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AD 523 33

Project LRAPP Test Bed

Technology Used in the Development of a Deep-Ocean Stable Platform

[Unclassified Title]

JOHN B. GREGORY

Ocean Technology Program
Ocean Science and Technology Division

October 24, 1972

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FOREWORD
(Unclassified)

The LRAPP (Long-Range Acoustic Propagation Project) Test Bed represented the first successful deep-ocean implantment of an instrumented stable suspended array. Though the array short-circuited 5 days after implantment, 14 months later acoustic means verified it to be in the installed position. The Test Bed was designed and installed for the Office of Naval Research by the Naval Underwater Systems Center, New London Laboratory and was the result of the integration of the then existing mechanical, electrical, and marine technology. The history of its development indicates that this technology was not quite well enough established for a confirming demonstration that such moors were completely within the state of the art. This opinion, in spite of the electrical failure of the Test Bed, is stated from the point of view that the technology needed to design the system the way engineers would have preferred to design it was not ready for deep-ocean application. For example, such hardware as microminiaturized electronics, neutrally buoyant electromechanical cable, and lightweight imbedment anchors appeared almost at hand but unfortunately were not then and are not now considered ocean worthy. When such developments do become of age, the design and implantment of moors and deep-ocean structures many times more complicated than the Test Bed will become routine.

Successful implantments in the deep ocean can be achieved by designing lightweight structures and, performing research and development of such moors from the systems viewpoint. The comparison of steam-turbine and gas-turbine technology will illustrate this point. Steam turbines and the associated condensers, boilers, and other hardware have been designed and developed as individual components by various companies not motivated by the optimization of entire plants. Thus the result has been a heterogeneous mixture of machinery connected by a jungle of piping. Gas-turbine technology, in contrast, evolved in an environment—the aircraft application—wherein the compressor, combustion chamber and turbine had to be optimized as a well-integrated machine. So too must deep-ocean moors be developed, for they are composed of many elements whose individual performances bear on the overall behavior of the moor during implantment and when installed.

The Test Bed was an instrumented, tensioned structural system composed of many general-purpose marine components and subsystems, but its overall design concept was a system comprising three major subsystems: the hydromechanical subsystem, the sensor and electronic subsystem, and the implantment subsystem. In optimizing the system, compromises were required in the subsystems because of schedule limitations, available funding, and restriction to existing technology. The first two of these limitations were clearly required, but the restriction to existing technology is not always so clear. The technology for a development exists only after it has been demonstrated satisfactorily, and at that time it becomes part of the engineering art. Although all of the components comprised by a system may be within the art, the system itself must demonstrate that it too is within the art. Thus, whereas the subsystems and components of the Test Bed appeared to be within the bounds of technology and were satisfactorily tested ashore, a fully successful installation was not forthcoming without incorporating technological gains.

This report discusses the technology used in the Test Bed and identifies the areas wherein technological gains either have since been made or need to be implemented. It is separated into the three major subsystems and their components for clarity of presentation, and at the end of the discussion of each subsystem is a brief summary and a recommendation. For more details on the design, fabrication, and installation of Test Bed the reader is referred to technical reports in preparation at NUSC, New London Laboratory.

Hopefully, engineers involved in the design of subsequent deep-ocean complex structures will benefit from the experiences of those involved in this experimental project.

PROJECT LRAPP TEST BED
TECHNOLOGY USED IN THE DEVELOPMENT OF A DEEP-OCEAN STABLE PLATFORM
[Unclassified Title]

INTRODUCTION

(U) The Test Bed (Fig. 1), was a truncated two-point moor which was tensioned by subsurface floats at the upper corners to provide essentially a taut, instrumented cable system. Along the leg cables and horizontal span were 20 hydrophones and 25 engineering sensors to obtain an understanding and validation of the static and dynamic performance of the structure in its ocean environment for surveillance purposes. (Appendix A lists the engineering test-plan objectives.) In addition, acoustic, ambient-noise, coherence, and propagation-loss measurements were planned for use in the LRAPP acoustic modeling validation program.*

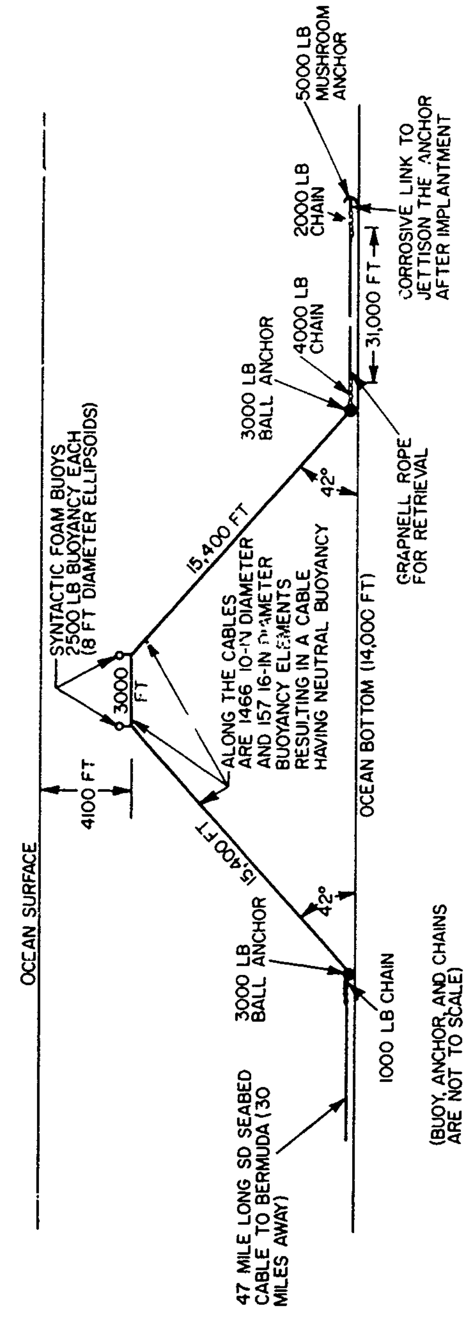
(U) The Test Bed was designed for the geographical area east of Bermuda where the ocean currents are low, where acoustic characteristics of the ocean are well known and suitable for the particular propagation studies of interest, and where the Office of Naval Research maintains a research station. Because of these favorable conditions, it was possible to implant the Test Bed only 30 miles offshore for obtaining summer and winter sound-channel propagation data. This relatively short distance allowed the use of seabed communications cable for telemetering information to the receiving station at Tudor Hill. Since no cable repeaters were necessary, the use of the cable instead of radio telemetry was cost effective for obtaining continuous acoustic and engineering information from the moor over the four seasons of the year.

(C) From examination of bottom survey charts, current profiling data, and bottom core samples, the position 32°05′N, 64°12′W was selected as the implant site. Seabed cable runs were planned in conjunction with Western Electric cable engineers, and detailed bottom survey and core sampling were ordered for a 10-mile-square grid about moor center.

(U) To provide meaningful engineering data from the moor, it was important that the Test Bed not be extremely stiff but that it be designed to exhibit a measurable degree of long-period excursion commensurate with acoustic research parameters. Therefore, before the preliminary design phase was begun, the Naval Research Laboratory was tasked to perform static analyses of various two-point moor configurations.† From these analyses a configuration was selected to provide optimum performance in the ocean-current variations of that area.

*"Long Range Acoustic Propagation Project," TRW Systems Group, Technical Development Plan R24-08, 30 May 1969.

†R.A. Skop, "Deflection Analysis of Some Two-Point Mooring Configurations," memorandum (8442-28 RAS:kcp, NRL Problem F02-24, Feb 12, 1970), Ocean Technology Division, Naval Research Laboratory.

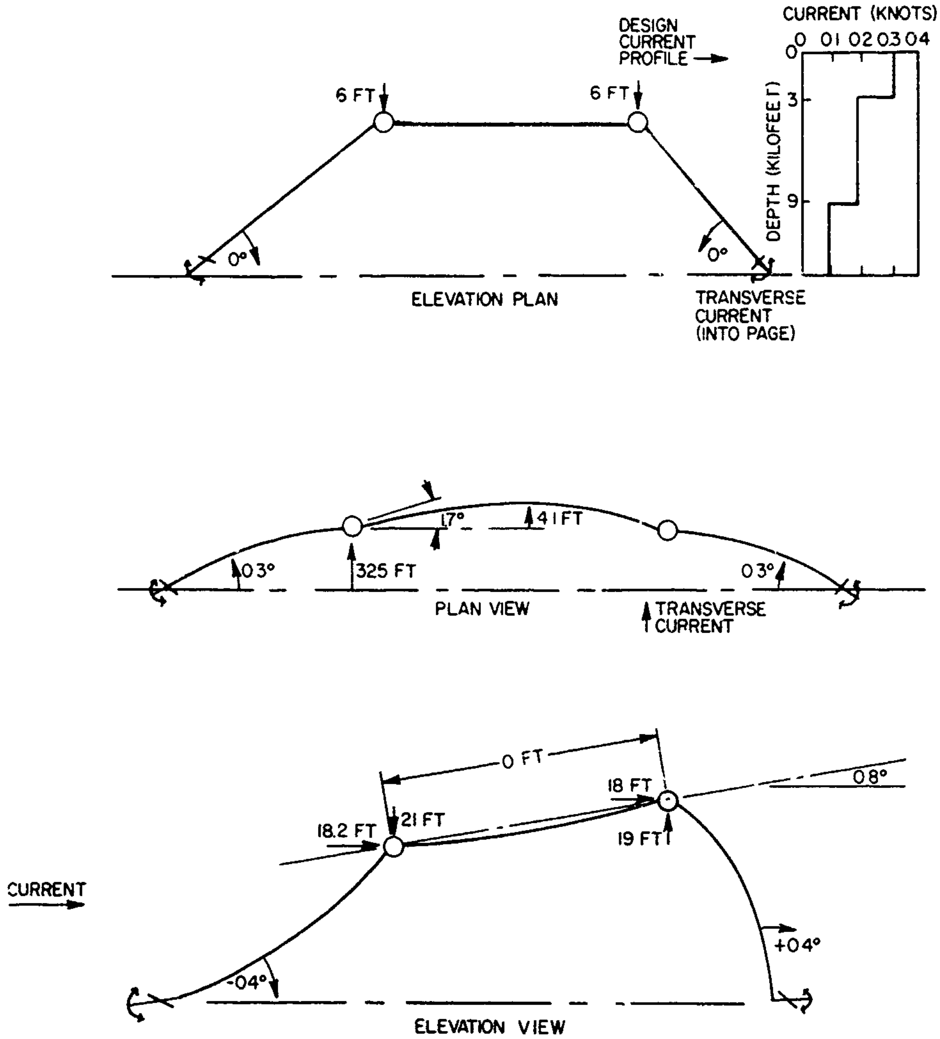


(U) Fig. 1—LRAPP Test Bed

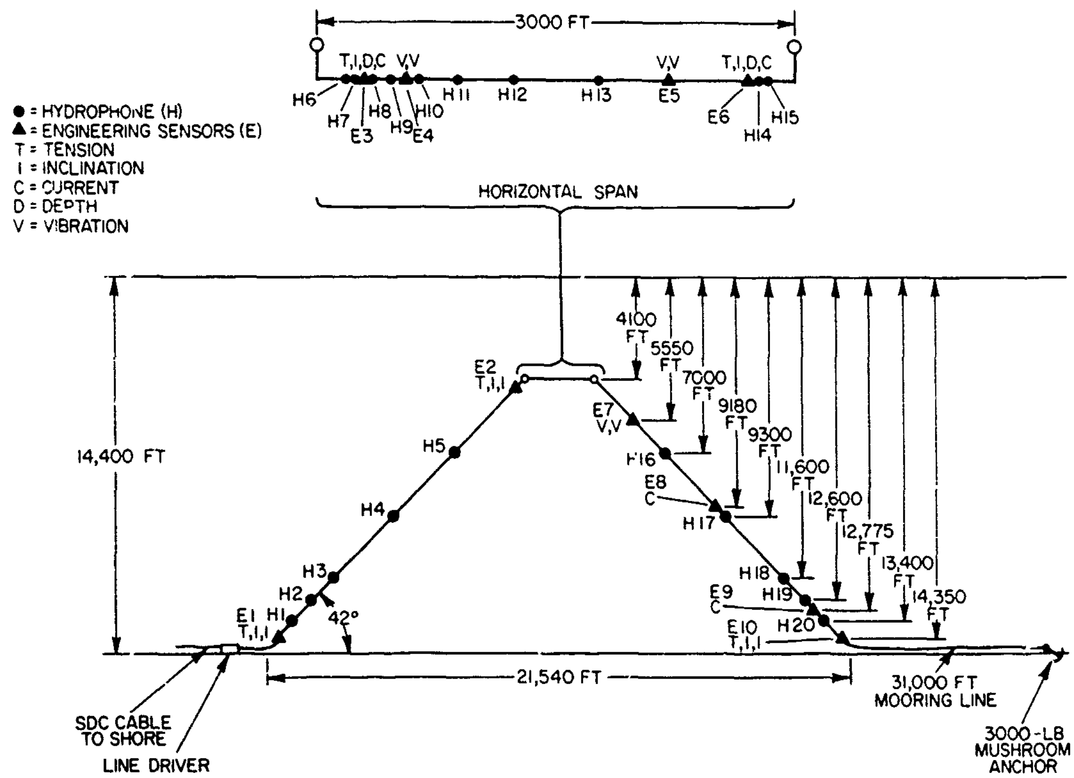
(U) Figure 2 summarizes the predicted long-term excursions for ocean currents transverse and longitudinal to the Test Bed array for the as-designed configuration and current profile. The profile shown was verified by measurements prior to installation to be a reasonable average for that area during spring and summer.

(U) Several configurations for retrieving the moor for refit at some future date were considered, and it was decided that it would not be cost effective to lift the lower end of the inshore leg because of its connection to the seabed telemetry cable. Instead, the offshore leg was provided with a long grapnel rope which was designed to be stretched out on the ocean floor as the means for retrieving the moor. The included angle of 42 degrees formed by the legs and the ocean floor was selected so that either upper corner of the array could be brought to the surface of the ocean without lifting the seabed cable.

(U) At the outset of the project it was stipulated that the offshore leg would be electrically dead. However, because of a desire for redundancy and correlation of acoustic



(U) Fig. 2—Predicted moor excursion from transverse and longitudinal currents data, both riser legs were identically configured with hydrophones. Figure 3 identifies the positions of the hydrophones and engineering sensors on the moor.



(C) Fig. 3—Test Bed acoustic and engineering sensor positions

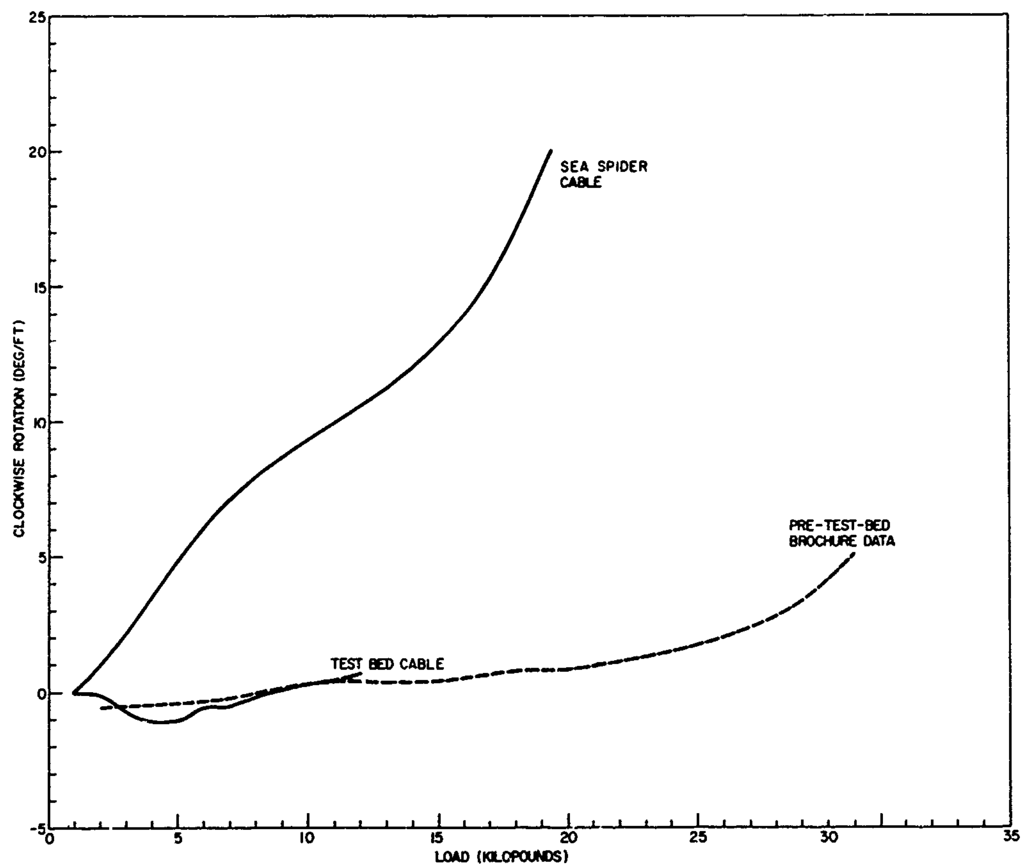
HYDROMECHANICAL SUBSYSTEM

Array Cable

(U) The electromechanical cable used on the legs and horizontal span of the Test Bed was a newly designed Rochester Corporation No. 20680 double-armored single-coaxial cable. The electrical characteristics were in essence a 10-gauge copper center core of seven twisted wires and a woven copper return shield. The dielectric material was high-molecular-weight polyethylene. These characteristics were identical to those of the predecessor deep-ocean stable moor, the Pacific Sea Spider, which was never implanted. (Pacific Sea Spider was an ultrastable three-point moor designed for the severe ocean environment north of Hawaii. The structure contained 30 hydrophones and miscellaneous sensors on its legs and signal-conditioning equipment as well as isotope-powered thermoelectric power supplies in its subsurface apex tensioning buoy. Telemetry was to be accomplished via a surface buoy tethered to the apex buoy below. An attempt to implant Sea Spider in the summer of 1969 failed, and the surplus project equipment was placed in storage.) Because the Test Bed maximized the use of equipment remaining from that project (such as electronics packages from the Sea Spider legs) it was necessary to match the electrical characteristics of the cable systems.

