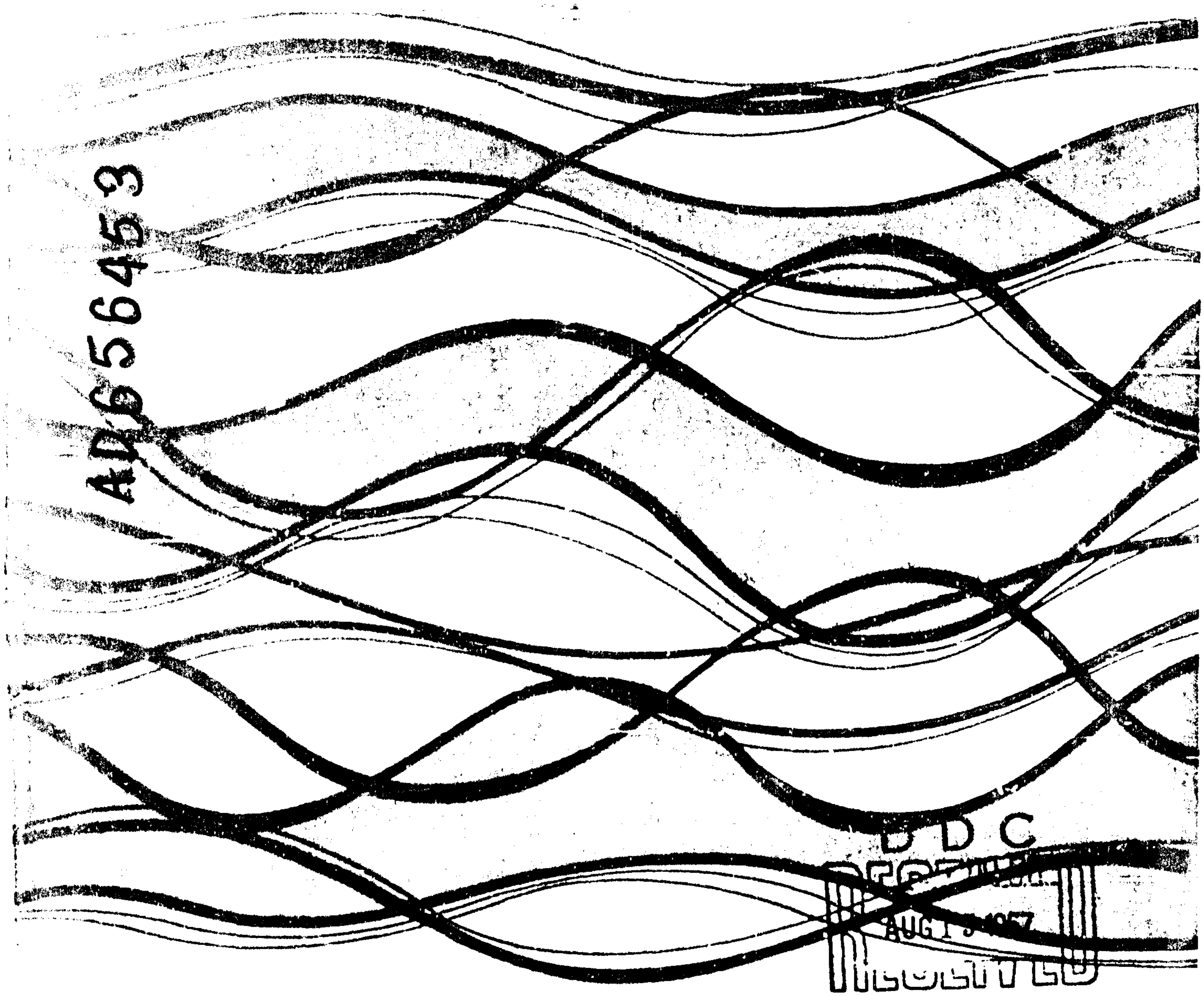


NCEL Ocean Engineering Program

March 1966—March 1967

May 1967 U. S. Naval Civil Engineering Laboratory Port Hueneme, California

53

FOREWORD

The ocean is being challenged to give up its secrets. Man will go down into the sea to satisfy his native urge for exploration and acquisition, to observe and perform those functions he considers necessary to complete his mission. Ocean engineering will provide him with the capability of doing so.

Some explorations will be at diver depths and will expose man directly to the undersea environment. Others will require him to go to greater depths in manned habitations and vehicles. Both types of exploration will place him directly at the site. He also has the choice of placing his capabilities at the site, while he remains remote at the surface. These methods of exploration are distinctly different, and yet they complement one another because they impose similar demands on technology and issue a challenge to the many disciplines of engineering and science.

This publication documents the efforts and research undertaken by the Naval Civil Engineering Laboratory in answer to this challenge. The period covered is, roughly, from March 1966 to March 1967, although the techniques described are results of work much deeper in the past, and the technology envisioned represents a long stride into the future.

NCEL's work supports that portion of the Navy's mission which is involved with planning, designing, constructing, and maintaining the Naval Shore Establishment. It represents, however, an expansion of that mission which will include fixed structures, installations, and equipment on the sea floor. Other work of equal importance is that associated with sea salvage missions.

Although sponsored chiefly by the Naval Facilities Engineering Command, this work is also supported by the Naval Ship Systems Engineering Command (Supervisor of Salvage) and the Deep Submergence Systems Project. NCEL is ideally situated for this activity, being located adjacent to the deep water harbor of Port Hueneme, 60 miles north along the Pacific coast from Los Angeles.

CONTENTS

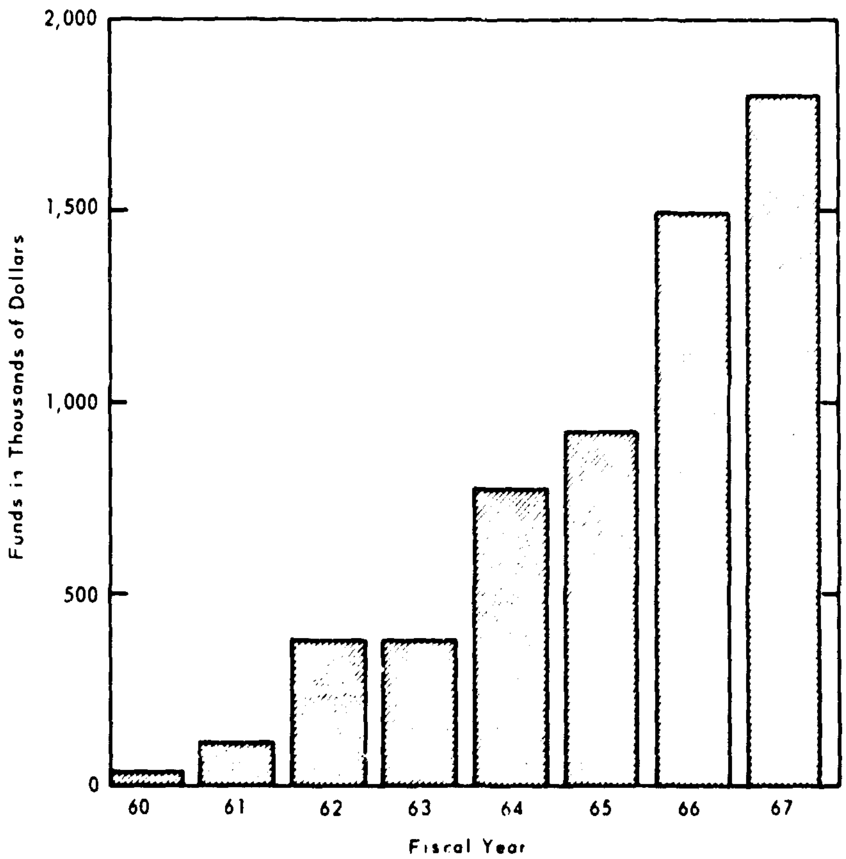
MANPOWER, FUNDING, CONTRACTS

Manpower

NCEL's ocean engineering program, while including specialists from many organizational groups in the Laboratory, is coordinated in the Ocean Engineering Division. There are about 30 professional engineers and scientists, with ocean engineering experience ranging from oceanography to marine geology and hydrodynamics, directly engaged in the program. In addition, professional staff members of varying disciplines are called upon from time to time to help with specific problems.

Funding and Contracts

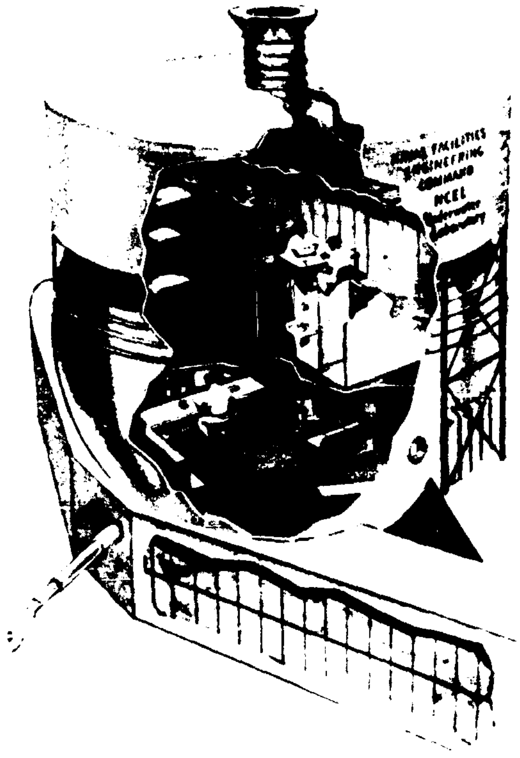
The following chart shows funds available to the NCEL ocean engineering program in recent years. In FY-67 approximately 30% of this funding went to private industry. Except as otherwise indicated, the tasks described in this publication are sponsored by the Naval Facilities Engineering Command.



MANNED UNDERWATER STATION

Concepts

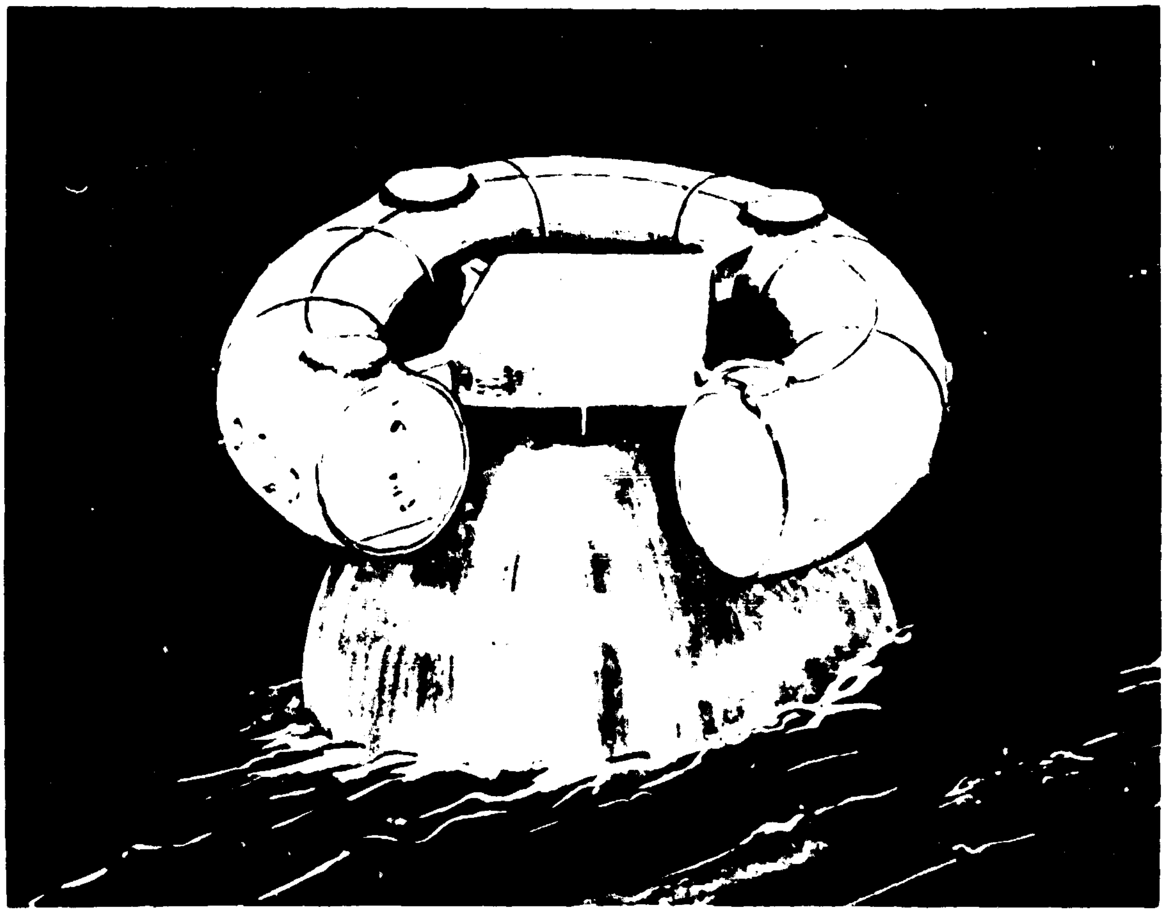
Preliminary concepts for a manned underwater station which would allow the U. S. Navy to establish fixed habitations on the sea floor at depths down to 6,000 feet were developed under contract. In developing the concepts, the state of the art was utilized to the maximum extent feasible and practical. The initial criteria defined a station capable of supporting five-man crews at standard atmospheric pressure for an indefinite period of time. The station will have a self-contained power source and a self-contained life-support system which will make it independent of the surface. It is planned to resupply the station and change the crew every 30 days, either by the station returning to the surface or by a submersible mating with the station on the sea floor. Upon completion of its mission, the station will be capable of being recovered and moved to other locations.



Southwest Research Institute concept for the manned underwater station.

The conceptual studies have revealed several feasible approaches. Southwest Research Institute, San Antonio, Texas, proposed a 20-foot-diameter spherical hull of HY-140 steel. Power would be provided for 30 days by silver-zinc batteries mounted externally on the top and bottom of the sphere. The 30-day life-support system would require 486 gallons of potable water, 330 cubic feet of compressed oxygen, 559 pounds of lithium hydroxide for CO_2 removal, and about 200 pounds of dehydrated precooked food. The station would be towed to the site and winched to the bottom.

Essentially, the winch-down delivery mode consists of a sea-floor anchor with a flexible line connected to a winch on the bottom of a positively buoyant hull. The structure is lowered to any desired elevation in the water column by winching against the anchor.



