrosion of carbon steel,

-a long-term study of the corrosion and macrofouling of cupronickel (CuNi); six month data show that the thin black film of corrosion products is easily removed by currents or surges and that no macrofouling has developed in this time period.

-a study of the crevice corrosion behavior of various high alloy stainless steels which are candidate materials for use as armour wire of the deep sea cable; initial results are presented, and

-a study of the abrasiveness of Hawaiian rock constituents to various stainless steels; the initial tests have been performed with silicon carbide abrasives for the purpose of ranking and have shown that the wear rate differs widely between ferritic and austenitic stainless steel types due to differences in work hardening behavior.

The background to each component of the work is discussed as well as the expected differences and similarities between Hawaiian and temperate zone conditions.

## INTRODUCTION

The Hawaii Deep Water Electrical Transmission Cable Demonstration Program (HDWC Program) is a research, development, and demonstration program<sup>1</sup> that is being conducted to

- 1) determine the feasibility of establishing an electrical transmission cable system in ocean depths of up to 7,000 feet and over a distance of more than 150 miles,
- 2) determine the engineering problems and their solutions of deploying, retrieving, and repairing a deep water cable in the Hawaiian environment, and
- 3) develop commercial cable criteria that can be used by private industry or government agencies for the design, installation and maintenance of deep water electrical transmission cable systems.

A successful cable system of this nature could be used to transport electric power generated from the geothermal areas on Hawaii to Oahu where most of the state's population and industry are located.

The work reported here is part of this HDWC Program. The general task is to develop information on the resistance of various cable materials to the various destructive forces in the environment in order to insure long life of the installed cable. Since the final cable design may be either a new design or an extension of an existing design and may use either conventional or new cable materials<sup>1</sup> to be decided later, the work includes both conventional materials and some possible candidate materials which have not been used in previous designs. It also includes a component of fundamental studies in order to make it easier to later predict the performance of materials which may become candidate materials at a later stage in the design process.

The areas of study are corrosion, abrasion, and fatigue of relevant materials in Hawaiian ocean waters obtained from both surface and deep ocean sources. This report presents the initial work performed during the start-up period.

The work accomplished to date can be divided into the following topic areas

- o long-term corrosion testing,
- o corrosion and fouling of cupronickel,
- o crevice corrosion of stainless steels, and
- o abrasiveness of Hawaiian rocks.

The background, experimental procedure and results are given below for each topic area.

#### A. LONG-TERM CORROSION TESTS

##### Background

Past experience is that the corrosiveness of seawater to many common metals is little influenced by geographic location. For example, data for carbon steel exposed for long periods of time in surface water around the world show corrosion rates varying only between 25 and 200  $\mu\text{m}/\text{year}$  (1 and 7.7 mpy).<sup>2</sup> It is thought that the variations with location in the various factors which affect corrosion counteract each other to give this relatively narrow spread. For example, higher water temperatures speed up chemical reactions but also lower the solubility of the oxygen which is necessary for the reaction to take place.<sup>3</sup> In warmer water the fouling layers also are thicker and thus provide a greater barrier to oxygen diffusion to the corroding metal surface.<sup>3</sup>

In some locations sulfate reducing bacteria may affect the corrosion process. These anaerobic bacteria can survive in sediments and under fouling organisms and corrosion films.<sup>3</sup> They can increase the corrosion of steel because they indirectly affect the corrosion process by depolarizing the cathode: they consume hydrogen in the sulfate reducing process and iron sulfide is a product of the total reaction--iron corrosion plus reduction of sulfate to sulfide.<sup>3</sup> Since the steel surface is at a different potential than steel corroding under aerobic conditions it is not uncommon to see "long line" corrosion effects in cables which pass through both sediments and open areas.<sup>3</sup> This results in increased corrosion because of the driving force from the potential differences between the different sections.

No data base is available for Hawaiian waters for comparison with these global data, which primarily are from temperate regions. Some tentative results from short exposure tests off Kewalo Basin and Lanikai on Oahu<sup>4</sup> indicate that the corrosion rate of steel may be considerably higher than those listed above, at least when there is substantial current.

In the deep ocean the temperature, the oxygen levels and the pH are lower than at the surface. Experiments conducted at 1,400 m (5,000 ft) depth offshore California<sup>5</sup> showed that many common metals corrode more slowly at depth, while those alloys which may corrode by pitting, such as

stainless steels and aluminum alloys, tend to pit more extensively at depth. It has been suggested that the cause of this behavior is the low oxygen concentration at depth.<sup>3</sup> However, an extensive laboratory study of the electrochemical behavior of aluminum alloys in seawater has shown that the pitting phenomenon is more complicated--it depends on the carbon dioxide/carbonate balance which is a function of pH, temperature and oxygen level.<sup>6</sup> Extrapolation from these results have resulted in a suggestion that most aluminum alloys will pit in temperate, arctic and deep ocean seawater while they may not pit in tropical surface seawater. These predictions have been confirmed in tests performed at the Natural Energy Laboratory of Hawaii (NELH) at Ke-ahole on the Island of Hawaii. It was found that aluminum alloys exposed in test loops fed with surface water do not pit but develop a protective inorganic film, while alloys exposed in water pumped from a depth of 630 m (2,000 ft) tend to pit.