(U) The counterwound double armor provided for the cable system of the Test Bed was developed for an oceanographic application of the Scripps Institution of Oceanography wherein high-strength, low-twist cable was required. Suitable low-twist-versus-load armor was not available for the Pacific Sea Spider project and was not stocked by cable companies, probably because of its high cost and low demand. (Usual double-armored oceanographic cables of this type are designed with 24 outer and 24 inner wires. With this limitation, the design of low-torque cables has not been possible. A consequence of the 24 by 24 wires is that cable-winding machines are fitted with 48 bobbins. Hence, if the winding of the armor is to be completed in one pass through the machinery, the total number of wires must not exceed 48. Rochester No. 20680 cable uses 22 wires in the inner lay and 36 wires in the outer, thus requiring separate winding operations for the inner and outer armor.)

(U) Figure 4 shows twist as a function of load for both the standard Rochester No. 20675 cable to have been used in the Pacific Sea Spider and the No. 20680 cable used in the Test Bed. From the figure it is seen that below 20,000 pounds, which is the approximate elastic limit of these 250-ksi steel cables, the Test Bed cable specimen twisted no more than 1 degree per foot. This low-twist cable appeared most suitable for the Test Bed in view of difficulties experienced with twisting of the No. 20675 cable. Test Bed project personnel also reviewed available nontorquing cables and found none suitable because of their low strength-to-diameter ratio. In addition without outer armor the possibilities of



(U) Fig. 4—Twist characteristic of the cable for the Test Bed as compared with that of the cable for the Pacific Sea Spider fish-bite damage or chafing during deployment excluded their usage. Nontorquing cables which exhibit "zero" twist have longitudinal strength members which are either composed of a single center core or run concentrically to it. While minor efforts for the development of neutrally buoyant, nontorquing cables are underway, it appears that none will be available before 1974 for ocean application.

(U) Corrosion, another major problem with ocean structures needed to be considered in addition to the mechanics of obtaining low-torque cables. The choice of a galvanized coating was made because of its generally successful usage in ocean applications over the years.

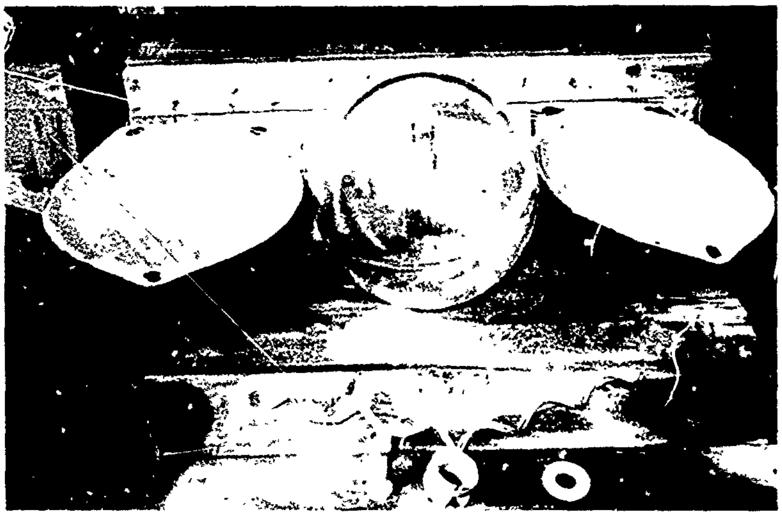
(U) Lastly, during the loading of the electromechanical cable aboard the USNS *Naubuc*, and the subsequent deployment of that array, the cable was observed to kink as it entered the cable handling system. Serious difficulties arose which required special measures by the implant crew. Since these difficulties were caused by the interrelationship of the cable and the handling system, they will be discussed in the section on the implantment subsystem. In essence when the cable is handled in a slack condition, the inner and outer armor slide over each other, thus distorting the overall torque characteristics of the cable. The use of cable tank and drum deployment is not satisfactory for this cable; it should be stored and paid out on reels under tension.

Leg Cable Buoyancy

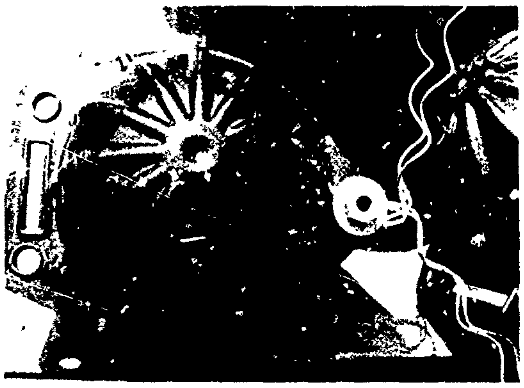
(U) Cable buoyancy is needed to prevent the legs and horizontal span from drooping into catenaries; also, the size of the corner floats and the load on the cable at its upper end, if it were not buoyed along its length, would be excessive. Not all stable moors require cable buoyancy; in some applications long-period excursions from shifting ocean currents are not a factor. For each moor application, the designer must consider the moor stability, the cable strength-to-weight ratios and the electrical requirements. The buoyancy distributed over the entire electromechanical cable system of the Test Bed was approximately 26 kilopounds.

(U) Building leg cables with integral buoyancy is not within the state of the manufacturing art for low-drag cable. Developments are being made. Personnel at the Naval Underwater Systems Center are developing lightweight electromechanical cables which exhibit low hydrodynamic drag. Fiberglass strength members and polypropylene dielectrics have been tested for coaxial as well as multiconductor cables. In the Test Bed the cable weight was neutralized by a discrete distribution of floats without difficulty.

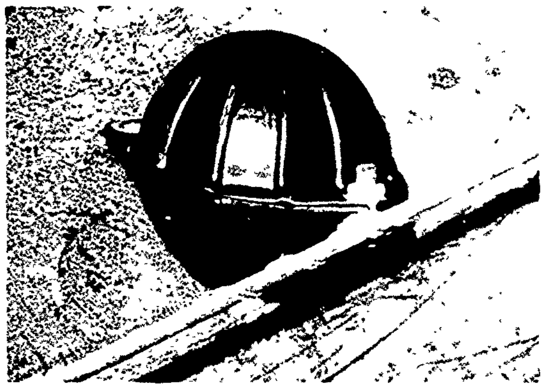
(U) For the deep ocean, glass floats offer the highest buoyancy-to-weight ratio, and ocean engineers have not reported any significant difficulties with their handling or performance. In the Test Bed as well as for the Pacific Sea Spider the floats were incapsulated in polyethylene jackets (Fig. 5) which provided a point of attachment as well as protection if the floats were accidentally dropped. A total of 1466 10-inch-diameter Corning Glass Works floats, generally spaced 22 feet apart, were used throughout the array. Where cable weights such as electronics packages and sensors required concentrations of additional buoyancy, 157 16-inch-diameter Corning glass floats of 48 pounds buoyancy each were used. No difficulties were observed in attaching these floats to the cable.



(a) Glass ball, polyethelene jacket halves, and a preformed cable-grip attachment before assembly



(b) Glass ball, jacket, and cable grip after assembly



(c) Glass ball attached to the array cable by the preformed cable grip

(U) Fig. 5—Glass floats

(U) By increasing the size of the 10-inch spheres to 12 or 13 inches, their buoyancy could be doubled, thus requiring only half the number and significantly reducing the deck-force labor in attaching them to the cable. In essence the 10-inch and 16-inch balls are too light or heavy respectively for a man to handle efficiently. In addition the drag resulting from intermediate-size spheres would be significantly less than the drag from 10-inch spheres providing equivalent buoyancy. Intermediate-size balls are not in production, but with the probability of increasing use over the next few years, this important addition could be made to ocean engineering.

(U) Glass spheres have a mature technology, but improvements could be made to alleviate the weak points in their manufacture; most important is the fusing of the seam in the joining of the two glass hemispheres from which the sphere is formed. The spheres are not generally pressure tested before use because of historically good performance in the deep ocean. Most of the spheres used in the Test Bed were those remaining from the Pacific Sea Spider project. A random sample of these had been tested after production at the factory, which testing stipulated that any spalling from the fused seam would be considered a failure. No failures in the sample of 100 were detected. Pressure testing is expensive, and it is usually prohibitive to test a large production run.

(U) Sympathetic implosion or chain collapse of spheres on the array from the implosion of a single sphere was studied and determined not to occur except where placed in very close proximity. Tests have been made at the Naval Ship Research and Development Center in connection with the use of glass sphere buoyancy for deep submergence vehicles. Spacings of 10 or 20 feet have been found to be sufficient.

(U) The method of attaching spheres to the cable has proven to be satisfactorily engineered but is labor consuming. The standard practice is to twist the preformed wire grip (Fig. 5) over the cable as it runs toward the stern chute during deployment. This operation requires two to four deck hands. For the Test Bed a quick-connect attachment was designed but abandoned in favor of the much less expensive and generally excellent performance of the preformed grip manufactured by Preformed Line Products Company. The development of a reasonable priced quick attachment would be most worthwhile. If this proposed grip could be implemented so that a loading machine could directly clip the ball to the cable, the size of the implant crew could be substantially reduced for sizable implantments which require round-the-clock operation.

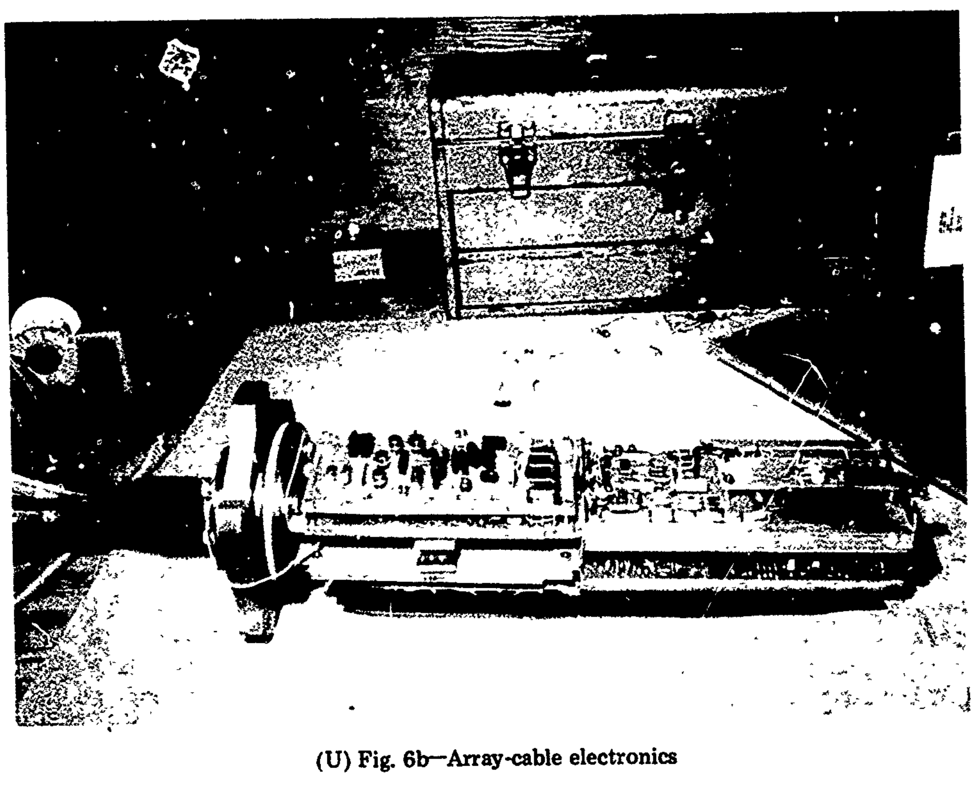
Underwater Electronics Packages

(U) Most of the electronics packages (Fig. 6a) and the electronics for them (Fig. 6b) remained from the Pacific Sea Spider project. That project used an implant technique wherein the packages were clamped to the electromechanical leg cable during deployment. For the Test Bed this technique was modified to provide for in-line electronics and sensors, except for current meters which required a vertical orientation and therefore had to be hung from the legs. The reason for the in-line configuration was a decision to pass the entire array from the cable tank of the implantment vessel, USNS *Naubuc*, through the cable machinery and thence over the stern chute into the water. This decision required a maximum equivalent diameter of any clump on the array cable to be not more than 6 inches.

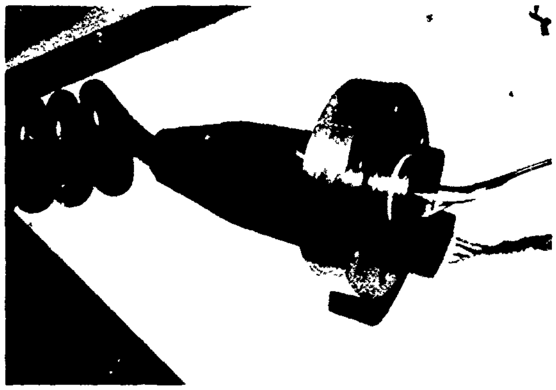
(U) In the Pacific Sea Spider project the electrical penetrators through the electronics-cannister flanges were molded to the flanges by the U.S. Underseas Cable Corporation in England. The method of providing a pressure-proof seal was complex, expensive, and required several months lead time. Instead of repeating that procedure, D. G. O'Brien Company electrical bulkhead penetrators (Fig. 7) were reconfigured for the application.

(U) Because of difficulties experienced in the Pacific Sea Spider project with the molding of tee splices, it was first decided instead to run the main line into the electronics package and out again, making the parallel-circuit electronics connection and the line-protection fusing inside the cannister. But upon assembly of the cannister penetrators onto the array at DeBell and Richardson Company, Hazardville, Connecticut, and the subsequent water-immersion test of each sensor and electronics station, moisture was electrically indicated to have wicked into some of the polyurethane penetrator boots and across

(U) Fig. 6a—Cannisters for the line driver shown in FIg. 3. Similar cannisters were used for the electronics for the sensors along the array cable.