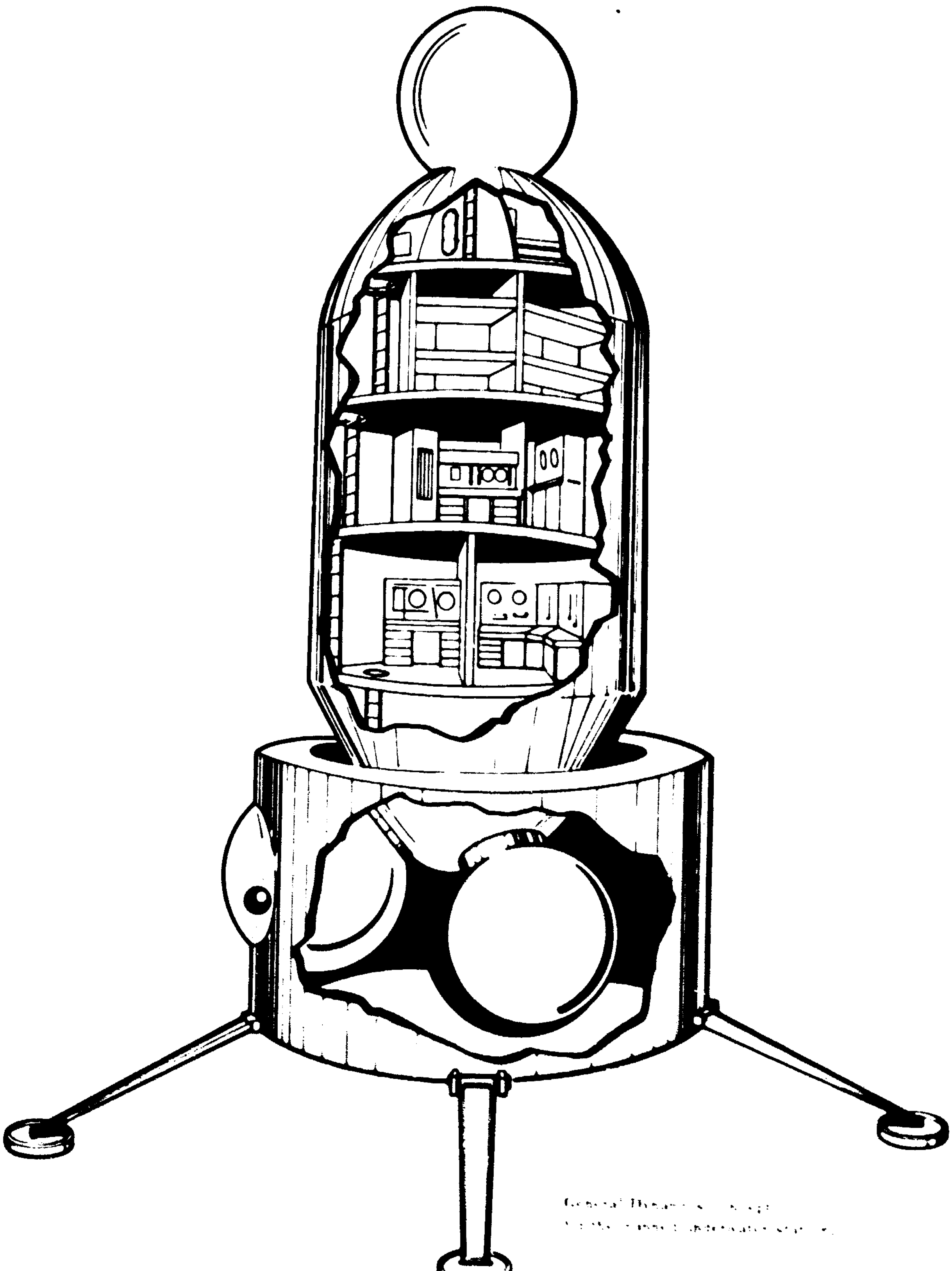
Westinghouse concept for the manned underwater station.

The Westinghouse Electric Corporation, Baltimore, Maryland, suggested a toroidal hull of HY-140 steel with a 40-foot overall diameter and a 10-foot inside diameter. The toroid would come to rest on the bottom on a conoidal foundation that would allow it to adjust to any bottom configuration up to a 15-degree slope. Power would be provided by four 7-KW radioisotope power supplies. The life-support system would be a regenerative system similar to that found on standard Navy submarines, but on a much smaller scale. The station could be towed to the site or carried in an LSD. The recommended emplacement mode was also by means of winching against a sea-floor anchor.

The station as conceived by General Dynamics/Electric Boat Division, Groton, Connecticut, included a basic vertical cylindrical steel hull (HY-130) with hemispherical ends. The hull diameter is 16 feet, and the overall station height is about 50 feet. Attached to the lower portion is an 8-foot spherical observation pod. Three power plant concepts were offered: a nuclear reactor system, a radioisotope power system, and an umbilical system with a surface buoy and conventional power plants. The life-support system suggested contemplated using chlorate candles for oxygen generation, lithium hydroxide for carbon dioxide removal, a refrigeration system for food, and a choice of water-supply systems. It was further established that the use of superoxides for atmosphere management could extend the endurance of the station.

The station would be towed to the site horizontally and "flipped" for descent. The emplacement concept involved a free descent using negative buoyancy as the motivating force. As the station approached the sea floor, suspended weights would come to rest on the bottom and increase the buoyancy until all downward velocity ceased. The station would be winched down the last hundred feet or so. Three legs are to be provided to stabilize the buoyant station.

During the early part of FY-68, the concept for a Manned Underwater Station will be fully developed. System characteristics selected on the basis of trade-off studies include a vertical cylinder for the main hull, a winch-down emplacement mode and a nuclear reactor power supply.



General Dynamics [illegible]
[illegible]

Power Transmission

The purpose of this study is to determine the economic and technical feasibility limits of deep ocean electrical power transmission systems for fixed installations and structures. Under consideration are shore-based, surface-tendered, or in-situ power sources.

The system concepts being investigated have continuous capacity of 30 kw, 100 kw, 300 kw, 1,000 kw, and 3,000 kw. Characteristics of the electrical power for each power load and the maximum distance from the load to the source are included, as well as optimization of the developed system concepts for installations at ocean depths of 600, 2,000, 6,000, 10,000, 15,000, and 20,000 feet. Definitive criteria for the design of selected systems will be established.

Comparisons of various power sources, such as batteries, fuel cells, nuclear, electromechanical, and possible combinations thereof are being investigated. The work is progressing under contract with General Dynamics Electric Boat Division.

Ocean Simulation Laboratory Studies

Creative work in the laboratory supports creative work in the field. Time, money, even lives are often saved by careful simulation and model studies prior to full-scale field efforts. Laboratory studies also yield results difficult or impossible to attain through field work.

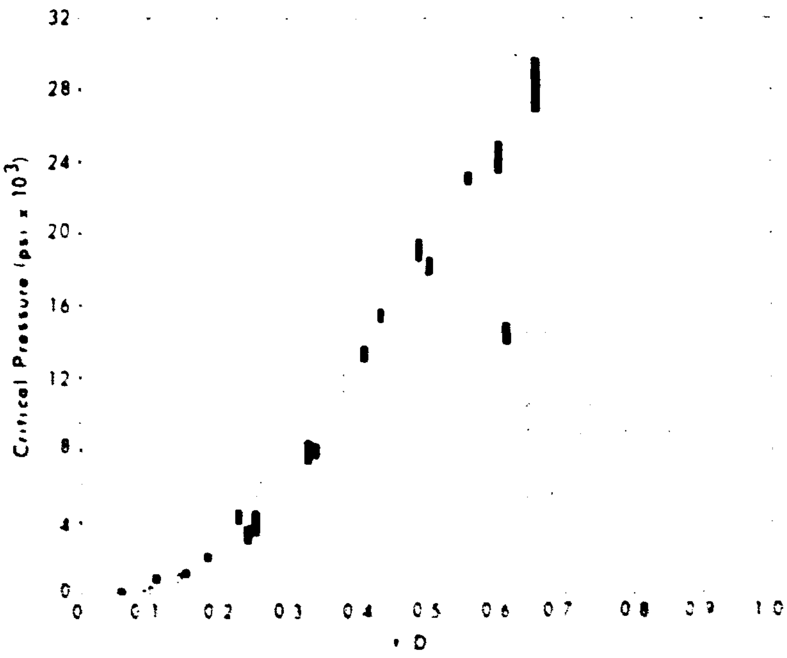
An Ocean Simulation Laboratory is operational to develop techniques for the simulation of the deep ocean environment inside pressure vessels and to investigate the behavior of materials and structural components in such an environment. The facility consists of a variety of pressure vessels of various sizes and operating characteristics. During FY-67, approximately 50,000 vessel hours were utilized in the conduct of RDT&E work.

A contract was awarded to Chicago Bridge and Iron Company during FY-66 for the fabrication of a 72-inch inside diameter, 120-inch inside length, 5,500-psi pressure vessel for use with seawater. Delivery of the vessel will be late in the fourth quarter of FY-67 and is scheduled to be operational early in FY-68.

Viewing Ports. In order to provide designers and engineers with basic data for the design of windows for undersea, externally pressurized structures (and internally pressurized vessels), a series of fundamental studies have been completed or are underway:

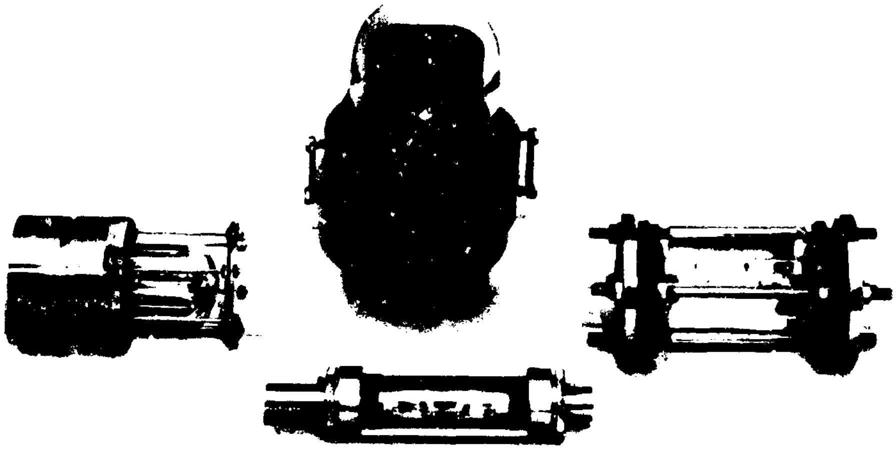
Phase I. Short-term critical pressure of conical acrylic windows.
II. Short-term critical pressure of flat acrylic windows.
III. Long-term behavior of conical acrylic windows at 20,000 psi.
IV. Short-term critical pressure of spherical acrylic windows.

Phases I and II are completed. (See listing of technical publications at back of report.) These studies produced design criteria for conical and flat acrylic windows for any ocean depth under conditions of short-term loading. These criteria may be applied to windows in either an internally pressurized vessel, such as those used to simulate the ocean environment, or externally pressurized vessels, such as deep submergence structures in the ocean. The flat windows under short-term hydrostatic loading were found to be comparable in performance to conical windows with a 90-degree included angle.



Critical pressures of 90-degree conical and flat circular disc acrylic windows under short-term hydrostatic pressure.

Phase III studies are in progress with a series of specimens of conical acrylic windows of 30-, 60-, 90-, 120-, and 150-degree included angle exposed for periods of 500 and 1,000 hours. The windows are instrumented to provide data on their rate of displacement through their mounting flange. Data from this study were used for the concept development studies on the Manned Underwater Station. Phase IV studies on the spherical window were started during the fourth quarter.



Glass dome, pipe, and tubular light housings for deep submergence application.

Underwater Lights. Many underwater lights, instruments and electronic assemblies require both waterproof and pressure-proof packaging for successful operation. Due to the high cost, limited availability, and limited variety of commercial deep sea instrument housings, a study was undertaken to explore the applicability and usefulness of commercially available glass closures, such as those used in vacuum technology and the chemical industry. These items have the advantages of wide distribution in the laboratory supply industry and low unit cost. The problem has been to determine their capability to withstand high hydrostatic pressure and to demonstrate their utility in the undersea engineering field. Three phases of the study were completed during FY 67.

Phase I of this study was on dome-shaped glass housings. A series of underwater light designs, utilizing dome-shaped glass housings useful at depths from 5,000 to 40,000 feet, were developed and tested.

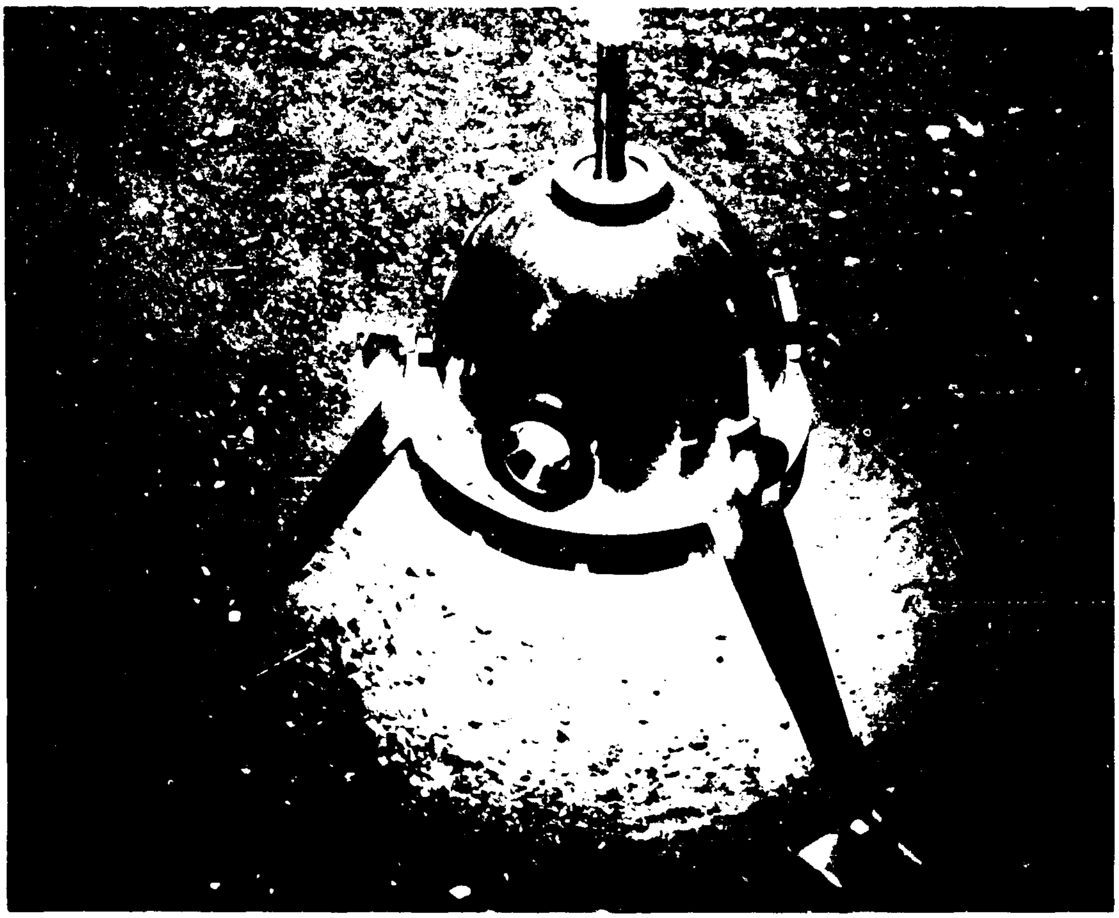
Phase II was concerned with tubular-shaped glass housings. Flanged glass pipes ranging from 1-inch ID by 6 inches long to 6-inch ID by 36 inches long were tested to determine their critical pressure. A series of underwater lights and instrument housing designs were developed and tested.

