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NCEL OCEAN ENGINEERING PROGRAM, MARCH 1968-MARCH 1969.

NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA

AUG 1969

FOREWORD

This publication documents the Naval Civil Engineering Laboratory program in ocean engineering. The period covered is, roughly, from March 1968 to March 1969, 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 Ocean Engineering Program supports the Navy's sea-floor missions. The program includes research in equipment, fixed structures, and installations on the ocean floor. Other investigations of equal importance involve developing new and more effective equipment and procedures for salvage at sea.

CONTENTS

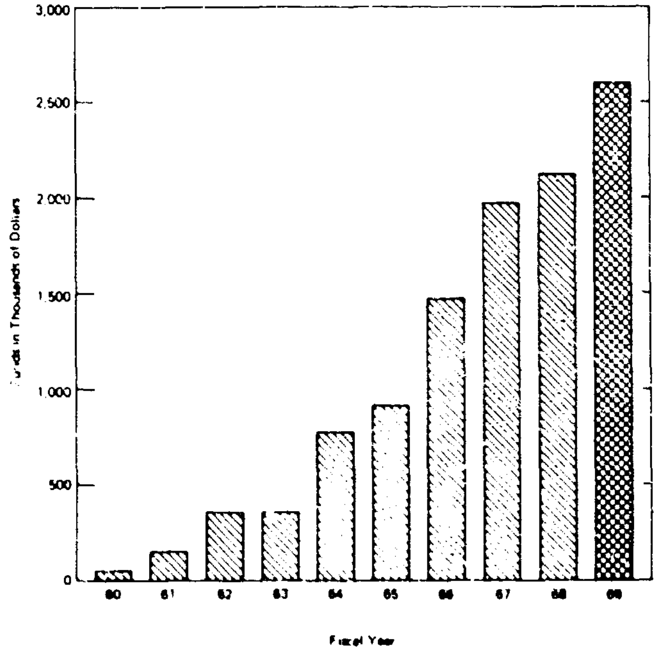
MANPOWER, FUNDING, CONTRACTS

Manpower

NCEL's ocean engineering program, while including specialists from many organizational groups in the Laboratory, is coordinated in the Ocean Engineering Department. There are about 40 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 from other 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-69 approximately 40% of this funding went to other government activities and private industry. To a large extent the tasks described in this publication were sponsored by the Naval Facilities Engineering Command, the Naval Ship Systems Engineering Command (Supervisor of Salvage), the Deep Submergence Systems Project, and the Chief of Naval Material (Deep Ocean Technology Program).



DIVER CONSTRUCTION AND SALVAGE

The Diver-Constructor

A long-range program is underway to develop adequate knowledge, techniques, systems, and equipment to support diver construction operations on the continental shelf. In order to achieve this end, specific construction projects will be accomplished.

The first diver construction experiment, DIVERCON 1, places major emphasis on handling components on the sea floor by divers without dependence upon the surface. Also emphasized are diver assembly techniques.

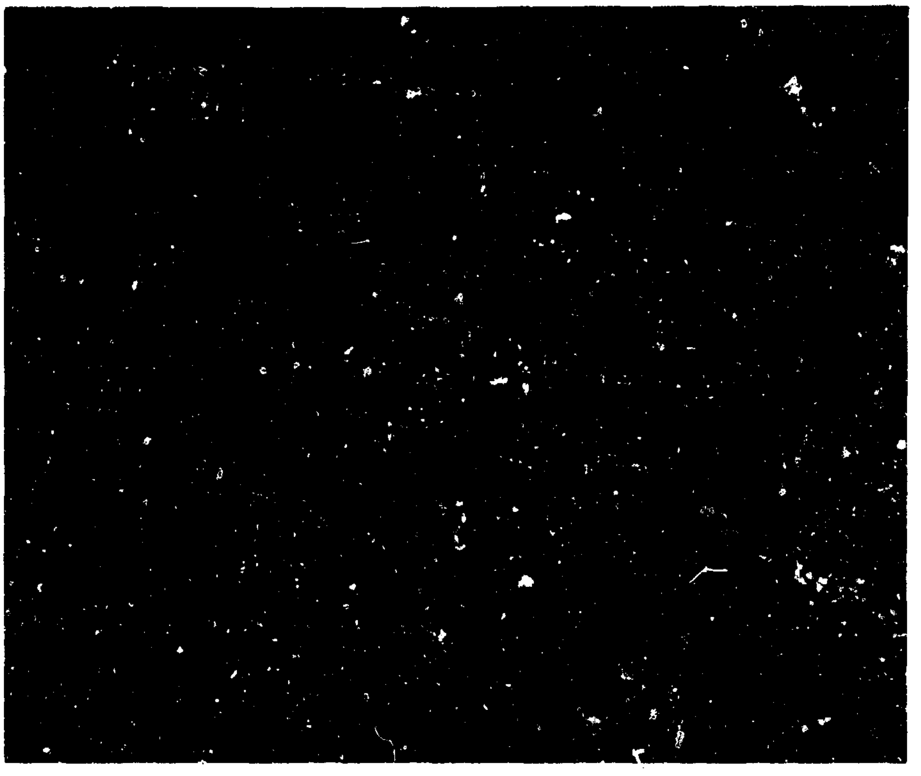
DIVERCON 1 is a diver-constructed underwater repair and storage facility designed to demonstrate the feasibility of constructing such a structure at ambient ocean pressure. This station may be built around an object such as a sonar device or power source, it may be used as a dry repair facility, or it may be built near an underwater habitation and used for dry storage.

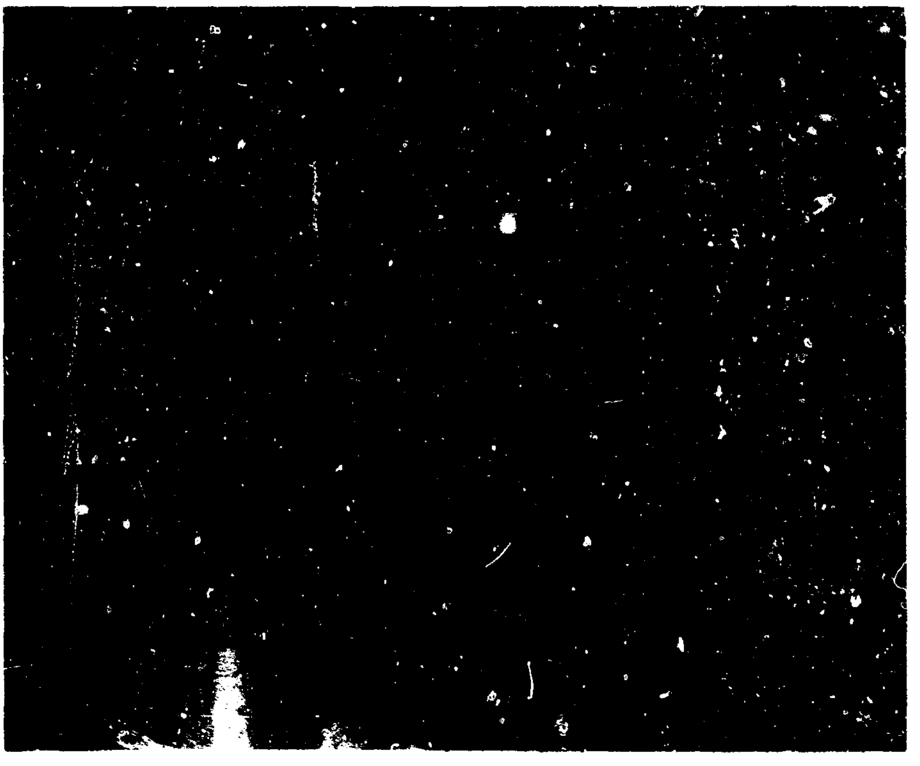
The facility model is a 120-inch-diameter structure that utilizes construction techniques which could be readily extended to larger structures. The assembly operation utilizes a system of guides to properly align the components. The fasteners are primarily quick-acting latches, with a minimum number of bolts used for backup. This type of structure would also provide an economical test chamber for research and development work with pressurized undersea habitations.

The weight-handling system used to lift and place the structural components utilizes a variable-buoyancy float as a "sky hook" and a hydraulic winch for the actual lifting operations. The divers control the buoyancy of the float and the operation of the winch, making surface support unnecessary.

Final shallow-water tests were successfully conducted during July and August of 1968. Surface support during placement and recovery was provided by the NCEL warping tug and by the USNS *GEAR*. During the diving operations, surface support was provided by the NCEL diving boat and by a small pontoon barge.

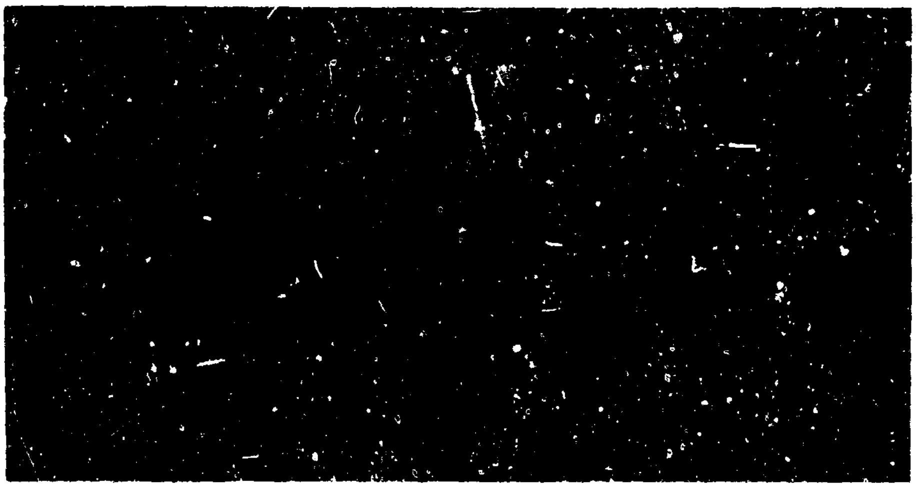
The experiment to date has demonstrated the feasibility of construction of large-scale installations on the sea floor by divers. The modular assembly concept and the design of the experiment around the diver are two important factors that have contributed to the success of this experiment.





Construction Assistance Vehicle

To transport divers, tools, power supplies, and equipment to ocean-bottom construction and salvage sites, NCEL is developing an experimental diver-operated work vehicle for depths to 120 feet. The vehicle, utilizing proven off-the-shelf hardware, such as electro-hydraulic power packages, oil-immersed lead–acid batteries, and hydraulic-motor-driven propulsion units, will be used to test and refine the work vehicle concept so that operational criteria and specifications can be written for a vehicle capable of operating to the limit of diver depths. Engineering design for the experimental vehicle is completed, with fabrication drawings and specifications scheduled for completion during 4th quarter FY-69. It is planned to let a fabrication contract in late FY-69 or early FY-70.



Construction assistance vehicle. Batteries and gas cylinders are concealed beneath deck and grating.

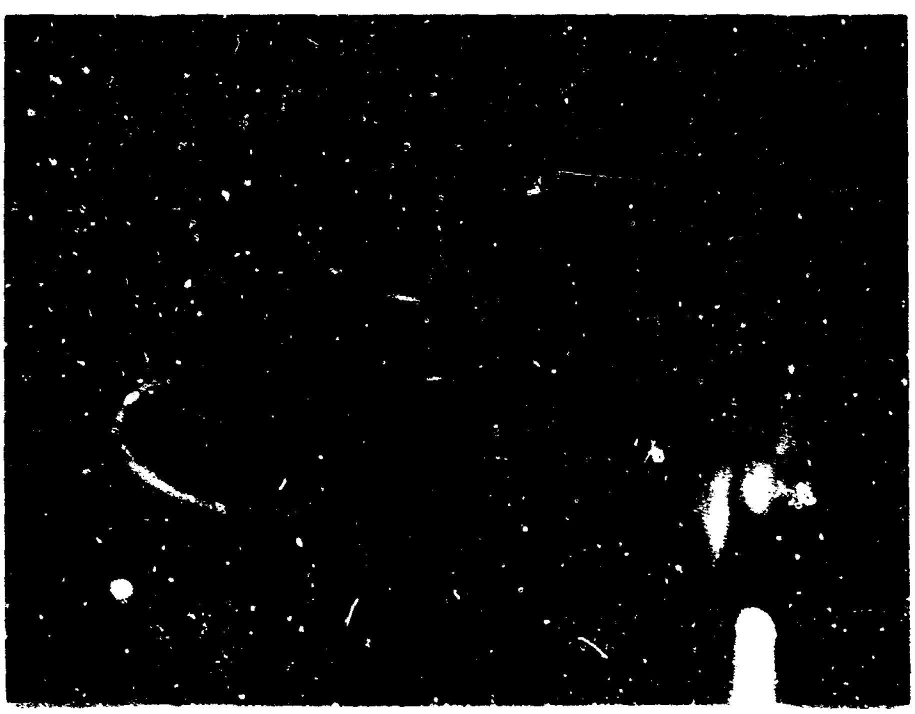
SEALAB III Salvage Experiments

The SEALAB III Salvage Program, sponsored by the Supervisor of Salvage (NavShips) is a series of experiments to demonstrate the field test latest techniques and equipment being developed for the Navy's salvage forces.

The salvage experiments (listed below) were conducted by SEALAB Team 2 during May 1968 from the USNS *GEAR*. The project experiments were conducted at Anacapa Island in 50 feet of water, using air scuba, primarily for training and familiarization.

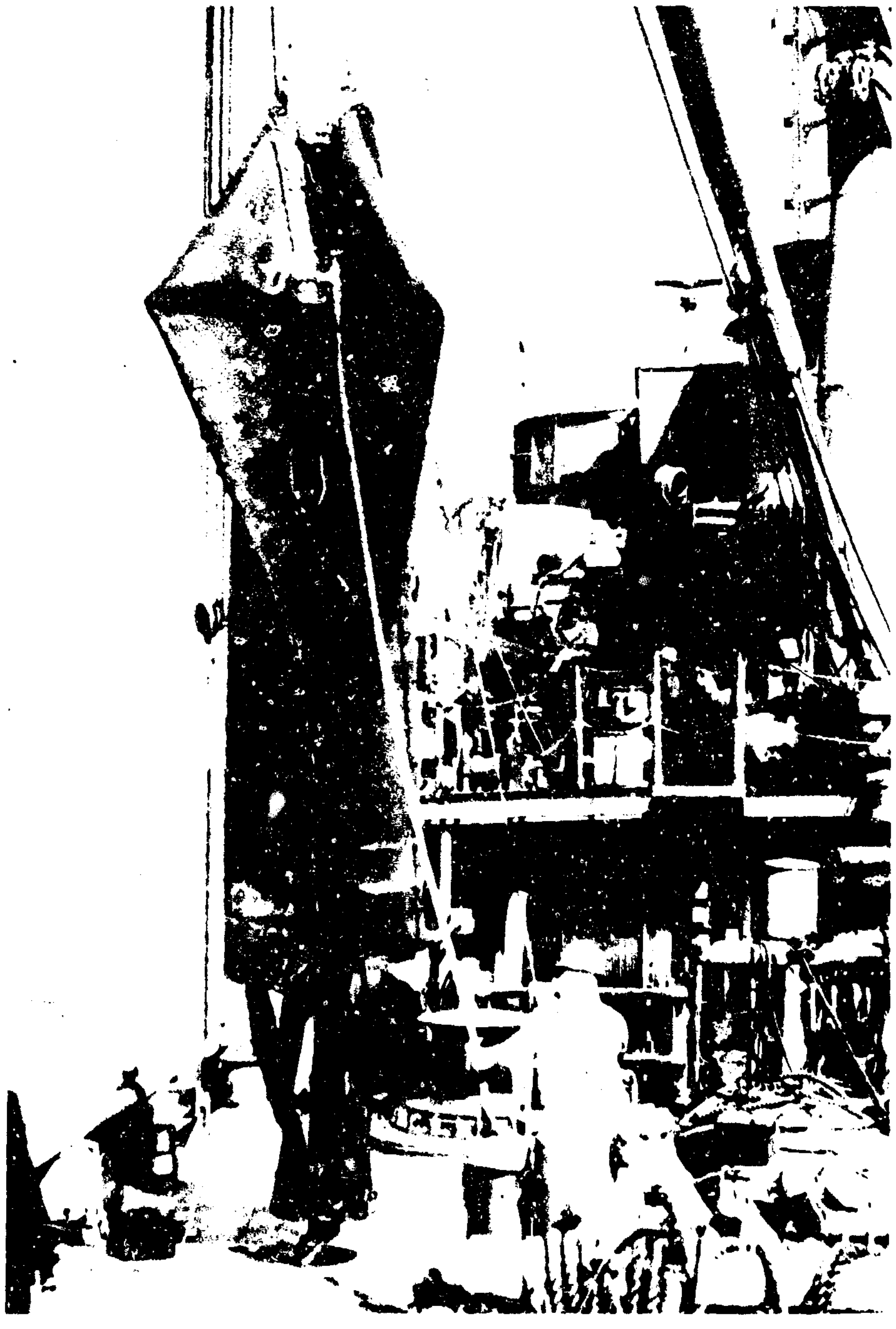
In August 1968, a successful shallow water "dress rehearsal" of all the salvage experiments was again held in 50 feet of water at Anacapa Island from the USNS *GEAR*. Aquanauts conducted all experiments while using complete aquanaut equipment and mixed-gas scuba. Baseline shallow-water data was obtained for comparison with data for tool and aquanaut performance at 620 feet.