(U) Fig. 6b—Array-cable electronics



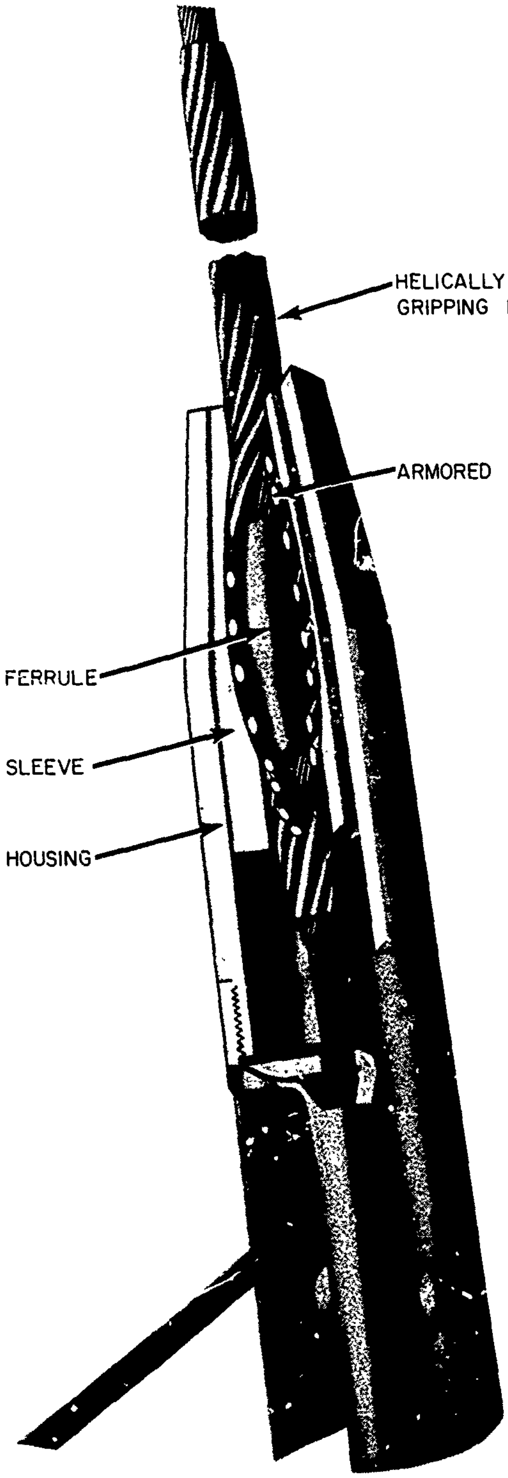
(U) Fig. 7—Standard cable termination (manufactured by the D. G. O'Brien Company) used as the electrical penetrator into an electronics cannister.

the outside of the terminals, thus shorting out the array system. This wicking, which had not become evident during high-pressure hydrostatic tests, was due to the subsequent handling and bending of the penetrator pigtails (Fig. 7) during assembly onto the array, which broke the bonding of the polyurethane boot to the polyethylene-covered lead wires. The mishap required modification of the penetrator boots and the addition of a main-line protection fuse outside the cannister. To effect a less compromisable system, the leads were not run into and out of the cannister but tee spliced into the main line after all.

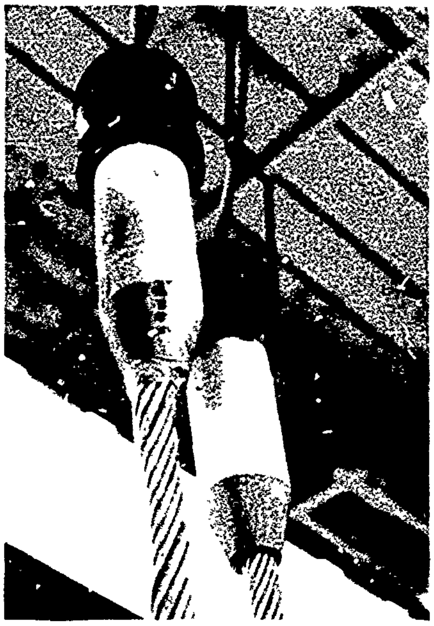
Mechanical Terminations Along the Cable Legs

(U) Cable terminations were required at each instrument station and at the ends of the Test Bed array cable, totaling about 50. All mechanical terminations were Preformed Line Products Company Dynagrips which, although of standard basic internal design (Fig. 8a), were sized and flanged for the Test Bed project. The internal design employed static friction upon the outer armor of the Rochester Corporation electromechanical cable. The exterior design (Fig. 8b) of these terminations was configured for the ball and socket requirements of the instrument packages into which they were connected. For easier movement through the cable-handling machinery during implantation the Dynagrips were encased in a polyurethane fairing (Fig. 8c), formed by pouring uncured liquid polyurethane in a removable mold.

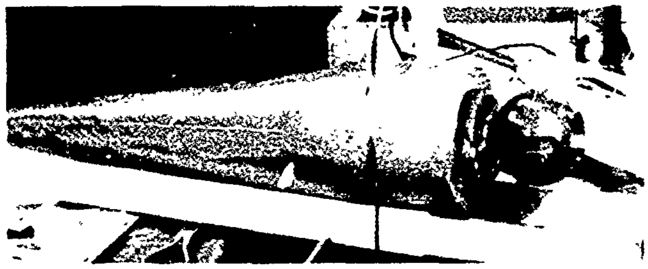
(U) The double armor of the array cable was cut as shown in Fig. 8a, leaving a core pigtail sufficient for electrical connections. A precision cast oval ferrule was slipped over the double armor. A set of the helically formed splice rods about 72 inches long, having an internal helix diameter slightly smaller than the double armor were wound over the array armor and ferrule. The manufactured helix diameter of the rods is enlarged at the position of the ferrule. Aluminum oxide fused to the rods provides sufficient friction to prevent slippage over the double armor. A metal split sleeve was applied over the rods and ferrule. The Dynagrip housing was slipped over the entire assembly. Epoxy filler was poured into the housing to prevent movement of the internal parts and prevent wear.



(U) Fig. 8a—Standard Dynagrip manufactured by the Preformed Line Products Corporation



(U) Fig. 8b—Dynagrip configured for a ball joint



(U) Fig. 8c—Dynagrip termination encased in a polyurethane fairing

(U) Of paramount interest to the user is that when the terminations have been sized for the cable, their performance will be not impaired by the usual factors which cause engineers concern over other known types of the mechanical terminations, namely, the craftsmanship used by the assembler and the field conditions under which he must sometimes work. In pull tests run on cables and ropes these fittings have not slipped and the ropes have been pulled to failure at a distance from the terminations. All Test Bed terminations were pulled to at least 14 kilopounds during the loading of the array aboard the implant vessel, which load was about three times the maximum static load of any of the terminations in the array.

(U) Preformed Dynagrips used in the Test Bed required epoxy glue to hold the preformed long wrap wires in place during assembly. The glue, however, added nothing to the termination strength. The manufacturer now markets a termination wherein the glue is applied at the factory so that the terminations can be assembled in the field without awaiting a cure of the glue. Thus a termination can be disassembled from the cable and another slipped on quickly.

(U) In the predecessor project, Pacific Sea Spider, various types of mechanical terminations were examined and deemed to be unsuitable. These types were sockets using epoxy and low-pour-temperature woods metal as well as mechanical grip terminations wherein each wire was separately spread and fastened. The 72-inch long preformed wrap in the Dynagrip used in the Test Bed (Fig. 8a) serves as a strain relief member to prevent fatigue from bending or flexing at the termination. This was the primary method used for such strain relief in the Test Bed except that, where instrument packages were in close proximity to each other, low-temperature-curing polyurethane moldings about 4 inches in diameter were poured to span the distance between the preformed wraps. (All molding operations on cables are at temperatures low enough to assure that the dielectric material in the cable is not melted.)

Electrical Terminations Along the Cable Legs

Electrical terminations of the electromechanical cable used in the Test Bed were by overmolding electrical splices with polyethylene. The entire system was electrically spliced and molded at the array assembly factory, DeBell and Richardson, Inc., at Hazardville, Connecticut. Because of that company's experience in assembling underwater surveillance-type systems, it was decided to perform the entire assembly operation at that plant and then truck the completed and tested array to the implant vessel.

(U) Figure 9a shows a molded splice just after the metal mold plates were opened. The small electrical wires leading into the upper mold plate were used for heating the mold sufficiently to obtain a thorough bond of the molded splice to the polyethylene jacket of the coaxial cable. The rubber hoses leading into both mold plates were used for cooling the mold during the latter part of the molding sequence. The molds were heated to 320° F, held at that temperature, and cooled to room temperature in a closely prescribed manner. Upon removal from the mold, the completed splices were inspected visually with a magnifying glass for bonding and for air inclusions. In addition each molded splice was x-rayed.

(U) Figure 9b shows a splice before the mold plates were bolted together. There was no attempt to continue the coaxial shield across the splice; instead parallel solid copper wires were used. Experience in the Pacific Sea Spider project showed it was virtually impossible to assure a splice properly molded to the extremities of the tee with the center conductor and shield kept concentric. Instead, the use of the stiff solid wires ensured proper wire separation and placement during the molding.

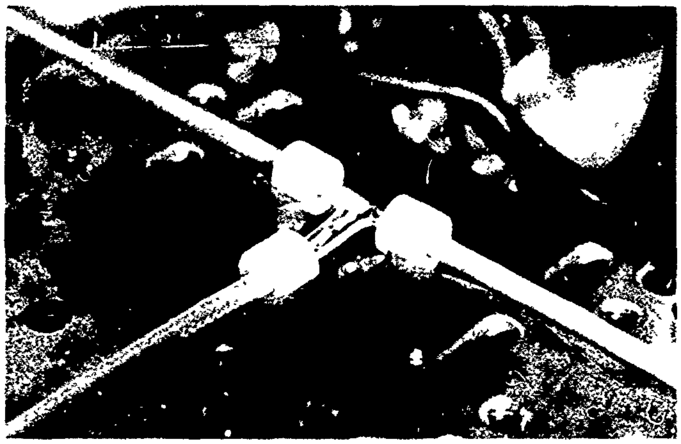
(U) Just below the bridge of the tee in the splice (Fig. 9b) is a fuse to isolate the center conductor of the electromechanical cable in the event of a short circuit at the instrument package. These fuses as well as representative splices were tested under hydrostatic pressure for deterioration from elevated pressure or water leakage. In certain tests for water leakage the fuse was replaced with a resistor to measure a resistance change in the event of water leakage. No difficulties with this molding technique were experienced, and the technology appeared well established.

(U) Paramount in the engineer's design is that the main line, which is a series circuit, must be protected. Thus fusing, water-blocking, and chafing gear must be provided throughout the main cable system. Although all of these measures were taken with the Test Bed, somehow the main line short-circuited between the center conductor and the sea, rendering the system useless.

Sensor and Electronics Housing Cages

(U) The in-line housing assemblies for the sensors and the electronics (Fig. 10a) were designed specifically for the Test Bed array installation and consisted of two cages 6 inches in diameter and 5 feet in overall length. Because strong rigid cages were needed for handing

(U) Fig. 9a—Molded polyethylene tee splice being lifted from the mold

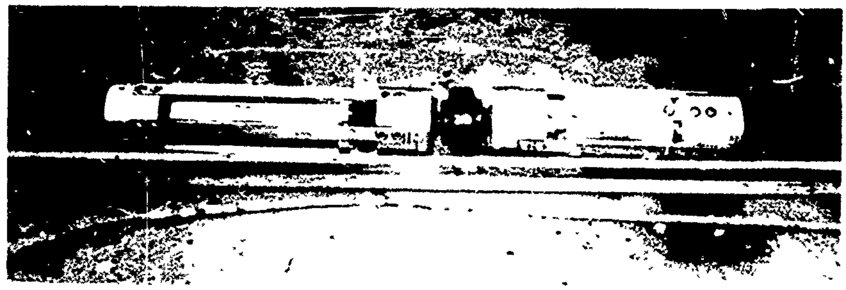


(U) Fig. 9b—Tee splice being readied for molding

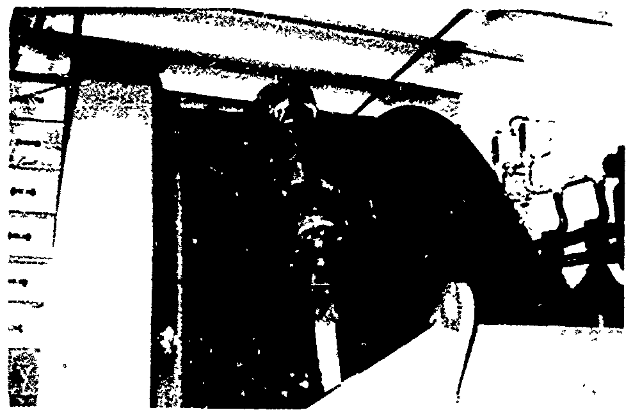
by the implantment machinery, each entire assembly weighed about 300 pounds and required two or three men for lifting where manhandling was required. However, once into the cable machinery system no difficulties with the design were experienced.

(U) The assembly was articulated (flexibly jointed) at the ends and between the two cages. This articulated configuration was designed for the 12-foot-diameter cable machinery of the implant vessel, USNS *Vaubuc;* that is, all curvatures over which the cable bent when passed from the cable tank to the sea were at least 6 feet in radius. At the ends of the cages were fairings of conically molded polyurethane (Fig. 8c), and likewise a polyurethane donutlike support was located between the center ball joints (Fig. 10a). This longitudinal symmetry of the cages allowed them to be hauled in either direction through the cable machinery. The staves of the cages, which were removable, were designed to take the full bearing loads of the drum (Fig. 10b) or fairings over which they passed.

(U) The ball joints providing the articulation were drilled and radiused to allow the electrical conductors to pass through them. The ball joints contained limiting stops which permitted the cages to bend up to 30 degrees in any direction but not to rotate, thus preventing the twisting-off of the electrical core which passed through them. Once inside the



(U) Fig. 10a—In-line sensor and electronics housings assembled inside articulated cages. The sensor housing is the shorter one at the right, and the electronics housing is the longer one at the left.



(U) Fig 10b—Electronics-housing assembly passing over the cable drum of the implant vessel, USNS *Naubuc*

(L) Fig. 1(:—Cable driver assembly, which is not directly in the array but is in the seabed cable near the array. Zinc bars are clamped between the staves of the cages.

cages, the array electrical core, which measured slightly less than 1/2 inch in diameter, was mold spliced to RG54 coaxial cable (Figs. 9a and 9b), which was half that diameter. The RG54 cable was then used for all interconnections within the cages and was of suitable flexibility for coiling and snaking around the cannisters. Chafing of the RG54 was prevented by covering it with polyethylene spiral-wrap material. In addition it was routed in a groove on the underside of one of the staves to protect it from being snagged by some part of the cable machinery.

(U) The RG54 coaxial cable required careful handling and molding because of its thin 18-mil-wall polyethylene jacket. Because this jacket was not pigmented, it was difficult to inspect visually. The choice of the RG54 cable was based on the availability of cable suitable for the system; as the assembly of instruments and electronics progressed, it was realized that a cable with thicker insulation should have been used. A leak in the outer jacket would not be quickly indicated as an electrical failure because the return shield of the cable system was grounded to the sea at the line driver (Fig. 10c) which was placed along the seabed cable near the inshore leg of the array. To prevent electrolytic deterioration at the line driver, zinc anode bars were mounted on the line-driver and amplifier housings.

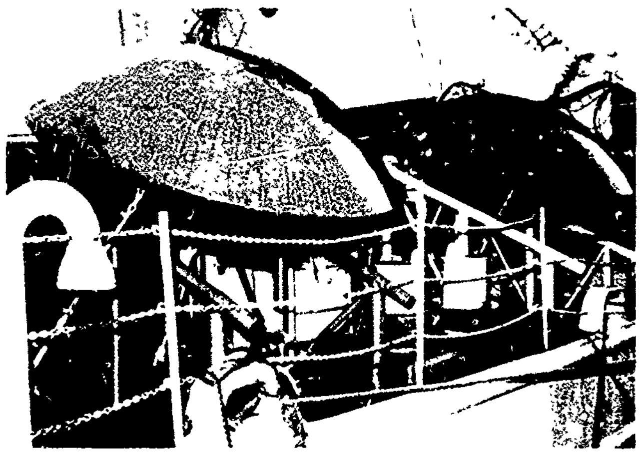
Tensioning Buoys and Pendants

(U) Single ellipsoidal tensioning buoys 8 feet in diameter and 4 feet high (Fig. 11a) were located at the two upper corners of the array to provide 2500 pounds buoyancy at each location, thus minimizing the motion of the legs and the formation of current-induced catenaries (Fig. 2). The buoys contained syntactic foam with a density of 36 pounds per cubic foot which was formed over a structural steel frame. They were covered with fiberglass for chafe protection and were fitted with lifting lugs for deployment and retrieval.