Phase III dwelled on miniature lights for use in pressure vessels. The study was undertaken to fulfill a need for small, powerful lights which could be used in laboratory pressure vessels, where space is at a premium. Three light designs were developed utilizing both dome and tubular glass closures. Tests demonstrated their usefulness at pressures up to 20,000 psi.

Concrete Hulls. The study on the application of concrete to ocean bottom habitations had as its objective for FY-67 the design, fabrication, and testing of typical spherical-shaped models for 1,500-psi operational pressure. The performance of the 16-inch OD by 14-inch ID waterproofed concrete models, with operational windows, hatches, and wire feedthroughs under simulated design depth was to be an indicator of how well a concrete pressure hull with penetrations can withstand hydrostatic loads. In addition, several identical waterproofed concrete models with solid steel, aluminum and plastic penetration inserts were tested.

The epoxy-coated concrete models, with operational windows, hatches, and feedthroughs, failed under short-term pressurization at simulated depths of 7,400 feet, the same nominal depth at which identical models without any penetrations failed. Since failure occurred at about the same depth for both types of models, it can be reasoned that properly designed penetrations do not reduce the critical pressure of concrete pressure hulls.

When the solid inserts possessed rigidity equal to or greater than the concrete, the models failed at the same or higher pressure than models without penetrations; on the other hand, when the insert was less rigid than the concrete, the models failed at significantly lower pressures.



Model of concrete habitation at night.

Acrylic Plastic Hulls. The testing of Naval Missile Center's NEMO (Naval Edreobenthic Manned Observatory) acrylic hull models was essentially a continuation of the testing program initiated jointly by NAVFAC and NMC in FY-65 to investigate acrylic plastic as underwater-vehicle hull material. The studies conducted in FY-67 had two objectives: detailed evaluation of acrylic plastic hulls in model form under long-term and cyclical pressurization, and development of a man-sized acrylic capsule.

The evaluation of acrylic plastic hulls took the form of subjecting a series of 15-inch OD by 14-inch ID acrylic spheres with metallic hatches to long-term submersion at simulated 560-, 1,120-, 1,680- and 2,240-foot depths. To date, only the hull model subjected to a simulated 2,240-foot depth failed, after ten hours of continuous pressure application. The models under simulated 560- and 1,120-foot depths have not failed after 3,000 hours of pressurization, and the model at the simulated 1,600-foot depth is still intact after 1,000 hours of pressure loading. A model undergoing pressure cycling to 1,120 feet has thus far withstood 40 cycles, where the 1,120-foot depth is maintained for 100 hours, followed by a 100-hour relaxation at atmospheric pressure. These tests show the model to be compatible with the 1,000-foot operational depth for which it was designed.

A 65-inch OD by 60-inch ID man-sized spherical acrylic hull is under construction and is scheduled for completion early in FY-68.

[illegible] NEMO [illegible]

UNDERWATER CONSTRUCTION AND SALVAGE

The Diver-Constructor

A long-range program is underway to develop adequate knowledge, techniques, systems, and equipment to support future diver construction operations on the continental shelf. In order to achieve this end, specific construction projects will be accomplished. The first, designated DIVERCON I, places major emphasis on the handling of components on the sea floor by the divers without dependence upon the surface and diver-assembly techniques. DIVERCON I is a diver-constructed underwater repair facility to demonstrate the feasibility of constructing a dry repair station at ambient pressure around an object such as a sonar device or power source. The concept of a wet repair station will also be investigated; in this, the water within the housing would be heated and cleaned with a floculating agent, permitting the diver to function in still, warm, clear water.

The facility to be constructed is a 120-inch model and utilizes construction techniques which could be readily extended to larger structures. The assembly operation will utilize a system of guides to properly align the components, and the fasteners will consist of both bolts and quick-acting clamping devices. This type of structure would also provide an economical test chamber for research and development work with pressurized undersea habitations.

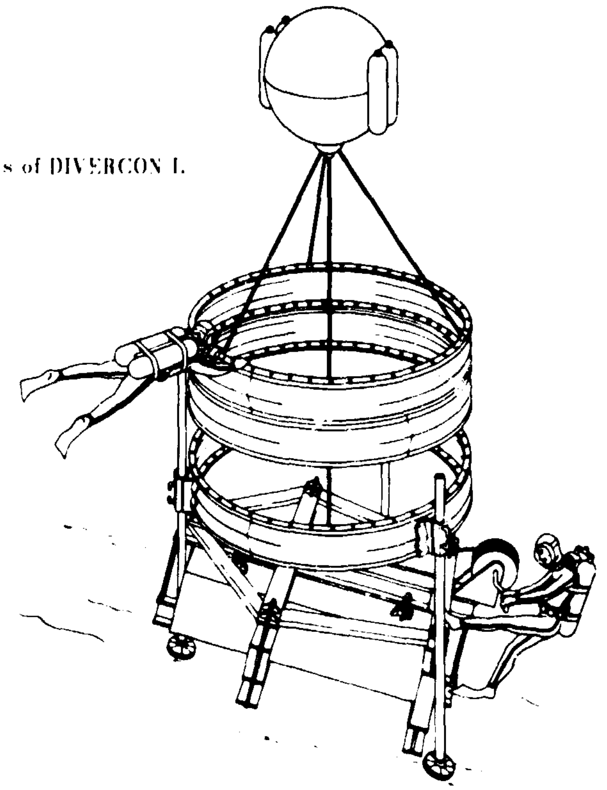
The weight-handling system to be used will lift the structural components from their positions on the bottom utilizing a variable buoyance float. The assembly will then be pulled down into place by a winch mounted on an anchor block. The divers will control the buoyancy of the float system and operate the winch, removing all dependency upon the surface during the operation.

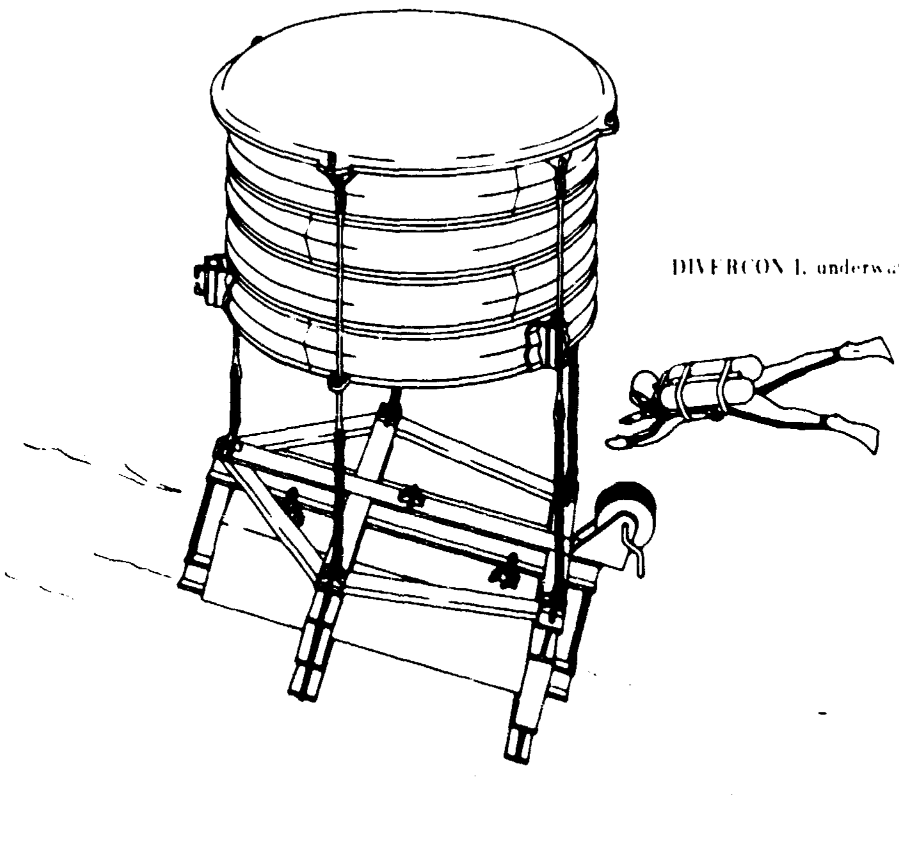
This program will also integrate other portions of the ocean engineering program such as site selection, handling of heavy weights from the surface (25-ton anchor block), biodeterioration of materials, and the NCEL-designed underwater lights discussed earlier. Model tests, utilizing a 52-inch-diameter structure, have been completed this year, and the full-scale (120-inch-diameter) assemblies are planned for early FY-68.

It is planned to demonstrate an assembly of DIVERCON I at SEALAB III. An NCEL engineer will be a participating aquanaut during this demonstration.

Future diver-construction projects will be planned to foster the development of techniques that are required to properly exploit the continental shelf.

Underwater diver assembly of segments of DIVERCON I.





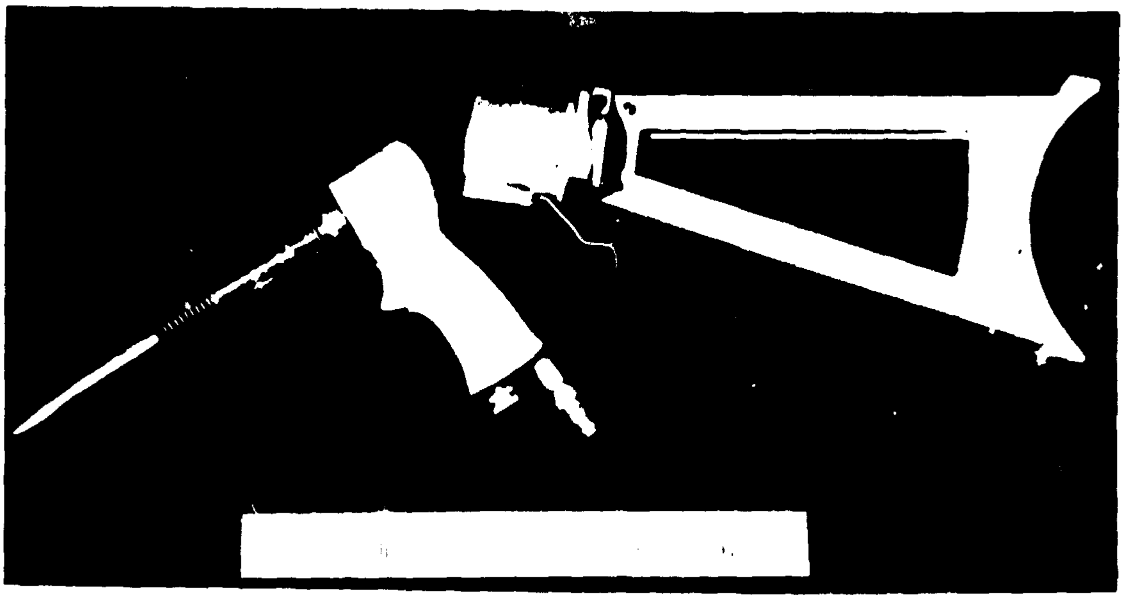
DIVERCON I, underwater repair facility.

Divers' Tools

The objective of this work is to provide the diver-constructor with restraint systems, including magnetic attachments and tools modified to allow the diver to approach the capabilities of the land-bound craftsman. Work accomplished this year was of an experimental nature, involving a tethering jacket, magnetic anchors, and modified pneumatic tools. Most modifications are of the type that make the tool more effective from the human factors point of view, as shown in the photographs. Such tools included drills, an air-powered saw, impact wrench, and chipping hammer.

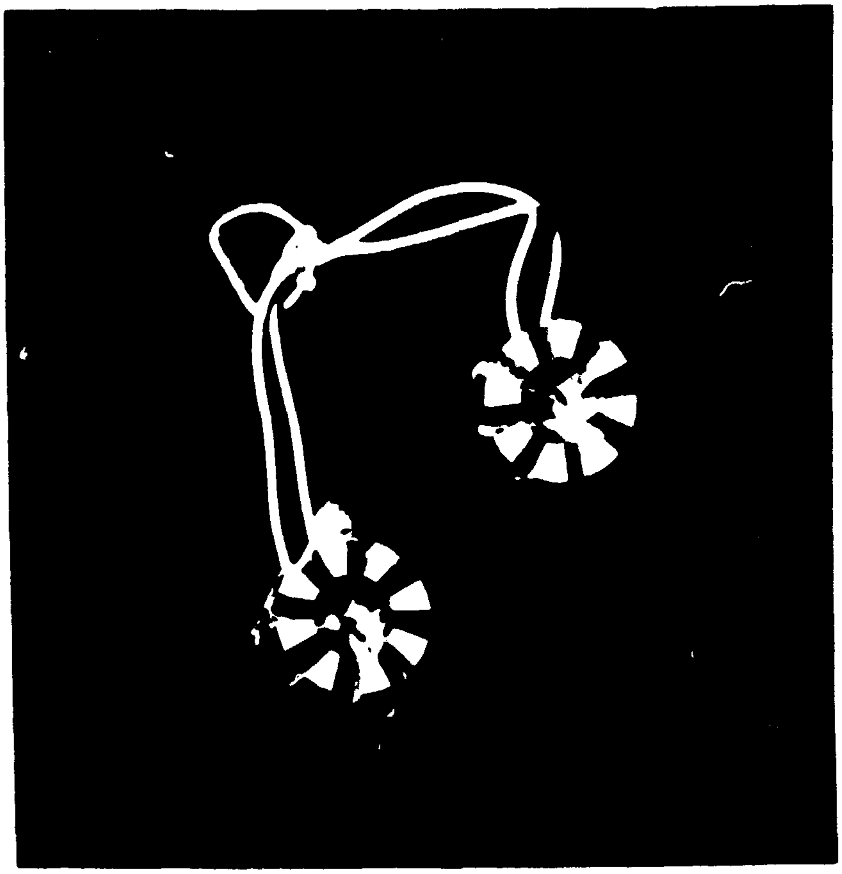
Future work will include the development of techniques and equipment to allow the diver to work effectively on surfaces with no natural foot-rests or handholds. An experimental program is established that will allow measurement of some of the variables in the diver work situation, such as land performance versus water performance and performance degradation versus time under various environmental conditions.