Salvage Experiment	Activity	Salvage Experiment	Activity
Bottom Stabilization	NCEL	Hand Tools	NCEL/NMC
Lift System (2-ton pontoon-hydrazine generator)	NWC	Diver Tools (NOL explosive cable cutter)	NOL
Lift System (8.4-ton collapsible pontoon)	NCEL	Diver Tools (NOL/MSA explosive stud driver)	NOL
Lift System (Hunley/Wischoeffer)	NUWC	Diver Tools (electric-powered hand tool)	Battelle
Lift System (small variable 200-pound hydrazine generator)	NWC	Search Procedures	SUPSALV/NCEL
		25-ton explosive padeye	NOL



Collapsible Salvage Pontoons

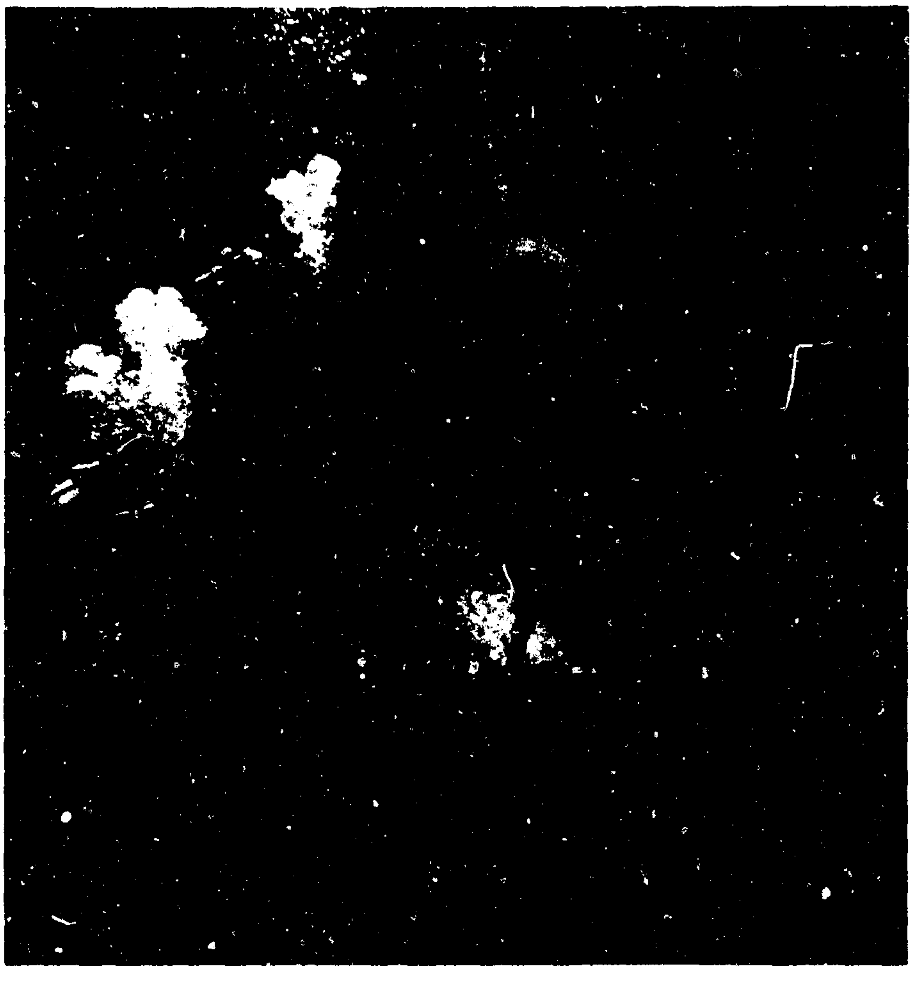
During 1968 tests on collapsible salvage pontoons continued. One UNIROYAL Type I (15-ton lift) pontoon was successfully tested off Anacapa Island in August 1968. Work was continued on the design modification, fabrication and testing of the UNIROYAL Type II (25-ton lift) pontoon. An eductor system was designed and fabricated for deflating collapsible salvage pontoons while on the surface to facilitate submerging them.



Collapsible salvage pontoon goes over the side for rigging and inflation.

Cementitious Caulking Materials for Ship Salvage

The Supervisor of Salvage (NavShips) has sponsored a technical investigation of cementitious caulking compounds (made with portland cement, select admixtures, and seawater) having the consistency of putty when first applied manually along the perimeters of steel-plate patches that are mechanically fastened over holes in the hull of any ship sunken in a harbor. At the 60-foot depth, the compounds must remain workable for at least 1/4 hour and must harden not earlier than 1/2 hour or later than 6 hours after mixing; they must be practicable for use in tropical, temperate, or polar harbors.



Cementitious caulking compound seals patch on sunken pontoon.

Five cementitious compounds have been evaluated in conjunction with experimental patching of a standard steel pontoon at a depth of 50 feet in the Pacific Ocean. During each trial the patched pontoon has been dewatered and the leakage rate computed from underwater readings of a water-level gage. The least leakage through the caulk has been at the rate of 5 gallons per minute.

The following laboratory testing phases involving cement pastes have been completed during the past 12-month period: (1) time of final set in 60°F and 34°F seawater; (2) leakage through hardened caulks in 88°F, 60°F, and 34°F seawater; (3) strength of bond to steel plate of hardened caulks that have set in 88°F, 60°F, and 34°F seawater; and (4) length change and compressive strength of hardened caulking compound in 88°F and 60°F seawater. Only those cementitious compounds that satisfied the time limits for final set and which did not crumble when kneaded in an aqueous environment were further investigated for leakage, bond, length change, and compressive strength. The testing program has involved 47 admixtures, some proprietary and some generic. Based on test data developed to date, three cementitious compounds apparently satisfy the physical requirements for acceptable caulking of underwater patches.

Bottom Stabilization Overlay

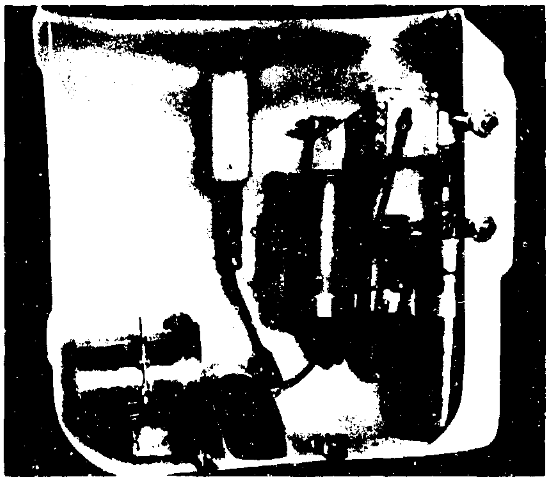
Under contract with NCEL the Battelle Memorial Institute developed a two-component system and equipment for dispensing a bottom-stabilization overlay. These will be field evaluated by NCEL.

NCEL has produced successful overlays 3-feet wide in 50 feet of water near Anacapa and Santa Cruz Islands. Orifice blocking was solved by use of a flap valve or solvent flushing but the latter technique produced some clouding. Laboratory experiments are concerned with optimizing the viscosity, cohesiveness, and setup time of the films produced. Dispensing equipment for producing films 10 feet wide is being designed at NCEL.

Chemical overlay (white) on easily disturbed bottom (green) reduces turbidity. Diver and applicator are visible in background.

Diving Suit Heating Systems

Radioisotope. A packaged system using the radioisotope plutonium-238 as the heat source was designed at the Laboratory. Following fabrication the system was installed in a fiberglass shell, also designed at the Laboratory, to match and be mated to the rear lower portion of a modified diver's Mark VIII mixed gas breathing apparatus backpack. The system is designed to provide heated water, pumped at approximately 1.5 liters per minute, to a diver wearing a closed-cycle tubing undergarment beneath his foam rubber diving suit. The isotope provides 420 thermal watts output. The system was tested for its effect on the maneuverability of the diver and was found satisfactory. Physiological tests with the diver wearing the system were conducted and subsequently recommendations were made regarding its use as a test item for SEALAB III. An operating procedure and hazard analysis dated October 1968 were issued.



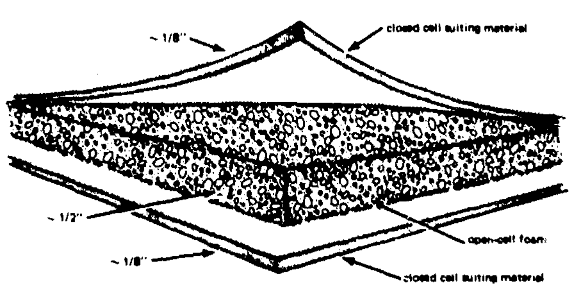
Radioisotope heater system as mounted in shell (left), and worn by diver (bottom).

Electrical Resistance. Twelve heater–pump units to heat and circulate water through closed-cycle, water-tube diving suits were received by NCEL for testing. These heater–pump units were designed to deliver about 2 liters of freshwater per minute at a pressure differential of 3.6 psi. The pump is an electrically driven, reciprocating type. The water is heated by a calrod type element which provides at least 750 watts at maximum setting. A controller permits regulating water temperature to the diver between 80°F and 110°F. These heater–pumps have undergone extensive testing at the Laboratory and five units have been delivered to the SEALAB III project for diver use.

Resistance heater–pump.

Steam Plus Heat Exchanger. A prototype diver-heating system, developed for the Supervisor of Salvage (NavShips) was received by NCEL for evaluation. This system supplies heated seawater to as many as four divers wearing open-cycle diving suits. The system is designed for diver comfort at ambient water temperatures as low as 40°F at depths to 600 feet while the diver is breathing helium-oxygen mixed gas, which accelerates body heat losses. The system consists of an oil-fired, closed-cycle steam generator and a heat exchanger through which the seawater to be heated flows. The hot seawater is blended with cold seawater and delivered through a 1-inch-diameter hose to a manifold to which 1/2-inch diver hoses are attached at the diving site. Divers may divert the flow to sea if desired. The system has been successfully tested and is being placed in standby for possible use in the SEALAB III project, pending delivery to the Supervisor of Salvage.

Chemical Heat. Preliminary tests have been conducted with prototype vests made of open-cell foam sandwiched between two layers of closed-cell neoprene foam. The cellular layer is filled with a chemical or mixture of chemicals with a melting point slightly below normal skin temperature. When the vest is submerged in a cooler medium, the chemical compound crystallizes and releases heat.



Initial experiments with prototype vests and a number of chemical compounds show that this approach to warming divers working in cold water shows considerable promise. Further investigation is underway to develop improved suiting to utilize this chemical heat source and thus extend the diver's period of activity in cold water without the encumbrance of backpacks or umbilicals. Preliminary tests conducted with mittens filled with a 1/2-inch layer of chemical indicate that warming for about 2 hours is obtained in ice water.

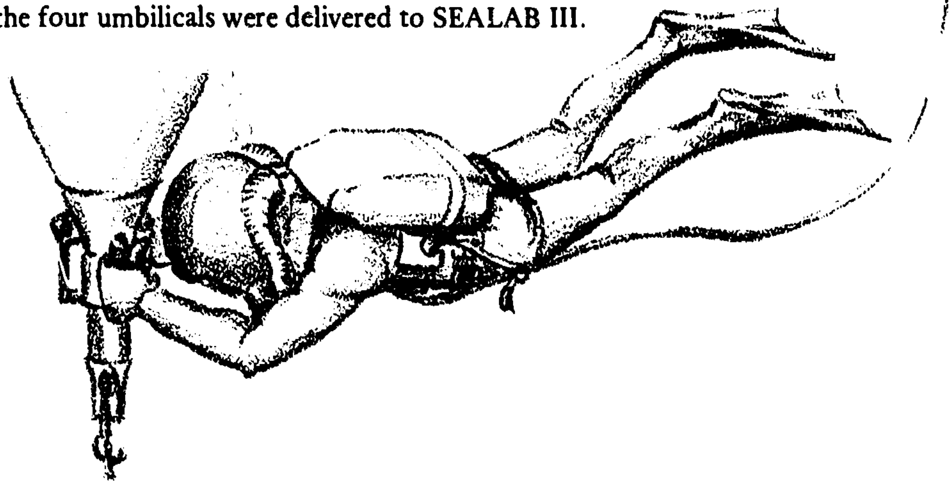
Umbilicals

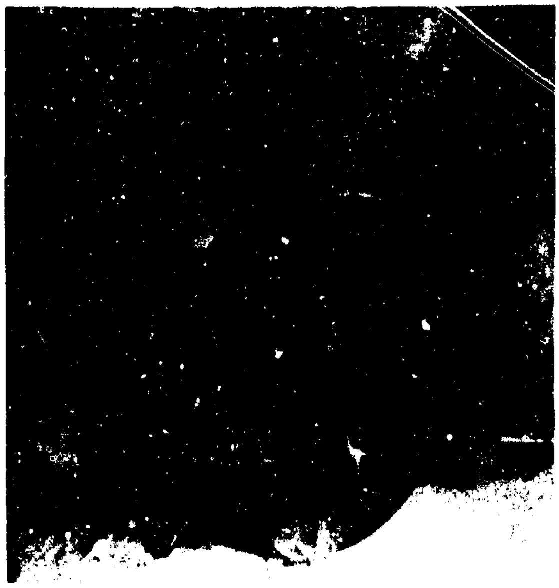
Sixteen primary umbilicals, designed to reduce negative buoyancy, and diver backpack electrical connector assemblies (umbilical to life support equipment) were received for evaluation. These umbilicals and connector harness assemblies were designed to carry power to provide heat for divers either by connecting with suits made of resistance-grid fabrics or to a diver-mounted resistance heater-pump which supplies heated water through a closed-cycle tubing undergarment. Other conductors service the diver's intercom, oxygen partial-pressure sensor and helmet light. The umbilicals also incorporate the diver's breathing gas hose. Both the umbilicals and harness assemblies passed initial acceptance tests; however, the umbilicals had insurmountable latent defects which became evident during diver training, and they were dropped from the SEALAB program. Twelve harness assemblies were delivered to SEALAB III.

Nine secondary umbilicals, which provided service for only the diver's intercom and oxygen partial pressure, were received and tested for continuity and resistivity both before and after being subjected to submerged pressure equivalent to that at 600 feet. Two 600-foot and five 200-foot secondary umbilicals were delivered to SEALAB III. Repair of damage suffered by the remaining two during test and training is pending at this time.

Six 200-foot primary umbilicals with 24-pin Electro Oceanics connectors were obtained in February 1968. These incorporate the breathing gas hose and service for diver's heating, intercom, oxygen partial-pressure sensor, and helmet light, but do not incorporate materials to reduce negative buoyancy. Following extensive electrical and pressure testing, four of these umbilicals were delivered to SEALAB III. Two are undergoing further study.

Four 200-foot primary umbilicals with D. G. O'Brien connectors at one end and an integrated, multibreakout, diver life-support equipment electrical harness at the other end were obtained in January 1969. These umbilicals did not incorporate any buoyant materials. They did include the diver's breathing gas hose, service for diver's heating, intercom, oxygen partial-pressure sensor, and helmet light. Following pressure and electrical testing, the four umbilicals were delivered to SEALAB III.





Kirby-Morgan diver's helmet.

Helmets

Twelve diver's clamshell helmets, including two-way communications, oral-nasal mask and buddy breathing equipment were obtained and delivered to SEALAB III. Ten helmets of the same design, but without communications equipment, were obtained and delivered to the Experimental Diving Unit, Washington, D. C. in September 1968.

Diver's Hose

The Supervisor of Salvage (NavShips) assigned NCEL the responsibility of (1) ascertaining the state of commercial development in surface-supplied diver's hose, (2) investigating other commercial hoses which appear desirable for diving operations, and (3) investigating methods for coupling the hoses.

Hose manufacturers were contacted to determine the availability of hose for diving purposes. Several firms stated that they manufactured diver's hoses; however only one firm (Hewitt-Robbins) actively promotes their hose for diving. Contacts with various diving firms showed that a large variety of hoses are being used. The primary considerations appear to be availability in long continuous lengths and cost.

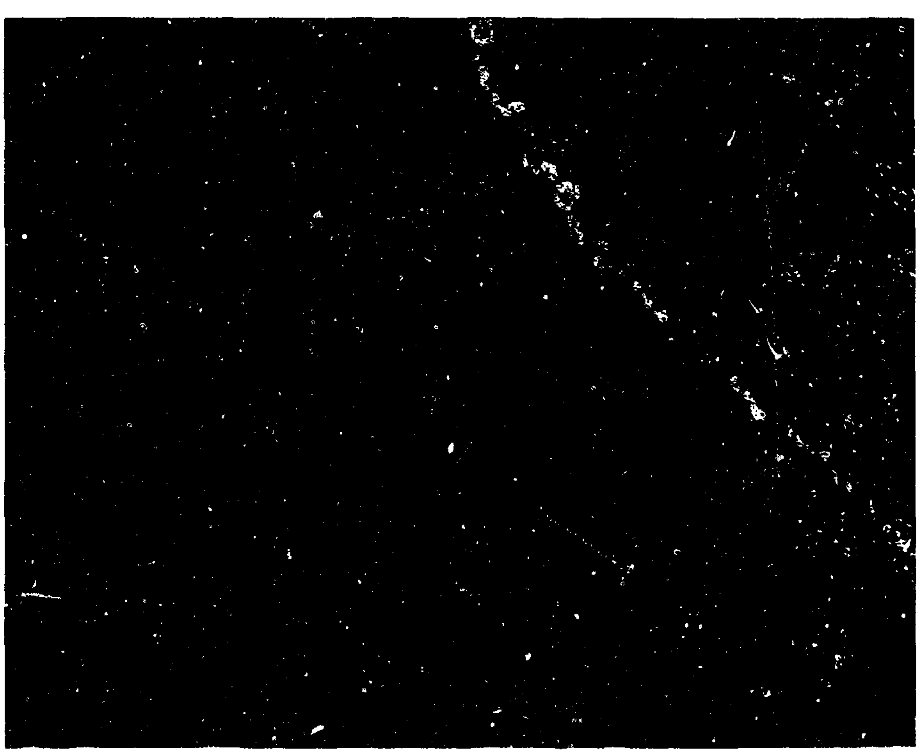
Manufacturing technology has advanced sufficiently to produce hoses of long continuous lengths with the desired dimensional stability. These hoses are more flexible than the current Navy diver's hose.