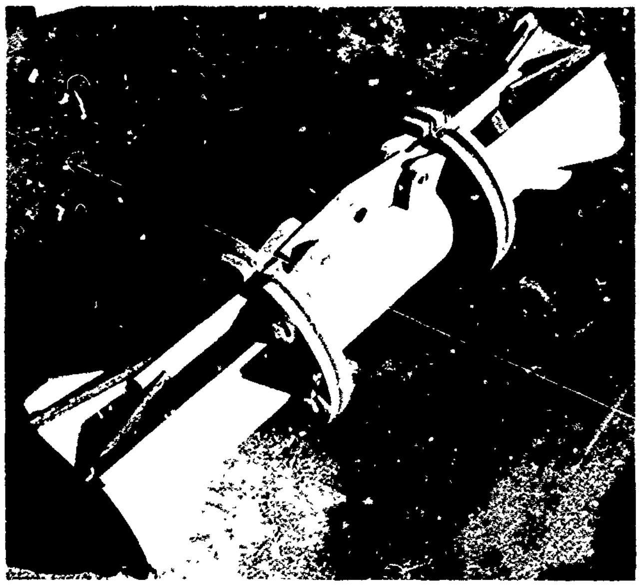
(U) Pour samples of the syntactic foam were hydrostatically tested to an equivalent depth of 12,000 feet, at which a tendency to squash was observed. Because of the propensity of syntactic foam to absorb water, the buoys were oversized by 5 percent so as to allow the deployed Test Bed array to reach its designed stability after about a week.

(U) The ellipsoidal shape of the tensioning buoys was chosen to minimize hydrodynamic drag. This shape also proved ideal for launching from skids mounted on the port side of the implant vessel. Such skids precluded the need for a heavy lift boom at that location.

(U) A wire rope from each tensioning buoy was attached during implantment to a thrust collar journal concentric to the cable and small enough to pass through the cable machinery (Fig. 11b). This collar was clamped onto the corner location along the cable during array fabrication During implantment the slotted bearing sleeve and bellmouth assembly was slipped over the journal and the assembly was bolted together longitudinally. The wire-rope buoy pendant was then attached. The wire rope was 1/2-inch-diameter 3 by 19 U.S. Steel galvanized torque-free wire rope 67 feet long. The torque-free design was verified in the Pacific Sea Spider project wherein 1-inch-diameter U.S. Steel 3 by 19 wire ropes were used successfully to lower 23-kilopound anchors to a depth of 18,000 feet. In two lowerings the anchor crown lines were cut and released at deck level, during which



(U) Fig. 11a—Tensioning corner buoys on launching skids



(U) Fig. 11b—Thrust collar to be clamped concentrically on the cable as the attachment point for the tensioning corner buoy

time no tendency to twist was observed in the remaining rope. In a third lowering the rope was cut by a pressure-actuated cutter at a depth of 12,000 feet, whereupon no twist tendency was observed.

(U) The buoy pendants required shock mitigation during the implantment because of the surging of the array from surface waves. Therefore, a 3/4-inch-diameter nylon preventer was bent-on to prevent the wire rope pendant from taking the load while the buoys floated on the surface prior to being pulled down by the inshore anchor.

(U) The bushed thrust collar (Fig. 11b) allowed the cable system to distribute its rotation, which manufacturer's test data indicated as being a twist of about 11 turns in the entire array. The collar was radiused at each end to permit a proper fairlead angle both during the implantment and in the installed configuration. The bearing surface of the collar was rulon, a hard fluorocarbon bearing material.

Anchor Assemblies

(U) The anchor assemblies were quite complex and unconventional for deep moors. Their configuration was based on the following constraints which were in addition to the usual requirements for holding buoyed systems to the bottom:

- The method of telemetering data from the array to the shore was via 1-megacycle-bandwidth cable (SD cable).

- The Test Bed was required to be implanted from seaward, so that the most critical aspects of implantment would be assured during good weather. (Schemes for implanting from both seaward and from shoreward were examined, since both had merits. For example, by implanting from shore the final offshore anchor could have been set using a strong crown line. By implanting from seaward, the crown line for setting the inshore moor had to be the seabed cable, which was of limited strength. However, the weather variable was of most concern, and it was deemed more prudent to design an anchoring system based on limited crown-line strength than to take a chance performing the most critical tasks in adverse weather.)

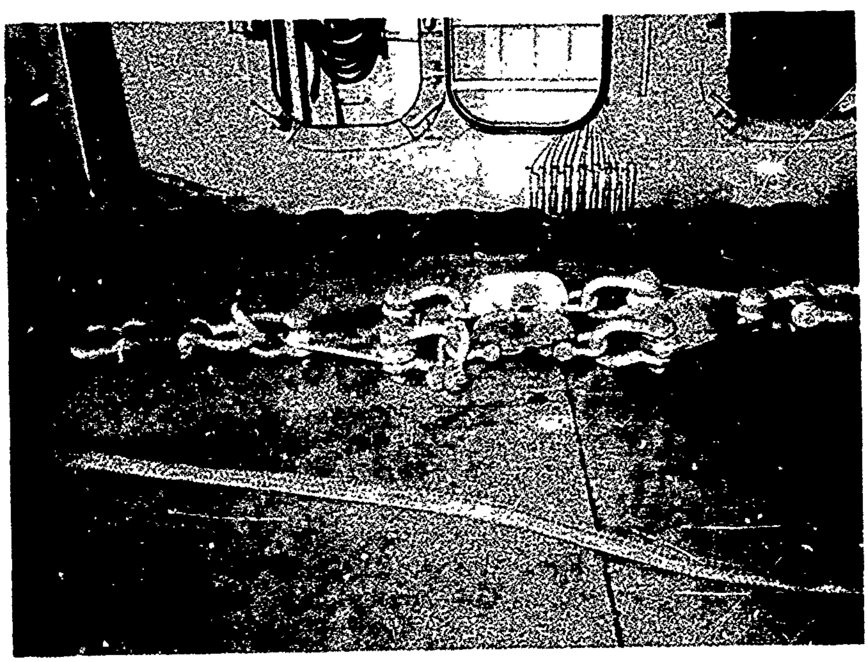
- The array would be designed for lifting and refitting at a future date, which lifting would consist of the ability to retrieve the horizontal span to the surface.

(U) In the design of anchors to comply with these constraints, it was necessary that they hold bottom in hard carbonate sand. Core samples taken in the implantment area revealed a layer of globigerina ooze (clay and hollow shells) surmounting a medium-dense hard carbonate sand bottom. The low shear strength of this ooze indicated a need to design anchors for holding in the sand.

(U) The seaward anchor system, being the starting point for the implantment (Fig. B1 in Appendix B) was used to restrain the array from shifting its position after it was deployed and set under tension. The philosophy used in obtaining the restraining force was to rely on the 5-kilopound mushroom (Fig. 12), chain, and grapnel rope to assist the seaward array anchor. The grapnel rope would release itself from the mushroom after about 5 days because of a zinc corrosive link (Fig. 13) between the seaward chain and the mushroom. The swivel visible in Fig. 13 prevented torque accumulation in the grapnel rope. The nylon rope, having completed the task of restraining the moor during implant, could be grappled and brought to the surface at some future date.

(U) The configuration of the seaward array anchor (Fig. 14a) was such that its design assured horizontal as well as vertical holding. The chain by itself had an assured friction or shear coefficient of 1.5, thus being capable of restraining the implanted array from dragging. The 3000-pound steel ball held the array down. The array was not exactly neutrally buoyant, even though the 3000-pound ball alone could restrain the 2500-pound

(U) Fig. 12—Deploying the 5-kilopound mushroom with attached chain



(U) Fig. 13—Corrosible links installed in parallel between two fish plates to free the grapnell line from the mushroom anchor used in implanting the array corner float. Instead the buoyancy of the array was designed to be 1500 pounds negative, thus adding to the effective weight of the anchors. The negative buoyancy was to insure that it would be suspended below the surface and out of wave action during implantment. This decision was based on experience gained during the implantment of the Pacific Sea Spider. In addition it was calculated that this negative buoyancy would reduce the dynamic behavior of the system during deployment.

(U) The spherical shape of the anchor was selected because it would minimize chances for fouling the array during lowering. This possibility was of concern in the deployment of the inshore anchor wherein the electrical cable would have to pass close to it.

(U) It was not feasible to back the inshore ball anchor (Fig. 14b) with 3000 pounds of chain as was the case in the seaward array anchor assembly. Instead the maximum weight of backing chain which safely could be added was 1000 pounds. This limitation was based on the strength of the SD seabed cable (Fig. 15) used as crown line. Specifications for the manufacture of SD cable* ensured high quality control and a breaking strength of 18 kilopounds. Western Electric Company engineers who procure and deploy this cable recommended that static loads of 10,000 pounds not be exceeded; therefore, a safety factor of 2, based on the breaking strength and static load, was considered necessary. In addition, Western Electric torque-to-load tests on the cable demonstrated that the center core essentially would not twist. Bowker, Nutt, and Riley give details on the way this 1 by 49 rope core is designed and wound for virtual twist-free characteristics.

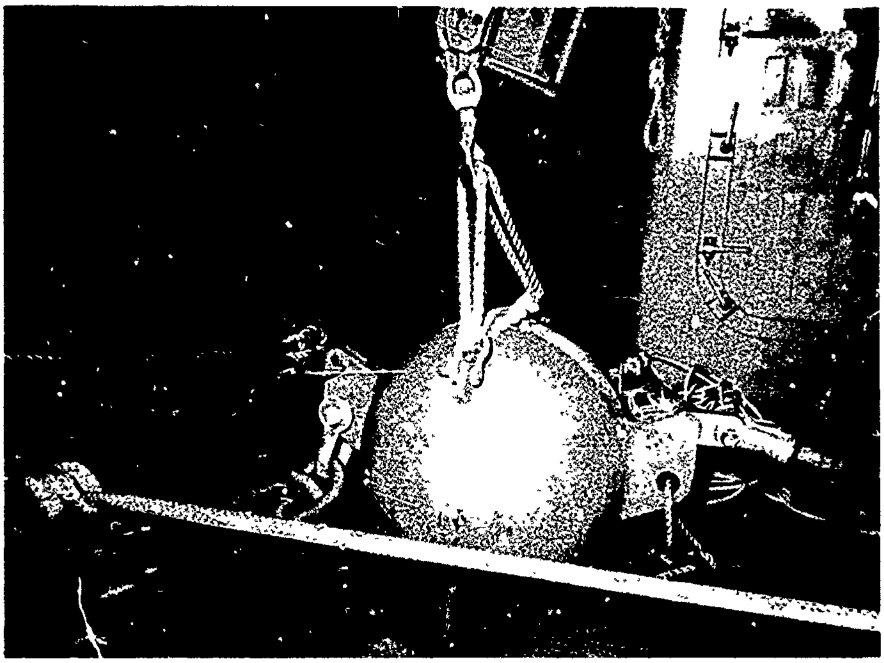
(U) To supplement the horizontal holding power of the 1000-pound backing chain bent to the seabed cable, a second chain was to be positioned 4 miles from the anchor, thus requiring that the seabed cable, like the grapnel rope, be laid under tension between anchors. During deployment of the array, this backing chain was omitted because of storm conditions. However, it was calculated that the horizontal resistance offered by the taut sea cable itself would effectively restrain the moor from dragging. Instrumentation on the moor verified this contention, since no dragging was observed during the several days the implanted array was electrically operative. Furthermore, acoustic observation of the moor on August 23, 1971, indicated that after being implanted for 8 months it was in essentially the same position.

Summary and Recommendation

(U) An array was implanted consisting of a 4100-foot-deep, 3000-foot-long horizontal span between two legs angling down at 42 degrees to 14,400-foot-deep anchor points. A 47-mile-long seabed telemetry cable runs from the inshore anchor to a station on Bermuda. A newly designed double-armored, low-torque, electromechanical cable was selected as the main array cable, and 1466 10-inch-diameter and 157 16-inch-diameter glass floats were used along the array to reduce its weight in water.

(U) The cable system was configured for deployment through the cable-handling machinery of the USNS *Naubuc;* that is, the cable was coiled in a tank and deployed over a cable drum. Electronics packages and sensors were placed inside articulated cages which

*M.W. Bowker, W.G. Nutt, and R.M. Riley, "Design of Armorless Ocean Cable," The Bell System Technical Journal, July 1964.

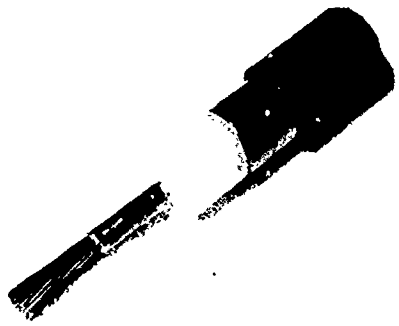


(U) Fig. 14a—Seaward array ball anchor ready for deployment. The chain is on the left side, and the array termination is on the right.

(U) Fig. 14b—Inshore array ball anchor showing preformed armor over array cable armor. Note the hinged thrust collars which control curvature of the cable.

were in line with the cable system. These cages were terminated by Dynagrips. The array was completely assembled at the factory including mold splicing of electronics into the array system.

(U) Ellipsoidal syntactic-foam tensioning buoys, each having a buoyancy of 2500 pounds, were positioned at both upper corners of the array to hold it taut and prevent formation of current-induced catenaries. The buoys were attached to the array cable by



(U) Fig. 15—Section view of SD cable

bushed thrust collars which permitted any twists in the cable to be distributed throughout the array.

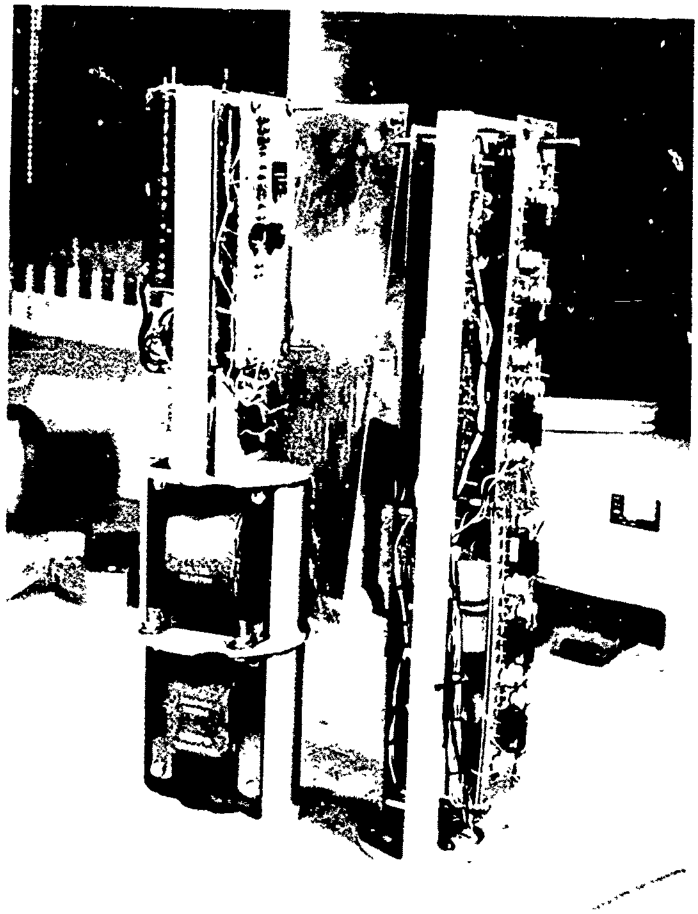
(U) Anchor design was predicated on deploying the array from seaward and upon using the seabed telemetry cable for lowering the inshore anchor. Because of the hard carbonate-sand ocean bottom, the array was restrained horizontally by 1-1/4 inch chain and restrained vertically by 3000-pound steel balls. This unconventional anchor design was selected to minimize chance of fouling during deployment.

(U) During the loading and deployment of the array serious kinking of the cable occurred which required special preventive measures by the implantment crew. The section on the implantment subsystem will discuss these difficulties and recommends that double-armored cable not be handled in the slack condition as in cable tanks but on reels under tension.