The experimental work is jointly funded by NAVFAC (for underwater construction), Supervisor of Salvage, NAVSHIPSYSCOM (for magnetic applications), and NOTS DSSP (for Large Object Salvage Systems). NCEL is being assisted in this work by the Human Factors Branch of the Naval Missile Center at Point Mugu. In addition to experimental work a study was completed to determine the present state of the art of divers' tools.



Standard terrestrial air chipping hammer with the addition of a shoulder stock attachment to enable the diver to exert a stronger, steadier force.

Drill [illegible] with shoulder stock operated by [illegible] construction [illegible]. The [illegible] is attached to the work by small permanent magnets.



Two-inch-diameter magnets with 70-pound holding capacity.

The usefulness of magnets in ship salvage and other underwater work is being investigated. The general conclusion, based on literature and patent searches, consultation with industry, and some small-scale test work, is that large electromagnets prove valuable in the salvage of ferrous cargoes from sunken ships, where the repetitive nature of the operation greatly reduces the requirement for divers and simplifies the attachment problem. Smaller magnets, mostly of the permanent type, as shown in the photograph, provide a productive area of development for use as divers aids. They can be readily used as anchoring devices for swimmer-divers and for positioning and holding aids for divers' tools.

Collapsible Salvage Pontoons

During FY-66, NCEL contracted for five each of three types of 25-long-ton collapsible salvage pontoons from the U. S. Rubber Company. These were for test and evaluation by NCEL for the Supervisor of Salvage, NAVSHIPSYSCOM.

The pontoon carcasses are constructed of 4-ply nylon cord, neoprene-coated, with an inner liner and outer cover.

The Type I pontoon is vertically oriented, nominally 13 feet wide by 27 feet long when collapsed, and 8 feet in diameter when inflated. The pontoon is open at the bottom and the upper end is sealed by a patented clamp arrangement. Two pipes through the clamped end provide for an air inlet and vents.

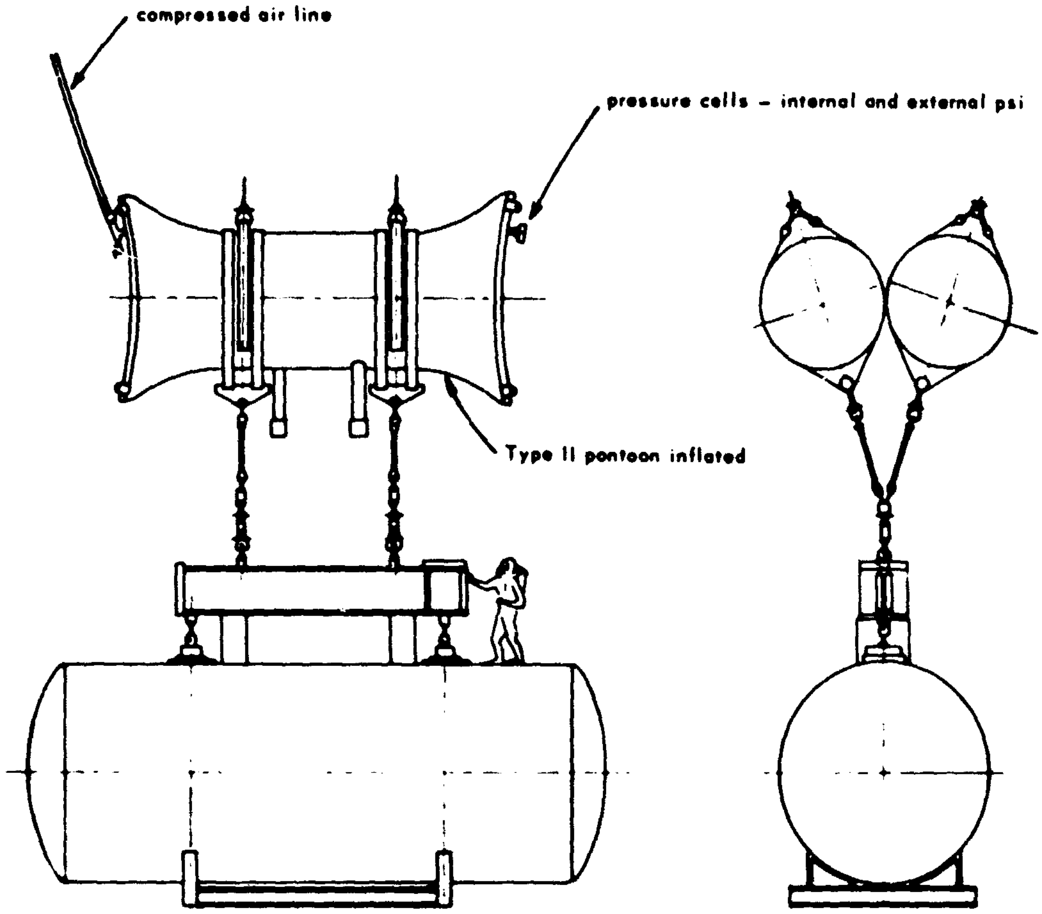
Vertically oriented salvage pontoons raise a 36,000-pound load from an 82-foot depth.

The Type II pontoon is horizontally oriented, nominally 13 feet wide by 23 feet long when collapsed, and 8 feet in diameter when inflated. The pontoon is sealed at the ends with patented clamps. Two 12-inch-diameter vent sleeves 4½ feet long hang down from the carcass. A pipe through the upper corner of each clamped end provides for an air inlet and vents.

The Type III pontoon was intended to be a dual-purpose unit to provide either 25-long-tons buoyant lift, or 160 tons jacking force at 20-psi internal pressure with a jacking height of 4 feet. Jacking pressure would be applied primarily by water.

During the factory tests, the Type III dual-purpose design was found to be impractical. Currently the pontoon will be used for jacking purposes only.

Two prototypes each of the Type I and Type II pontoons were delivered to NCEL in FY-67, and these were tested in joint operations with the Naval Ordnance Test Stations, Pasadena and China Lake, and the salvage ship USNS GEAR (ARS 34) at the San Clemente Island Sea Range in February 1967. The results of these tests, given in the table, indicated a need for redesign of the Type I and some revision to the Type II before continuing with the testing program.



Arrangement for test of Type II collapsible salvage pontoons.

Collapsible Salvage Pontoon Tests

Pontoon Type	Test Condition	Results
Vertically oriented	One pontoon attached to a 36,000-pound lift in 82-foot depth	Lift successful
Vertically oriented	Two pontoons attached to 80,500-pound lift in 82-foot depth	Both pontoons ruptured under separate inflations; one at a buoyant lift of 53,300 pounds, the other at 56,700 pounds
Horizontally oriented (1st pontoon)	Successive load tests of 56,850 and 58,3[illegible]0 pounds in 84-foot depth	Both load tests successful
Horizontally oriented (2nd pontoon)	Successive load tests of 58,200 and 58,1[illegible] pounds in 84-foot depth	Both load tests successful
Horizontally oriented	Both pontoons attached to 83,000-pound lift from 84-foot depth	Lift successful; minor hardware revisions required on pontoons at conclusion of testing

Bottom Stabilization Studies

NCEL is investigating, for the Supervisor of Salvage, NAVSHIPSYSCOM, materials and methods for producing overlays for ocean bottom silts. Disturbance of these silts during salvage operations reduces visibility to a point where diver operations are usually hindered or even stopped until the suspended material has settled.

Chemical Overlay. Work is being conducted in-house in an effort to produce overlays by salting-out, precipitation, or gelation. Under contract, the Battelle Memorial Institute is investigating a series of film-producing materials.

Dispensing equipment is also being investigated. Diver testing of candidate materials and techniques is planned for the summer of 1967. From the results of these data, materials and equipment will be prepared for evaluation at SEALAB III.

Concrete Overlay. The FY-67 objective was to establish technical data for use in planning the construction of concrete overlays on the ocean floor at depths to 450 feet. Subsequently, strengthened overlays can serve as platforms for supporting personnel transfer capsules and as landing pads for submersible vehicles.

A comprehensive search of the technical literature, pertaining to underwater deposition of freshly mixed concrete and underwater production of prepacked concrete, was completed. Factual information was developed concerning currently known methods of underwater concreting. The pumping method is considered the most desirable means of building any cementitious overlay. Freshly mixed concrete will be conveyed from the ship via a hose system which will be connected to the forms previously installed on the ocean floor.

Data concerning the rate of concrete hardening under water are necessary, because time is of the essence during constructional operations as well as during salvage operations. Test data were obtained regarding the setting times of various hydraulic cement pastes subjected to a hydrostatic pressure of 191 psi at 40°F. The testing was conducted in a walk-in refrigerator at the Laboratory. The constant hydrostatic pressure was maintained by means of compressed helium acting through a small spherical accumulator tank.

Environmental Control in Pressurized Underwater Habitations

A study was made to identify those environmental factors which would have to be controlled in order for man to live and work in the sea. The many facets of the problems considered are listed here. The study described the state of the art of undersea habitation, limitations, and possible approaches to major improvements. Although the study treated the problems from an engineering standpoint, the problems were largely physiological. The results describe the problems in terms familiar to engineers working in the field of environment control.

Diving Practices

Narcosis in Diluent Gases

Heat Transfer Considerations

Voice Distortion

Helium Diffusion

Habitat Heating

Atmospheric Contaminant Separation

Other Aspects of Atmospheric Control

Potable Water Supply

Sanitation Possibilities

Storage of Makeup Oxygen

Gaseous Contaminant Control

STUDIES OF OCEAN BOTTOM SOILS

Laboratory Analysis of Core Specimens

To develop both laboratory and field procedures for determining engineering properties of sea-floor sediments, including methods of procuring samples, NCEL is conducting a variety of physical tests in the laboratory and interpreting the results in terms of engineering design parameters.

During FY-67 the ocean soils laboratory provided assistance on the DSSP work, Bottom Breakout Forces. Sixty-seven core specimens were taken in the process of locating, selecting, and investigating a suitable site for conducting breakout tests in San Francisco Bay sediments. Twenty-eight of the specimens were taken in the area in which the breakout tests are now being conducted. A similar survey for site selection was conducted in the Gulf of Mexico, where 43 cores were obtained. The results from these tests, in addition to satisfying the needs for the breakout analysis, are additional input values that will be used to meet the specific objectives of (1) verifying statistical analyses for site selection and reconnaissance purposes and (2) establishing statistical correlation constants for particular soil types. By way of example, the statistical equation developed for vane shear strength is

$$VSS = k_1(D) + k_2(LL) + k_3(MD) = k_4$$

where VSS = vane shear strength, psi

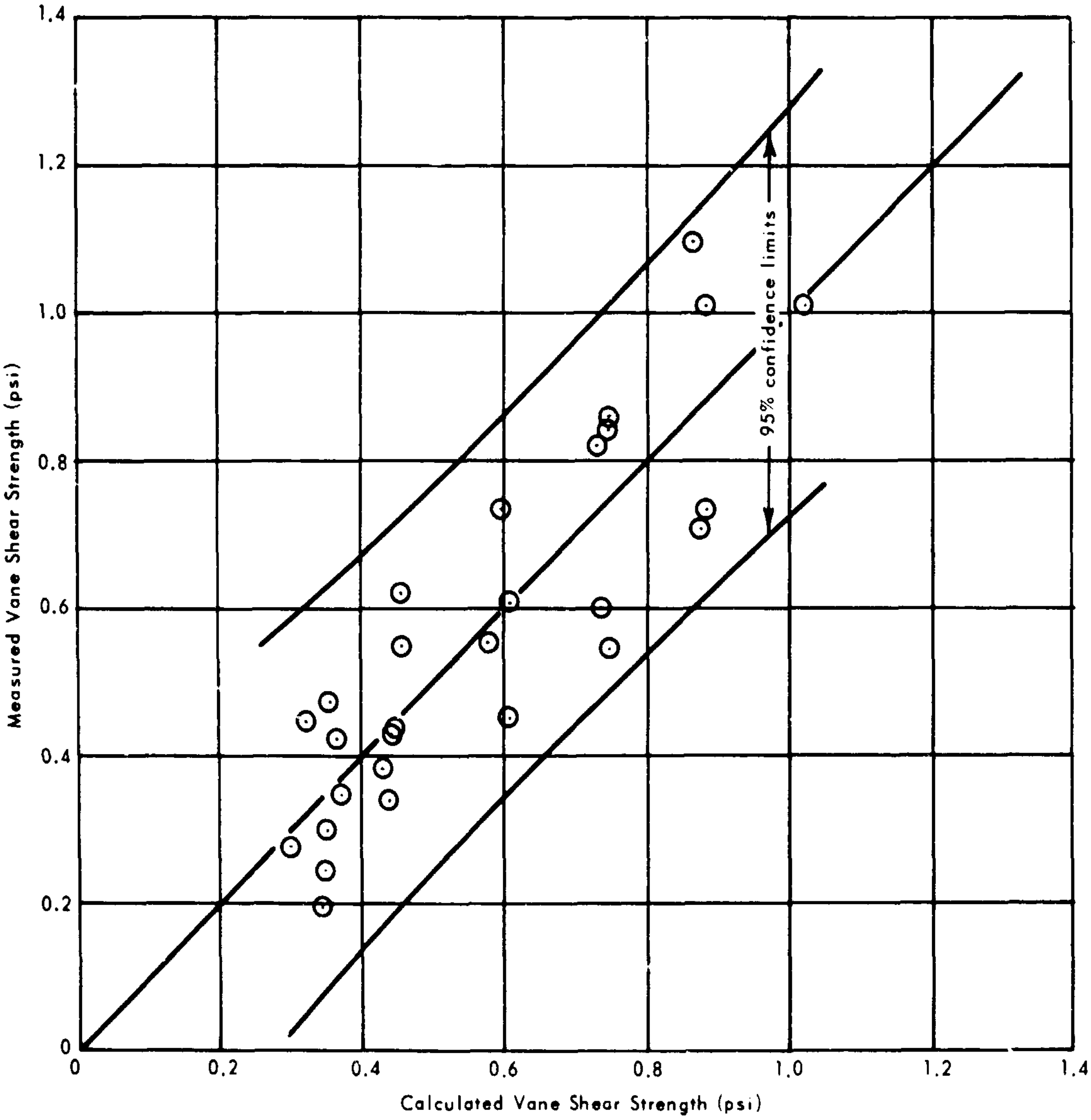
D = depth in sediment, inches

LL = liquid limit, %

MD = median diameter, mm

k_n = constants (n = 1, 2, 3 ----)

The comparison of the measured versus calculated values are shown in the accompanying graph. Results to date indicate the statistical correlations are satisfactory for site survey and reconnaissance.