Tests are being conducted to determine the best type of coupling to use with the new hose.

Battery Power Backpack

A Mark VIII mixed gas breathing system backpack was modified by removing one of the pair of gas cylinders and replacing it with a packaged 28-volt Silvercel battery system with controller. Syntactic foam molding was utilized to offset the in-water weight imbalance created by the modification. This unit can be used by a diver to power tools and equipment. Primary use is for diver heating, either through a resistance heater-pump supplying warmed water to a closed-cycle tubing suit or providing power for diver's suits made of resistance-grid fabrics.

Modified Mark VIII breathing system.



Diver's Tools

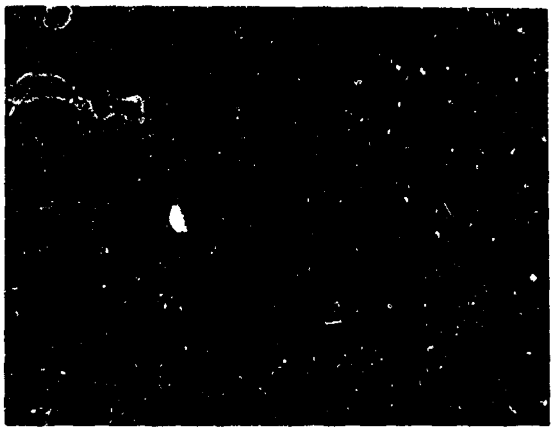
Human Factors. NCEL is continuing to develop diver aids and techniques to optimize diver operation of hand and power tools on vertical surfaces, deck surfaces, and overhead surfaces with no natural foot rests or hand holds. The formal test program with four subjects was completed in the summer of 1968.

Results indicated that on the average the divers required almost twice the time to accomplish the tasks underwater as workers on land. The tasks on the vertical and overhead surfaces required approximately equivalent times, while the times for performance of tasks on the deck were slightly less.

Work on diver's tools is now being done in coordination with the hydraulic and cryo-pneumatic tools work unit and is directed toward completion of simple work projects instead of single functions as in previous work. For example, a single work project includes installation of a bulkhead pipe flange requiring punching, drilling, tapping, nut running, and hole sawing.

NCEL is being assisted in developing diver's aids and techniques by the Human Factors Branch of the Naval Missile Center, Point Mugu, California.

Oil hydraulic power source.



Oil Hydraulic and Cryo-Pneumatic Power Sources. Two underwater tool power systems are presently being evaluated by NCEL. The first is a lead–acid battery powered electro-oil hydraulic system capable of operating to diver depths for 4 working hours. The second system, for operating pneumatic tools, utilizes liquid nitrogen as the primary source and is capable of operating a 205-cfm pneumatic tool for 15 minutes at a depth of 120 feet. Extensive shallow water operational tests of the cryo-pneumatic system indicate that this system is a reliable and easily handled power source for diver operations. In normal diver operations, when a 1/2-inch impact wrench (125 cfm) is used for drilling and tapping 1/2-inch thick mild steel plate and for nut running, a work duration of 3 hours can be expected at a depth of 25 feet.

Seawater Hydraulic Power Sources. Following a determination that small conventional hydraulic rotary hand tools and motors could not be used in a simple open seawater system, methods and materials for developing suitable units were investigated. Recent literature disclosed the use in seawater systems of certain combinations of stainless steel with Teflon and other new elastomers as piston packing in reciprocating motors. The use of high-strength alumina ceramics on wear surfaces of moving parts holds even more promise. These ceramic surfaces tested with seawater and an abrasive at the Naval Ship Research and Development Center, Annapolis, Maryland, have shown virtually no wear. The application of ceramics to either reciprocating or gear motors appears feasible.

While most of the small tools powered by hydraulic motors use a rotary motor output, reciprocating movement is sometimes useful and more desirable. To date, the plan was to use rotary motors with suitable mechanisms for conversion of rotary motion to reciprocating motion. Recent developments in hydroacoustic transducers, which impart linear motion, if adapted to once-through seawater use will allow very high, rapid impacts in very compact tools with only one or a few moving parts. This probably will be the next area for prototype development.

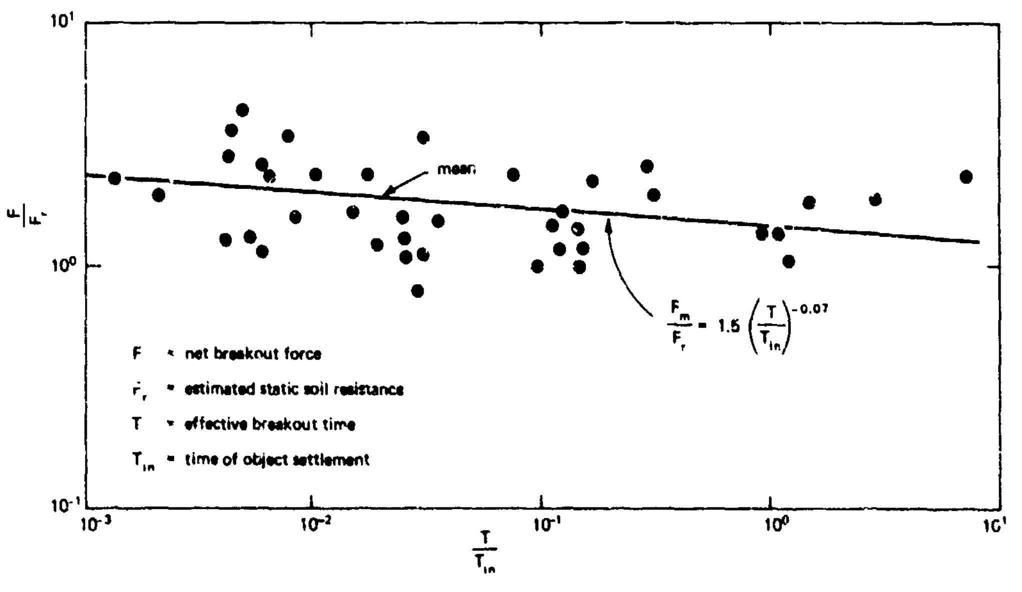
Negotiations are underway for purchase of a prototype 5- to 10-hp rotary motor and pump set capable of driving four of the small tools. Testing is expected to be in progress in early summer, 1969.

SEA-FLOOR SOILS

Bottom Breakout Force

In many deep-sea operations, the force necessary to lift an object from ocean sediment must be determined. The time required for breakout (hereafter referred to as "breakout time") is generally considered a function of the lifting force. To provide data for estimating breakout force, tests were conducted in the soft sediments of San Francisco Bay, in off-shore Louisiana, and in a small-scale model tank Objects of different geometries were first settled into the sediment and then extracted by a constant force. All tests were completed by January 1968.

The data have been nondimensionalized and arranged to correlate breakout force with breakout time. It has been theorized that breakout force is directly proportional to the static soil shear and tension resistance and will be affected by the in-situ settling time and breakout time. The results have shown that the variation in breakout time is too sensitive to allow an exact estimate of breakout time. However, the breakout force can be calculated with confidence by an empirical formula. These data will facilitate the salvage operations, instrument recovery, mineral extraction, and underwater construction.



Breakout force versus time.

In-Situ Tests

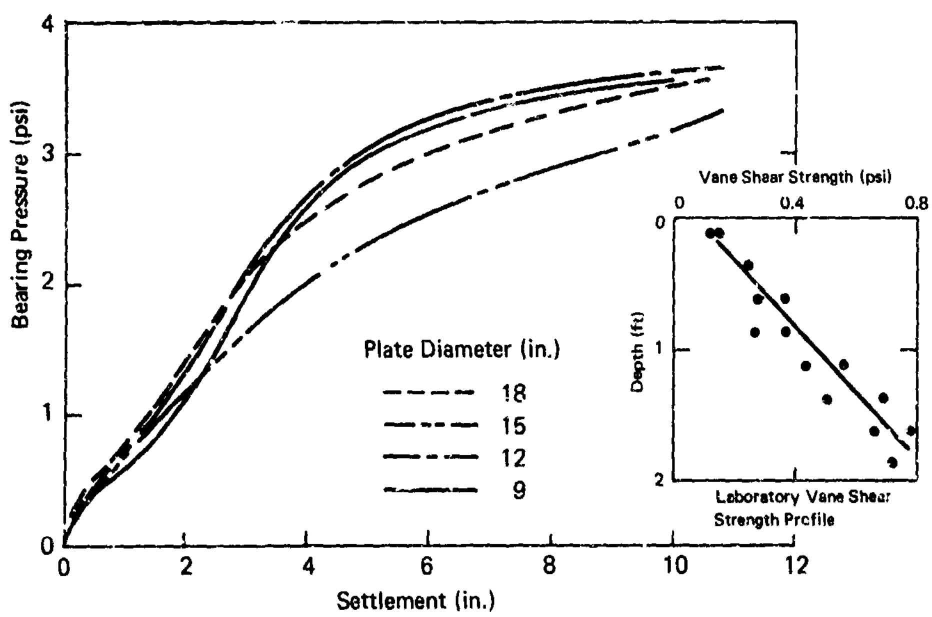
Reliable data on the engineering properties of sea-floor sediments are essential for selecting suitable sites and designing foundations for structures on the sea floor. Development of equipment and techniques for obtaining and evaluating in-situ data on these properties is continuing.

During the past year the in-situ plate bearing device used to determine the short-term bearing pressure–settlement response of marine sediments has been operated at two test sites having water depths of 1,200 and 6,000 feet. Cores of the soft, cohesive sediments at these sites have been collected and analyzed. A report on a tentative scheme for correlating the results of the in-situ plate bearing tests and laboratory vane shear tests for three test locations is being prepared.

Problems with the torque- and axial-load-measuring transducer have delayed the performance of additional in-situ vane shear and cone penetrometer tests. A new transducer has been designed and is currently being fabricated.

In order to provide a more accurate basis for comparison of in-situ and laboratory soil data, a coring tool which will be located adjacent to the vane shear–cone penetrometer system of the DOTIPOS* support platform has been designed and is in the fabrication stage. The thin-walled corer is designed to be pushed into the sediments at a rate of 15 feet/minute to obtain a sample up to 10 feet long, 4-1/8 inches in diameter. The corer can be used either with or without a piston.

* Described in "Undersea Equipment and Installations."



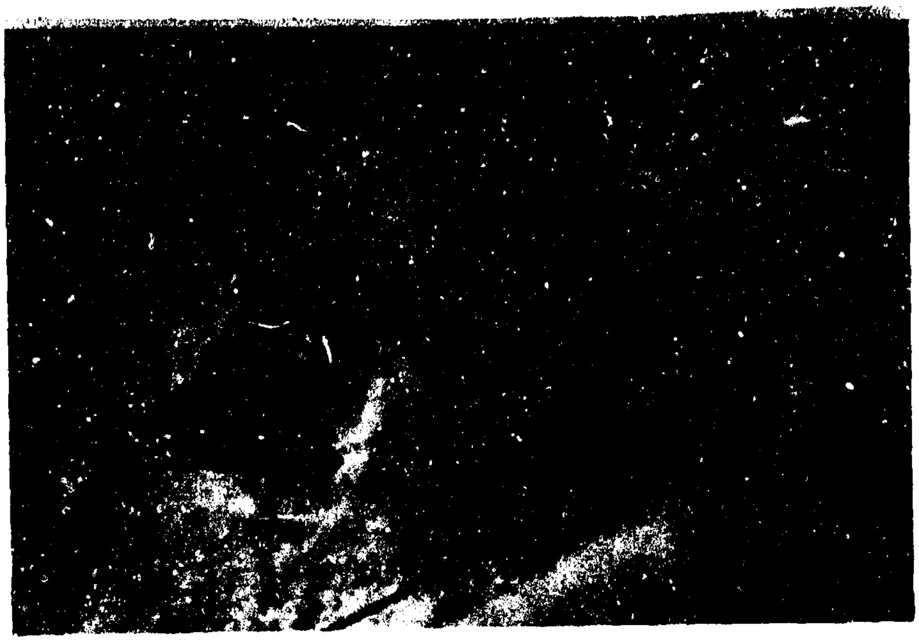
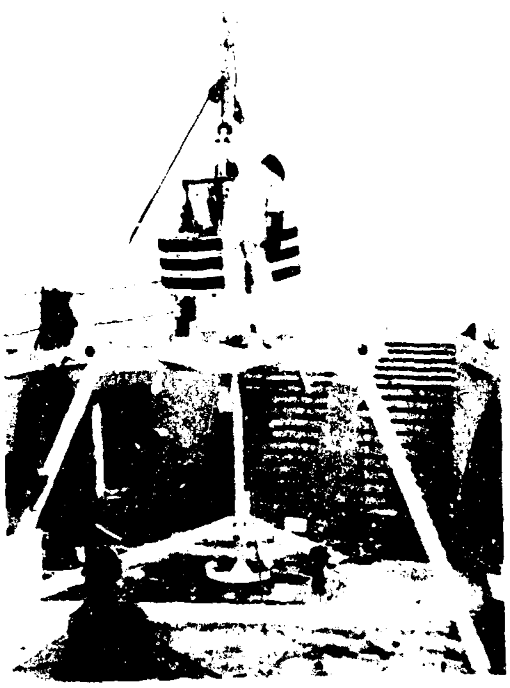


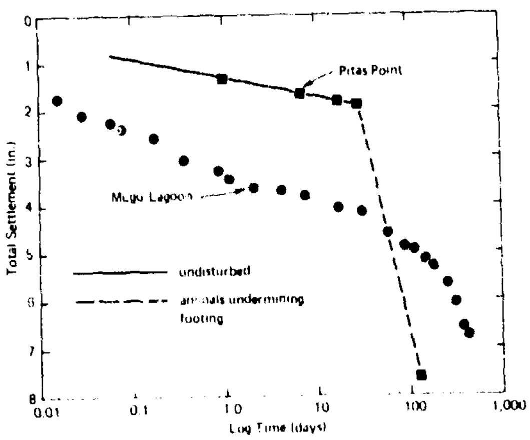
Plate bearing device is lowered to 6,000 feet for tests on ocean-floor sediments.

In-Situ Model and Prototype Foundations



Lobster footing and placement frame.

Four model footings have been in place on the sea floor from 4 months to over 1 year. Three of the footings are located 3 miles offshore at Pitas Point, California, in 120 feet of water. SeaBee divers visit the site regularly to record foundation performance data. The importance of such in-situ experiments has been demonstrated by the finding that in two instances the larger portion of total footing settlement has been caused by undermining of the footing by burrowing animals, rather than by compression of the underlying soft sediments as might be expected.

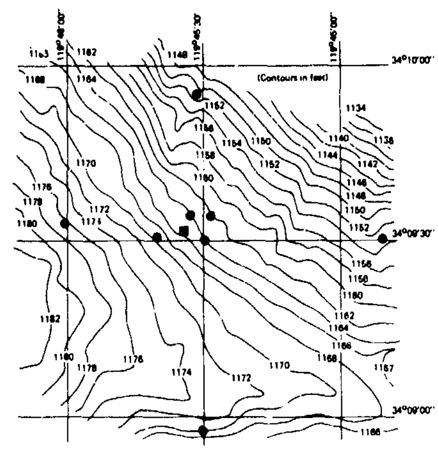


The effect of underlying soft sediments on long-term foundation performance has been determined by footing tests in Mugu Lagoon. Total settlement has been continuous for over 1 year, and the rate of settlement has in fact accelerated slightly in recent months.

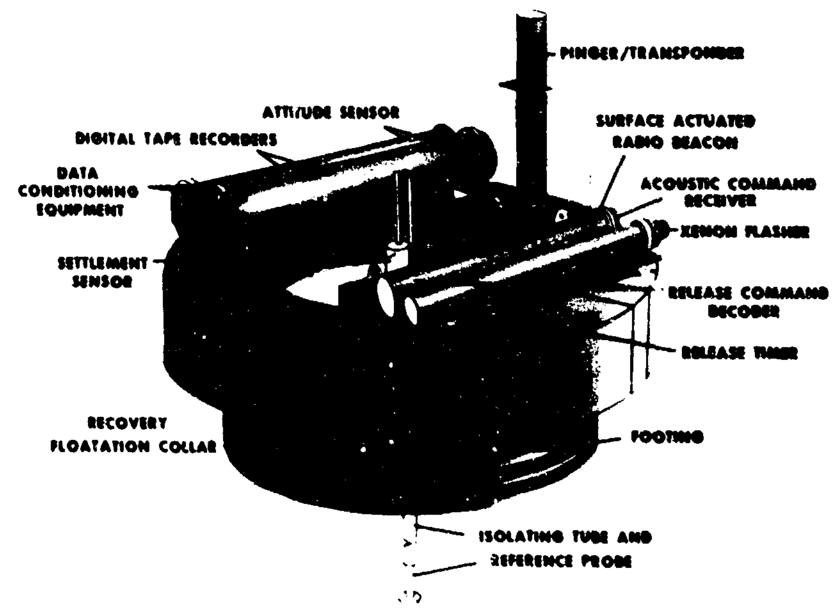
Test-Site Evaluation

In conjunction with several other projects, test sites have been selected, mapped, cored and in some cases sediment properties have been determined by in-situ tests. These sites include Pitas Point Site (120 feet), Twelve-hundred Foot Site (in the Santa Barbara Channel), and the Six-thousand Foot Site (southwest of San Miguel Island). The sediment properties at these sites which most directly influence long-term foundation performance—consolidation and compressibility—have been extensively evaluated.