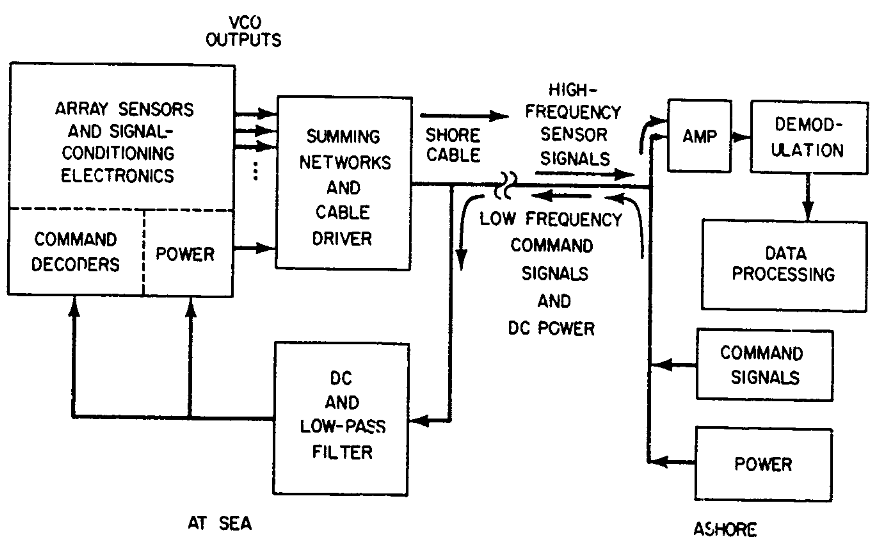
SENSOR AND ELECTRONIC SUBSYSTEM

(U) The design of the sensor and electronic subsystem was predicated on the use of existing underwater electronics packages which remained from the FM telemetry system of the Pacific Sea Spider. Because of schedule and funding limitations, and the large number of test hours on the Pacific Sea Spider electronics, they were considered appropriate for the Test Bed. These electronics had been inspected and bench tested subsequent to the attempt to implant the Sea Spider and were evaluated as being suitable for the Test Bed.

(U) The underwater package (Fig. 16) consists of four main circuits: signal multiplexing, command and control, gain control, and calibration. To provide amplification to telemeter the signals over the 47 nautical miles of cable required to contour the 30 miles of upward sloping ocean floor to the shore station at Tudor Hill, a cable-driving amplifier was located at the base of the inshore leg at the junction of the array cable and the SD seabed cable. Figure 17 is a block diagram of the telemetry subsystem.



(U) Fig. 16—Electronic package



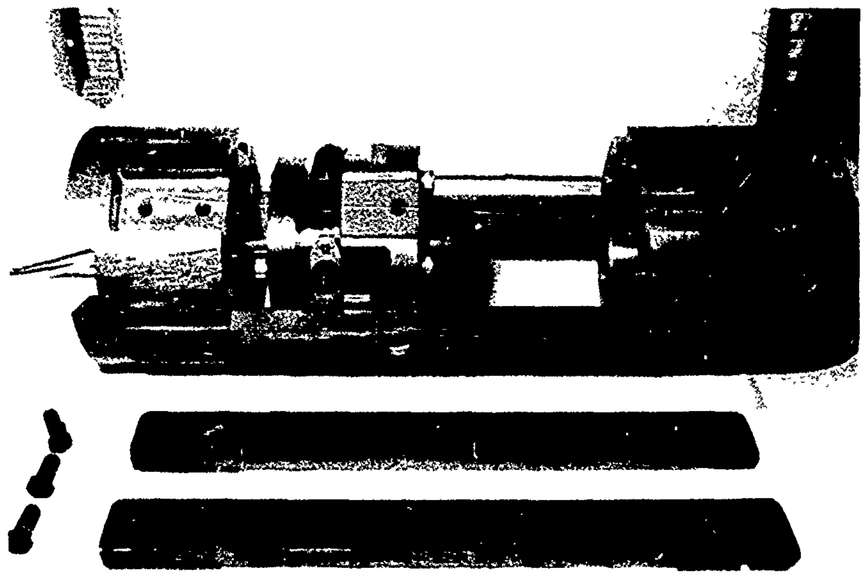
(U) Fig. 17—Telemetry subsystem

Sensor Mountings

(U) All sensors, with the exception of the large Savonious rotor-type current meters, were mounted inside in-line cages and were molded into the system.

(U) The NUS Corporation hydrophones (modified Model LM-3) used lead metaniobate sensing elements. For maximum reliability the phones were double booted, and, to mount them to the array, they were provided with mounting flanges. In the time available for design, the most suitable form of vibration isolation of the phones was to hard-mount them to the cages (Fig. 18a). Three phones, however, were soft-mounted (Fig. 18b) and strategically located for vibration comparison. This latter mounting consisted of neoprene springs in the bending mode (not compression, since the hydrostatic pressure would flatten them out) to isolate the phones from the structure. Acoustic testing of the phones in the mounting cages, indicated that their omnidirectional properties were not impaired within the frequency band of interest, 5 to 1000 Hz.

(U) Fig. 18a—NUS hydrophone hard-mounted within an electronics package



(U) Fig. 18b—NUS hydrophone soft-mounted using rubber washerlike springs

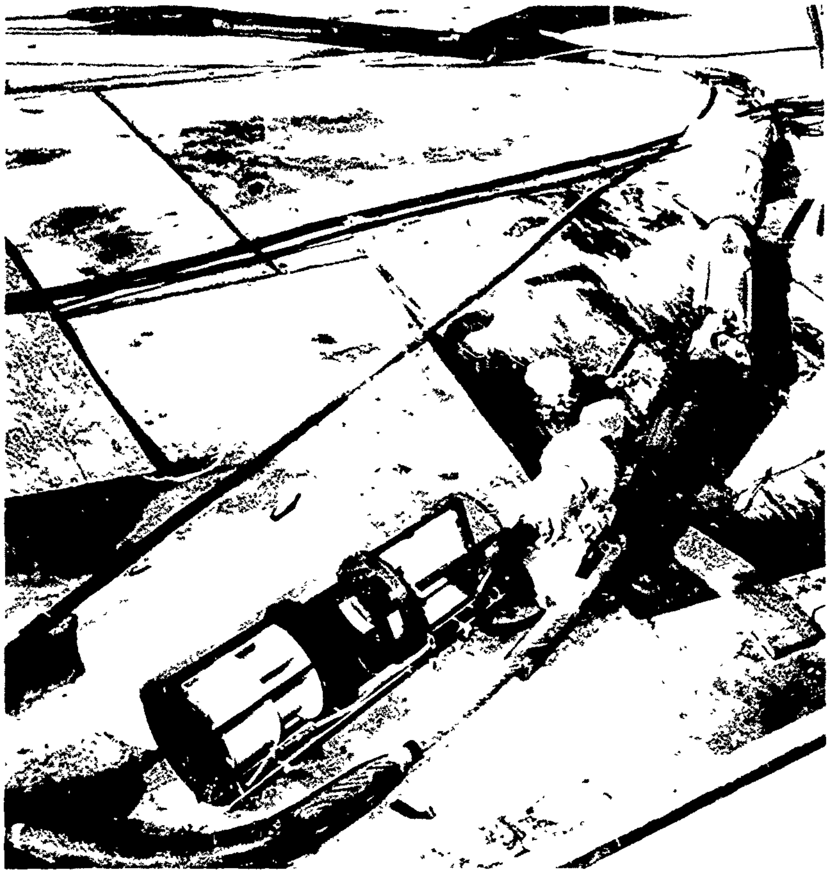
Engineering Sensors

(U) Engineering sensors (tension sensors, depth sensors, current sensors, and inclinometers) were provided primarily to measure the characteristics of the array after implantment. However, they were selected and positioned as well to monitor the forces, motions, and positions of the array during the implantment.

(U) Since no appreciable operating experience was obtained in situ, it was not possible to describe their performance other than to state that during implantment they appeared to work well and verified the implantment analysis to be suitably accurate.

(U) Five hydraulic-piston-type tensiometers manufactured by Oceanic Industries were mounted inside array cages. These sensors were compensated for depth and provided readout from 0 to 15,000 pounds ±100 pounds. Two pairs of orthogonally mounted piezoelectric accelermeters were mounted to provide a response of up to 0.2 g double amplitude from 0.1 to 10 Hz. One additional pair read to 0.3 g and to 100 Hz at a lower sensitivity.

(U) The current vector was measured by a Marine Advisors vane and a Bendix Savonious rotor. Both were contained in the same housing. Velocity readout was from 0.1 to 7 ±0.05 knots, and the direction readout was from 0 to 360 ±3 degrees. The current meters were suspended vertically from the array and read azimuth with relation to it. These meters were not mold-spliced but were plugged into a pigtail from the electronics package with neoprene connectors. This method was required because of the bulk of the meters and the need to orient them vertically. To prevent damage to the current meters during deployment of the moor, they were clamped to the array inside a protective cylindrical cover (Fig. 19) held by a strap with a corrosible link for release after deployment.



(U) Fig. 19—Current meter with protective housing for deployment to be held with a corrosible strap so the inner elastic cords could release the housing after deployment. An electrical pigtail runs from the cable cage to the hinged connection.

(U) Hymphrey pendulum-type inclinometers mounted inside electronics packages were provided and measured tilt of the array with reference to the riser cable. Three two-degree-of-freedom inclinometer were located on the legs of the array to measure tilt angles up to 60 ±1 degree and azimuth angles from 0 to 355 ±1 degree. Two single-axis inclinometers on the horizontal span measured tilt from horizontal from 0 to 70 ±1 degree.

Single Conditioning

(U) In the design of the Test Bed for a 50-dB dynamic range, it was possible to record all 20 acoustic and 25 engineering sensors simultaneously by selecting a prescribed combination of voltage-controlled-oscillator (VCO) frequencies. The center frequencies of the 25 engineering-sensor VCO's ranged from 700 Hz to 27 KHz in constant bandwidth steps. The 20 hydrophone VCO frequencies ranged from 40 KHz to 325 KHz in 15-KHz increments.

Command and Control Circuitry

(U) A command decoder circuit was contained in the electronics canisters to allow for selection of the various operational modes: gain control, sensor channel selection, and sensor calibration. The command and control unit was at the shore station. Since all modes of operation were selected through relay control, the performance of these mechanical devices was critically important. Subsystem tests of both the Pacific Sea Spider and the Test Bed indicated that the use of such relays had not proven as reliable as the remainder of the electronics because in a few cases they did not actuate properly.

Voltage Regulators

(U) Voltage regulators in the sensor packages converted shore power, which was about 85 volts dc at the cable driver and between 42 and 60 volts at the sensor stations, to voltages from +20 to -15 volts for hydrophone circuitry.

Line Driver

(U) The line driver (Fig. 10c) was located 500 feet shoreward from the base of the inshore leg of the array for the dual purposes of passing dc power and control tones from the shore station to the electronics packages and then of returning equalized and amplified signals to shore. A filter network was required to isolate the command signals from the sensor signals. Proper operation of the line driver was critical to the electrical system because dc power and all signals had to pass through its circuitry. Thus, failure of this unit would disable the array.

(U) Though the line driver was not suspected as being responsible for the electrical failure of the array, it was a component for concern during deployment because of its weight, bulk, and close proximity to the inshore array anchor. The line driver could be eliminated from subsequent systems, but in the Test Bed, wherein the existing electronics would have required extensive modification, or new electronics procured, the decision was made to incorporate a separate line driver into the system.

Shore-Station Electronics

(U) Electronics at the shore station mainly consisted of a transmitter for interrogating the individual sensor stations and receivers for separating the multiplexed sensor signals into their original components. A voltage-and-current-limiting power supply which contained an isolation network for preventing its interference with multiplexed or interrogation signals was provided. A special computer which remained from the Pacific Sea Spider Project was programmed to automatically interrogate and calibrate the array electronics.

(U) A Univac Model 1230 data processing system was to be used to record and process the data. This system incorporated a seven-channel magnetic tape system to store the data in real time and a digital system for on-line printout.

Summary and Recommendation

(U) The sensor and electronic subsystem was predicated on use of electronics equipment which remained from the Pacific Sea Spider project. Mechanical relays were used in the packages for circuit switching. These relays were found to be of less reliability than the rest of the electronics in the subsystem.

(U) The multiplexed hard-wire telemetry system was capable of channel selection, gain control, and calibration. Data from all 20 hydrophones and 25 engineering sensors could be read and recorded simultaneously at the shore station. The system was designed for a 50-dB dynamic range.

(U) A separate cable driver was located 500 feet shoreward of the inshore array anchor. Since this electronics package was heavy, bulky, and critically important to the operation of the entire Test Bed electrical system, future systems of this type should consider the elimination of such packages in favor of providing its functions at each sensor location.

IMPLANTMENT SUBSYSTEM

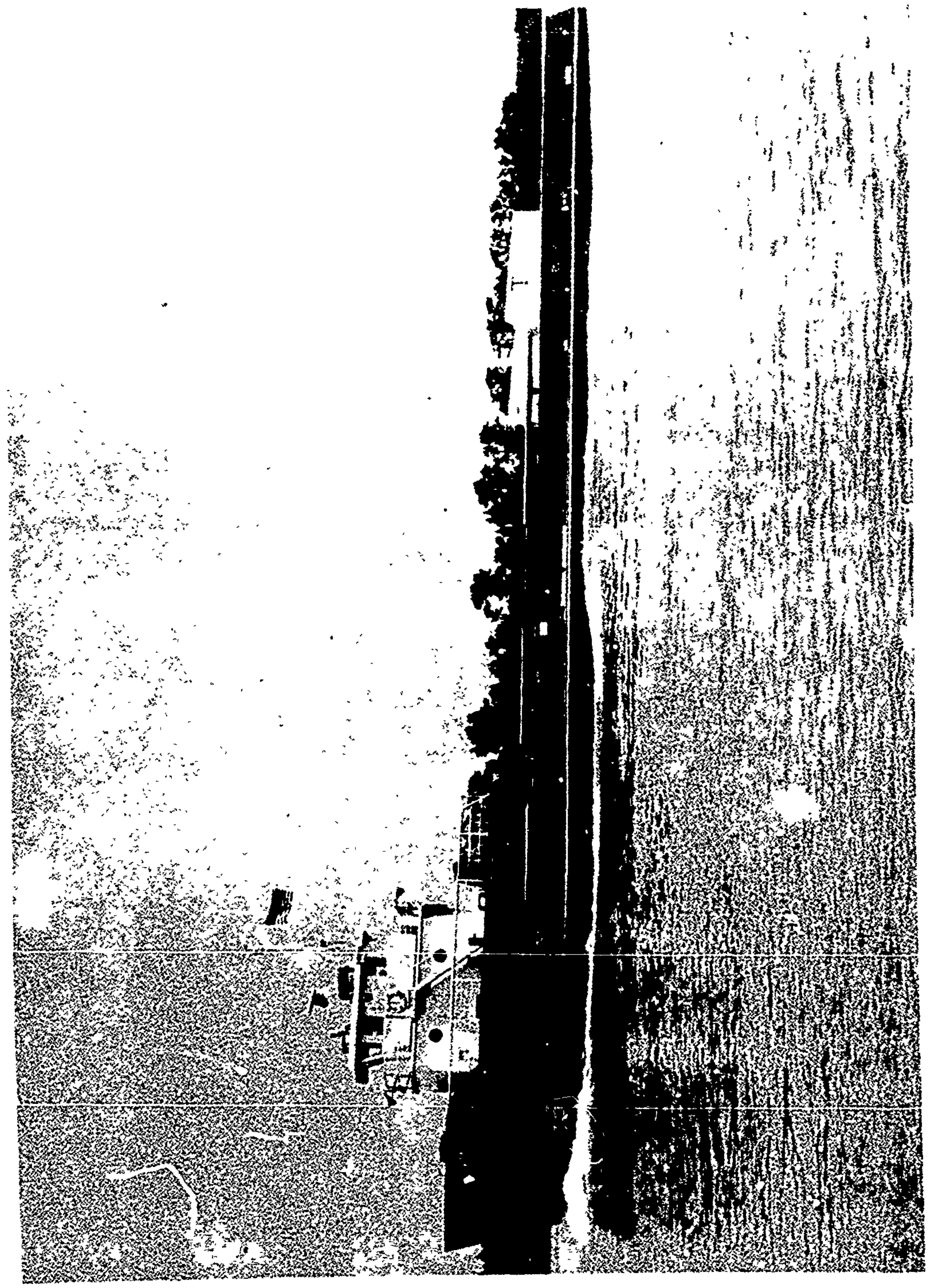
(U) The implantment of complex, suspended instrumented moors is a specialized operation and should not be considered a mooring or cable-laying task. Installing a deep-ocean complex moor is a one-of-a-kind operation requiring the infinite attention and optimization of the many relevant details such as bottom surveying, cable handling, and navigation. Such implantment attempts require specially configured ships and trained implantment personnel. Even to the extent of the direction and leadership of such an undertaking, there is a need for a special cooperative relationship between the commander of the implant vessel and the project leader.