Measured versus calculated vane shear strengths, core MH-1 to MH-8.

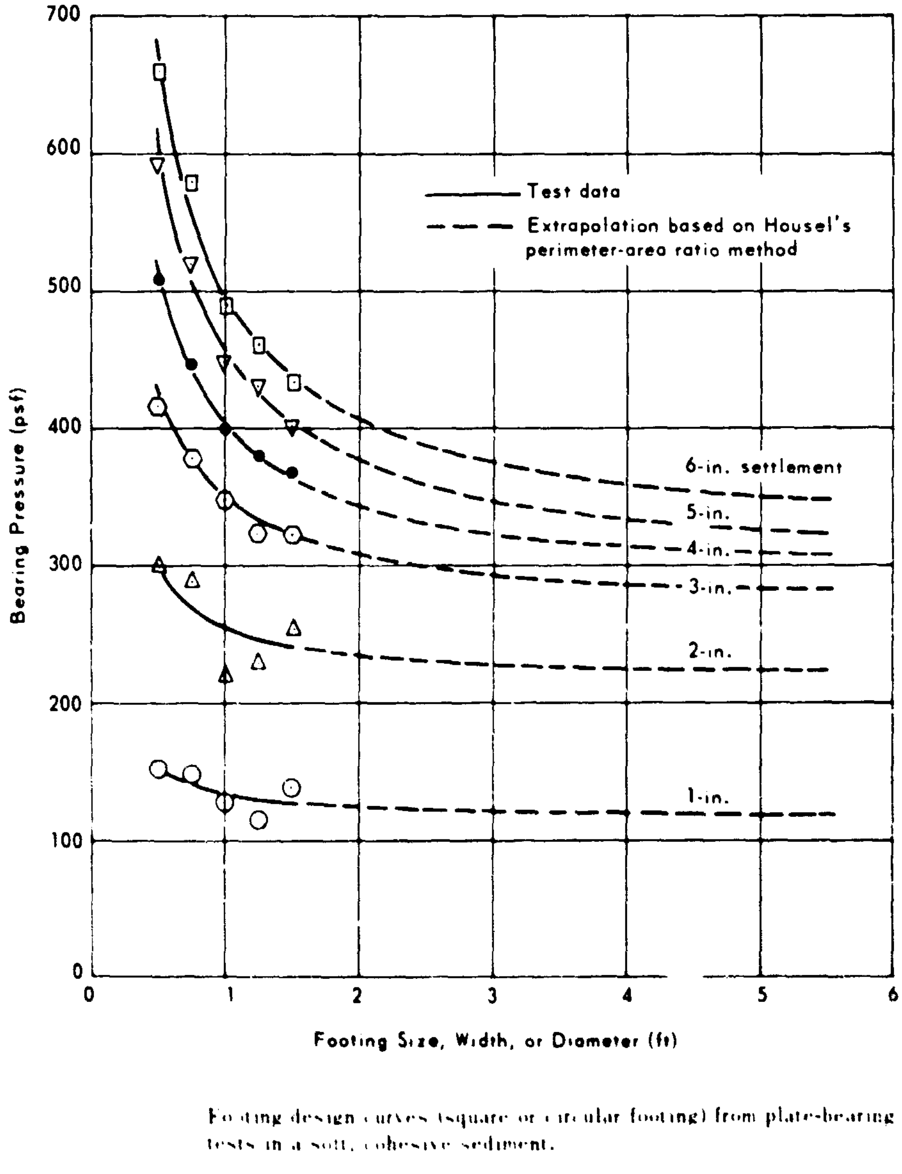
In-Situ Tests

To provide methods, equipment, and research necessary for the investigation and design of foundations for fixed structures on the ocean bottom, NCEL has developed an in-situ plate bearing device. This device is capable of determining the short-term bearing pressure and settlement response of marine sediments as it operates on the sea floor while connected to a surface vessel only by a load-bearing line. The unit was built and checked out in shallow water during FY-66.

Two series of tests were performed on both cohesive and noncohesive soils. In FY-67 the tests were extended to 1,200 feet, and the data from all tests were analyzed. It was found that the size of the bearing plate was the most significant parameter affecting the bearing pressure and settlement response in both major sediment types. Plates loaded to a given bearing-pressure level in a nearly homogeneous cohesive soil were found to undergo short-term settlements which were nearly proportional to the lateral dimension of the plates. Plates loaded to the same bearing-pressure level in a noncohesive soil exhibited short-term settlement which was nearly directly proportional to the empirical factor $(2B/B+1)^2$, where B is the lateral dimension of the plate expressed in feet. Sea trials are scheduled for depths to 6,000 feet.

A second device, the in-situ vane shear, is in the late stages of fabrication as an accessory of the Deep Ocean Test Instrumentation Placement and Observation System, discussed later in the section on Undersea Equipment. This device will be capable of performing vane shear tests to a depth of ten feet below the sea floor in a maximum depth of 6,000 feet of water. The device will also be capable of obtaining cone penetrometer logs by replacing the vane with a standard cone. Provisions are included for the application and measurement of vertical force up to 1,000 pounds. Research will be performed to (1) obtain in-situ measurements of soil strength properties, (2) relate in-situ data to laboratory tests of cores taken from the test sites, and (3) determine the relationships between in-situ vane shear measurements and the more rapidly obtained cone-penetrometer measurements for the various sediment types.

A third type of in-situ test being planned is concerned with methods of determining the long-term settlement behavior of seafloor sediments. It is anticipated that the Deep Ocean Test Instrumentation Placement and Observation System could be used to place and activate the long-term settlement device.



Footing design curves (square or circular footing) from plate-bearing tests in a soft, cohesive sediment.

Soil Testing in Pressure Vessels

To determine if the high-pressure, low-temperature environment of the deep ocean exerts a significant effect on the engineering properties of ocean-bottom sediments, a contract was awarded the Illinois Institute of Technology Research Institute (IITRI).

The initial contract was completed in December 1966 and is the subject of contract report CR 67.020, entitled "Environmental Effects on Engineering Properties of Deep Ocean Sediments." The environmental effects were investigated through consolidation, direct shear, and vane shear tests on four different ocean-bottom sediments within pressure chambers at hydrostatic environmental pressures up to 10,000 psi. The pressure chambers were also refrigerated to provide a 1 to 3°C environmental temperature.

It was reported that "The direct shear tests indicated that there was a decrease in shear strength with increased environmental pressure for fine-grained soils at high void ratios. The vane shear tests showed an increase in shear strength with an increase in environmental pressure for the more plastic soil and a decrease in strength with an increase in environmental pressure for the less plastic soil. The consolidation tests showed no effects that could be attributed to the environmental conditions. However, the apparatus was not sensitive enough to measure effects of loose sediments under small loads. Such effects might be expected to occur based on the shear test results."

The contract with IIT Research Institute has been extended for an additional year in order to permit the contractor to (1) modify testing equipment to allow more accurate load application and measurement; (2) concentrate testing on fine-grained soils at high void ratios; and (3) perform a sufficient number of tests of each particular type to allow statistical analyses of the data to be made.

Bottom Breakout Forces

Efforts during the second year were directed toward the field tests conducted in San Francisco Bay. The requirement to conduct long-term pullout tests in essentially undisturbed deposits led to the installation of a counterweight loading system aboard NCEL's warping tug. Continuous measurements of force, displacement of the specimen relative to the barge, and displacement of the barge relative to the bottom are recorded.

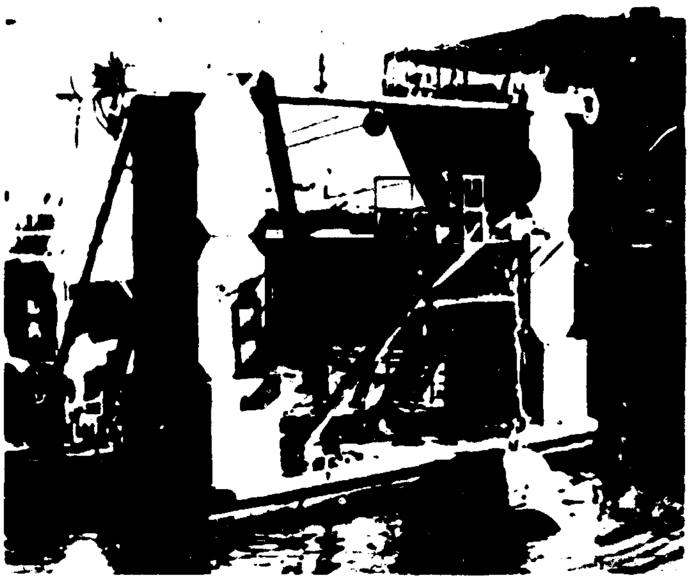
Six specimens were fabricated as test objects and include a sphere, a cube, a prism, a cone, a cylinder, and an ellipsoid. Based on the data obtained from tests with the cube and the prism, the maximum loads for various time durations required to break away a rectangular keel of a submersible in sediments of this type are estimated to be as follows:

Time to Breakaway	Applied Load
1 hour	110,000 pounds
2 hours	80,000 pounds
4 hours	55,000 pounds
8 hours	20,000 pounds

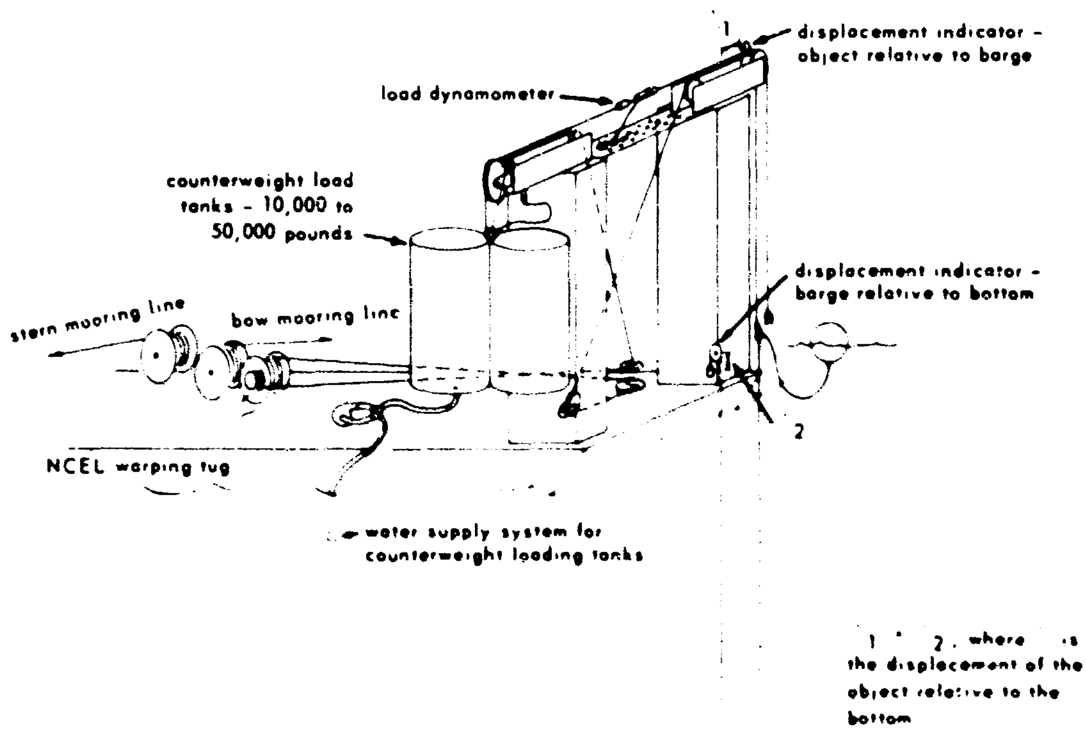
This assumes that San Francisco Bay clays are representative of one type of softer deep ocean marine impermeable clays in which a submersible may become embedded.

Future work will be directed toward a series of tests using the same specimens in the harder, silty clays of the Northeastern Gulf of Mexico and in fine-grained carbonate deposits off Florida. Appreciably greater applied loads are anticipated to effect a breakout in the harder sediment types.

This work is sponsored by the DSSP in connection with the Large Objects Salvage System



Counterweight loading system.