Aluminum is not a commonly used armor material in power cables. The above information is provided, however, to illustrate that performance of materials in Hawaiian waters may not be readily predictable from data obtained in other locations and there may be differences in corrosiveness between deep ocean and surface waters. It is suggested that these differences may be more pronounced for materials which tend to pit and which depend on a steady oxygen supply and possibly other factors to maintain resistance to pitting. Stainless steels belong in this group of materials and certain stainless steels could be candidates for use as armour wire on power cables. The above discussion also illustrate the need for a general data base on corrosion in Hawaiian waters.

#### Experimental

Initiation of this study coincided with start-up of an ASTM (American Society for Testing and Materials) comparative test of the corrosiveness of seawater around the world. The effort is organized and coordinated by ASTM's subcommittee G-1.09 on Corrosion in Natural Waters. This study provides an excellent opportunity for obtaining comparison data which would improve the certainty with which corrosion data from other parts of the world can be applied to particular Hawaiian uses.

Three test racks were deployed on July 7, 1983. They each contain eight specimens of the following materials: low carbon steel, copper alloy C 70600 (90-10 cupronickel) and aluminum alloy 5086-H 116 (Al-0.45Mn, 5.0 Mg. 0.15 Cr). Removal is scheduled after 0.5, 1, 3, and 5 years. The last

samples will be removed after scheduled completion of the HDWC Program. However, the information should prove to be of general interest and data from the short term samples may be of benefit in the design and construction of laboratory at at-sea test lengths of cable planned for the latter part of the HDWC Program.

Each rack is 1.5 m long, 0.3 m wide and made from angle profile material: monel for the CuNi and steel, and aluminum alloy for the Al 5086 samples.

The racks are fastened to the cold water intake pipe at the NELH. They are some 230 feet from shore at water depths of 45 feet (Al), 48 feet (steel) and 50 feet (CuNi). The racks are 1.5 - 2 m apart and strapped to the top of the 1 foot diameter polyethylene pipe with plastic tie straps. The samples are located horizontally and are about 2-3 feet above the ocean floor.

The site represents essentially open ocean conditions as it is close to the point where the ocean floor begins to drop off rapidly and is affected by a large gyre of current which almost continually brings open ocean water past the Point. At the time of deployment, for example, the current was about 0.5 knots, flowing North, and this represents very mild conditions. The site location is shown in Figures 1 and 2. Typical water conditions are listed in Table 1.

### Results

A dive to the racks was made NELH personnel on November 3, 1983. Visual inspection revealed that the cupronickel samples had turned black but showed no fouling, and the aluminum plates had developed a film of aluminum hydroxide and some fouling.

Two samples were removed from each rack on January 10 after 6 months of exposure. At the time of removal the coast was exposed to substantial southwesterly swells which could be felt even at the depth of the samples.

The cupronickel samples were found to be free of any film. Some remnants of the black film reported from the November 3 dive could be seen in surface irregularities. It is suggested that the water turbulence associated with the swells may have removed the black film.

The samples of 5086 aluminum alloy had a calcareous film on the surface and colonies of bryozoa which showed indications of fish grazing on the fouling. No pitting was observed.



The steel samples had a 2-3 mm thick layer of corrosion products. The upper layer was typical rust and covered a thick layer of black iron sulfide which clearly indicates the action of sulfate reducing bacteria. The steel surface under this layer showed the micropitting which is typical of this kind of attack.<sup>3</sup>

The samples have been forwarded to the LaQue Center for Corrosion Technology for final cleaning and weighing and comparison with samples from other parts of the world.

#### Discussion

Definite conclusions should not be drawn at this early stage in the experiment. It is noteworthy, however, that clear evidence of the action of sulfate reducing bacteria was seen for the steel. This could mean that possible long line effects, as discussed above, may have to be counteracted by some corrosion protection system if carbon steel wires are used in the deep water cable construction.

### B. CORROSION AND BIOFOULING OF CUPRO-NICKEL

#### Background

Almost any surface that is exposed in the upper 200-300 m of tropical ocean waters for only a few months will develop a thick film of biofouling. The film may be beneficial to the material by reducing the diffusion rate of the oxygen which is necessary for corrosion to take place; and by reducing local water velocities it may protect materials with weak surface film otherwise destroyed by rapidly flowing water. The biofilm may also be detrimental to the base material in many cases: it may penetrate and destroy organic coatings; it may result in local oxygen concentration cells which may give pitting of some materials; and it may be the medium in which sulfate reducing bacteria grow and these bacteria may increase corrosion rates. The fouling may also substantially increase the weight and hydraulic diameter of suspended structures. For a potential interisland submarine cable it is not clear at this stage whether biofouling will be beneficial or detrimental: that will depend on the final design and other considerations. However, the option to design for biofouling control should remain open at this time and some of the necessary knowledge on the rates of fouling of different materials should be obtained.