(U) Ships suitable for such implantments are difficult to acquire, because vessels are not built, configured, or crewed for them. Of those ships which are available and suitable for proper outfitting, their cost to a project is often prohibitive.

(U) Coupled with the extraordinary requirements for implanting a complex deep moor, the Test Bed project also required the laying of 47 nautical miles of seabed communications cable from the moor to shore. The laying of the seabed cable was necessary immediately upon the implantment of the Test Bed array. Thus the project required a vessel suitably outfitted and crewed for both tasks.

Implantment Vessel

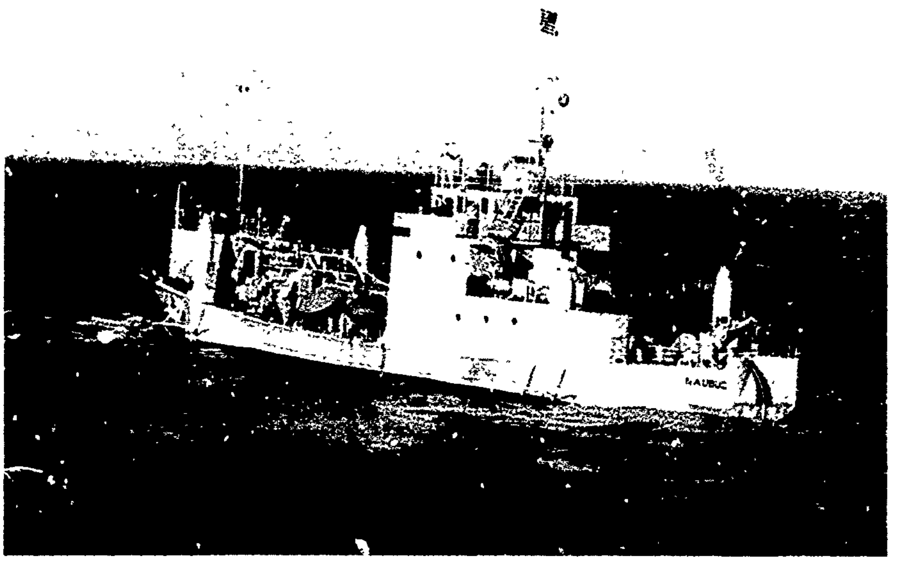
(U) At the outset of the project an oilfield supply vessel (Fig. 20) appeared most suitable for implanting the Test Bed as the result of favorable experience gained in the Pacific Sea Spider project. Though these vessels are designed to carry machinery, drill pipe, and various other supplies to the offshore oil fields and are usually devoid of heavy winches and cranes, they are seaworthy, maneuverable, and afford about a city lot of clear deck space for stowage of equipment and project machinery. In addition they can carry more than ample fuel and water for extended operations. However, berthing, messing, and sanitary facilities are extremely limited, and because they have little deadrise, their roll



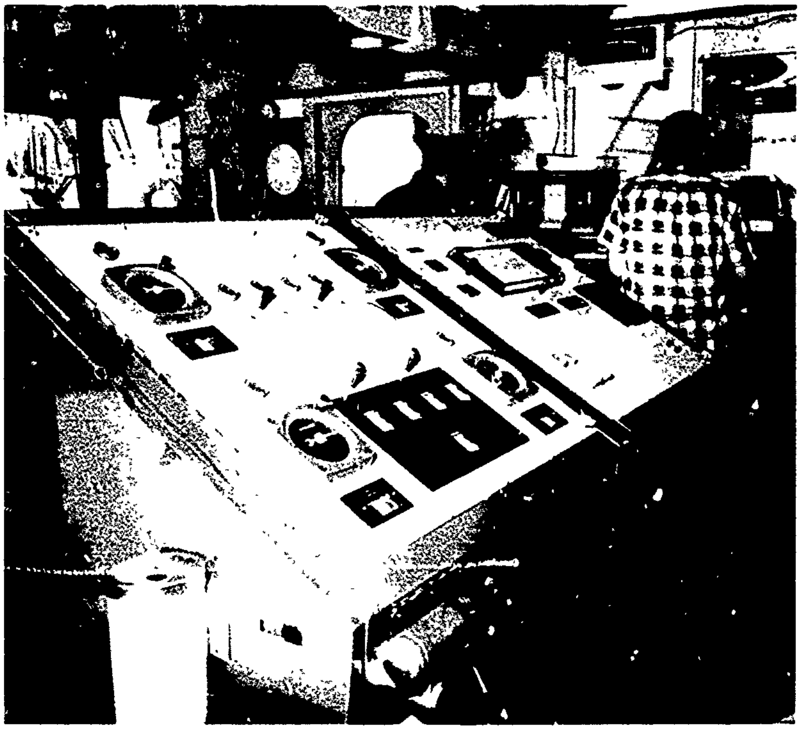
(U) Fig. 20—Typical configuration of an oilfield supply vessel is quick and somewhat uncomfortable in a s. way. In the Sea Spider project these two problems were significantly alleviated. Additional berthing spaces were installed to increase the number of bunks from 7 to 27, and about 20 additional crew members (the second of the two-section deck gang) were berthed on other ships. The stability of the vessel was improved by the carriage of 400 tons of project equipment and by ballasting the vessel's tanks with water and fuel.

(U) But, before a decision was required to freeze the preliminary design for the implantment subsystem, the project was offered the use of a unique craft, the USNS *Naubuc* (Fig. 21), developed for another underwater cable system, Project Colossus. The *Naubuc* had just been converted from a wartime net tender to a peculiarly configured craft and had completed her sea trials; she was in excellent condition and fully outfitted. The *Naubuc* and her trained crew appeared ideal for the dual purpose of implanting the Test Bed array and laying the seabed cable. The vessel was in essence a miniature cable layer.

(U) Sea trials of the *Naubuc* were observed by Test Bed project personnel, who were impressed with her maneuverability and control, crew, outfit and readiness. She was equipped with right-angle-drive propulsion units on either bow and quarter which enabled her to steam in any direction while oriented on any heading. In addition she could perform this task automatically by a computerized navigation and control system (Fig. 22) which received its position information from Decca Hi-Fix stations ashore. Because of these factors and her availability to this project she was selected as the implantment vessel.



(U) Fig. 21—USNS *Naubuc* deploying grapnel rope during the Test Bed implantment



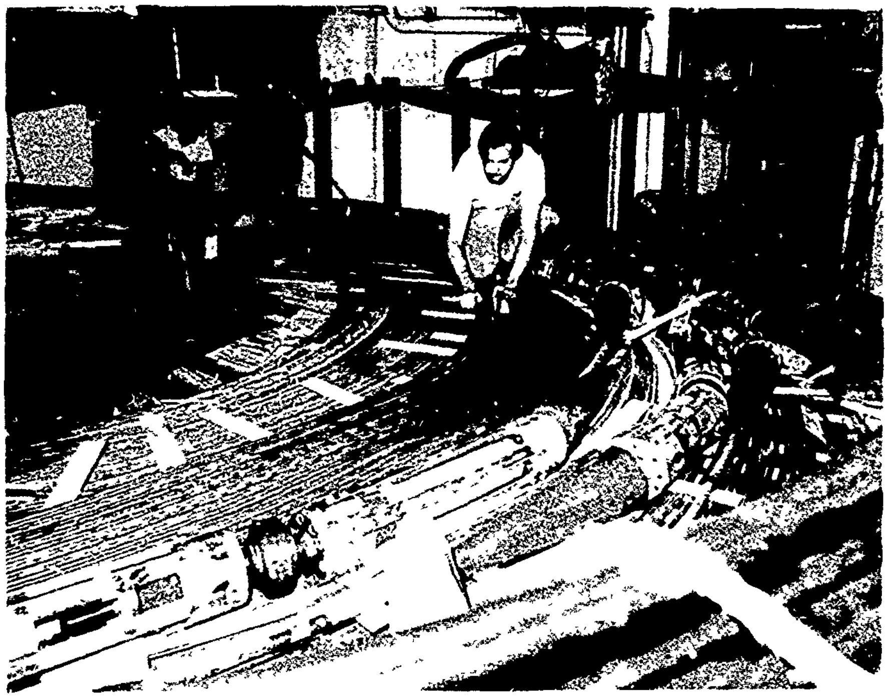
(U) Fig. 22—Computerized steering console on the *Naubuc*. The crew members are reading Decca Hi-Fix coordinates transmitted from Bermuda.

(U) Outfitting of the *Naubuc* mainly required the removal of special Colossus Project handling equipment from her deck and the installation of a special heavy-lift crane on her fantail to lift the Test Bed anchors over her stern.

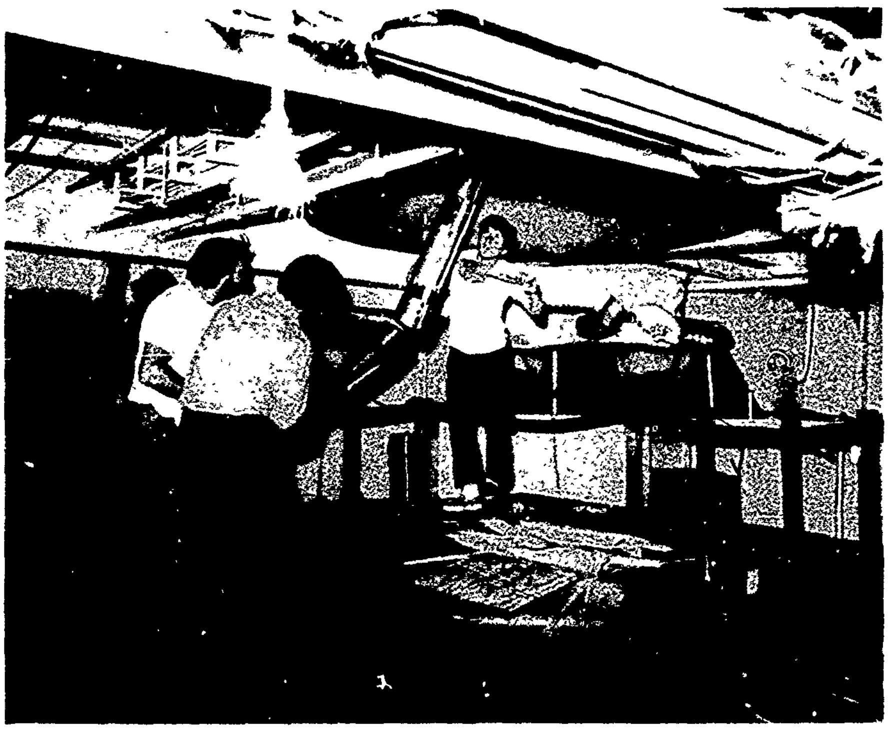
(U) Since the *Naubuc* was configured as a cable layer, there would be no problem deploying the 47 miles of 1-1/4-inch-diameter seabed cable. This cable could be coiled comfortably into her single tank. However, handling of the array cable which had been determined to be a double-armored cable required analysis by project personnel and consultation with those familiar with the operation of cable-laying machinery.

Cable Handling

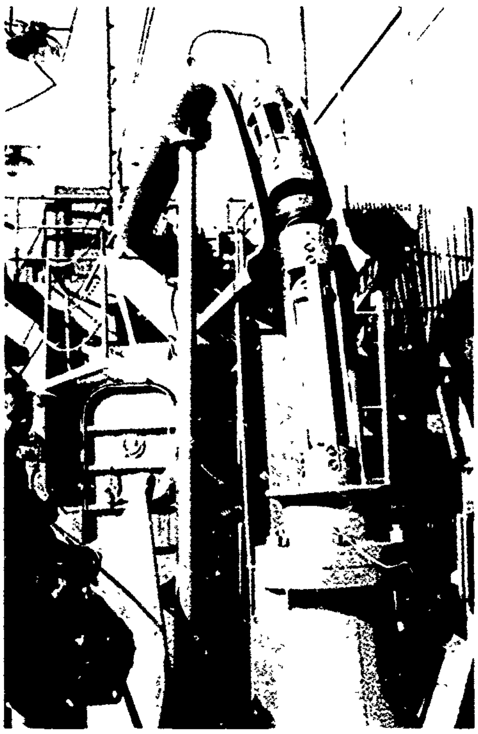
(U) The method of laying cable from the *Naubuc*, which deployed over the stern instead of the usual practice of laying over the bow, was as follows. The cable was coiled in counterclockwise fakes (loops free for running) in the cable tank, each tier separated from the one below by dunnage (Fig. 23a). As the cable was drawn out of the fakes upward through the bellmouth (Fig. 23b), it proceeded forward through a trough (Fig. 23c) to the draw-off and hold-back machine (Fig. 23d). From there it continued forward and passed around the cable drum (Fig. 10b), entering on the starboard side at the top (at the right in Fig. 10b) and leaving at the port side at the bottom, having completed 4-1/2 turns. The drum pulled on the cable, and the rubber-lined draw-off and hold-back machine worked against the drum, thus maintaining enough back tension on the cable so that friction



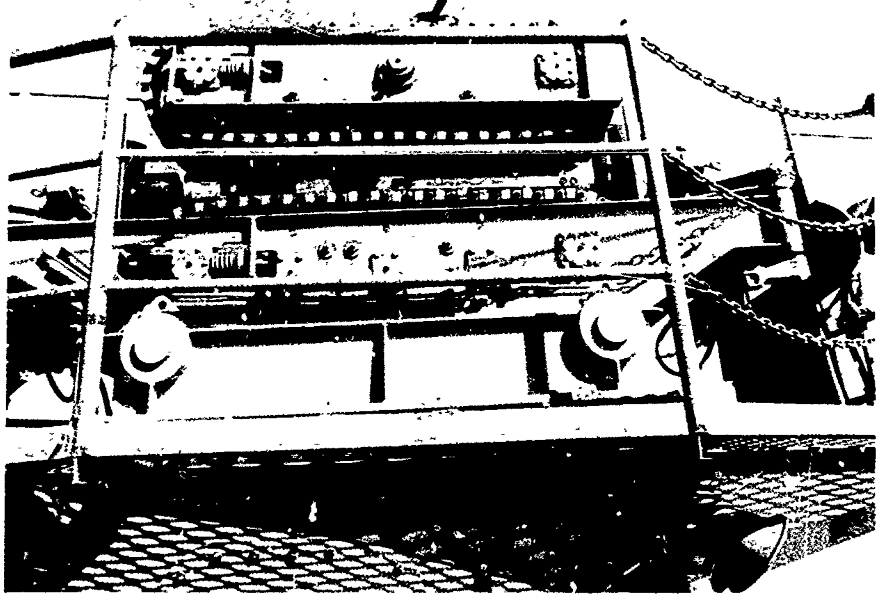
(U) Fig. 23a—Test Bed array coiled in cable tank. Some of the SD seabed cable is visible near the center under the dunnage.



(U) Fig. 23b—Test Bed array package being drawn upward through the bellmouth



(U) Fig. 23c—Test Bed array package passing up out of the bellmouth and onto the radiused trough



(U) Fig. 23d—Draw-off and hold-back machine prevented cable slippage. After leaving the drum, the cable travelled aft over the dynometer shoe (Fig. 23e) which measured the tension in the cable at that point, and finally over the radiused stern chute and into the water (Fig. 21).

(U) Between the dynamometer shoe and the stern chute, all other assemblages to the cable were made. For example the 1623 glass buoys and four current meters were hung onto the cable be:ween the shoe and the stern chute. Since the current-meter assemblies and particularly the instrument assemblies were heavy, the latter weighing 300 pounds, they were helped along by the deck crew (Fig. 23f) until they reached the stern chute.

(U) The deployment of the array at about 1 knot appeared optimum, since at that speed the cable was implanted expeditiously and yet its motion was slow enough for proper handling and inspection. Deck personnel could affix glass buoys to the array cable at payout speeds of a knot or so without difficulty. If a sphere was inadvertently omitted from the cable at the assembly position, which was just forward of the deck house, the deck supervisor had enough time to correct the deficiency because of the considerable distance to the stern chute. (In the Pacific Sea Spider implantment this distance was only about 40 feet, which was somewhat short for a 1-knot deployment.) This 1-knot speed is not a fundamental limitation in array deployment, but in the Test Bed and Pacific Sea Spider operations, wherein the systems were optimized by using existing hardware

(U) Fig. 23e—Test Bed array traveling aft after leaving the dynamometer shoe at the lower left. The radiused trough (Fig. 23c) is at the upper center, and a corner buoy (Fig. 11a) is at the right.

(U) Fig. 23f—Deck force manhandling instrument packages along the main deck during deployment. Under the packages are rubber pads.