● core data
■ in-situ soil test data



Santa Barbara Channel 1,200-foot test site.



LOBSTER.

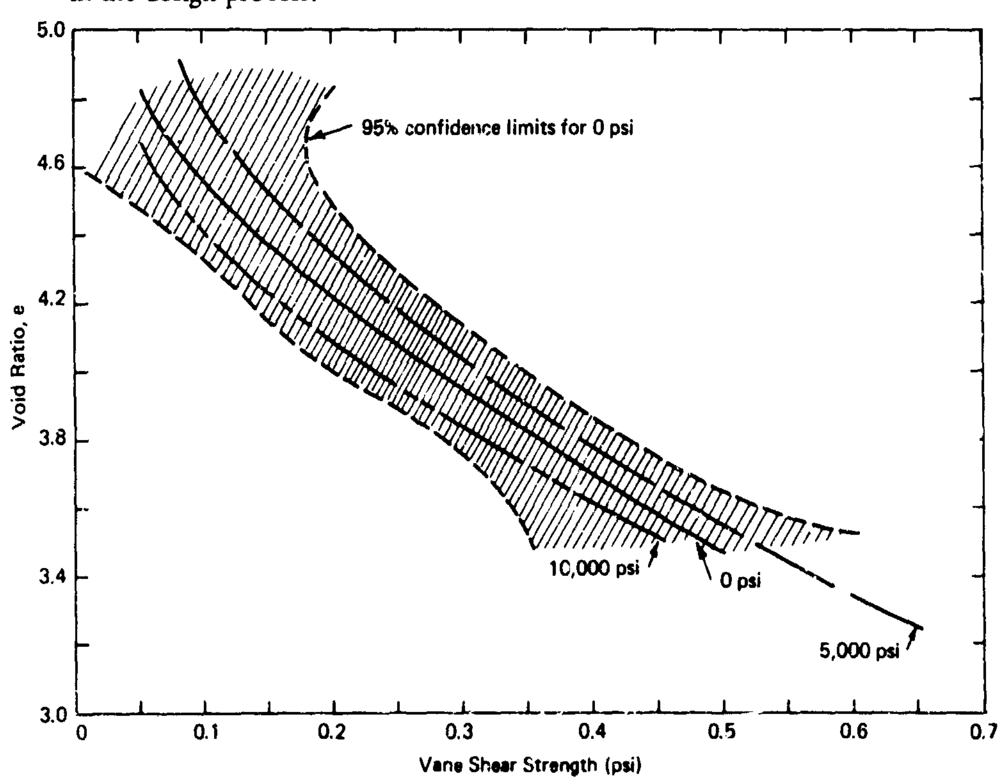
The LOBSTER System was developed to obtain data on the long-term performance of in-situ footing foundations. The System includes model footing, data collection and storage system, reference system, installation system and recovery system. Design of the total system has been completed as well as fabrication of the LOBSTER device. The device has been checked out in-the-dry, in harbor tests and in a pressure vessel test under simulated environmental conditions at the design depth of 6,000 feet.

Soil-Testing in Pressure Vessels

At the present time, most analyses of the engineering properties of sea-floor sediments are performed on core samples in the laboratory. One of the factors which clouds the interpretation of the laboratory data is the significant difference between the usual laboratory and in-situ hydrostatic pressure environment.

During the past several years, the Research Institute of the Illinois Institute of Technology (IIT) has investigated the effect of the high hydrostatic pressure on the strength and consolidation properties of remolded sea-floor sediments. The IIT report concludes that varying the hydrostatic pressure between 0 psi and 10,000 psi caused no appreciable effect on the direct shear or vane shear strength of the silt- and clay-sized sediments tested. Also, the consolidation characteristics of the silt-sized soil particles did not appear to be affected by variation in hydrostatic pressure. However, for the clay-sized soil particles, the time period to reach 100% primary consolidation appeared to be increased a small amount by an increase in hydrostatic pressure; the ratio of primary to secondary consolidation was not appreciably influenced.

Although it is difficult to generalize from the results on two remolded sediments, it seems probable that any effect of hydrostatic pressure on engineering properties will not be of sufficient magnitude to be considered in the design process.



Quadratic regression fit to vane shear data for soil from 12,000-foot depths tested in pressure vessels.

Sediment Density—Water Content Probe

Preliminary study of the use of nuclear radiation sources for measuring in-situ water content and density of sediments revealed that this method shows promise. However, determination of the water content requires further studies, which are currently being conducted by Oregon State University under contract. These studies will include a literature search, investigation of nuclear radiation sources and detectors, theoretical investigation of the behavior of the radiated energy and the factors which affect water content measurements, and laboratory experiments. The ultimate objective of this effort is to develop a combined probe for measuring both water content and density of sediments in-situ.

Deep Corer

Present oceanographic corers are inadequate for obtaining samples for soil mechanics and foundation engineering studies. The objective of this work unit was to develop a corer to obtain samples of sufficient quality for these studies. To minimize disturbance, incremental sampling techniques must be used. The initial search was for existing equipment that uses this technique but none was suitable for deep-ocean applications. Therefore, specifications were established for the design of a corer utilizing a bottom-sitting platform that will take samples from sediment strata 30 feet thick in water depths to 6,000 feet.

Foundation Engineering Studies

In addition to the in-house research being conducted to determine sea-floor soil characteristics and sea-floor foundation behavior, seven short-term contracts were awarded by NCEL for the study of the following related sea-floor foundation engineering problems.

Breakout Forces
Penetration
Slope Instability
Turbidity Currents
Scour and Fill
Earthquake Occurrence and Effects
Trafficability

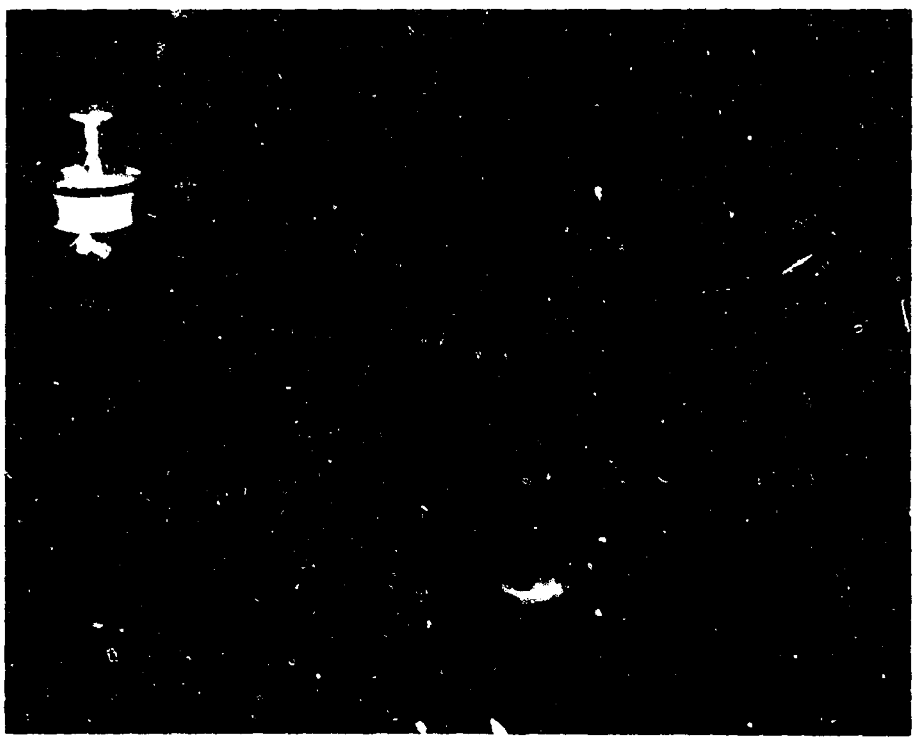
These studies are intended to provide (1) examination of existing theoretical and empirical procedures for handling the problems, (2) review and evaluation of potential methods for reducing the extent of the problems, (3) recommendations for immediate measures to deal with the problems, and (4) suggested research for obtaining further information.

UNDERSEA SITE AND MATERIAL STUDIES

Site Selection and Survey

Site surveying is a requirement for all sea-floor installations. NCEL investigators continued to define significant parameters, requirements, and methodology for (1) surveying and selecting an ocean site and (2) conducting a preliminary site survey for sea-floor construction experiments (SEACON). Data were developed on the site parameters that should be considered in surveys and the instruments and techniques that are available for conducting these surveys. NCEL also studied several sites off the Southern California coast and near the Hawaiian Islands that would be suitable for conducting these experiments.

In another phase of the investigation, the Westinghouse Deep Star 4000 was used to determine the applicability of submersibles to site surveying. Visual reconnaissance is a must for site surveys to identify slide areas, tension cracks on slopes, scour and fill areas, and other features important to sea-floor structures; a submersible is an excellent means of conducting reconnaissance. Because bathymetric surveys conducted from surface ships do not reveal such physical features, bathymetric surveys must be conducted by near-bottom or on-bottom systems; a submersible would be effective in this capacity. During a Deep Star 4000 dive in 2,100 feet of water, fish and other animals were observed disturbing the surface of the bottom sediments. Such benthic activities of marine life give important indications of the stability of structures to be built on ocean-floor sediments.



Sediment disturbance by sea life in vicinity of penetrometer.

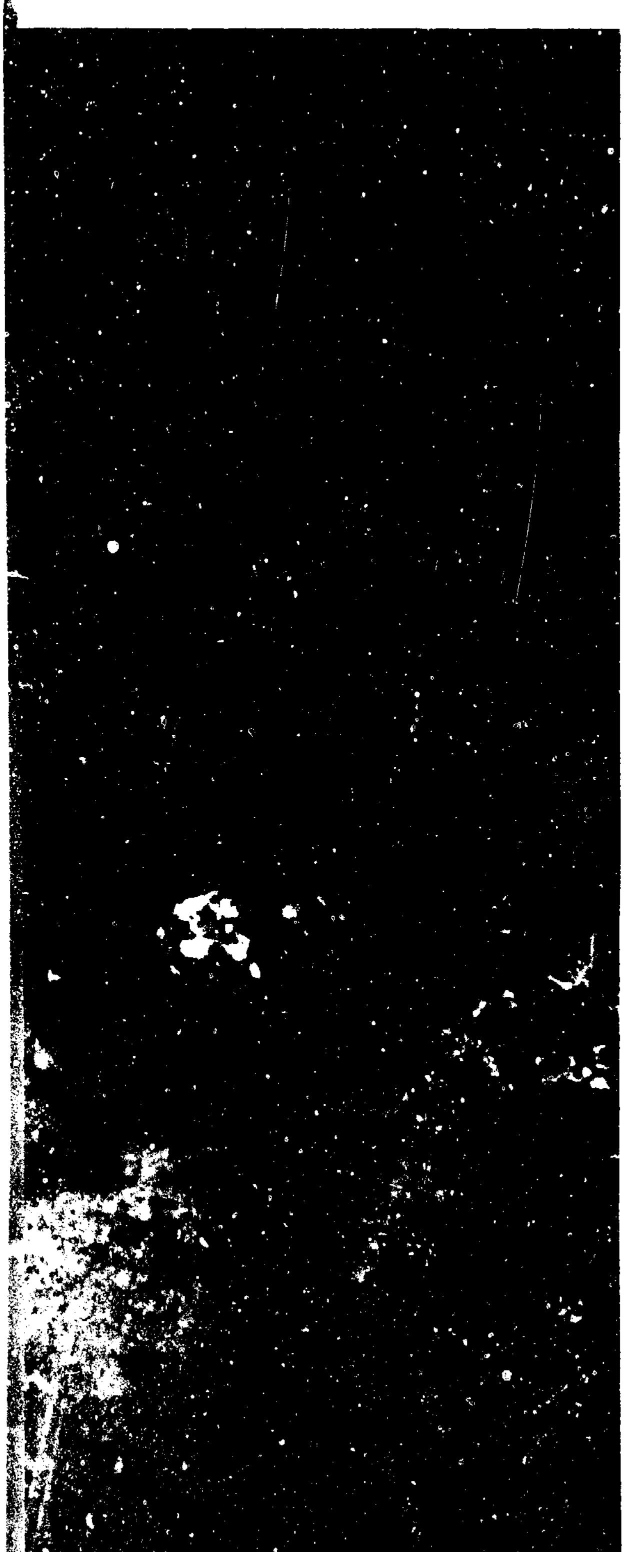
Submersibles for Ocean Engineering

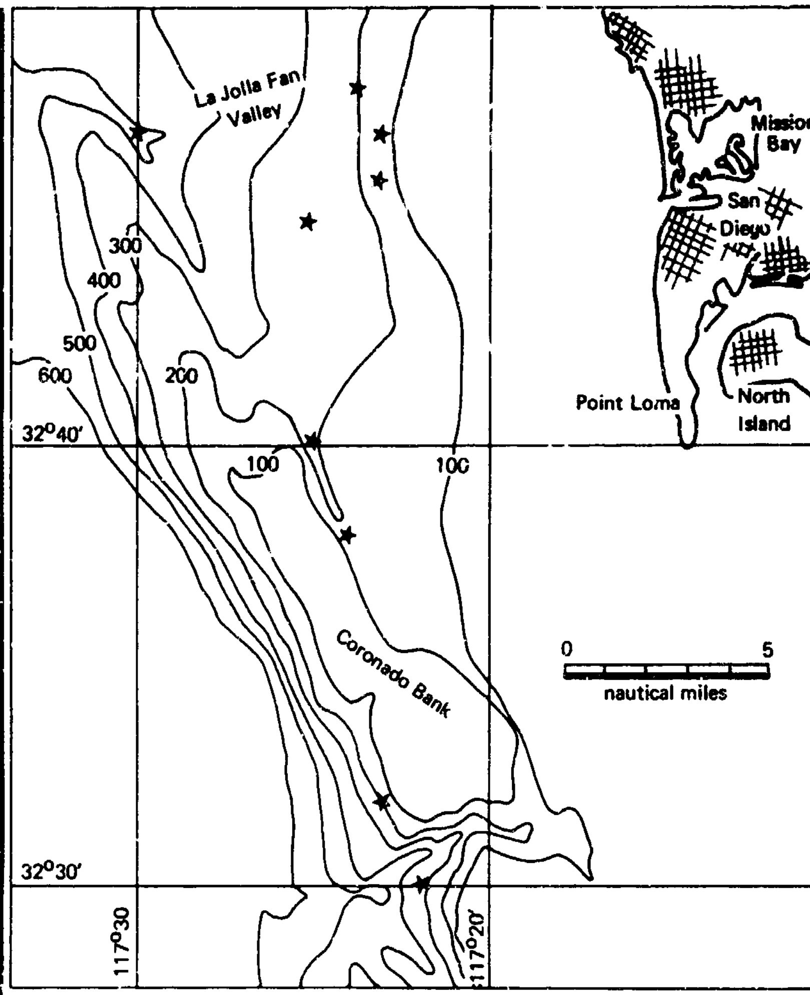
As part of the evaluation of vehicles (DORVs) and their potential value to ocean engineering, 15 NCEL engineers and scientists participated in nine familiarization dives in the Westinghouse Deep Star 4000. Descriptions of each dive with the observations and impressions of the participants were recorded.

Three of the familiarization dives were concerned with soil mechanics research and involved the use of soil penetrometers and coring devices. The operational capabilities of the submersible were of primary interest on two dives during which the submersible was taken through its paces in maneuvering and navigating. The sciences of marine biology and mineralogy concerned two dives, and samples were collected for subsequent analysis. Observations in the water column were of special interest on two dives, during which oceanographic measurements and ambient light determinations were made.

The knowledge gained from these Deep Star 4000 dives was combined with information from study of other submersibles. The requirements of DORVs which would be useful to NCEL were postulated, and in turn the capabilities available on currently operational DORVs were examined and compared with the postulated requirements. The results of this comparison were given in terms of what DORVs can or cannot do for the Ocean Engineering Program. It was concluded that DORVs have great potential value in the Program.

Deep Star 4000 samples sediment.