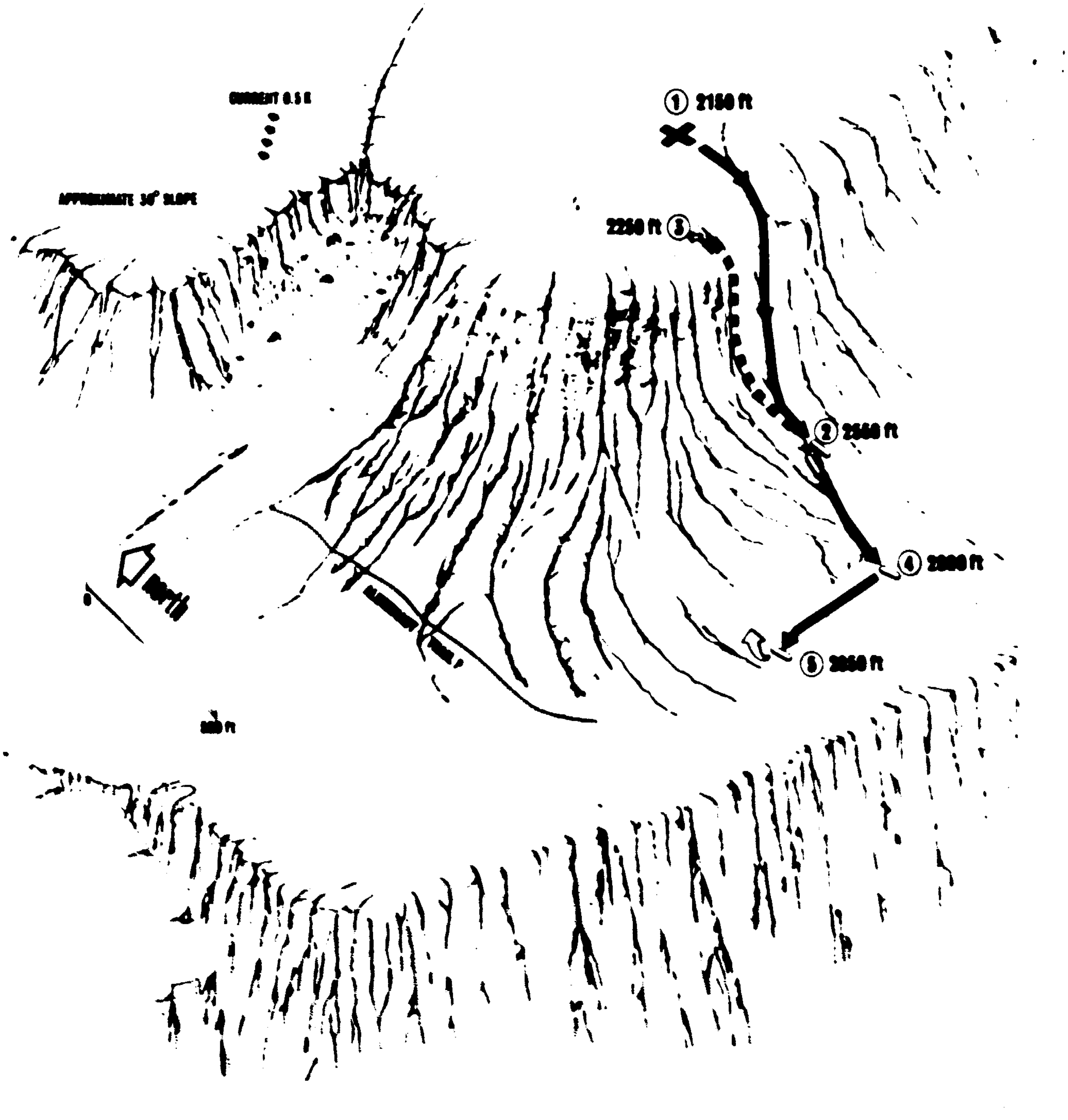
General scheme for DSSP breakout-force test program.

Aircraft Salvage Operations, Mediterranean

During FY-66, personnel from NCEL were involved in the aircraft salvage operations conducted by Task Force Sixty-five for the recovery of a missing nuclear weapon in Mediterranean waters off the coast of Palomares, Spain.

Functions dealt chiefly with detailed examination and testing of the bottom sediments in the area of concern to determine both the probable penetration of the missing weapon into the sea floor and the breakout force required to retrieve it. Some fifty gravity cores were secured in conjunction with the Naval Oceanographic Office in the process, and these were subjected to detailed physical testing in a soils laboratory established in the Spanish port of Cartagena.

As a secondary effort in the operations, very detailed studies of the submarine topography in the search and recovery areas were made. The resulting plots, sketches, and charts, made with the assistance of the submersible operators and tracking ships produced one of the most detailed pictures of deep-water topography in existence. The findings were translated to three-dimensional models of the undersea topography for use by Task Force Sixty-five staff in their activities.



Detailed drawing of operational conditions at the nuclear weapon recovery site.

UNDERSEA EQUIPMENT

Radioisotope Power Sources

The need for small power sources for long-life acoustic beacons and various types of oceanographic instrumentation is recognized. Chemical batteries cannot fulfill the need. The potential reliability and long life of radioisotope power sources is most attractive, but as yet, is unproven.

A program of test and evaluation in both laboratory and undersea environments of state-of-the-art radioisotope power sources is underway at NCEL. Power outputs from 0.1 to 25 watts and the required peripheral electronic devices are being considered. Controlled environmental testing will be performed on each device before operational evaluation is undertaken at sea.

At present a 0.7-watt United Kingdom RIPPLE III device and a 2.6-watt Martin MW-3000 device have been received and are being tested. One-watt units are on order from Atomics International and Aerojet General Nucleonics. In addition, two 0.1-watt devices from NUMEC are scheduled for a June delivery.

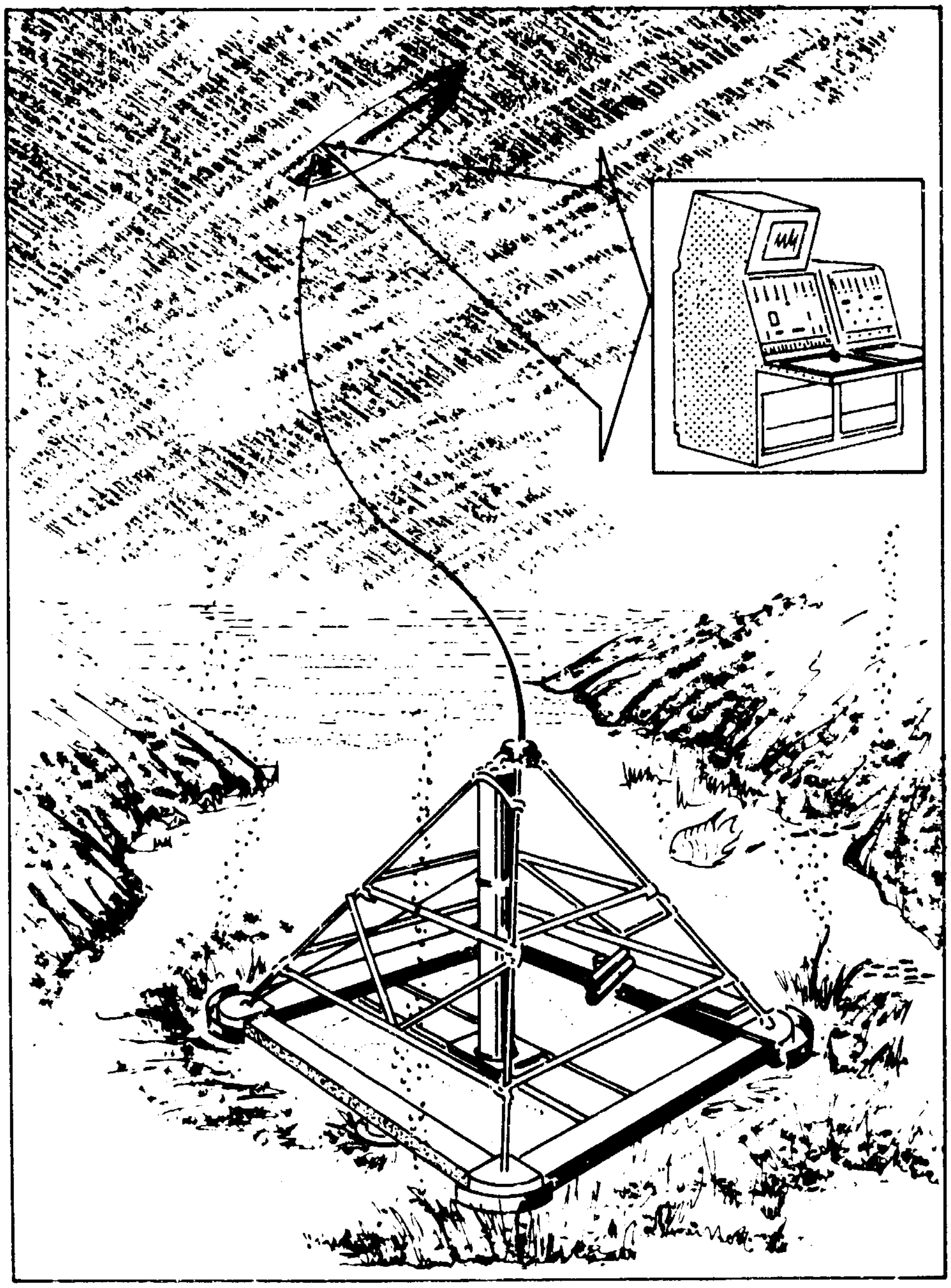
[illegible] Martin MW-3000 [illegible]

Deep Ocean Test Instrument Placement and Observation System

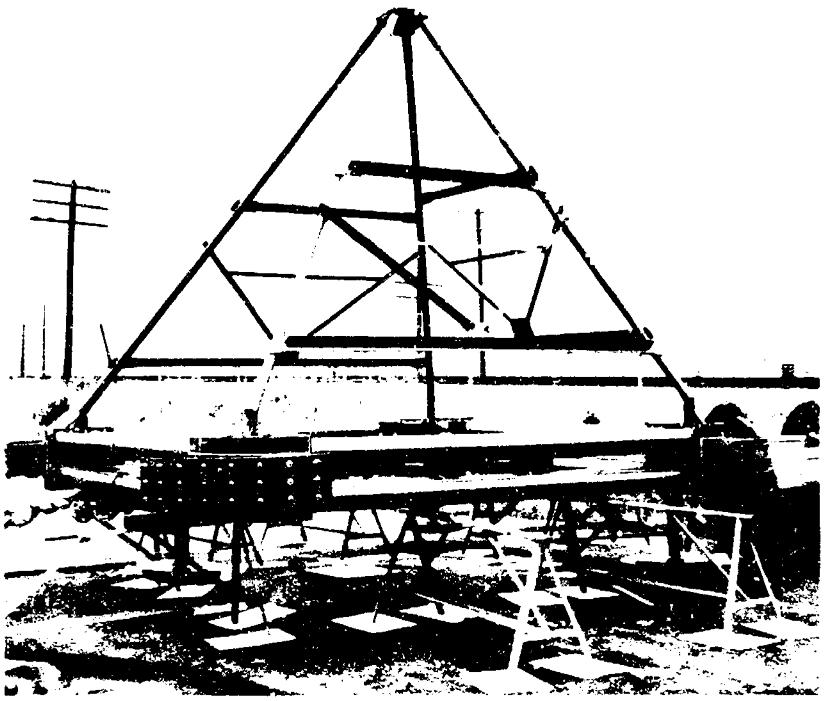
It has often been claimed that in order to obtain a true understanding of sea-floor processes the scientist must transport himself into the environment and conduct his tests and observations there. Simulation has limited value, and the collection of specimens and data using remote "probes" (for example, hydrographic casts) is often misleading and not necessarily sound scientific practice.

To bridge the gap between the luxury of a deep manned submersible and the austerity of the remote probe, a bottom-resting underwater observation, control, data transmission, and power supply system has been designed and fabricated. The bottom-resting part of the system is a support platform to which a TV camera, a photographic camera, a data and command telemetry package, and suitable lights are attached. Provision is made to supply up to 15 kw electrical power to in-situ sensors, tools, and other devices which may be needed in support of various studies. The platform is connected by multiconductor coaxial armored cable to a deck console which can be placed aboard ship and from which all control is exercised and through which all data are received. The TV monitor surmounts the console. The cable is designed to support the load of the underwater unit during emplacement and retrieval operations. The system has a 6,000-foot depth capability.

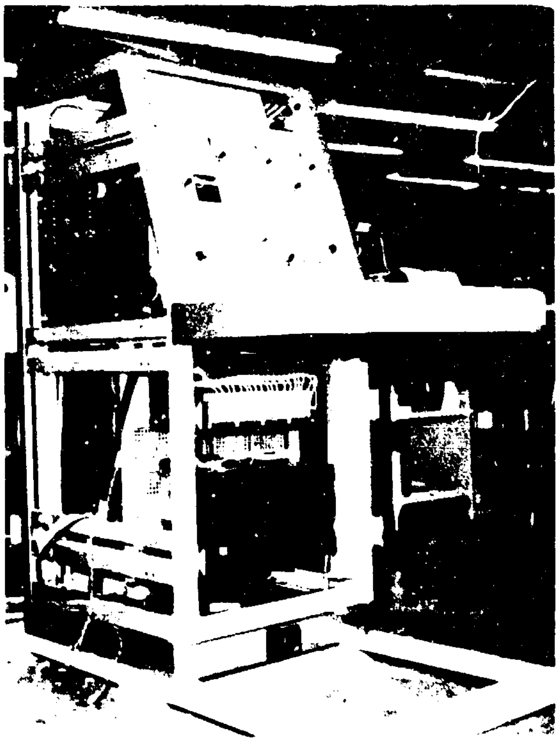
The first accessory for use with the system is a vane shear sediment-testing device from which data can be collected at depths of up to 10 feet in sediment and transmitted to a shipboard console.



Undersea Eyes — Scientists will be able to study the ocean's floor at depths up to 6,000 feet by using this newly designed platform.



Preliminary assemblage of structural frame.



Shipboard control console with front and side panels removed.

Propellant-Embedment Anchors

The ultimate goal of the anchor development program is to meet most current and future requirements for securing structures in ocean locations at any depth. Early efforts of the program are limited to depths of 6,000 feet and are concerned primarily with the type of implement to provide a firmly fixed, reliable anchor point, the means of placing it, and the means of attaching to it.

Before FY-67, two small commercial propellant-embedment anchors, nominally rated at 5- and 10-kip capacity, were investigated.* Successful discharges and test loading to depths of 6,000 feet demonstrated their potential for deep-water application. But the tests also pointed out limitations in reliability and capacity.

In FY-67 a larger propellant-embedment anchor rated at 50,000 pounds capacity is being investigated. The anchor, developed by the U. S. Army Research and Development Laboratory for use in coastal waters, is being modified by NCEL for use at greater depths, with the target depth set for 6,000 feet. It is desired to determine the attitude of the anchor at discharge, the depth of penetration achieved, and the displacement relationship versus applied load during testing. Currently, a tripodal supporting frame with all the necessary instrumentation has been designed and fabricated. The acoustic command signal device for activating the anchor firing mechanism has been successfully tested with the anchor in shallow water, while the acoustic command device for signaling the anchor attitude, penetration, and displacement under load has been successfully tested in a depth of 1,000 feet. Laboratory checkout of the modified anchor in NCEL's high-pressure test facility indicated no leakage at pressures up to 10,000 psi.