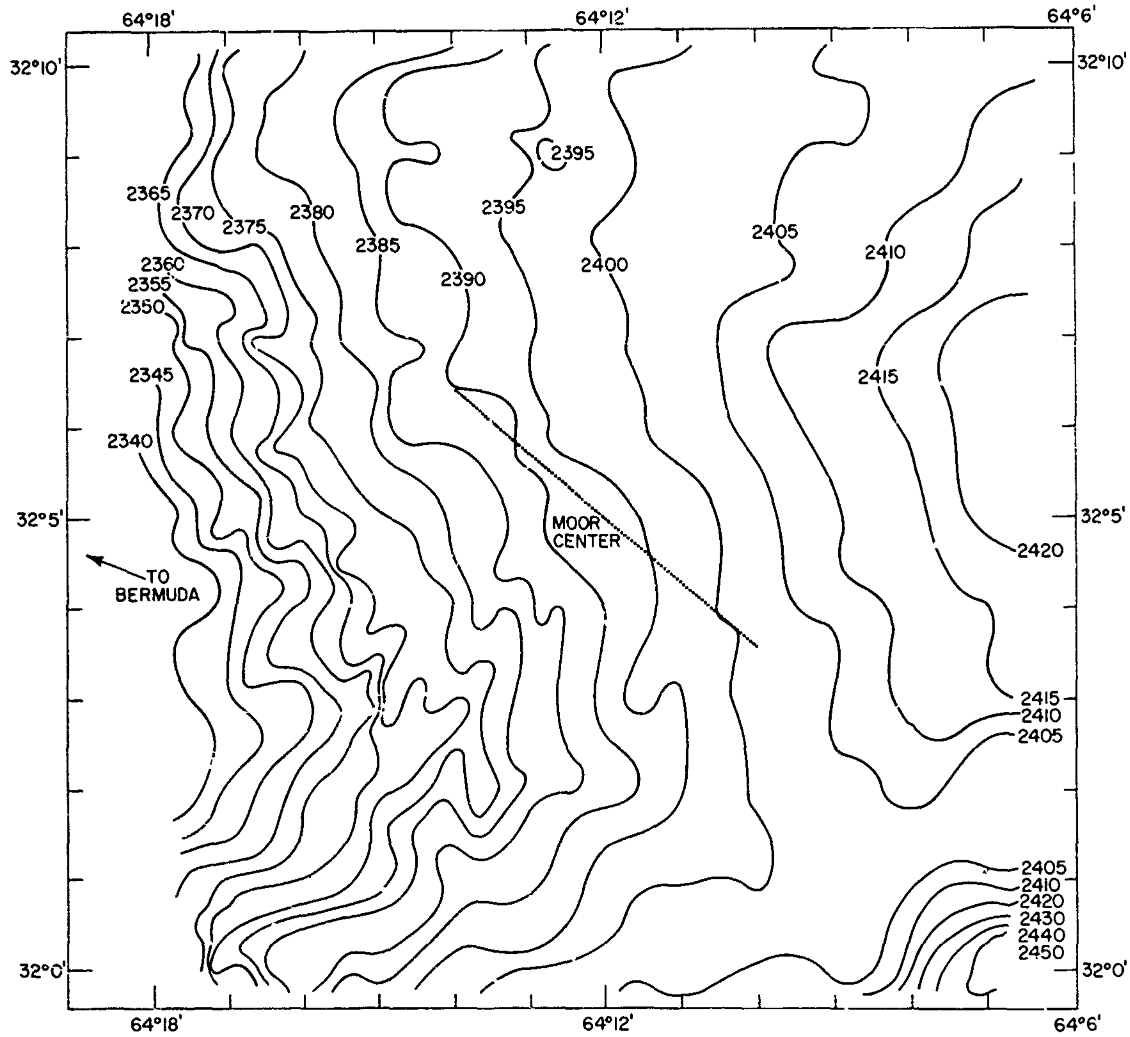
designs, machinery, and ships, higher payout speeds would have been foolhardy. In the Test Bed operation the seabed cable was laid at varying speeds from about 0.1 to 2 knots.

Bottom Survey

(U) To design the anchors and to work out the methodology for implanting the Test Bed, a fine-grain bottom survey of the selected site was necessary. This survey (Fig. 24) covered 100 square miles about the moor center. The results indicated a relatively smooth bottom topography which sloped as much as 1/2 degree shoreward. The water at the moor center was 14,370 feet deep.

Weather Reporting

(U) A weather forecaster as a team member of the project proved of much value. He was located at the Naval Air Station to maintain continual comprehensive interpretations of the various weather systems affecting Bermuda. (During the implantment of Pacific Sea Spider, 350 miles north of Hawaii, where weather forecasting was difficult, forecasts from Navy Weather Central in Pearl Harbor were out of phase with the weather by as much as a day. During the first implantment attempt in late August 1969, the implantment team relied upon weather information from Pearl Harbor. However, in the second



(U) Fig. 24—Topographic survey of the Test Bed site showing the position of the array (depths are given in fathoms)

attempt 6 weeks later, a weather forecaster who was familiar with project requirements accompanied the implantment vessels and compared the forecasting to the local weather.)

(U) The Test Bed was originally scheduled for implantment in August 1970, but was not installed until early December stemming mostly from procurement delays. Thus the winter weather system had displaced the summertime Bermuda high, causing a continual formation of frontal patterns in the area which provided weather windows lasting only a few days. After considering the tradeoff between the cost of failure and the cost of delaying until the return of the Bermuda high the following spring, the decision was made to implant the Test Bed during a weather window which began on November 30, 1970, and remained until the complete array was underwater. Though the array failed electrically 5 days later, there was no indication that the severe storm which closed the weather window was a cause of that failure.

Crew Training

(U) One advantage of using the *Naubuc* as the implantment vessel was the ability to berth her at the Naval Underwater Systems Center, New London, from the outset of the project so that she could be fitted properly into the overall systems concept. In addition to her modifications and outfitting, the crew could report aboard at intervals for readying her for sea and for the subsequent training exercises.

(U) For training, a special training array was built which simulated the various components of Test Bed in full scale with the exception of cable length. The training array was deployed repeatedly in Long Island Sound by each of the two watch sections. This training proved of great value during the Bermuda operation, when the only difficulties which did occur probably would not have been detected during a training exercise. The major difficulty was the formation of kinks in the double armored array cable, which was not a difficulty with the short training model.

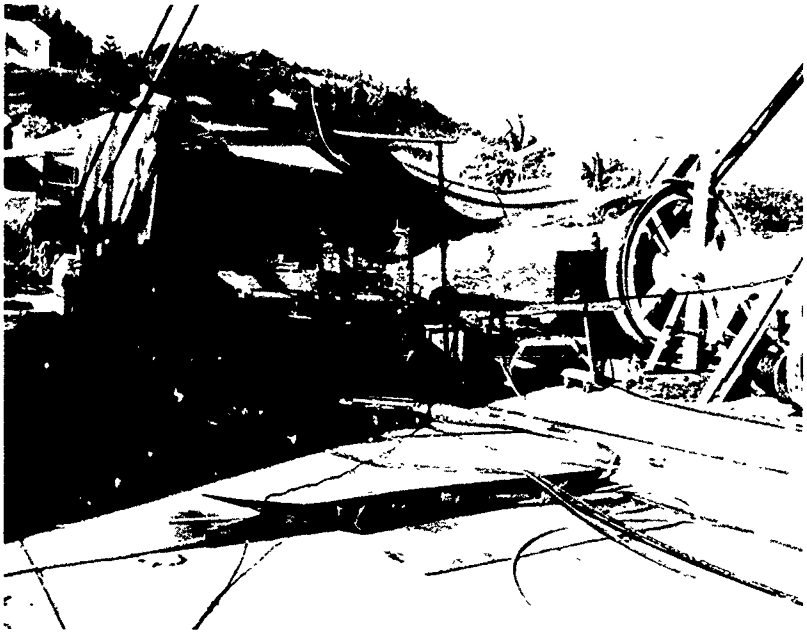
Implantment

(U) Because of project delays, incurred by the need for rebuilding the Test Bed array at DeBell and Richardson, it was decided to tow the *Naubuc* to Bermuda without the array, towing being less expensive than sailing her under her own power. This procedural change allowed preliminary navigation checks and the implantment of auxiliary moors, both of which minimized the delay.

(U) Upon repair, rebuilding, and retesting of the array it was coiled counterclockwise into a flatbed truck, which was rolled into a C-133 aircraft, and flown to Bermuda. At Bermuda the truckbed with the array was lightered (transported on a barge used in loading ships) from Kindley Air Force Base (now US Naval Air Station, Bermuda) to a loading pier at St. George, where the *Naubuc* came alongside to load the cable. The seaward end of the seabed cable, which had been loaded into the *Naubuc's* tank in New Hampshire, was brought from the cable tank to the barge, where it was spliced to the shoreward end of the Test Bed array cable. Splicing equipment was installed in a portable splice shack (Fig. 25a) on the barge. Upon electrical testing of the entire system the lengthy process of backhauling or loading of the array into the *Naubuc's* tank was begun (Fig. 25b).

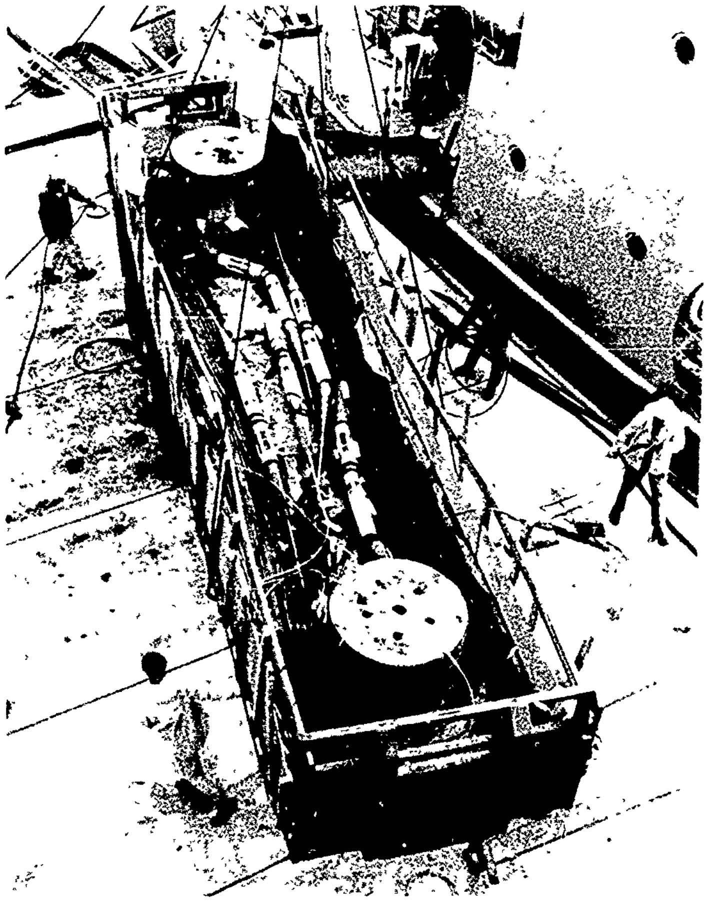
(U) Before half the inshore leg was uncoiled from the flatbed truck and coiled in the cable tank of the *Naubuc*, twists in the cable (Fig. 25c) required the disassembly of instrument cages to remove the twists and allow the cable to lay dead in the tank. Twenty-nine turns were removed from the 44,000 feet of array cable.

(U) The formation of multiple turns in the array was not detected until this time, though the cable had been handled three times previously: The cable was delivered to DeBell and Richardson on three cable reels. It was cut at prescribed lengths (always reeled off and not pulled off the reels axially); the instruments were connected, and the cable was coiled in an open tank, whereupon water testing indicated faulty instrument-package electrical penetrators. The instrumented cable system was rebuilt, coiled into the flatbed truck, and delivered by air to Bermuda.



(U) Fig. 25a—Splice shack located on the barge during array checkout and loading at Bermuda.

(U) Fig. 25b—Loading of the array cable at Bermuda



(U) Fig. 25c—Removal of twists in the array cable during loading into the *Naubuc*. The truck bed, supported by the crane, is being rotated.

(U) The foregoing details on cable handling have been included in this report as background for events which occurred during deployment of the Test Bed, which difficulties may have contributed to the electrical failure of the array 4 days after implantment.*

(U) On November 30, 1970, on the recommendation of the project meterologist, the *Naubuc* put to sea for the implantment of the Test Bed, and in the early afternoon of December 2 the implantment commenced with the lowering of the mushroom backing anchor against which the entire system was subsequently tensioned. Details of the Test Bed deployment plan are diagrammed in Appendix B; the salient features are as follows.

(U) The mushroom anchor, corrosive link, and chain (Fig. 1) were lowered with 31,000 feet of 1-5/8-inch-diameter braided nylon grapnel line without incident. Water was sprayed onto the cable drum and stern chute to prevent heating of the grapnel line, and no deterioration was observed even at payout speeds of 1 knot. Once the anchor was on

*"LRAPP Test Bed Array Cable Failure Analysis," TRW Systems Group, McLean, Va., May 14, 1971.

bottom, back tension was maintained in the grapnel lines to help place the offshore array anchor shackled to its shoreward end.

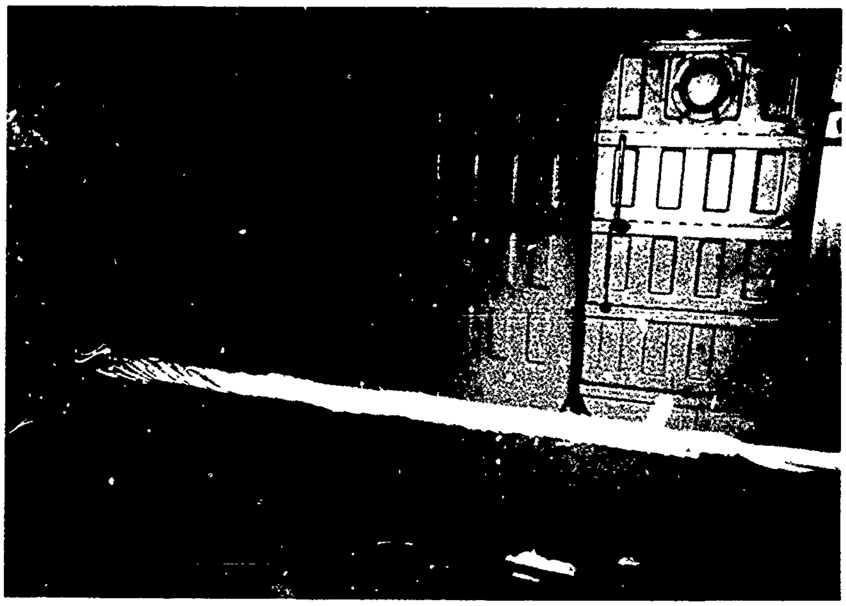
(U) Late that evening the offshore chain and anchor assembly was shackled onto the array and lowered by the double-armored array cable. (In the connecting of all shackles in the system, the threads were locked by applying weld rather than by seizing them with wire, since seizing wire might have snagged or chafed as the cable was passed over the stern.) No difficulties were encountered in handling the cable through the draw-off and hold-back machine and the cable drum. In addition, the hardened-steel stern chute (Fig. 21) did not groove substantially, which deterioration would have torn the polyethylene-jacketed seabed cable, which was deployed following the array.

(U) As the array cable was payed out, it tended to stiffen in the vicinity of the sensor assemblies. Near the third sensor station, after the deployment of 3000 feet of cable, a kink occurred in the armor as the cable passed upward through the deck bellmouth. This kink was straightened and stiffened with preformed cable grips (Fig. 26a), and since there was no apparent mechanical or electrical deterioration, the cable was again payed out. Early the following morning, after paying out most of the offshore leg, a short circuit between the center conductor and the shield was observed, estimated to be near the kink.

(U) The decision was to continue deploying cable after electrically isolating the cable already payed out. The offshore leg was redundant with the inshore leg, and it was estimated that if the cable were retrieved for repair the weather window would close and the implantment would be postponed at least until the following spring. Subsequently the offshore syntactic-foam tensioning buoy was implanted without difficulty by leading its wire-rope pendant and the accompanying nylon shock chord around the port side of the ship and bending the shackled end to the thrust collar at the upper seaward corner of the array. Thereupon the buoy was launched from its mounting skids (Fig. 11a). Early that evening a second kink occurred at sensor assembly E5 in Fig. 3. Since no deterioration was noted, the kink (Fig. 26b) was strain-relieved and cable deployment continued.