It has been known since the 1830s that copper resists biofouling, presumably because of the slow release of toxic cuprous ions in the

corrosion reaction.<sup>3</sup> Copper has very low resistance to high velocity seawater but when alloyed with nickel the combination of fouling and velocity resistance is optimized. The Cu-10%Ni-2%Fe is the best alloy for fouling resistance while the 30% Ni alloys have somewhat better velocity resistance.<sup>3</sup> Cable wraps of Cu10Ni were tested as part of the development of the OTEC riser cable. Some of the tests were performed by the author off-shore at Ke-ahole, at 8 and 65 m (25 and 200 ft) depths.<sup>11</sup> The results were that absolutely no biofouling developed during the 13 month duration of the test but that some localized corrosion did take place.

The present study was initiated in order to develop more detailed information on the performance of cupronickel in Hawaiian waters.

#### Experimental

Copper-10% Nickel-1% Iron alloy (CA 00706) is part of the ASTM study discussed above. Details of the methods of testing are given there.

#### Results

As previously discussed, the Cu10Ni develops a black surface film due to corrosion. No fouling is seen after six months exposure. The black film appears to be loose, as found earlier,<sup>11</sup> and apparently may be washed away by moving water.

#### Discussion

It is, as yet, too early to make a detailed evaluation of the results. The Cu10Ni obviously has substantial resistance to bio-fouling in Hawaiian waters.

### C. CREVICE CORROSION OF STAINLESS STEELS

#### Background

The armour wire most commonly used in power cable construction is so-called "plow steel" or "improved plow steel," i.e., medium carbon steel or high carbon (1085) steel wire cold drawn or hardened and tempered. For OTEC riser cables it has been proposed that some of the relatively newly developed high alloy stainless steels be used.<sup>10</sup> These steels are resistant to general seawater corrosion under most conditions and also to the stress corrosion and hydrogen embrittlement problems which the "plow" steels may encounter. OTEC riser cables conduct the power generated by a floating OTEC plant from the platform to the land-connected power cable lying on the ocean bottom several thousand meters below. The riser cables will experience more fatigue, static stressing, abrasion and exposure to

corrosive conditions than bottom laid cables because of the long, suspended length of cable and the motion of the floating platform due to waves and currents.

For a potential interisland submarine cable system it is conceivable that demands of long life and repairability involving lifting of long sections of cable from deep ocean could work in favor of using the more expensive stainless steels for armour wire instead of the conventional "plow" steels. Until the final decision is made it is useful to collect some information on the performance of these steels in Hawaiian waters. This information can then become part of the decision making process.

Long-term tests in flowing warm seawater at the NELH have shown that stainless AL-6X does not corrode.<sup>12</sup> Preliminary results from one year exposure in flowing cold, deep ocean waters from the same facility indicate that AL-6X and 29-4-C are fully resistant to general corrosion in this water also.<sup>13</sup>

During offshore testing of OTEC riser cable models<sup>11</sup> it was found that AL-6X was resistant to attack except that serious crevice corrosion developed under pieces of fiberglass tape which had been used to hold the wires in place and which were not really part of the test. This was unexpected, as AL-6X is considered to be generally resistant to crevice corrosion in seawater.<sup>3</sup> It was felt that the attack could be explained in a number of ways. It could, for example, be due to attack from the chlorinated compounds in the fiberglass tape glue; it could be caused by the fact that the crevice formed under the tape is very tight which promotes attack; or it could be due to differences in water chemistry between the Hawaiian site and the temperate zone waters where previous tests had been conducted. It is also possible that AL-6X is inherently less resistant than generally thought--it is a relatively new steel for which the data base is still being developed. These considerations generated the current study of crevice corrosion of stainless steels in Hawaiian seawaters.

Crevice corrosion is localized attack of a metal in a crevice or immediately outside a crevice. The latter case is typical of copper alloys and is due to metal ion concentration cells.<sup>14</sup> The former case is more common and is typical of stainless steels and aluminum alloys. The attack develops after the oxygen in the crevice is used up in the normal surface reaction. The crevice then becomes anodic to the open surface exposed to oxygen containing water. Because of the usually large area difference

between anode and cathode the attack may proceed rapidly. The process may result in the accumulation of highly acid liquid in the crevice ( $\text{pH} < 2$ ) and when this liquid leaks out it may dissolve metal outside the crevice.<sup>14</sup>

In stainless steel wire rope and cable there usually are very many crevices where the wires contact one another and, although the cathode:anode area ratio is favorable it is not uncommon to see serious crevice corrosion of these items in seawater.<sup>14</sup> Crevice corrosion can be prevented by cathodic protection.

#### Experimental

The specimens are exposed in slowly flowing pumped seawater at NELH. Water from the two supplies--surface seawater from 100 m offshore and deep ocean water from 630 m depth--flow into a series of covered troughs. The flow rate through the troughs is around 0.2 m/s. The troughs are constructed of marine plywood covered with fiberglass epoxy. The layout and details are shown in Figures 3 and 4.

Plate specimens are used, generally 10 cm x 10 cm with a central hole. Standard multiple crevice washers are located on each side of the plate and tightened together with a plastic bolt. The washers are made of delrin and each has 20 wedge-shaped crevice formers, 2 mm and 2.5 mm on the sides and 2.5 mm wide, separated from one another by 1 mm gaps. Figure 5 shows a sample with a partially disassembled washer assembly. The compositions of the alloys tested to date are listed in Table 2.