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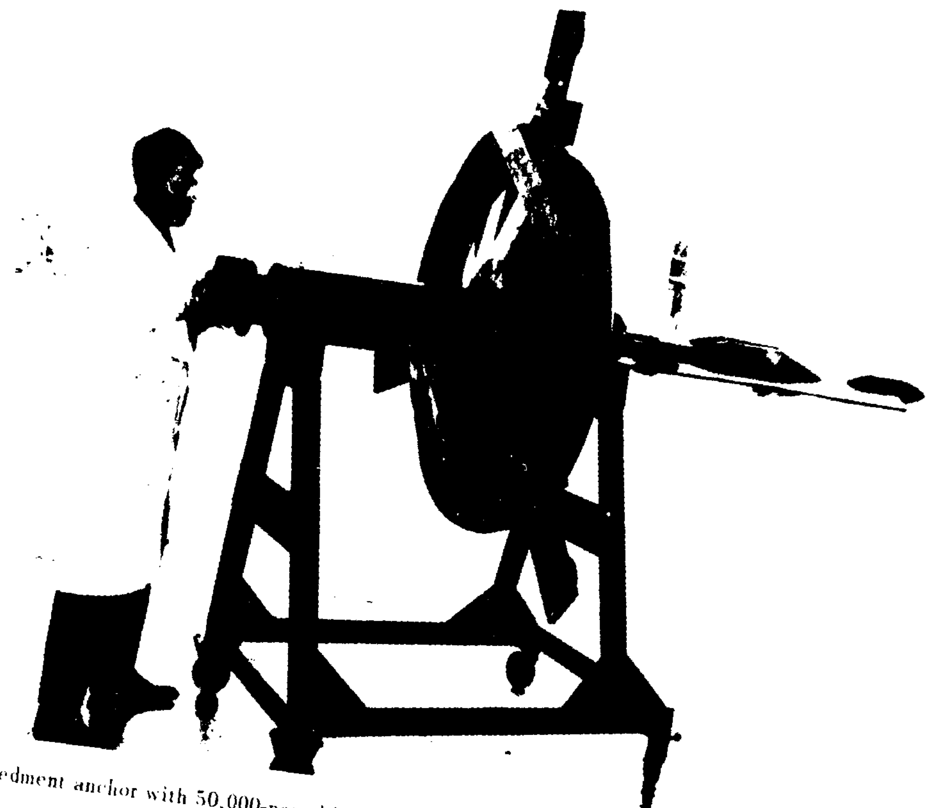
* The propellant-embedment anchor is a self-contained device similar to a large-caliber gun consisting of a barrel, a recoil mechanism, and the projectile which is the anchor.



Embedment anchor with 50,000-pound holding capacity.

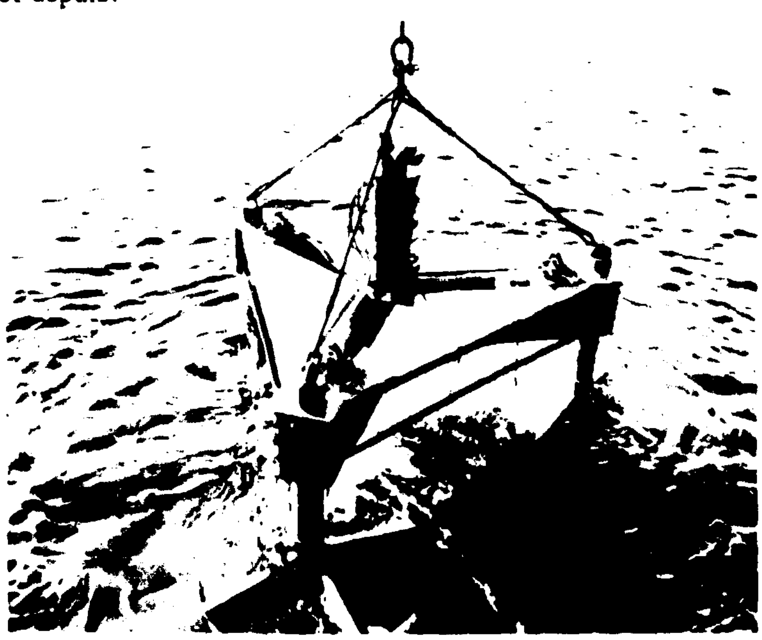
PADLOCK Anchor

To provide an anchor point in the sea floor that is totally fixed and will support an applied load from any direction, NCEL applied the propellant-embedment-anchor concept to an anchorage complex for bottom-mounted structures. The design as produced is a tripodal frame with articulated bearing pads at the extremities. Propellant-actuated embedment anchors with rated holding-power capacities of 20 kips each are mounted in each of the three arms above the bearing pads. The anchors are driven into the sea floor through openings in the pads. The other end of the cable that is attached to the anchor is connected to a cable-rewind mechanism at the center. The rewind mechanism pretensions the anchor lines after the anchors are embedded.

During FY-66 the complex was demonstrated to be workable in the major areas of concern, such as cable rewind, cable payout, blast effect, and bearing-pad acceptance of activated anchors and cable; but it was determined that improvement of the performance of the embedment anchors in each of the three arms is necessary. Further development was delayed pending development of improved embedment anchors.

Modified anchors were received in FY-67, and the complex was reassembled and tested in shallow water. All components functioned satisfactorily during this test. A second shallow-water test and one at 1,200 feet are scheduled for late FY-67.

One of the major efforts completed was the development and test of an electronic activation unit that directs the operations of the PADLOCK system in deeper water. The activation unit, housed in about a 1- by 2-foot package attached to the anchor frame, receives signals initiated from the surface and detonates the embedment anchors individually and activates the rewind mechanism. This unit eliminates the need for conductor cables, thus making it possible to handle the PADLOCK with a single line from the surface. The activator unit was tested successfully in 100-, 300-, and 1,000-foot depths.

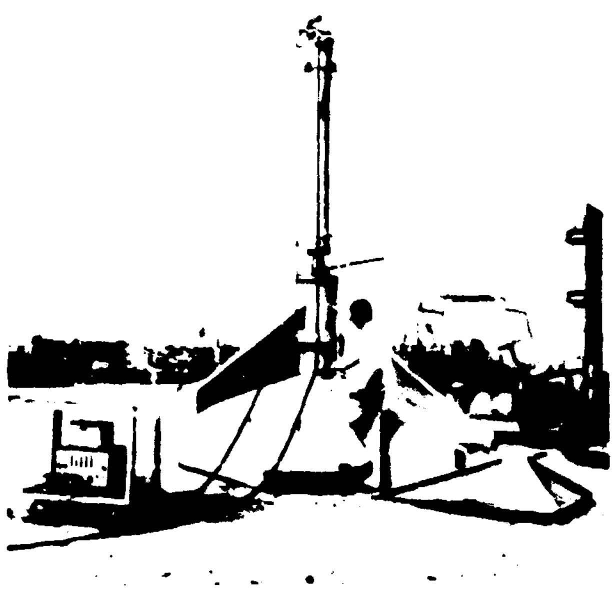


Recovery of PADLOCK after shallow water test.

Hydrostatic Power Unit

With the prospects of extensive activity in the deep ocean, there have been a number of attempts to utilize the high hydrostatic pressure found at depths to power various types of equipment. A typical example is the derivation of power from a basic fluid ram device. These ram devices are similar to fluid-power units commonly found, with the exception that the environmental high pressure is external. For deep ocean work, the fluid ram lends itself to single-impulse operations, such as locking, fastening, shearing of cables and bolts, or the embedding of anchors.

The objective was to determine the available single-impulse energy that a hydraulic ram could develop at various ocean depths. Fifty-four tests were conducted with a specially designed hydraulic ram under simulated hydrostatic conditions. Pressures up to 2,000 psi were used to drive a piston through a 48-inch barrel with a 2-inch-diameter bore. Piston velocities up to 460 feet per second were attained. The experimental velocities approximated theoretical values. It is concluded from the tests that piston velocities can be predicted for combinations of piston weight, barrel length and bore, and pressure.



Testing of hydrostatically actuated piston.

Improved Weight-Handling Systems

During FY-66, sea tests were conducted on high-mass/low-drag bodies of formalized shape in relatively shallow water. The purpose of the tests was to collect experimental data on dynamically induced stresses in long cables which could be compared with the theory presented in TR-433.* Tests were conducted on a sphere, a cylinder, and a parallelepiped using both steel and synthetic wire ropes in water depths of 1,000 feet and shallower. Measurements of the dynamically induced stresses and the accelerations were recorded as a function of time.

Some of the results of these tests are indicated in the graph, which is an analysis of a portion of the data pertaining to the cylinder while suspended by nylon line. This particular analysis compares the relative frequency distribution of the absolute peak values of the dynamically induced forces with the theoretical distribution function (Rayleigh). To interpret the figure, the shaded portion indicates the probability of inducing a dynamic load between 700 and 800 pounds. The theoretical probability is determined to be approximately 10.2% – 100 lb x 0.00102/lb – whereas the frequency distribution of an actual record was measured to be approximately 11.7% – 100 lb x 0.00117/lb.

These results are particularly useful in establishing design criteria for winching systems, both for load handling and for mooring in the ocean environment.

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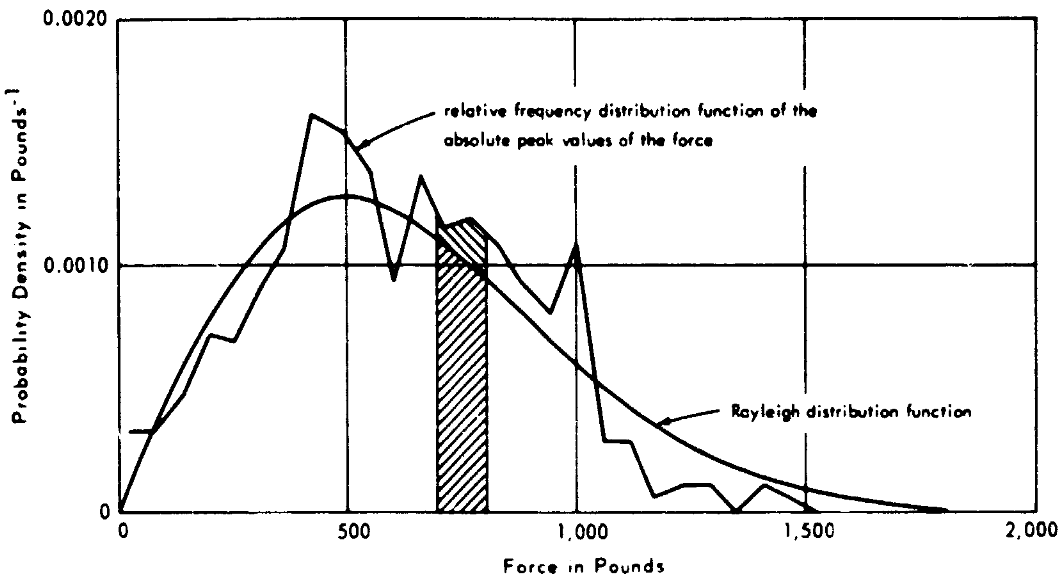
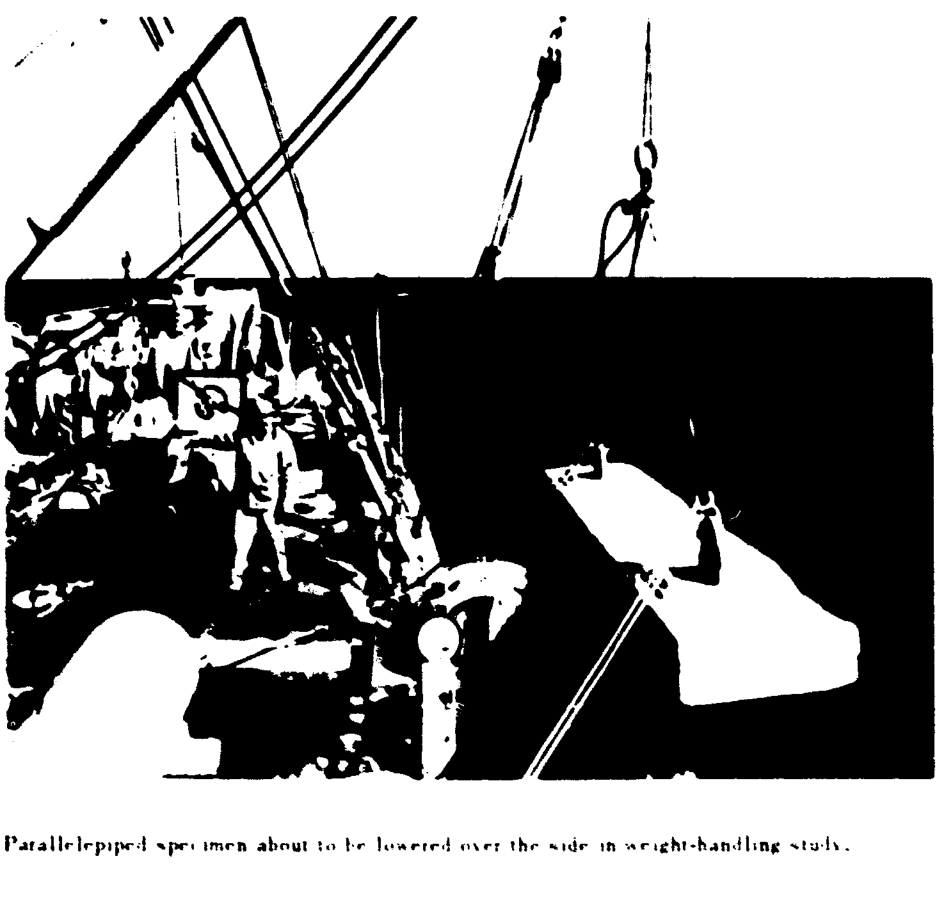
* See publications listing in back.





Parallelepiped specimen about to be lowered over the side in weight-handling study.

UNDERSEA ENVIRONMENT

Effects on Materials

The objective of this task is to determine the effects of deep ocean environments on the corrosion of construction materials and to determine the corrosiveness of bottom sediments.

All submersible test units were emplanted or retrieved prior to FY-67, as indicated in the following table.