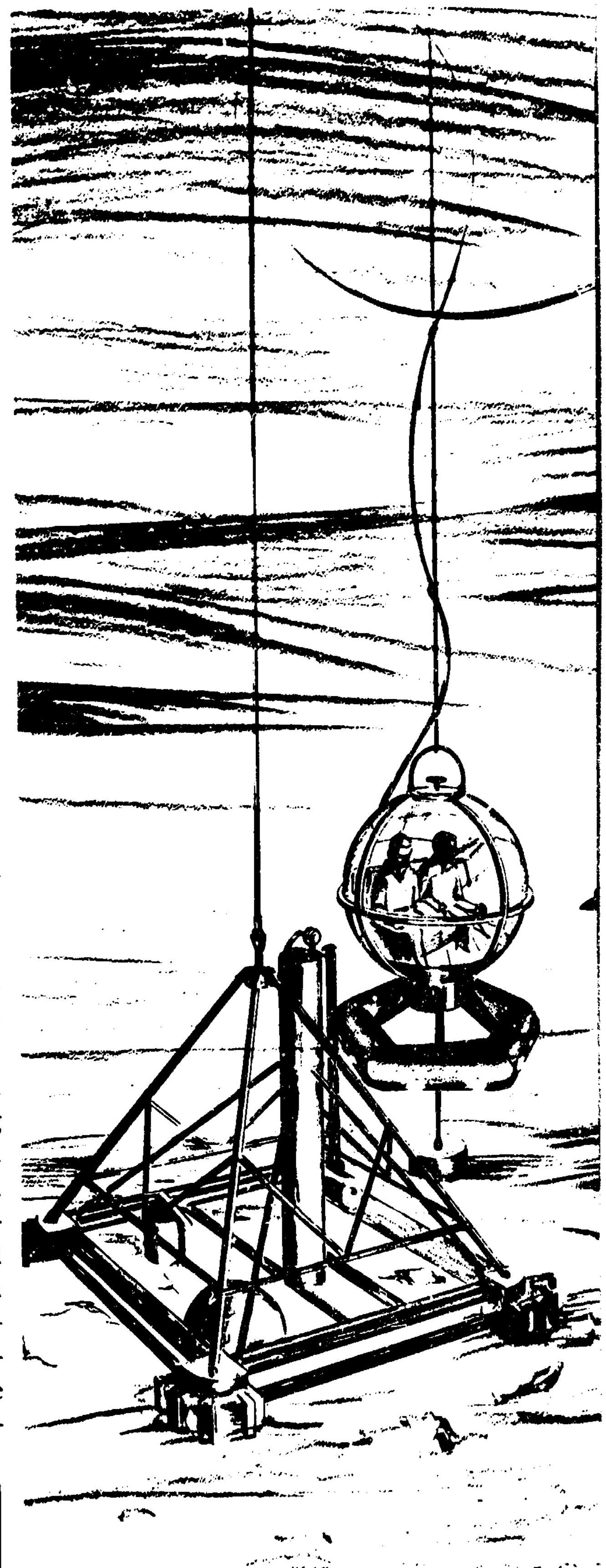
Deep Star 4000 dive sites.

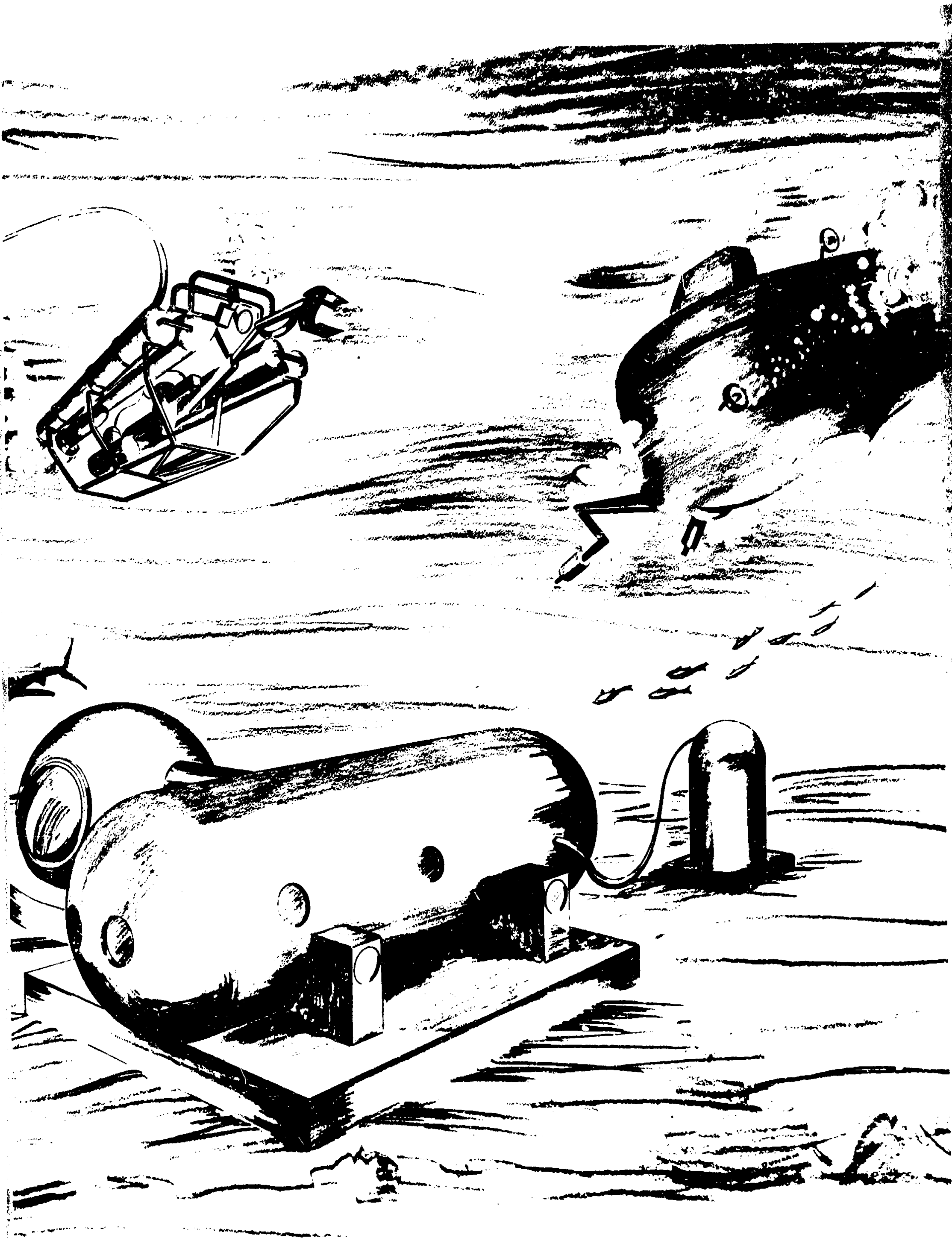
Deep Star drops penetrometer (right).

Sea-Floor Construction Experiment (SEACON)

SEACON is an integrated experimental program which consists of interrelated sea-floor engineering experiments involving both equipment and construction techniques. The program is designed to provide visible achievements of specific technological milestones, to stimulate technological advancement of complete operating systems, and to identify deficiencies in existing technology. The ultimate goal is to develop a capability for the construction of manned bottom installations.

Plans were drafted to conduct experiments with SEACON I near Port Hueneme, California, at a depth of 600 feet. SEACON I is scheduled for late FY-70. Preliminary site selection experiments are being conducted to acquire data on the sea-floor sediment and oceanographic environment. Recent technological developments in surface vessel surveying are being applied and evaluated. Unmanned and manned submersibles will also be used in these surveys to provide information, including detailed topographical data. By means of deep coring, in-situ strength tests, and bottom and sub-bottom profile surveys, the characteristics of the site will be defined for use in the detailed planning of the construction experiments.





STU Emplacement and Recovery

As part of the material evaluation program, a submersible test unit (STU I-5) was emplaced in the deep ocean and retrieved after 6 months' exposure. This STU weighed approximately 8,000 pounds in air and contained seal and gasket samples as well as metal alloy, plastic, wood, and other specimens. The site of this emplacement was 12 miles southwest of San Miguel Island at a depth of 5,900 feet.

Chronology for STU I-5

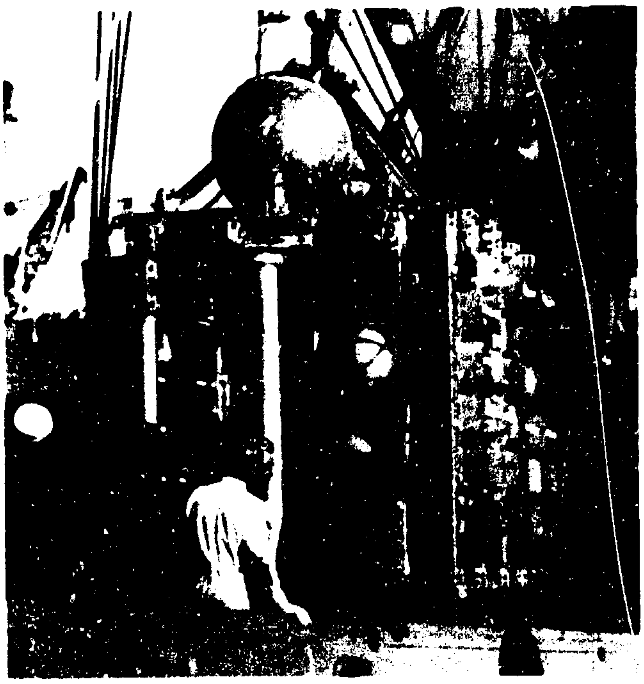
(LORAC navigation system provided precise site location for all operations)

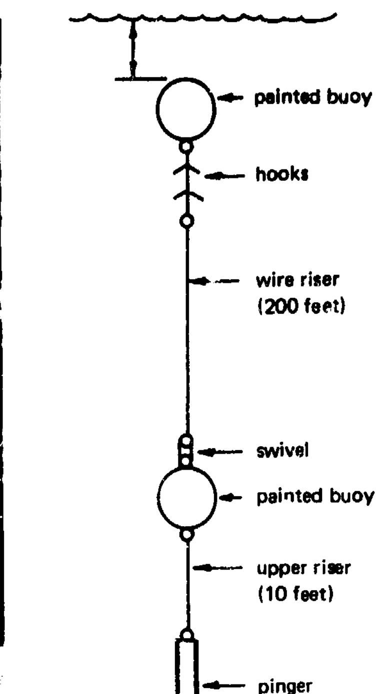
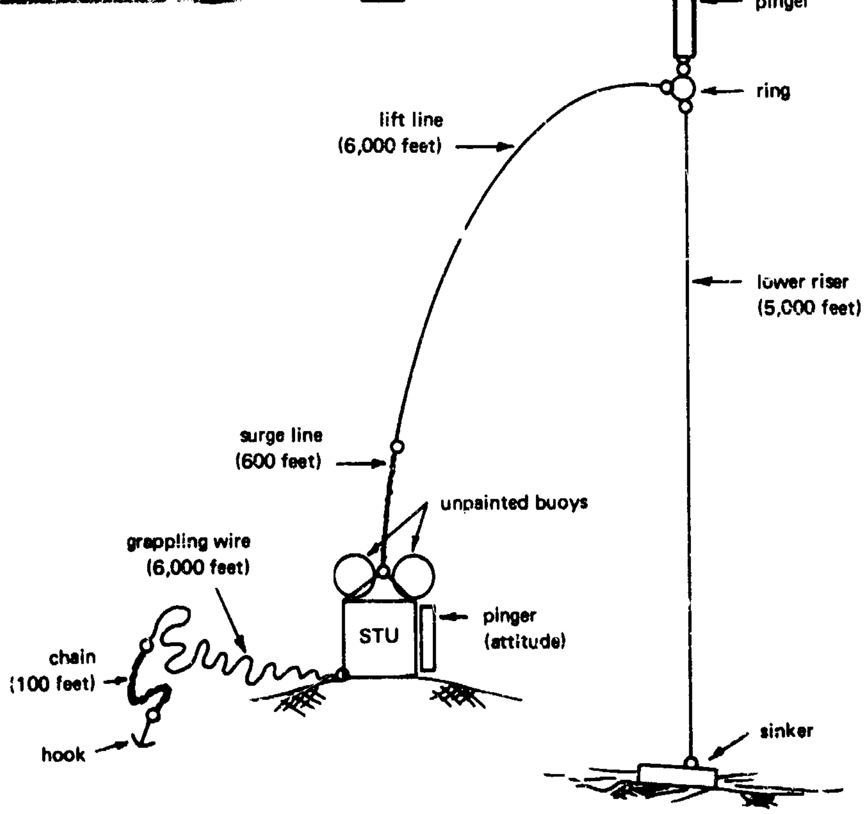
Date	Operation
7 August 1968	Emplaced by USNS *GEAR* (ARS 34)
December 1968	Site surveyed by USNS *CHARLES DAVIS* (AGOR 5)
12 February 1969	Retrieved by USS *SIOUX* (ATF 75)

STU I-5 aboard the USS Sioux after retrieval.

A single 6,000-foot-long lift line was used as the key to the emplacement and recovery of the STU. This line, which was made with a nylon jacket for strength and abrasion resistance and a polypropylene core for buoyancy, was used to lower the STU from a surface vessel to the sea-floor. After installation this line formed an inverted catenary, which was caught by a grapnel in the recovery operation.

Installation of STU I-6 at essentially the same site is being planned. This STU will continue the exposure of materials, seals, and gaskets to the ocean environment and will initiate the NCEL ocean evaluation of radioisotope power sources by the use of one such source to power an acoustic transmitter.



STU I-5 emplacement.

Seals and Gaskets

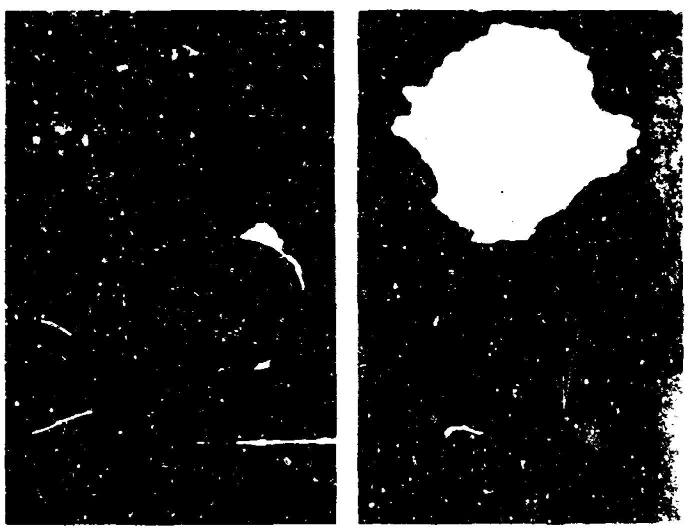
The objective of this work unit is to evaluate the performance of seals and gaskets for use in fixed structures on the ocean floor.

Static 16-hour tests and cyclic loading tests at 5,000 psi external pressure in the laboratory pressure vessels were completed without leakage of any of the 15 seal systems. There was damage to only one seal system in the cyclic test. The damaged system consisted of an angular seat, rectangular groove, and a lip seal. However, even in the damaged condition, the seal effectively prevented leakage.

In the ocean tests, after 6 months of exposure on STU I-5 at a depth of 6,000 feet, there were no failures (leakage) of the seal systems because of corrosion. Zinc galvanic anodes afforded some protection against corrosion in the seal crevices. There was no corrosion of the noncorrosive weld metal seal inserts. Some seal systems failed because of improper design.

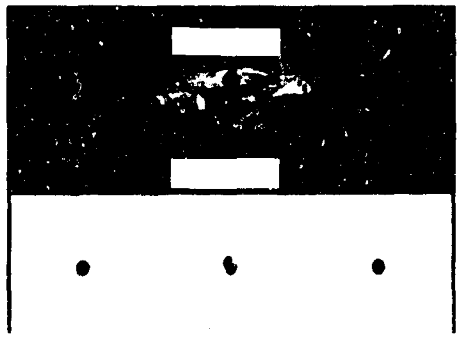
Effects of Environment on Metals

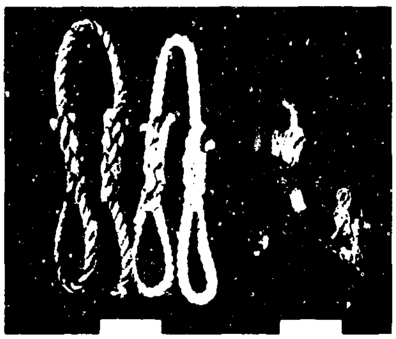
Experiments are continuing to determine the effects of deep ocean environments, bottom sediments, and surface seawater environment on the corrosion of construction materials. After 6 months of exposure, the corrosion rates of the copper-base alloys, some nickel-base alloys, steels, and cast irons decreased as the concentration of oxygen in seawater decreased. The rates of the modes of corrosion of most alloys were faster at the surface than at depth except for the aluminum alloys. Seawater was more aggressive to aluminum alloys at depth than at the surface. Titanium alloys, highly alloyed nickel alloys, columbium, tantalum, tantalum-tungsten alloy, and high-silicon cast irons were uncorroded both at the surface and at depth.



Crevice corrosion of precipitation hardened stainless steel exposed for 6 months at a depth of 5,640 feet. The specimen is shown before and after the bolt securing it has been removed.

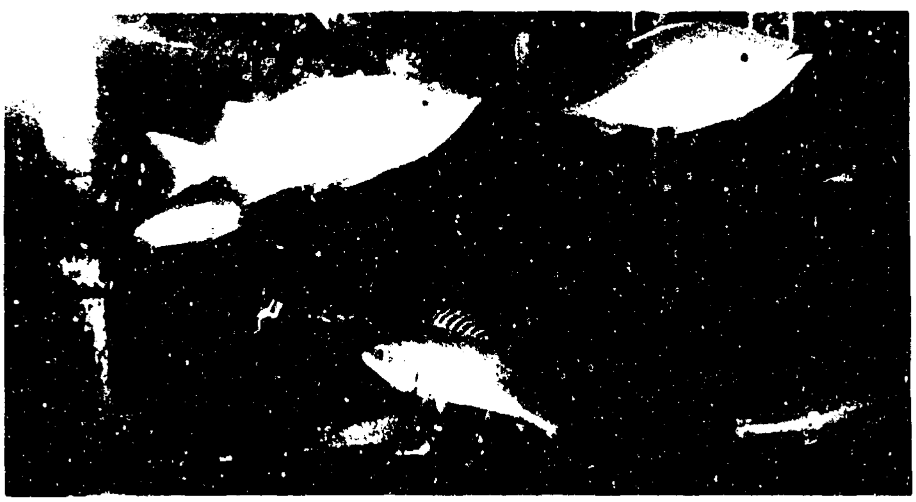
Exposure at 6,000 Feet. Test specimens from STU I-5 are being evaluated for biodeterioration and fouling. Replicate test specimens are being assembled for placement on STU I-6 which in June 1969 will be emplaced on the sea floor for a longer period of exposure.