The list includes some highly resistant alloys--Hastelloys G3 and 276; some high-alloy stainless steels--Ferrallium 255, Jessup 700 and 777, Nitronic 50, and 254 SMO; and some aluminum alloy samples and samples of stainless 304. The latter group of samples were included not as possible cable materials, but to verify that the test set-up worked well and to test the use of potential monitoring as a means of determining the onset of crevice corrosion.

Samples are exposed for two different periods of time--approximately 30 days and approximately 90 days. After exposure the samples are rinsed and dried, the washers removed, and the degree of attack evaluated by low power microscopy. The following classification is used

- a) the number of crevices which show attack is counted, and
- b) the severity of attack is assessed on a scale from 1 to 5 with 1 set as beginning discoloration, 5 as complete penetration.

It is known that the size of the crevice opening can have a significant effect on whether crevice corrosion does occur for a given material in a given environment.<sup>14</sup> The effect has not been quantified but it has been shown that the level of torque used in tightening the multiple crevice washers onto the plate specimens has a similar effect.<sup>15</sup> In the present work a constant torque was used for all samples except for a series of stainless steel 304 specimens which were specifically selected for initial tests of the torque level effect.

The delrin creeps under load and this may affect crevice size. At the present stage this phenomenon is of low priority. However, the torque to loosen the washers at the time of sample removal was measured for general reference and possible later use.

It is known that the potential of a sample changes when crevice corrosion starts.<sup>16</sup> It was felt that if adequate techniques could be developed to determine the time of crevice corrosion onset then this measure might be a more reliable and more readily obtained measure of crevice corrosion susceptibility than the evaluation of gross attacks after long periods of exposure. Accordingly, a set of initial experiments was run with samples in the warm water. The potential of a number of samples was monitored at intervals with pure zinc as the reference material. Zinc was chosen because it does not significantly change its potential with time and it can be left for long periods of time without attention, whereas standard reference cells require considerable maintenance and care. The potential was measured with a multiplexer unit controlled by an HP 41-CV calculator with a time module. The data were stored on tape and later transferred to an HP-85 for plotting. The interval between measurements varied from one hour during the first two days to one day after one week of exposure.

#### Results and Discussion

Considerable "shake down" problems were encountered with the automatic data collection system and with the wire-sample connection. At this stage no reliable data have been obtained from this part of the study.

A number of corroded samples were evaluated after 26 days exposure in the warm water. The results are listed in Table 3. The three aluminum alloys and the two nickel alloys tested were included in the test for comparison purposes. While the results are limited at this stage the following initial conclusions can be drawn:

- o stainless 304 is the only alloy to show complete penetration of the 1 mm thick sheet,
- o aluminum alloy 3003 shows the same degree of attack as the notoriously corrosion-prone alloy 2024,
- o aluminum 5456; the ferritic, high alloy, copper containing stainless Ferralium 255; and the two high-nickel Hastelloy compositions show no attack,
- o copper contents do not appear to improve the performance of Jessup 777 (2% Cu) over Jessup 700 (0.3% Cu), both austenitic Mo-containing stainless steels, and
- o increased initial torque generally results in increasing crevice corrosion attack, presumably because of the tighter crevices.

The results also indicate that considerable sample duplication will be required in order to obtain reasonable reproducibility.

Additional, longer term tests are in progress.

#### D. ABRASIVENESS OF HAWAIIAN ROCKS

##### Background

Cables can fail due to abrasion from sea-bottom rock outcroppings as the cable moves due to ocean currents or to thermally induced length changes as electric load changes. The principal abrasive rocks in Hawaiian waters are coral and the olivine constituent of basalt. These abrasives have a relatively low hardness compared to quartz and to commercially used abrasives.

It is well known<sup>17,18</sup> that the abrasion of a metal may be strongly dependent on the relative hardness of the abrasive. When the abrasive has a hardness below 1.2 times the metal surface<sup>19</sup> hardness the abrasive wear takes place by a very slow surface fatigue mechanism. When the abrasive is more than 20% harder than the metal material is lost by a micromachining process which can remove material quite rapidly.<sup>20</sup>

The metal hardness of interest in this connection is the hardness of an abraded surface and this generally means a severely strained material—equivalent of 500-600% strain<sup>21</sup>.

Many austenitic stainless steels have very high rates of work hardening. It can therefore be expected that they will develop high levels of surface hardness due to abrasion. Since the abrasives of interest for the HDWC are of moderate hardness it is not inconceivable that some

candidate stainless steel armour wire materials could be highly abrasion resistant under Hawaiian conditions--if their abraded surface hardness is within 80-90% of the hardness of the abrasives.

The present study was undertaken to obtain an initial indication of this possibility.

#### Experimental

A range of stainless steels, from austenitic over ferritic-austenitic to the high ferritic alloy materials are abraded under various conditions. Initial tests are done with silicon carbide abrasives. These commercial abrasives are not directly relevant to Hawaiian conditions because of their high hardness but they are used to provide a baseline and to test out equipment performance. Tests with olivine and coral are in the planning stage.