Submersible Test Unit Data

STU	Depth (ft)	Weight in Air (lb)	Total No. Specimens	Materials Represented	Emplaced	Retrieved
I-1	5,300	7,000	1,282	396	Mar. '62	Feb. '65
I-2	5,640	5,600	1,521	429	Oct. '63	Oct. '65
I-3	5,640	5,200	1,367	398	Oct. '63	Feb. '64
I-4	6,780	6,710	1,852	567	June '64	July '65
II-1	2,340	7,350	2,385	603	June '64	Dec. '64
II-2	2,370	8,750	2,588	811	Apr. '65	May '66

During FY-67 a surface seawater exposure site was established at the Point Mugu Naval Missile Center, and specimens were exposed completely submerged in seawater for 6 months.

The stress corrosion specimens have been removed and inspected weekly. Some specimens failed early from stress-corrosion cracking in the surface exposure, as indicated in the following tabulation.

Alloy	Yield Strength (%)	Tensile Stress (ksi)	Days to Failure
18% Ni Maraging steel, unwelded	75	237	7, 21, 21
18% Ni Maraging steel, welded	75	237	14, 14, 21
18% Ni Maraging steel, welded	50	158	21, 28, 91
Titanium alloy, 13V-11Cr-3Al, welded	75	95	35, 77 edge of weld bead

There were no failures of any of these alloys after 402 days of exposure at equivalent stresses at a depth of 2,370 feet.

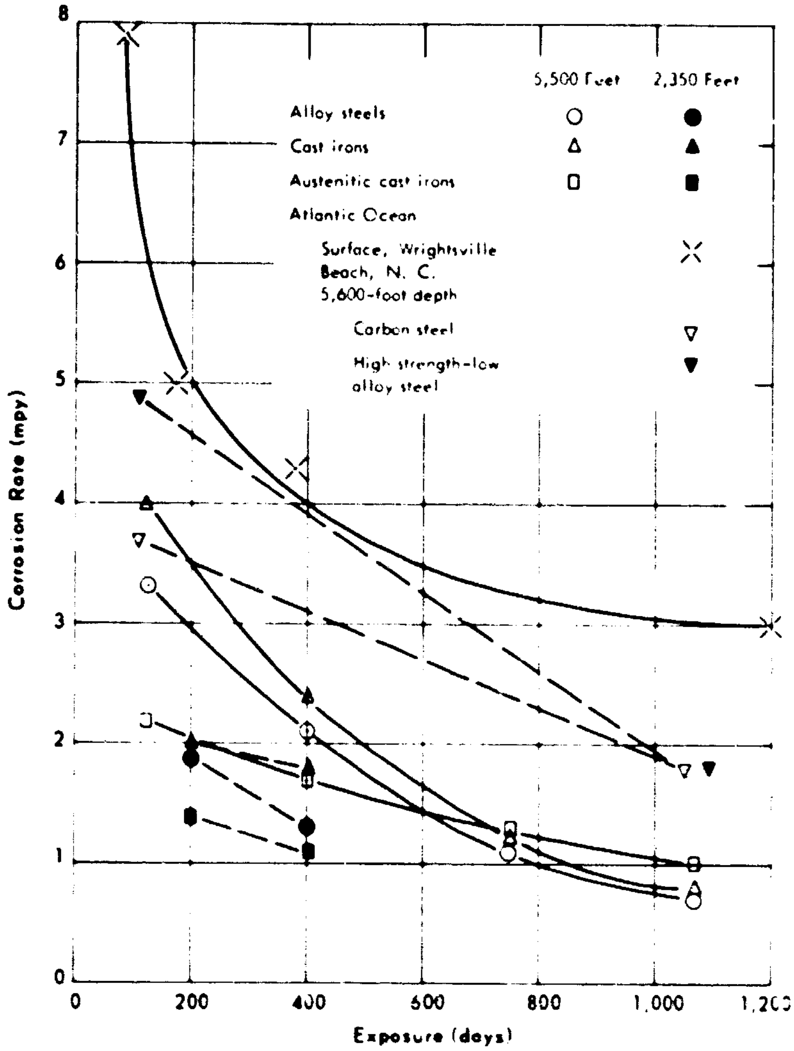
The Technical Report R-504 entitled "Corrosion of Materials in Hydrospace" was issued, which included the results from three submersible test units: STU I-1, STU I-3, and STU II-1.

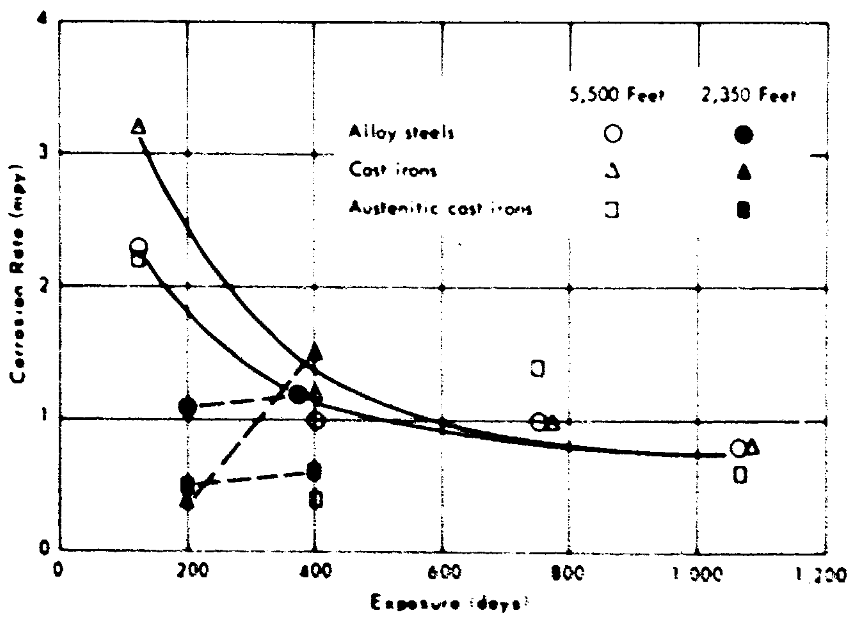
Another report, a Technical Note entitled "Corrosion of Materials in Hydrospace – Part I. Irons, Steels, Cast Irons, and Steel Products" was issued. This report contains the results of all six exposures indicated in the table.

Statistical median corrosion rate curves for the three classes of alloys were plotted to show the effect of time at depth and the effect of depth in seawater. Surface data for mild steel exposed in the Atlantic Ocean at Wrightsville Beach, N. C., and data from a depth of 5,600 feet are shown for comparison. The corrosion rates at both depths in the Pacific decreased with increase in time of exposure. At a nominal depth of 5,500 feet, the rates became asymptotic with time.

It has also been found that at depth in the Pacific Ocean, (1) the corrosion rates of the copper-base alloys decreased with time; (2) pit depths and corrosion rates of most aluminum alloys increased with time; (3) titanium alloys were immune to corrosion, except that one all-beta alloy (13V-11Cr-3Al) with a circular weld bead was susceptible to stress-corrosion cracking; (4) depending upon the chemical composition, some nickel-based alloys corroded, while others were uncorroded. The corrosion behavior of these alloy systems will be reported upon fully in reports which are in varying stages of preparation.

Biodeterioration, microbial corrosion (effects of marine microorganisms on corrosion metals), fouling growth, and marine borer studies have been conducted on materials exposed at various depths to 6,800 feet. Investigations are also in progress on various types of material specimens exposed to study fouling and biodeterioration which may occur at shallow depths.



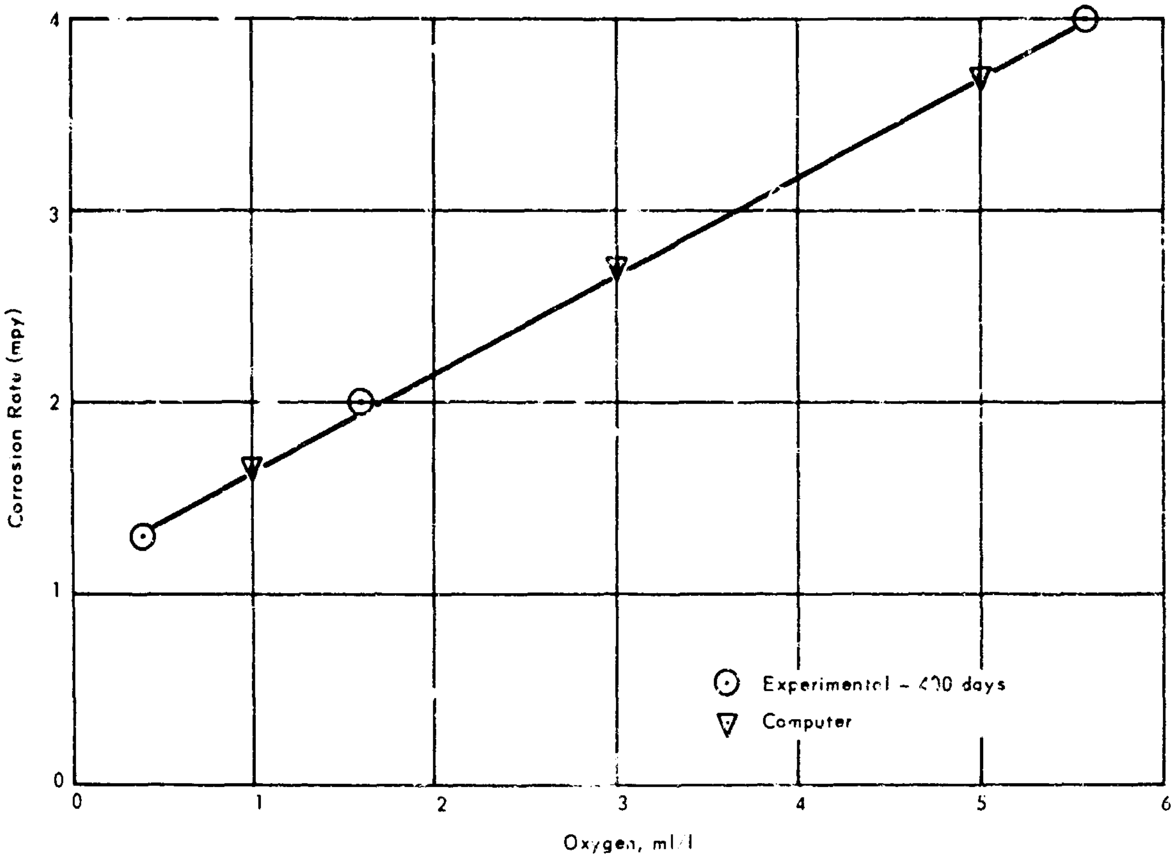


Statistical curves for steels, cast irons, and austenitic cast irons in bottom sediments.

Statistical curves for steel, cast irons, and austenitic cast irons in seawater.

Statistically, the 5,500-foot depth in the Pacific Ocean is significantly different from a similar depth in the Atlantic Ocean with respect to the corrosion of steels. At these depths, the decrease in corrosion rates of steels in the Atlantic Ocean are due chiefly to the low temperature, while those in the Pacific Ocean are due to both low temperature and low oxygen concentration. The corrosion rates at depths of 2,350 and 5,500 feet after 400 and 1,050 days of exposure, respectively, in the Pacific Ocean are approximately 1/3 those at the surface in the Atlantic Ocean.

The statistical median curves for the materials in the bottom sediments at a nominal depth of 5,500 feet are the same as those in seawater at this depth. However, the corrosion rates tended to increase slightly in the bottom sediments at the 2,350-foot depth.



Effect of oxygen on corrosion of steels.

Corrosion rates calculated by using an equation, obtained by linear regression analysis of a set of data, for the effect of oxygen at depths and at the surface agreed quite well with corrosion rates calculated from weight losses as shown in this graph. Corrosion rates of steels increase linearly with oxygen concentration.

(a)

(b)

Wood panels damaged by molluscan wood borers, *Xylophaga washingtona*, at depths of 6,800 feet on the ocean floor. (a) Exterior side of wooa panels. (b) Interior side of same wood panels.

Protective Coatings

Protective coatings for steel structures were applied to steel test specimens and subjected to 3,000 psi hydrostatic pressure inside the 18-inch pressure vessel containing seawater. The objective of the test was to determine if blisters formed during exposure at 3,000 psi or during the release of pressure simulating retrieval. Blisters were found in these coatings after retrieval from 6,800 feet on a STU. Blisters were not found in the paints when the test specimens were removed from the pressure vessel, which had been held for 2 weeks at 32°F, 3,000 psi, and about 3 ml of oxygen per liter of water. Additional tests were made at 3,000 psi, at room temperature (73°F), and at the same oxygen content. Blisters were found in the coatings when the specimens were removed. Experiments will continue through FY-67.

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Technical Reports*

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Deep Water Salvage Pontoon, 25-Ton Lift Capacity, NCEL TR, by J. J. Bayles and D. Taylor. (To be published)

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High Hydrostatic Pressure Ram Device, NCEL TR, by P. A. Dantz and J. Ciani. (To be published)

Light Housings for Deep Submergence Applications – Part II. Miniature Light Housings, NCEL TR, by J. D. Stachiw and K. O. Gray. (To be published)

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* Government agencies may obtain copies through the Defense Documentation Center, Building 5, Cameron Station, Alexandria, Va. 22314. All other requesters may obtain copies through the Clearinghouse for Federal Scientific and Technical Information (CFSTI), Sills Building, 5285 Port Royal Road, Springfield, Va. 22151.

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Preliminary Plans for Breakout Tests in Pressure Vessel, NCEL TN, by B. J. Muga. (To be published)

Proposed Experimental Methods for Determining Material Damping Qualities of Synthetic Fiber Cables, NCEL TN, by B. J. Muga. (To be published)

* Technical Notes are internal working papers of limited distribution.

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13. ABSTRACT

The ocean is being challenged to give up its secrets. Man will go down into the sea to satisfy his native urge for exploration and acquisition, to observe and perform those functions he considers necessary to complete his mission. Ocean engineering will provide him with the capability of doing so.

Some explorations will be at diver depths and will expose man directly to the undersea environment. Others will require him to go to greater depths in manned habitations and vehicles. Both types of exploration will place him directly at the site. He also has the choice of placing his capabilities at the site, while he remains remote at the surface. These methods of exploration are distinctly different, and yet they complement one another because they impose similar demands on technology and issue a challenge to the many disciplines of engineering and science.

This publication documents the efforts and research undertaken by the Naval Civil Engineering Laboratory in answer to this challenge. The period covered is, roughly, from March 1966 to March 1967, although the techniques described are results of work much deeper in the past, and the technology envisioned represents a long stride into the future.

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