After 13 months in the sea at 120 feet marine organisms foul Plexiglas (upper left) and have nearly destroyed wood and rope specimens (upper right and lower left).

Exposure at 120 Feet. Plexiglas, wood, and ropes (manila, cotton, nylon and polypropylene) were recovered by divers after 13 months of exposure on the sea floor at 120 feet on STU IV-1. Plexiglas was covered with moderate fouling growth, including barnacles. Manila and cotton rope and wood were nearly completely destroyed by marine wood borers and microorganisms. The nylon and polypropylene ropes were not affected by biological organisms.



Fish are attracted to fouled specimens exposed at 120 feet off Port Hueneme.

Deep Submergence Rescue Vessel Corrosion Studies

These studies were initiated (1) to determine the behavior of galvanic couples composed of different alloy fasteners in hull materials, other dissimilar couples, and welded alloys, and (2) the protective value of galvanic anodes, paints and sealing compounds in seawater.

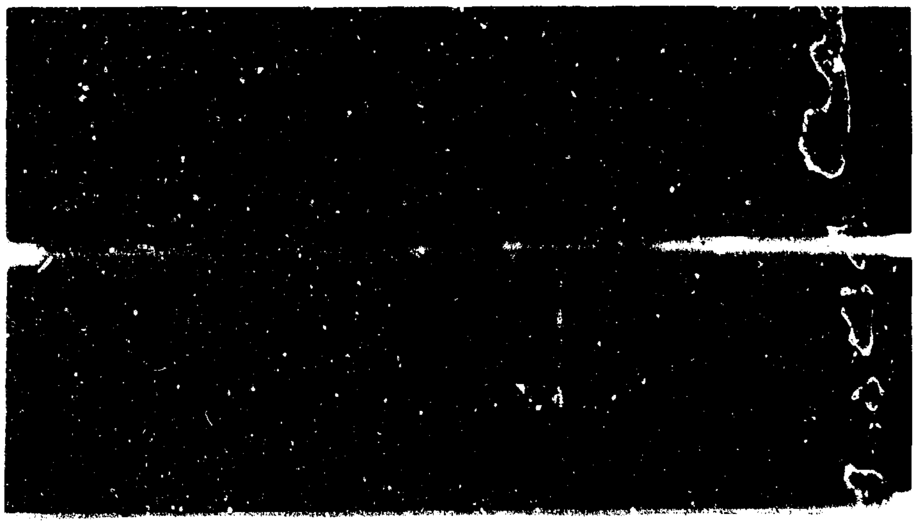
One set of specimens was removed after 6 months of exposure at the surface in the Pacific Ocean and another set was removed after 1 year.

Sacrificial anodes protected aluminum alloys and type 321 stainless steel from corroding; however, they did not afford complete protection to the contacting surfaces of a titanium–aluminum galvanic couple. Four of seven sealing compounds were satisfactory sealants at contacting surfaces. Paint coatings prevented galvanic corrosion of an aluminum alloy when in contact with 6A1-4V titanium alloy and A-286 stainless steel only as long as the paint coatings remained intact. After 6 months of exposure, there were paint failures on seven of nine specimens and on 10 of 10 specimens after 1 year of exposure.

Effects of Environment on Coatings

A study was completed on the effects of pressures equivalent to a depth of 6,000 feet in the ocean on the blistering of paints applied over steel. It was found that blistering of paint in the deep ocean is similar to that in the shallow ocean.

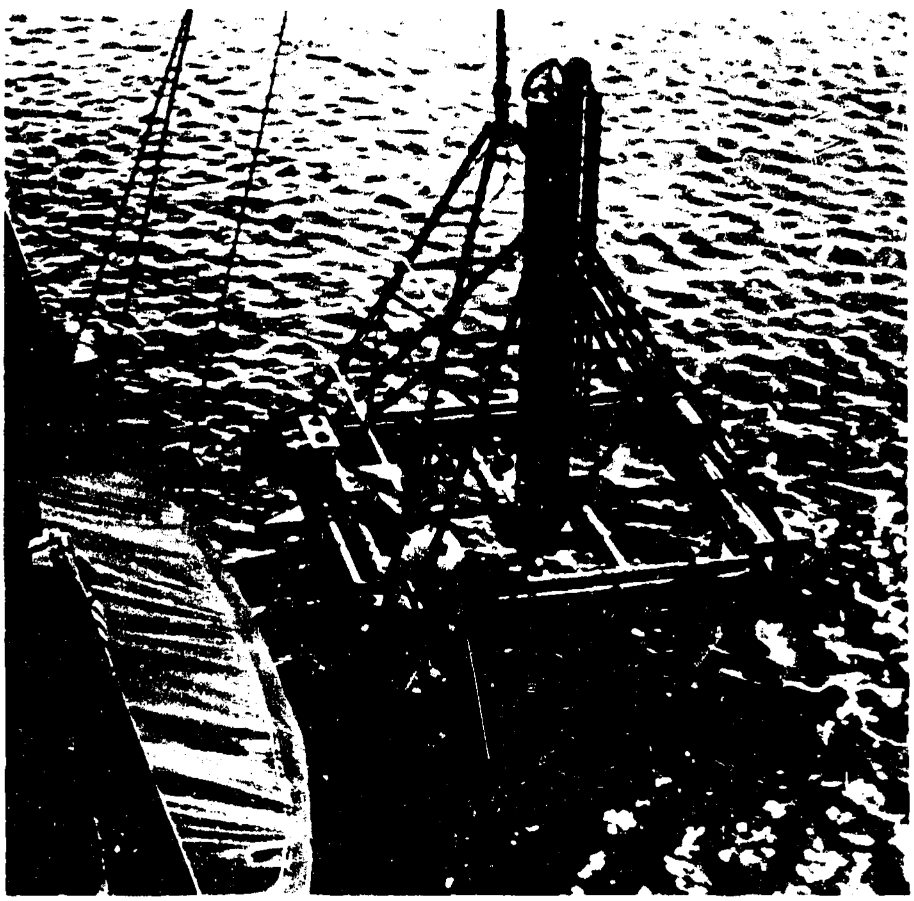
Steel specimens were coated with zinc-rich epoxies and a zinc-rich Saran, with and without topcoats, and exposed in the deep ocean on STU I-5. After 6 months of exposure, the non topcoated zinc-rich organic coatings were giving excellent protection to the steel panels, even along a scribed cut made in the paints prior to exposure. Of the test specimens below, the lower-left panel was not topcoated and shows bright steel at the scribe mark. However, when the panels were topcoated with a catalyzed epoxy (lower right), a Navy alkyd (upper left), and a silicone alkyd over the Navy alkyd (upper right), varying degrees of corrosion occurred.



UNDERSEA EQUIPMENT AND INSTALLATIONS

Deep Ocean Test Instrumentation Placement and Observation System (DOTIPOS)

DOTIPOS, an observation, control, and data transmission system with a power supply tether for 6,000-foot operational depth, has been delivered by the contractor. The in-situ vane shear and the cone penetrometer accessories were tested in 170 feet of water and functioned properly. A 10-foot corer and oceanographic sampling equipment have been added to the instruments.



DOTIPOS.

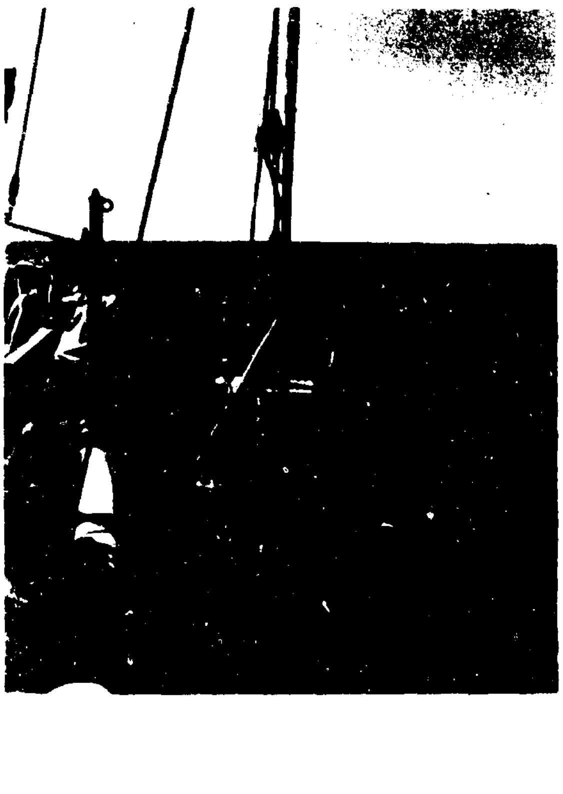
Sea trials in 1968 indicated the need for improvements and modifications, which are currently being made. The addition of a new lighting system should improve the performance of the recently modified TV system. The control and data-transmission capability is being increased from 40 to 70 channels to accommodate system expansion. The expansion includes additional subsystems for foundation studies and oceanographic data collection. These additional subsystems, when ready in late 1969, will make DOTIPOS a more versatile tool for in-situ soil studies and physical and chemical oceanographic surveying.

Deep-Water Embedment Anchors

The NCEL embedment anchor research is aimed toward deep-water anchoring, high resistance to uplift loads, and rapid emplacement without dragging. Explosive and vibratory embedment anchors are currently being investigated.

A vibratory anchor prototype was developed on contract. It has a design capability of embedment in 6,000 feet depth in sand or mud bottom. Weight of the total assembly is about 2,500 pounds. During testing in 50 feet of water on a mud bottom, a 62,000-pound vertical pull did not free the anchor. In a later test in 2,400 feet of water on a mud bottom, the anchor pulled out at 52,000 pounds.

Preliminary data indicate the present configuration may be rated at 50 kips minimum and possibly 65 kips.



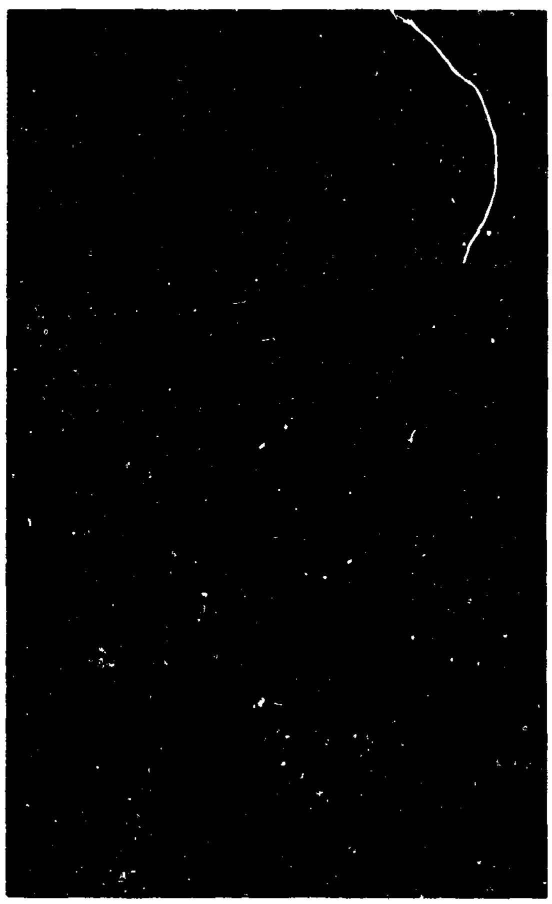
Vibratory anchor with flukes in driving position (top), and in active holding position (bottom).

Explosive Embedment Anchor For Salvage Operations

Development of a new type of anchor to provide improved capability for salvage operations progressed to the operational test and refinement phase. The program is sponsored by the Navy Supervisor of Salvage. This anchor represents a unique approach to anchor placement and use. It is embedded directly into the bottom by an explosive charge and is intended to be functional in sand, mud and hard bottoms in depths to 500 feet. The holding power objective is 160,000 pounds of pull measured horizontally at the hawser on the salvage vessel.

Prototypes of the new anchor have been fabricated and tested in each category of bottom. Greatest success has been achieved in coral and rock, the bottoms that create the greatest problems in salvage operations. Ultimate holding power of 130,000 pounds in coral and 170,000 pounds in rock have been measured. Holding power of over 100,000 pounds in sand and 80,000 pounds in mud also have been attained.

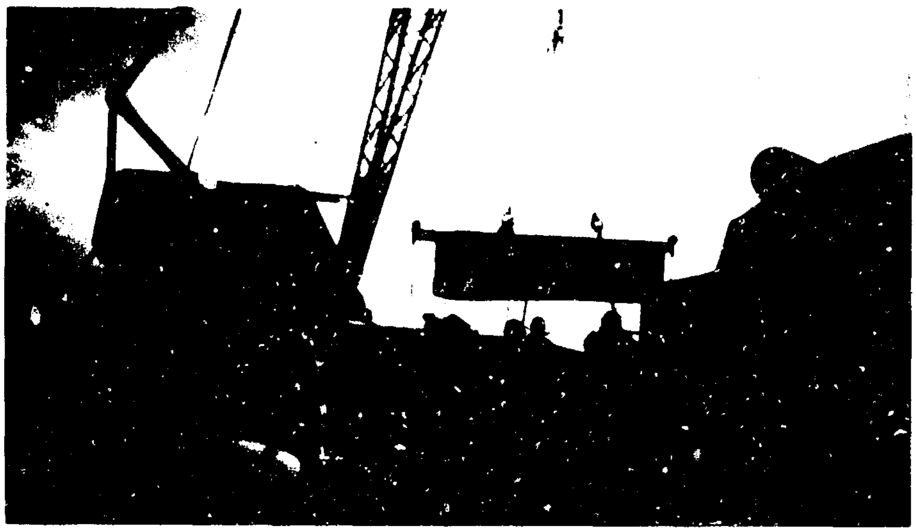
The design represents a major extension of the state-of-the-art for direct-embedment anchors. Investigation is continuing to improve the performance and attain operational acceptance standards.



Load Handling in the Open Sea

Lifting and lowering heavy objects between the surface and ocean bottom is frequently required in salvage operations, underwater construction and many other research projects. NCEL has conducted two field tests concerned with the safe handling of loads on board a ship or a floating platform. The project was funded under the Deep Ocean Technology (DOT) Program.

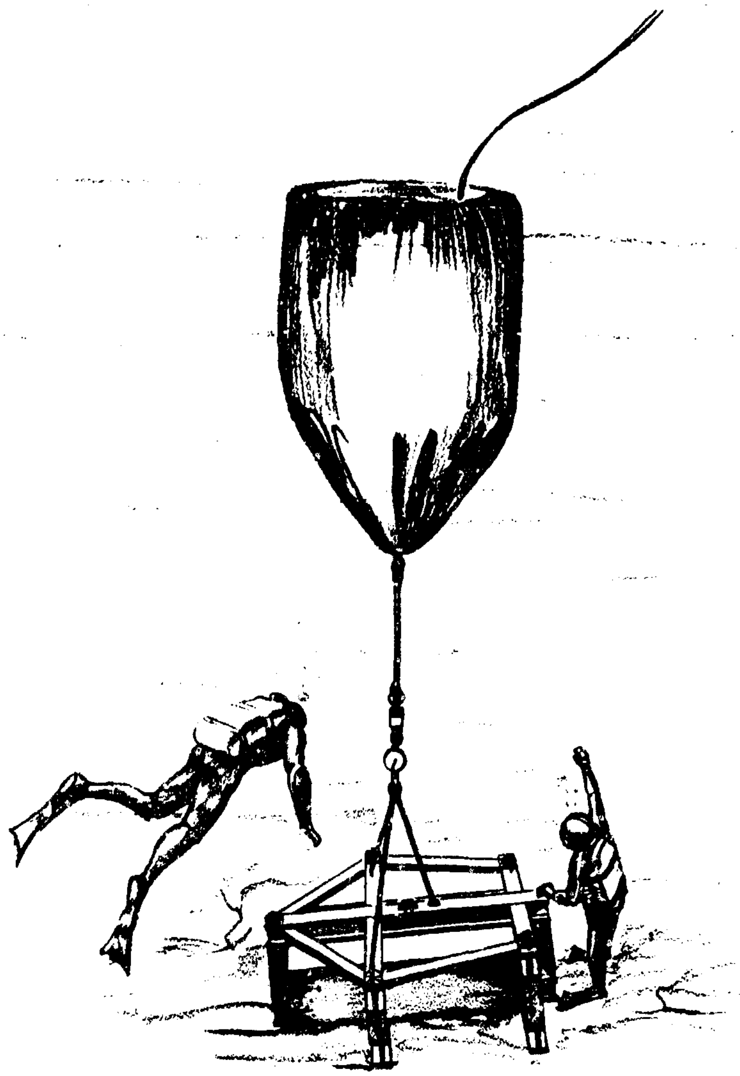
The first field test involved only a conventional winch and cable and was designed to study line tension response to motions induced by ocean waves acting on a ship. In October 1968, three concrete objects weighing as much as 8,000 pounds were lowered to various depths to 5,000 feet. The measured dynamic tension response checked well with the analytical transfer function calculated by the Arthur D. Little method. Therefore, when the physical properties of the rope are known, the analytical method can be used to statistically predict the dynamic line force.