Samples are pulled under load over a track of SiC abrasive paper, grit size 120 (120µm average diameter). The weight loss and the cutting force are determined and selected samples are studied by scanning electron microscopy of the worn surface and of the wear debris.

#### Results

Early indications are that, as expected, austenitic stainless steels have better abrasion resistance than ferritic stainless steels of the same hardness. Additional studies and evaluation of the data are underway. The microscopy studies indicate that surface fatigue may be a more common wear mechanism than previously thought. Additional work is in progress.

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Table 1. Typical Water Quality Data for Offshore Test Site

Current (est.), m/s	0.25 - 1
Temperature, °C	24.5 - 27.2
Salinity, o/oo	34.4 - 34.6
Alkalinity, meq/liter	2.25 - 2.35
pH	8.2 - 8.3
Oxygen, ppm	saturated, 6 ppm
Nutrients, microgram-atom/liter	
$PO_4$	0.35
$NO_3+NO_2$	0.20
$NH_4$	0.65
Si	3.30
TDN (Total Dissolved N)	4.50
TDP (Total Dissolved P)	0.50

Table 2. Nominal Composition of Alloys Tested  
for Crevice Corrosion Resistance

Al Alloys	2024	4 Cu	1.7 Mg	.5Si	.5 Fe	.5 Mn	.1 Cr	.25 Zn	
	3003	1.2 Mn	.7 Fe	.2 Cu	.6 Si	.1 Zn			
	5456	5 Mg	.7 Mn	.4 Si	.1 Cu	.1 Cr	.25 Zn	.2 Ti	
Stain- less	304	18 Cr	10 Ni	.08C	.045P	.03S	2 Mn	1 Si	
	Jessup 700	20.7 Cr	24.8Ni	4.45 Mo	.29 Cu	.37Si	1.68 Mn	.025C	
Jessup 777	21 Cr	25 Ni	4.5 Mo	2 Cu	.04 C				
Ferra- lium	255	26.15 Cr	5.64Ni	3.20 Mo	2.7 Cu	.37Si	.77 Mn	.02C	
Nitro- nic	50	21 Cr	13.7Ni	2.28 Mo	4.81 Mn	.045C	.47Si	.012S	
	254SMO	20 Cr	17.9Ni	6.1 Mo	.49 Mn	.013C	.41Si	.78 Cn	
Hastel- loy	G 3	22.76Cr	43.7Ni	7.01 Mo	.82 Mn	.006C	.37Si	.95W	1.85Cu
	"	276	15.5 Cr	54.72NI	15.5Mo	.46 Mn	.003C	3.82W	.11 Cu

Table 3. Results of First Series of Crevice Corrosion Tests\*

Sample	Alloy	<u>Severity of Attack</u>				
		1	2	3	4	5
1	2024	--	2	--	--	--
2	"	--	2	--	--	--
3	3003	--	2	--	--	--
4	"	--	--	--	--	--
5	5456	--	--	--	--	--
6	Ferralium 255	--	--	--	--	--
7	Jessup 700	8	5	--	--	--
8	Hastelloy G 3	--	--	--	--	
9	" 276	--	--	--	--	--
10	Jessup 777	--	6	--	--	--
11	Nitronic 50	1	2	--	--	--
12	254 SMO	2	2	--	--	--
13	304	2	1	--	--	--
14	"	24	1	--	--	4
15	"	--	--	5	--	--
16	"	12	2	--	--	5

\*Samples were exposed for 26 days (July 29 - August 26, 1983) in the warm water trough at NELH. Numbers listed are the numbers of attacked crevice sites (of a total of 40 possible sites).