The second sea test in March 1969 yielded data for a guided load handling system. The system differed from the conventional ones by including a taut wire stretched vertically to guide the load to and from a desired site. In a 1,000-foot lift test, an 8,000-pound concrete sphere was successfully lowered and lifted without entanglement of the lines.

More guided load-handling tests are anticipated in the near future. A theoretical study has been initiated to determine the probability of entanglement of two vertical lines in the ocean. Laboratory testing of a steel wire rope and a braided synthetic rope has also begun. Their dynamic response parameters will be accurately measured.

The load-handling information collected by NCEL is not only useful to field engineers now using the conventional handling equipment, but also necessary to design engineers for the specification of large-capacity, constant-tension winches.



Construction of undersea installations, for example, manned station complexes, will require developing a greater capability for lifting, lowering, and accurately positioning heavy loads on the ocean floor. A study is underway which is investigating the relative merits of several candidate load-handling systems, including:

Multiple-line cable and winches
Tubular support (drill pipe string)
Buoyancy-aided support

Results so far suggest that winch and cable systems should be used to lift loads in the 100-to-200-ton range to depths of 6,000 feet, while systems employing drilling pipe could possibly lift much heavier loads, possibly more than 600 tons, at the same depth. A system capable of handling 600-ton loads to depths of 6,000 feet will represent a considerable advance over the present capability, which is on the order of 2 to 4 tons at that depth.

Certain ancillary problems such as accurate positioning of heavy construction modules at great depth and transfer of modules at the sea–air interface will require especially careful consideration. Positioning schemes relying upon taut-wire guidelines, acoustic sources, and mechanical devices such as underwater winches and work vehicle subsystems are under investigation.

Basic Chassis for Bottom Systems Support

The development of a basic chassis capable of work in even the finest of deep, unconsolidated sediments is proposed. Proposals for a comprehensive preliminary design which will consider the most effective track and power systems, change of direction on different bottom materials, and sustaining the reaction of various augers and other over-the-side tools are being sought. Later work will extend the basic design to include power application, control, active buoyancy systems, and materials handling.

Earthmoving and Drilling on the Ocean Bottom

A comprehensive study to define the problems concerned with drilling, excavating, and earthmoving in ocean bottom materials was started in midsummer 1968, and the first interim report draft was completed.

Areas considered in some detail were:

Power Transmission Systems (surface-to-shore-to-bottom installation)
Power Conversion Systems at Point of Use
Equipment Chassis and Bottom Mobility
Buoyancy Systems (both passive and active)
Shallow Drilling and Surface Excavation
Spoil Removal From Work Site
Remote Control Systems
Casing Through Sediments
Penetration of Competent Rock by Large Holes
Sealing of Large Holes and Dewatering of Subbottom Cavity
Subsurface Entry and Excavation

In this report, appendixes keyed to the above research areas describe the work necessary to achieve operational capability and the approaches planned. This report provides the rational and technical input for two Deep Ocean Technology Work units: Basic Chassis for Bottom Systems Support and for Drilling Equipment, and Rotary Cutter and Hydraulic Earthmoving Equipment.

Specific items under study are augers suitable for soft, hard, and semiconsolidated soils, and possibly for soft sedimentary rock. The concept for the first prototype device is a cutter head mounted on a mixed-flow, open impeller pump driven by a hydraulic motor from a central power supply. "Earth Mill" might be an apt name for this unit. Spoil material is to be finely divided to permit pumping from the work site through a flexible duct as a seawater slurry.

Planned research includes direct application of power to a cutter, auger, or blade, and use of high-energy rapid hydraulic pressure pulsations to reduce reactions, increase cutting forces, and improve fragmentation of material.

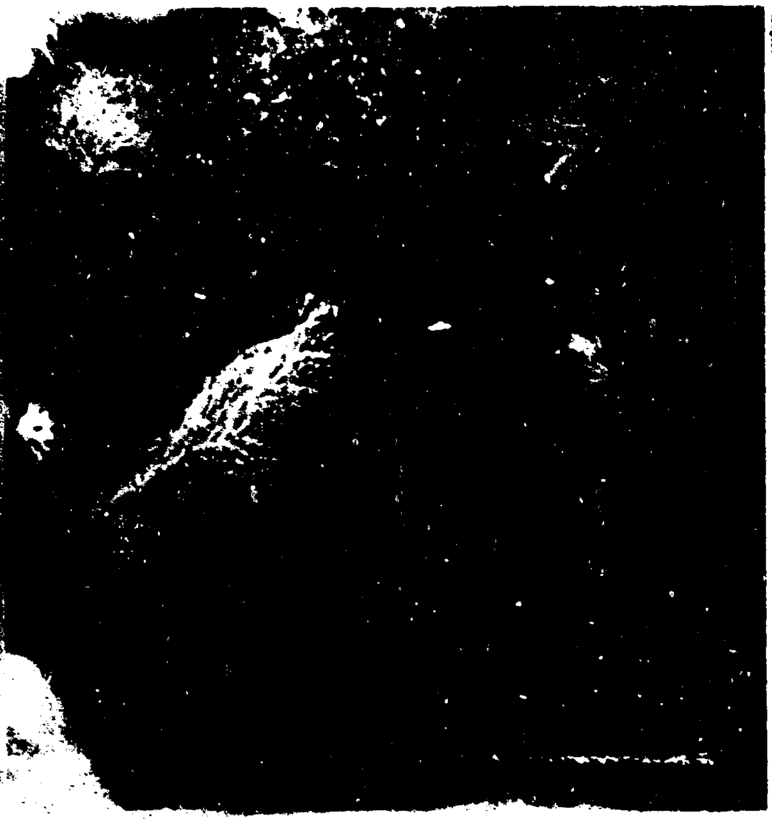
Underwater Acoustic Guyot-Mounted Installation

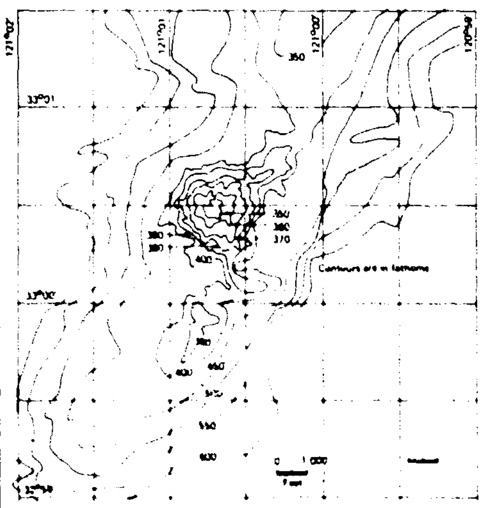
The Naval Underseas Warfare Center plans an interseamount acoustic range for long-term investigations of underwater acoustics. The transmission station of the range is to be placed on the San Juan Seamount at 33°N, 121°W with receivers on another seamount 300 miles away. NCEL provided support in ocean engineering design and fabrication of the San Juan facility.

The southern portion of the San Juan Seamount was selected as the site for the facility and a site survey was conducted. A detailed topographic chart was developed using a precision depth recorder coupled with LORAC positioning. Underwater photographs were taken, and water and sea-floor samples were collected and analyzed.

It was found that the surface of the area is irregular and rough; it is volcanic in origin, consisting of vesicular basalt bearing a ferro-manganese coating. The current at depth is judged to be slight—no greater than 1 knot. It is anticipated that unless the biological and chemical environment is materially changed locally by acoustic energy or heat emission from the operation of the installed equipment, no more than normal corrosion or fouling will result.

When it is emplaced, the facility will consist of three buoyed systems. One will contain four acoustic-signal transmitters supplied by a radioisotope-powered thermoelectric generator located in a structure resting on the bottom. This transmission system will be flanked by two positioning and recovery systems moored to the bottom and connected to the structure by a floating grappling line in one case and bottom-laid grappling line in the other. These two systems will each have acoustically activated release devices and pingers with radioisotope power sources.





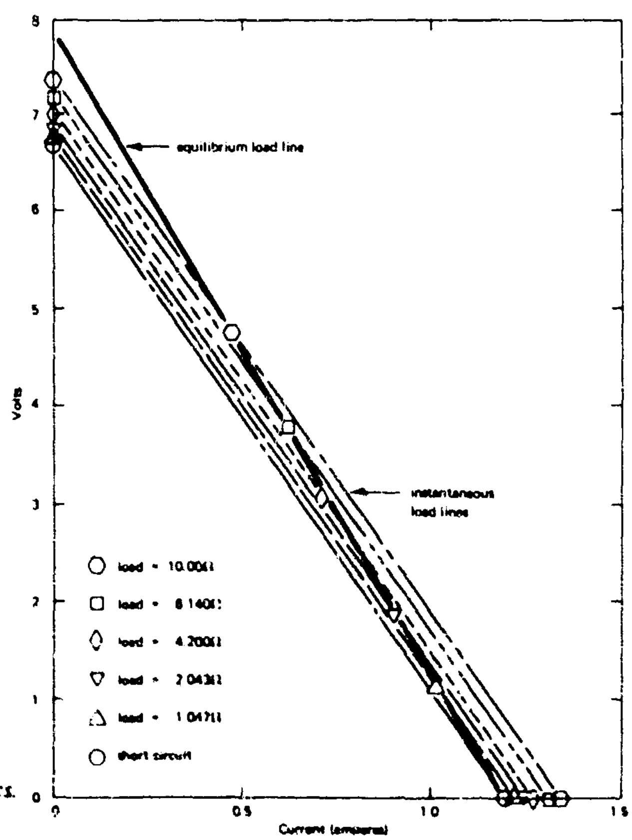
San Juan Seamount: location (above), sea life (left).

Radioisotope Power Sources

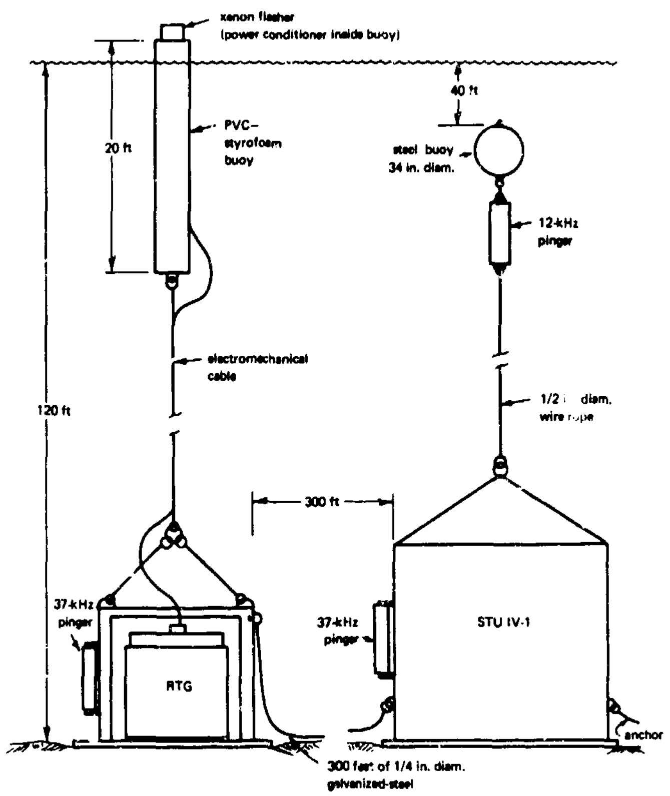
Plans have been completed for the emplacement in June 1969 of the radioisotope thermoelectric generator (RTG) RIPPLE III (radioisotope-powered pulse-light equipment). The RTG will be positioned on the ocean floor at a depth of 6,000 feet; it will be installed on an NCEL Submersible Test Unit (STU) and will be used to supply approximately 0.65 watt at 24 volts to an acoustic beacon attached to the STU structure. The RTG will be on the ocean floor for about 1 year, after which it will be returned to the United Kingdom, where it was manufactured.

Plans for the shallow-water testing of three RTG's have been revised to include the testing of only one generator, the 2.5-watt MW3000, built by Martin Company. This emplacement is scheduled for August 1969. The other two RTG's originally scheduled for the NCEL shallow-water test will be tested at other Naval facilities. One, the 1-watt URIPS-P1-1001, has been delivered to the Naval Underseas Warfare Center, San Diego, and will be used in the Underwater Acoustic Guyot-Mounted Installation beginning in April 1969.

The RTG volt-ampere measurements in the laboratory tank facility will continue. Equilibrium load lines, instantaneous load lines, and the RTG time constant will be determined.



Volt-ampere characteristics.



Shallow-water radioisotope thermoelectric generator emplacement.

Power Transmission

A contract for the development of deep-ocean cable connectors was awarded to review and analyze existing technologies and programs concerned with underwater electrical power transmission systems cables and connectors. The initial effort of the program has been completed.

The program plan also calls for detailed evaluation of all technical areas associated with designing, fabricating, assembling and testing prototype "wet" and "dry" electrical connector assemblies, establishing techniques for interfacing connector assemblies with marine transmission cables, and describing all research and development efforts to be undertaken in extending the state of the art.

Materials for the wet connectors and cables for service in depths to 6,000 feet have been selected. The remaining tasks to be completed are the design of dry connectors, writing performance specifications, and preparation of a test plan for wet and dry connectors and cable assemblies. The interim report on the first phase of the program is in preparation.

The second phase of the program, to be contracted separately, calls for fabrication of prototype wet and dry connectors (mated with suitable marine transmission cable), testing, and delivery to NCEL for additional evaluation.

OCEAN STRUCTURES

Development of Manned Underwater Station

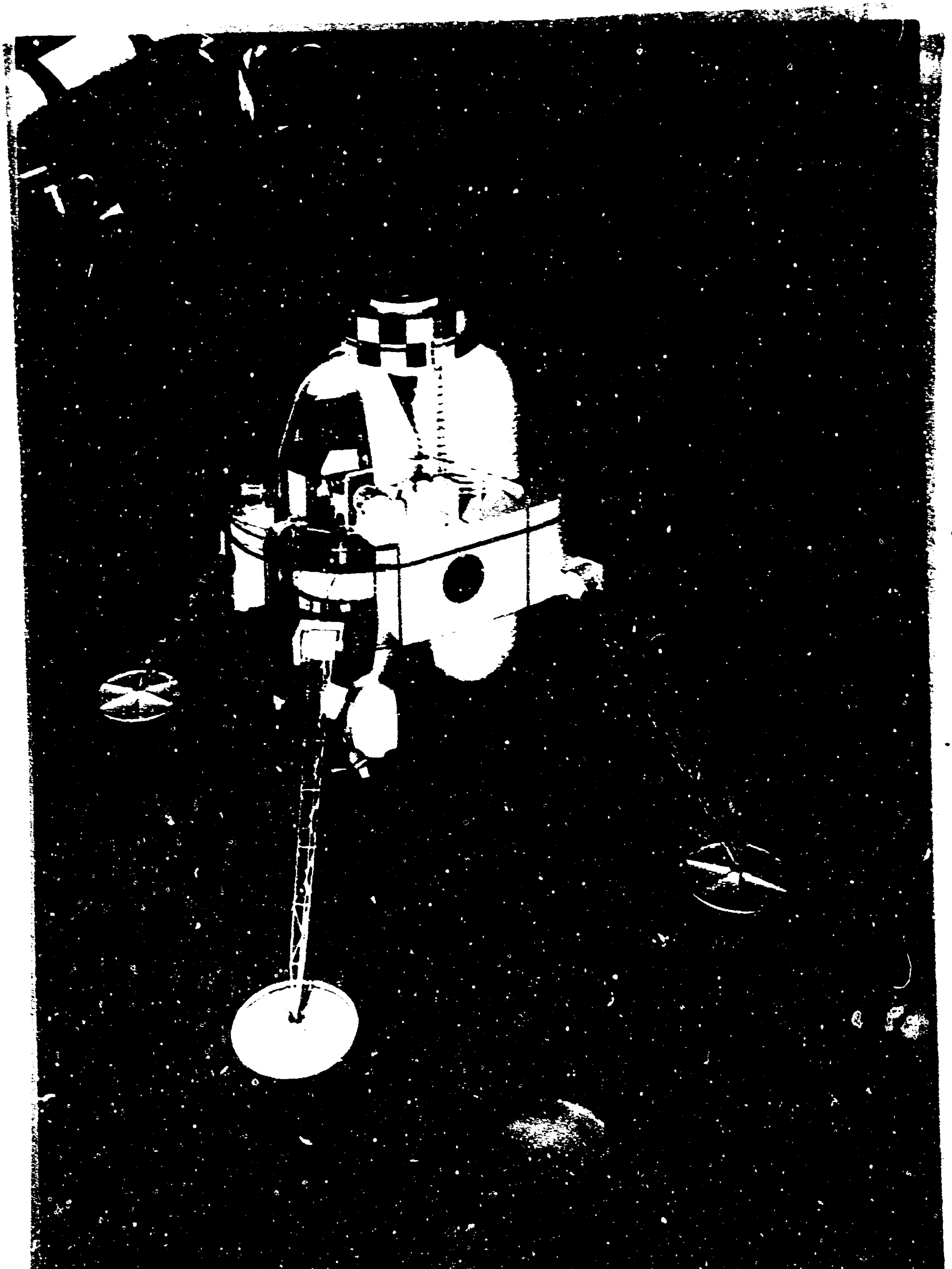
In the previous year, a concept for a transportable station was developed for depths down to 6,000 feet. A few items needing additional development have subsequently been given special attention.

A design analysis of bolted joints for use on deep-ocean pressure hulls was made by General Dynamics (Contract No. N62399-67-C-0044-P001). Bolted joints are considered necessary for future designs in order to provide versatility of construction utilizing standardized modules. A program was developed which provides a balance between analytical studies and model tests to obtain design certification in a cost-effective manner.

In anticipation of utilizing viewing ports in underwater stations, tests were run on full-scale windows under simulated operational conditions. The tests were performed for 1 year (13 cycles) with the temperature ranging from 70°F to 34°F and the pressure from 0 to 4,000 psi on each cycle.

Scale models of two underwater stations are being tested in the towing tank facility at the University of California at Berkeley. The purpose of these tests is to determine the drag and stability of this type of station. Data for towing in waves is being analyzed and the response will be presented as a function of the wave frequency. Ocean current effects on station stability during its vertical excursion are being studied in a wind tunnel at the Naval Postgraduate School, Monterey, California.

Two Fortran computer programs have been written for the calculation of the force in a taut mooring line and the response of a subsurface buoy in a cross current. The dynamic force in the mooring line is generally smaller for nylon ropes than for wire ropes. Much higher line tension can be caused by subsurface currents.



Unstiffened Toroidal Shells

The objective of this study is to determine the stress response, buckling modes, and ultimate load of toroidal hulls in an ocean environment so that a rational design for such structures can be developed. The hulls may include hatches, ports, supports, and geometrical discontinuities and imperfections.

Theoretical and experimental studies have been completed on the behavior of isotropic homogeneous circular toroidal shells subjected to hydrostatic pressures.

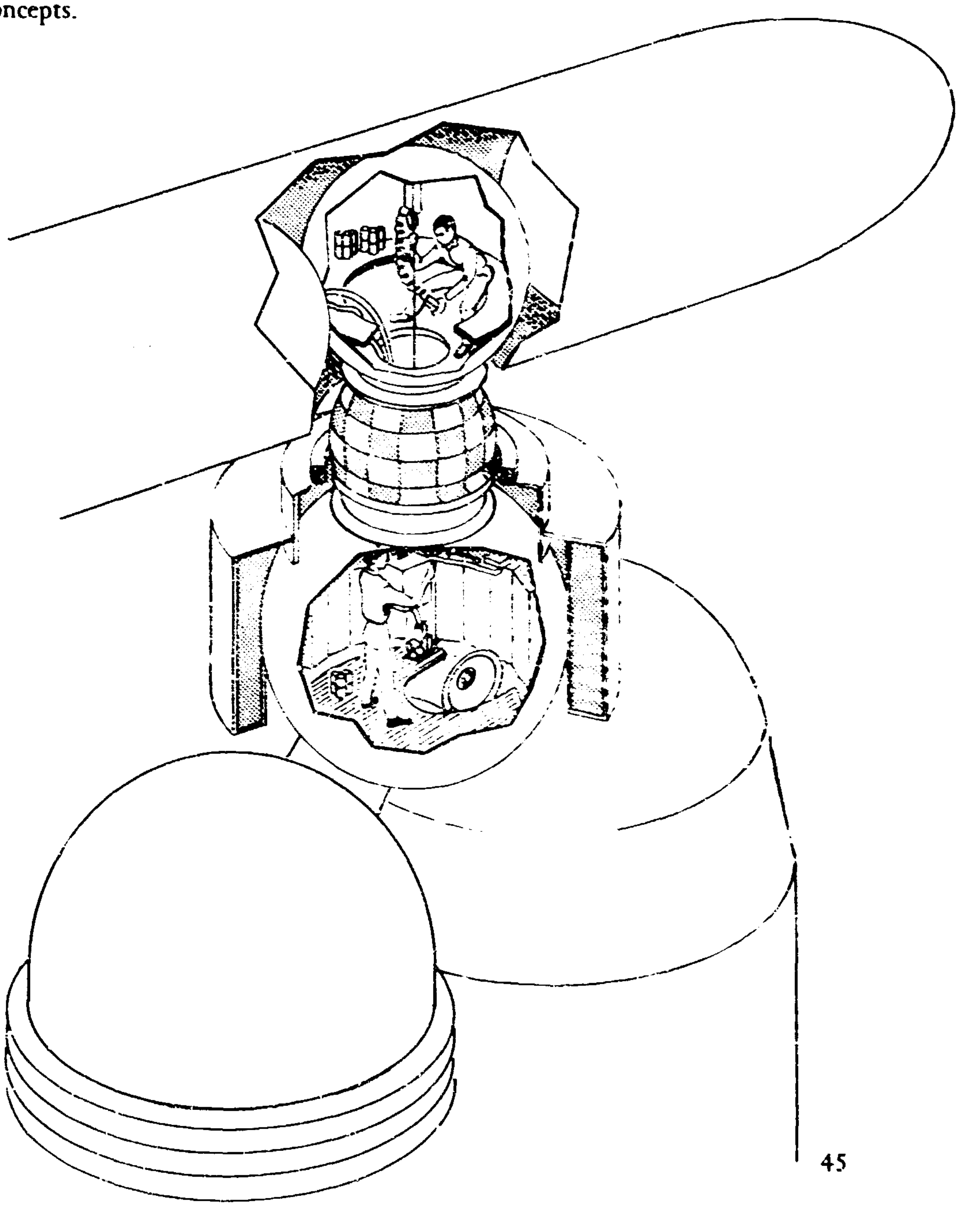
Tests were completed on epoxy toroidal shells having a major radius of 6 inches, a minor radius of 2 inches and a shell thickness of 0.08 inch. The measured critical elastic buckling pressures were in excellent agreement (within 4%) with values obtained from an existing buckling theory for axisymmetric shells. A finite-element computer program for predicting the stress–strain response of toroidal shells was developed, and the results were compared with the experimental data. The strain measurements obtained from external strain gages operating in the pressurized water environment were inconsistent and inconclusive. However, the internal strain value output of the computer program agreed with the corresponding measured values to within 5%.

Epoxy toroidal model shell instrumented for hydrostatic tests.

In late FY-68, a contract was let to extend existing computer codes to include the determination of the linear buckling modes of axisymmetric shells with evenly spaced uniform meridional stiffeners. Under this same contract the development of a finite element computer program for predicting the large deflection response of axisymmetric shells has been completed. The response of toroidal shells has been solved using this program.

Underwater Ingress and Egress System

The Ingress–Egress System provides means to supply a manned underwater station with a replacement crew and fresh consumables. The baseline system incorporates a deep submergence rescue vehicle (DSRV) as a resupply submersible and an ASR (Rescue Ship, Submarine) as a surface support ship. Access to the station is attained through a 9-foot-diameter sphere located at the top of the station structure. The final contractor report presents the results of the design effort, the constraints, and rationale which influence design decisions and alternate solutions to design problems. The report recommends further study be directed toward sea elevator control, a manned underwater station technical development plan, and aerial resupply concepts.



Viewing Ports

The short-term testing of spherical shell acrylic windows has shown that (1) the data generated with small-scale spherical windows in FY-68 is also applicable to large-scale spherical windows, and (2) the largest and thickest spherical window that can be fabricated today from off-the-shelf commercially available acrylic plate is adequate for viewing at 1,000-foot depth.

The study of small-scale conical windows under long-term 10,000-psi hydrostatic pressure was completed this fiscal year. The findings demonstrate that a thickness-to-minor-diameter ratio of 1 is adequate for conical acrylic windows subjected to long-term hydrostatic loading of 10,000 psi. Determination of whether this t/D ratio is adequate to sustain cyclic loading at that pressure was beyond the scope of the program. In addition to the long-term study, some exploratory investigations were performed with model windows on methods of sealing windows inside their retaining flanges to prevent leakage even after the windows have displaced substantially through the porthole. The radial O-ring seal was found to be the most tolerant to axial displacement of the window (inward as well as outward).

Largest acrylic spherical shell window tested by NCEL is 34 inches in diameter and suitable for 1,000-foot depths.

Acrylic Pressure Hulls

The evaluation of the 66-inch-diameter spherical acrylic hull prototype under simulated operational service marked the successful completion of the first phase in the development of spherical acrylic hulls for manned operations in hydrospace. The 72-inch-diameter pressure vessel with 5,500-psi pressure capability was used to subject the hull to simulated operational service.

During the evaluation program, the acrylic hull prototype spent approximately 2,500 hours inside the pressure vessel while both the pressure and the temperature of the water were varied. During that time, the acrylic hull withstood a total of 335 hours of hydrostatic loading applied during 61 simulated dives whose depth varied from a maximum of 2,400 feet to a minimum of 225 feet. Although the type 316 stainless steel hatch and bottom plate yielded somewhat during the simulated maximum depth dives, no visible damage was observed in the acrylic hull.

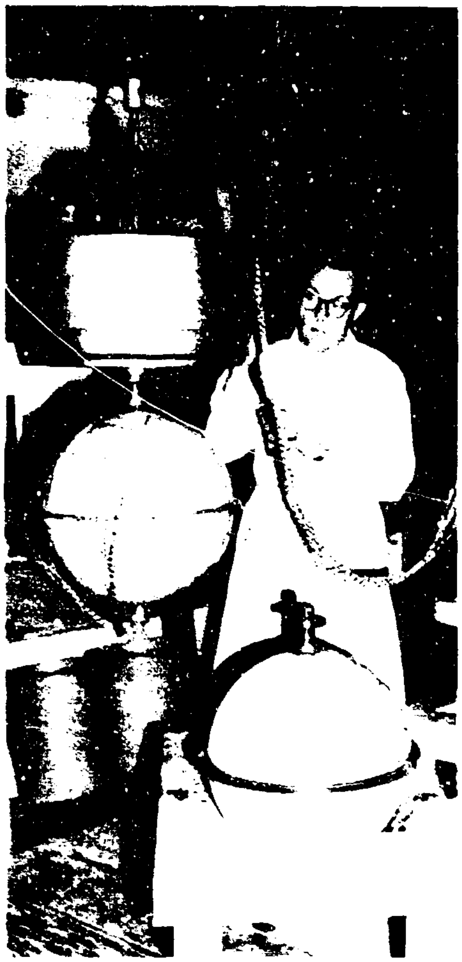
The extensive evaluation program, and particularly the simulated dive to a maximum depth of 2,400 feet, have conclusively shown that acrylic hull prototype appears to be structurally adequate for depths in excess of its rated operational depth of 600 feet. In view of the satisfactory performance of the prototype hull a contract was placed for two additional hulls, one of which when mated with the support and depth control subsystems will be used as a Navy Experimental Manned Observatory (NEMO) system.

Concurrently with the evaluation of the hull prototype the cycling of 15-inch-diameter models to a pressure of 500 psi continued. To date, one model completed 100 cycles of 100-hour duration at maximum pressure, a second model 300 cycles of 24 hours duration, a third one 600 cycles of 12 hours duration, and a fourth one 3,600 cycles of 1 hour duration. None of the models failed catastrophically, but some minor cracking of the acrylic contacting the steel end plates was observed.

NEMO descends to simulated depths.

Concrete Hulls

The FY-69 study of using concrete for ocean-bottom stations and instrumentation vessels was directed toward four principal areas, including experimentation on thick-walled concrete spheres and on thick-walled model concrete cylinders capped with hemispheres. All experimental work was performed with specimens capable of being tested to destruction in the NCEL ocean-simulation facility.



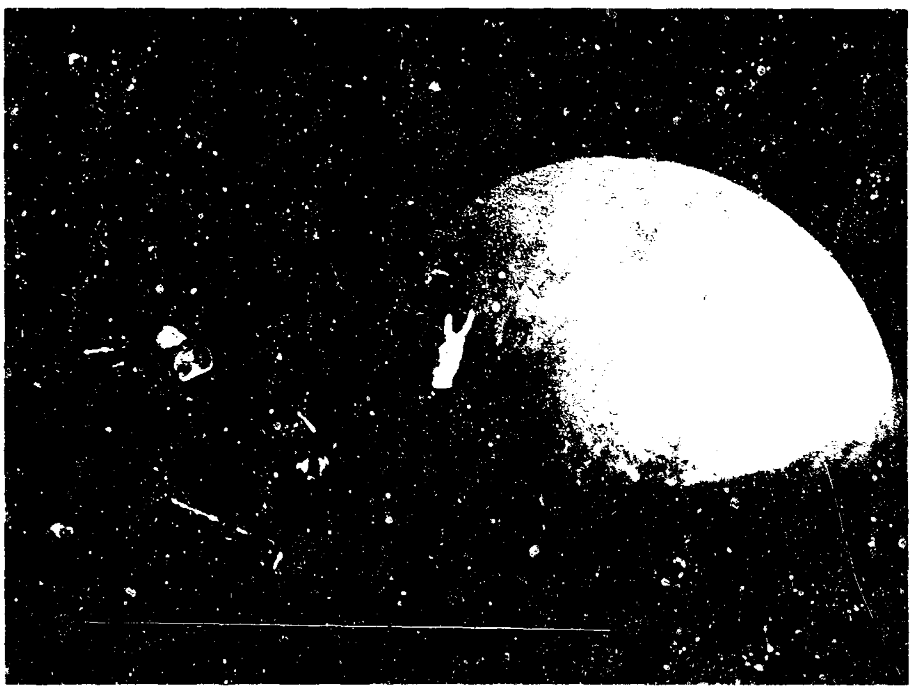
Instrumenting thick-walled model spheres for pressure vessel tests.

Four thick-walled concrete spheres with 16-inch outside diameter and inside diameters ranging from 8 to 14 inches were tested to complete a preliminary study of the effect on the implosion pressure of concrete strength and wall-thickness-to-diameter ratio. The results indicate a quasi-linear relationship between (1) the ratio of implosion pressure to concrete strength and (2) the thickness-to-diameter ratio.

In the study of thick-walled concrete cylinders, the major structural parameter being investigated is the relationship between the L/D (cylinder length/outside diameter) ratio and the implosion pressure of the hull under short-term hydrostatic loading. The cylinders have an outside diameter of 16 inches with a 2-inch wall thickness. The L/D ratios investigated range between 0.5 and 8. Results show that elastic thick-wall theory predicts with fair accuracy the implosion pressure of long cylinders, but underestimates the failure of the short cylinders.

Model spheres were also used in a study to determine the effect of a mechanical joint between two concrete hemispheres. Such a joint would allow repeated opening and closing of the hull for actual operational use. How the joint affects the behavior and strength of the hull must be understood for correct joint design. By using ring joints of various materials and stiffnesses, the NCEL study is determining the effect on hull performance of joints with rigidities different from that of concrete and the effect of concrete plasticity and stress redistribution behavior under hydrostatic load.

To understand how the model concrete spheres simulate the behavior of prototype structures, scaled-up concrete spheres with 66-inch outside and 58-inch inside diameter are being tested. As with the model spheres, the scaled-up spheres are fabricated by bonding the concrete hemispheres together with epoxy cement. Early results indicate that there is some size effect and that the failure mode of the prototype is the same as that of the model. A prototype sphere has been prepared for a long-term ocean test; it will be placed at a 1,000-foot depth on the ocean floor for a period of several months. Creep, permeability, and corrosion of the hull will be studied. An operational, mechanical joint is also being fabricated for use in a 66-inch sphere. The jointed prototype sphere will not only show the relationship between model and prototype behavior but also demonstrate the operational capability of concrete in an undersea structure.



Divers rig concrete sphere for undersea tests.

DEEP SUBMERGENCE SIMULATION FACILITY

The various ocean environment simulators of this facility provide a capability of simulating the hydrostatic loading conditions of any ocean depth with seawater. In addition to supporting NAVFAC work units, the facilities are made available to other government agencies and to industry. The 22 pressure vessels in the facility range from a 5-inch (ID), 0.2-ft^3, 50,000-psi vessel to a 72-inch (ID), 357-ft^3, 5,500-psi vessel with a working length of 120 inches.

Two-man submarine about to be lowered into 72-inch pressure vessel for proof-testing.

The outside work performed in the 72-inch vessel included:

Ripple III Isotopic Power Source Housing Proof Test for NUWC, San Diego, California

56-Inch (OD) Glass Sphere Joint Test for NUWC, Hawaii

DSRV Ballast Tank Proof Test for Lockheed Missiles & Space Co., Sunnyvale, California

Divers Suit Insulation Test for SEALAB III

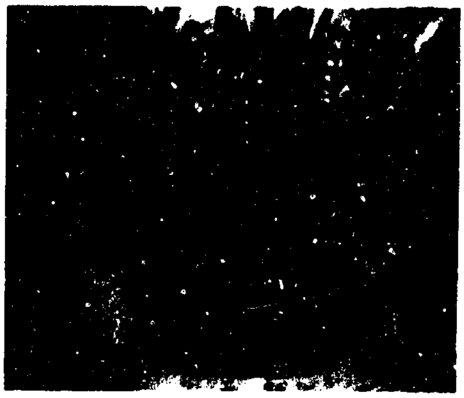
Submersible Hydraulic Winch Test for Ocean and Science Engineering Company

Control and Instrumentation Capsule for CURV III Vehicle for NUWC, Pasadena, California

Salinity-Temperature-Pressure Transducer Calibration for Oceanography & Geodesy Section Pacific Missile Range, Point Mugu, California

Automatic Impact Location System (AILS) Winch and Buoy Proof Tests for AC Electronics Defense Research Laboratory, Goleta, California

Submarine Loop Antenna & Cable Tests for Bunker-Ramo Co., Canoga Park, California



The 72-inch pressure vessel enables NCEL engineers to conduct simulated deep-submergence tests on large undersea objects and systems such as the loop antenna (left), isotope power source (top), glass sphere (middle), and control capsule for CURV (bottom).

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