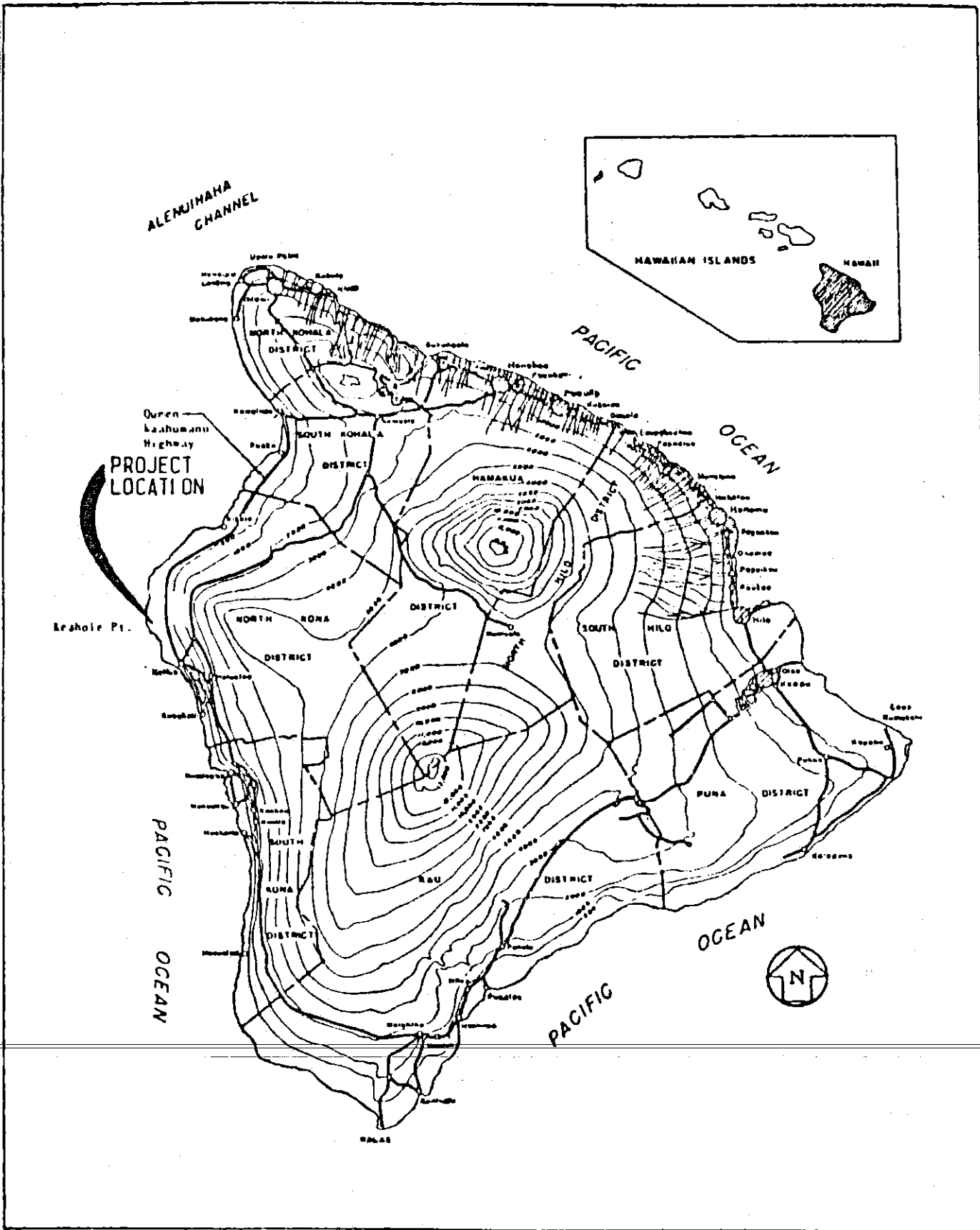


Figure 1. Map of Test Site

321,000N

Figure 2. Detailed Map of Sample Rack Location

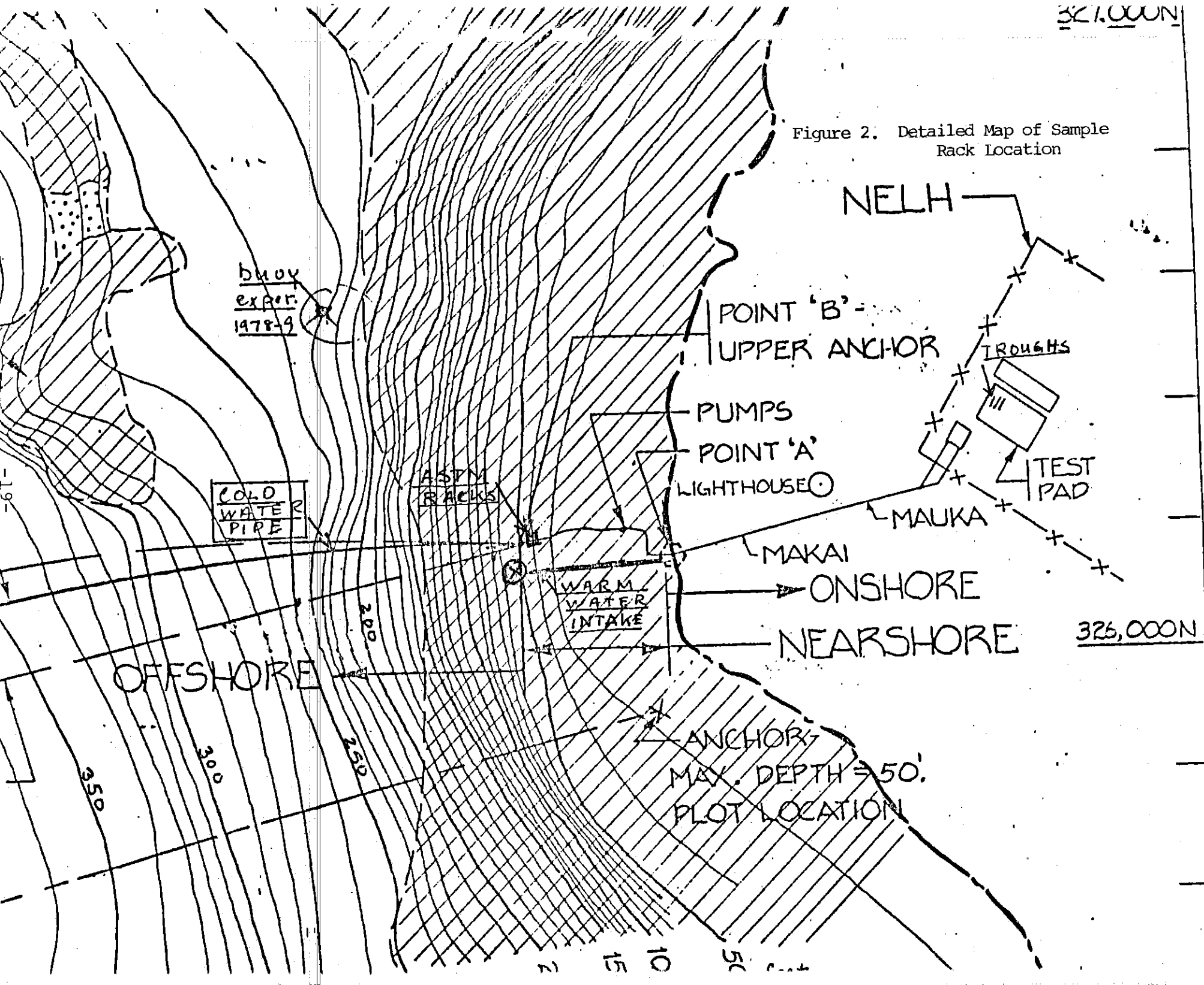
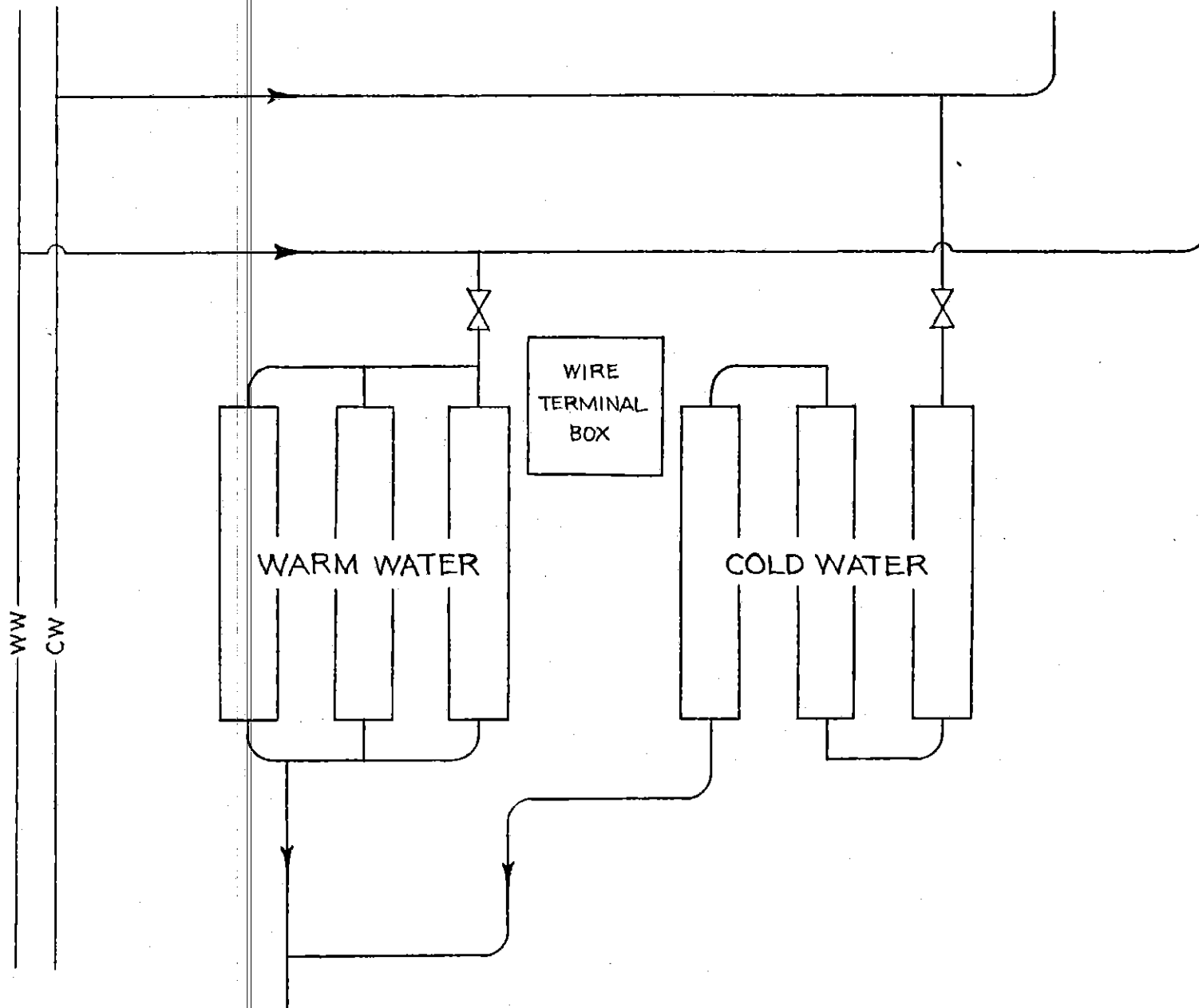
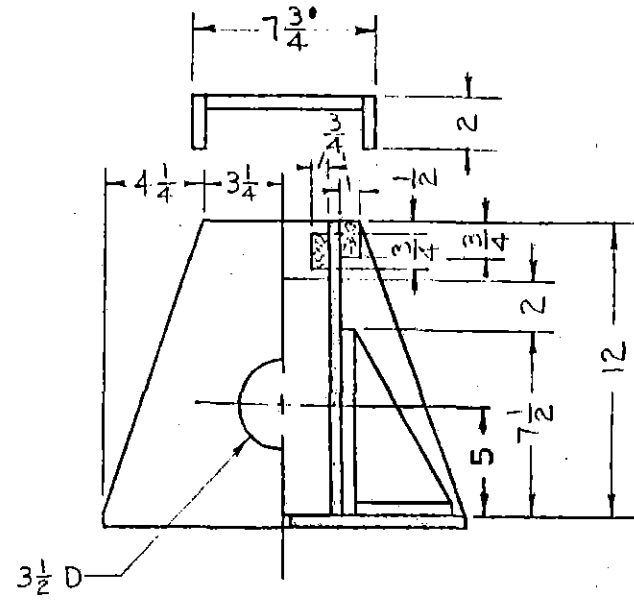


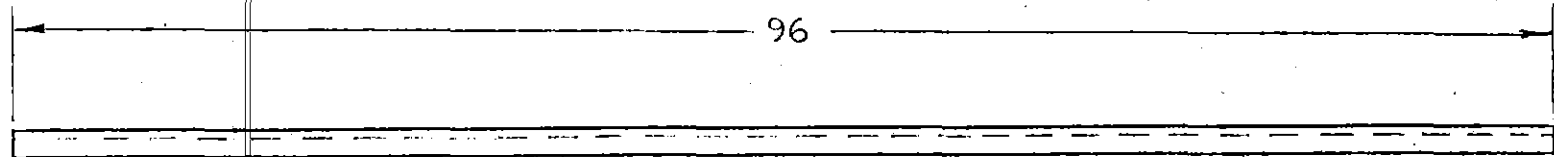
Figure 3. Overall Arrangement of Warm and Cold Water Test Troughs



END VIEW



\* ALL PIECES  $\frac{1}{2}$  INCH THICK, EXCEPT WHEN NOTED.

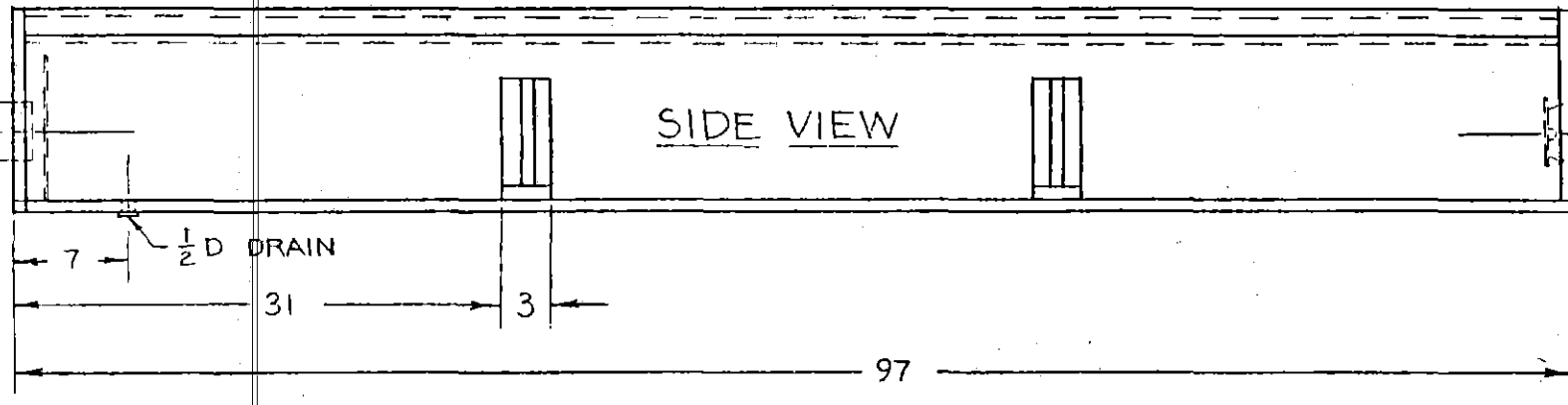


96

OUT

SIDE VIEW

IN



7  $\frac{1}{2}$  D DRAIN

31

3

97

Figure 4. Details of a Test Trough





Figure 5. Crevice Corrosion Sample with Partially  
Disassembled Multiple Washer Assembly

## PERSONNEL

The following personnel, all from the Department of Mechanical Engineering of the University of Hawaii at Manoa have worked on the project.

1. Jorn Larsen-Basse, Principal Investigator, Professor and Chairman
2. Ko Moe Htun, faculty associate (July), Associate Professor
3. P. Nuti, graduate student (since September), Teaching Assistant
4. Calvin Lee, undergraduate student, 0-10 hours a week
5. Leilani Wai, undergraduate student, 0-10 hours a week
6. Marsha Inoue, undergraduate student, 0-10 hours a week
7. Ken Yamabe, undergraduate student, 0-10 hours a week
8. David Lee, undergraduate student, 0-10 hours a week