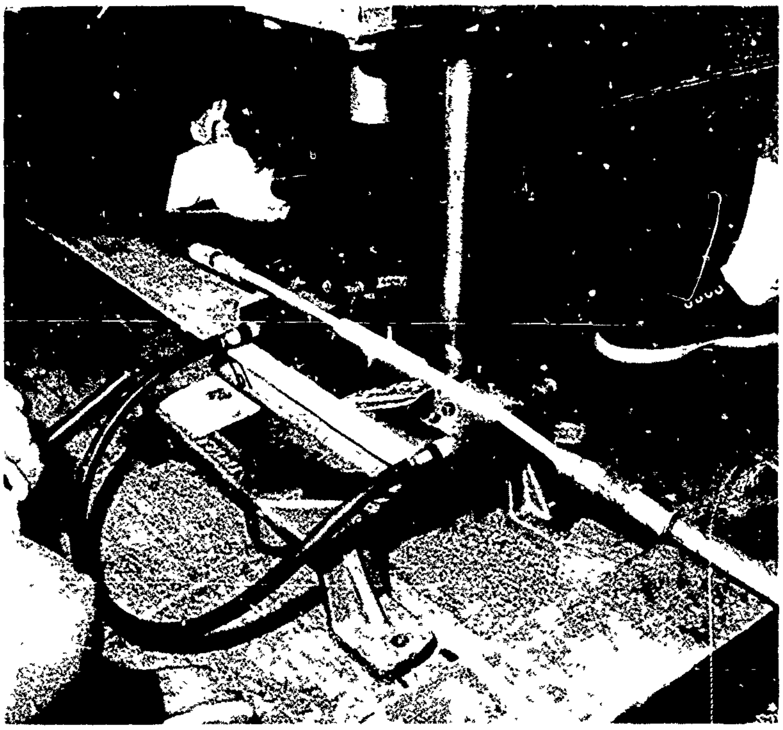
(U) At about 8 p.m. on December 3, the second buoy was deployed in the same manner as the first without incident and the payout of the inshore riser leg begun. However, later that evening a third kink developed between the cable tank and the draw-off and hold-back machine which required that the damaged area be cut out and mold spliced (Fig. 26c). The severed armor was then bridged with a 13-foot length of preformed grip, which in addition was strain relieved with a 1/2-inch-diameter wire-rope preventer. This repair task required a half day, and it was not until early afternoon on December 4 that the inshore anchor assembly and the cable driver were deployed. By that time the project had exhausted the fair weather.

(U) The seabed cable was payed out without incident, and the inshore anchor was set down late that evening in the midst of a gale. The ability of the vessel to maintain station on a preferred heading proved the value of the *Naubuc* and her specially trained crew. By that time it was not practicable to bend-on the inshore backing chain which was to be placed 4 miles shoreward of the inshore main anchor because of the adverse weather and concern for the safety of the ship and the moor. Therefore it was decided to rely on the holding power of the seabed cable, of which the first 4 miles were slowly laid without slack.



(U) Fig. 26a—Preformed cable grip used to stiffen the first kink formed during array deployment

(U) Fig. 26b—The second kink formed during deployment of the Test Bed array



(U) Fig. 26c—In-line splice, necessitated by the third kink, is removed from the mold

(U) After daylight, the gales, which reached about 50 knots intensity during the night, moderated. The following morning the vessel reached the position for splicing to the shore cable. Final electrical tests were performed, and the cable was cut, lowered to the bottom, and buoyed off. It was not until December 10, five days later, that the weather permitted the connection of the shore and sea cables.

(U) Within 1/2 hour of the completion of that 5-hour splicing operation, the array electrical cable deteriorated, and within 1 hour was completely short circuited between center conductor and the sea. This short was subsequently analyzed by two independent groups using differing techniques and estimated to be about 1/3 of the distance up the inshore leg.

Summary and Recommendation

(U) The USNS *Naubuc*, a specially configured cable layer, proved suitable for the combined operations of implanting the Test Bed array and laying the seabed cable to Bermuda. Because of her automatic and precise navigating and maneuvering capability she was able to complete the operation in storm conditions.

(U) The double-armored array cable was observed to kink during its deployment. Three of these kinks required the application of either strain relief or cable-straightening preformed grips; one of the three kinks was cut out and electrically spliced. Because of these cable difficulties and diagnosis of the problem, it is recommended that helically armored cables be handled only from reels under back tension and not laid into cable tanks. Though conclusive proof has not been presented yet, it appears that the torque properties of such armored cable vary when handled and coiled in a slack condition. This change is believed to occur from relative shifting of the inner and outer armor.

(U) The electrical fault with the array has been located, but the nature of its occurrence has not been diagnosed. The moor has remained in its installed configuration and position, but it is expected that it will eventually be retrieved. Upon such retrieval much valuable information will be obtained from the environmental effects upon it.

APPENDIX A (Unclassified)
ENGINEERING TEST PLAN OBJECTIVES
(As outlined by the Naval Underwater Systems Center, New London Laboratory)

PHASE I—IMPLANTMENT

Objective: Support the Test Bed Installation.
Approach: Provide real-time tension, inclination, and depth information to assist the implantment director in carrying out installation procedures.

Objective: Evaluate sensor performance.
Approach: Record sensor output data and verify that the sensors are operating properly.

Objective: Provide data for future analysis of the dynamic behavior of the array during installation.
Approach: Record all sensor outputs continuously and in such form that a future analysis of dynamic behavior can be performed.

PHASE II—ENGINEERING EXPERIMENTS

Engineering-Sensor Performance

Objective: Evaluate engineering-sensor performance and accuracy for adequately describing the array configuration and verify the accuracy of the assumptions used in analytical prediction models.
Approach: Using various combinations of sensor output data and current data in the available analytical models, generate a series of predicted array configurations and compare them to the configuration as determined by the acoustic beacon.

Objective: Optimize the sensor types and distribution for future arrays.
Approach: Use configuration comparison results to determine which sensors provide the most consistently reliable information. Collect data on individual sensor stability and reliability over the lifetime of the Test Bed.

Array Motion

Objective: Determine the short-term periodic motion of the array about the static equilibrium configuration.

Approach: With the existing current profile, measure the sensor output variations and correlate them with measured current variations to determine the extent of array oscillation about equilibrium. Compare the motions obtained by sensor readings with the motions obtained using the acoustic beacon.

Objective: Determine the array response to large-scale variations in current structure.

Approach: When large variations occur in the current profile, measure the array motion with both the sensors and with the acoustic beacon and compare the results. Use this information to predict response times of future arrays and to aid in developing dynamic prediction models.

Current Structure

Objective: Determine the accuracy with which the current sensors on the array measure the existing current profiles.

Approach: Install a separate self-contained vertical array of current sensors in the vicinity of the Test Bed to measure current profiles as accurately as possible. Compare the results with the Test Bed sensors.

Objective: Measure vertical and horizontal current profiles to obtain long-term data for correlation with tidal, diurnal, seasonal, and meteorological variations.

Approach: Record the sensor outputs continually.

Flow-Excited Motions

Objective: Determine the flow-induced cable motions and verify the accuracy with which present analytical techniques and assumptions can predict cable vibrations from a knowledge of the current structure.

Approach: Determine the frequencies of the biaxial cable vibration and compare them to the analytical values predicted by existing current or flow conditions.

Array Noise

Objective: Determine the extent to which cable vibrations introduce noise into the acoustic sensors.

Approach: Compare the biaxial frequencies of the accelerometer outputs and compare them to any observed line spectra at the hydrophone outputs.

APPENDIX B (Confidential)
PRELIMINARY DIRECTIONAL DIAGRAMS FOR THE DEPLOYMENT

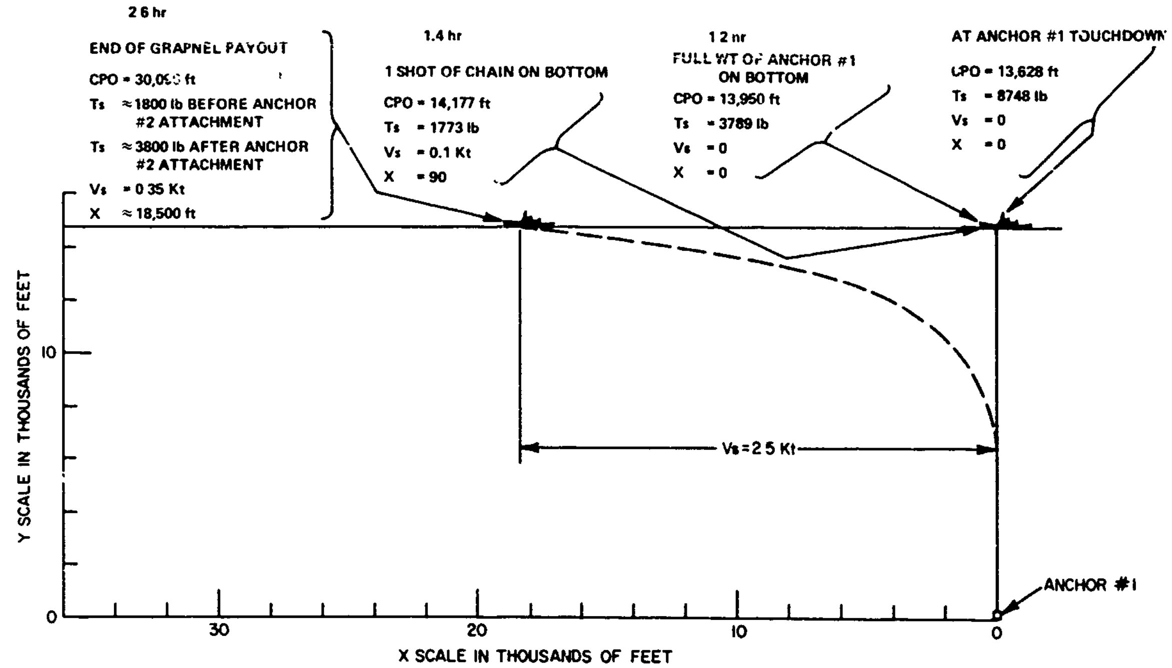
(U) In preparation for the project, the Naval Underwater Systems Center, New London Laboratory made a preliminary analysis for the implantment. Reproduced here are five diagrams that resulted from that analysis. Symbols and abbreviations used in the diagrams are as follows:

CPO = cable payed out

TS = cable tension at the ship

VS = velocity of the ship

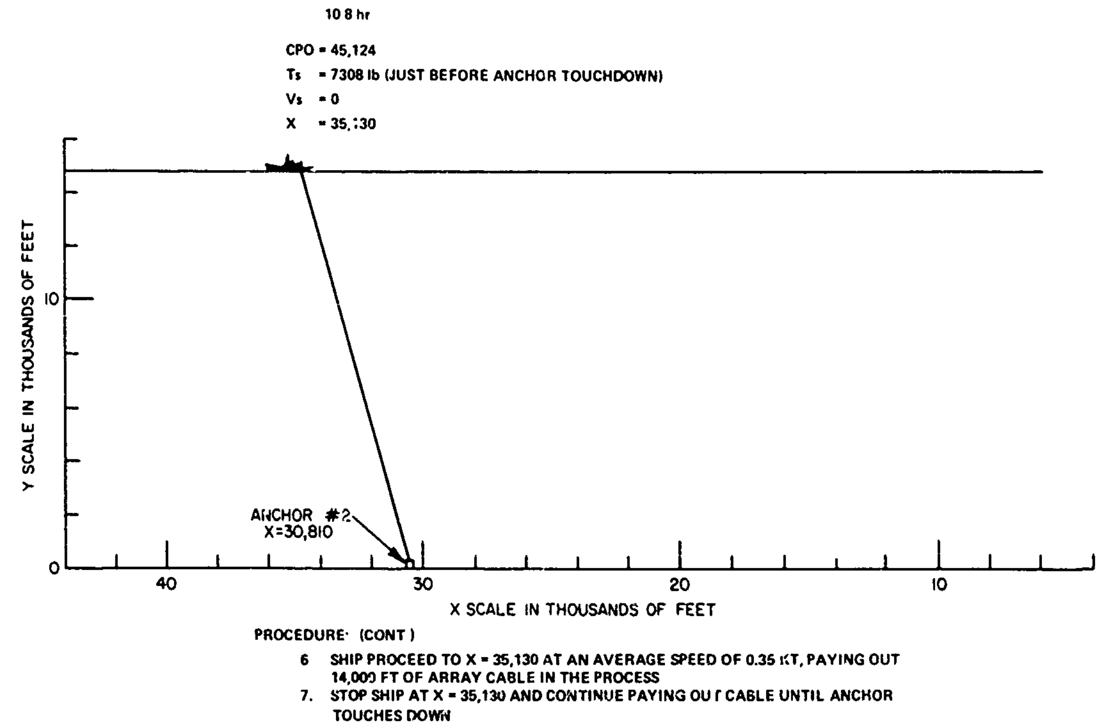
KT = knot



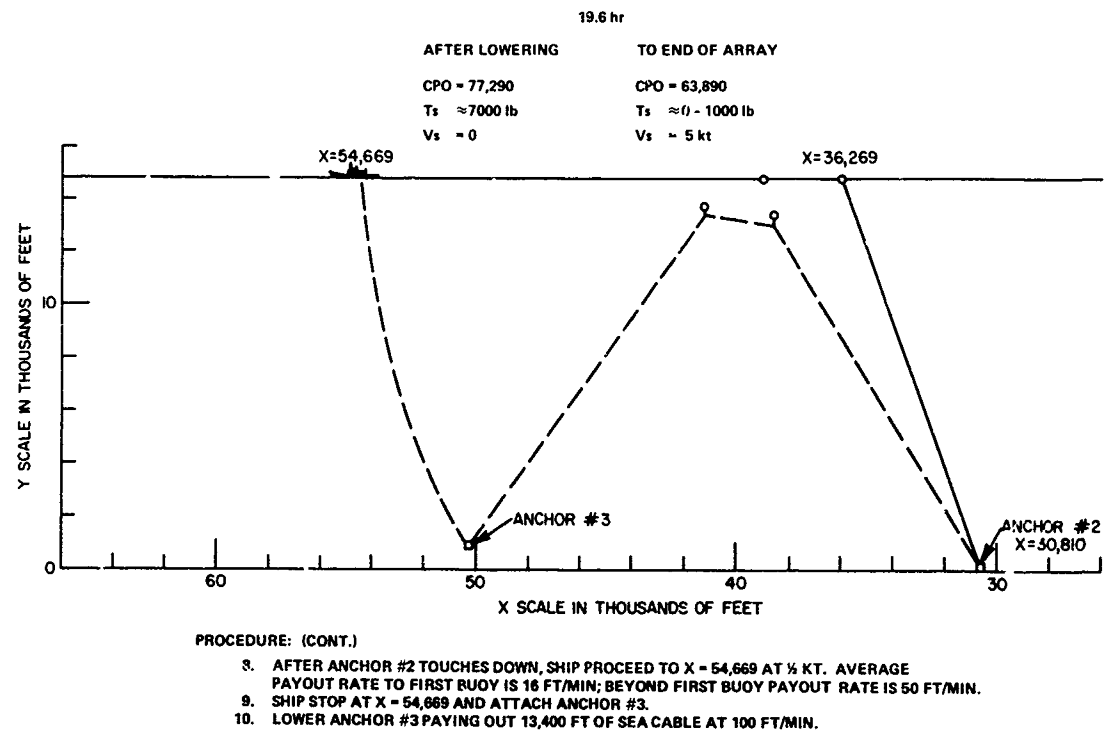
PROCEDURE:

1. POSITION SHIP AT X = 0 AND LOWER ANCHOR #1 AND CHAIN AT 200 FT/MIN
2. ANCHOR WILL TOUCHDOWN WHEN CPO = 13,628. AN ADDITIONAL 322 FT OF CABLE WILL BE PAYED OUT TO FIRMLY SET ANCHOR ON BOTTOM.
3. SHIP PROCEED AT 0 1 Kt to X = 90 PAYING OUT 327 FT OF CABLE IN THE PROCESS.
4. SHIP PROCEED TO X ≈ 18,500 AT 2.5 KT, PAYING GRAPNEL AT Ts ≈ 1800 LB.
5. AT X ≈ 18,500 REDUCE SHIP'S SPEED TO 0.35 Kt, STOP PAYOUT AND ATTACH ANCHOR #2.

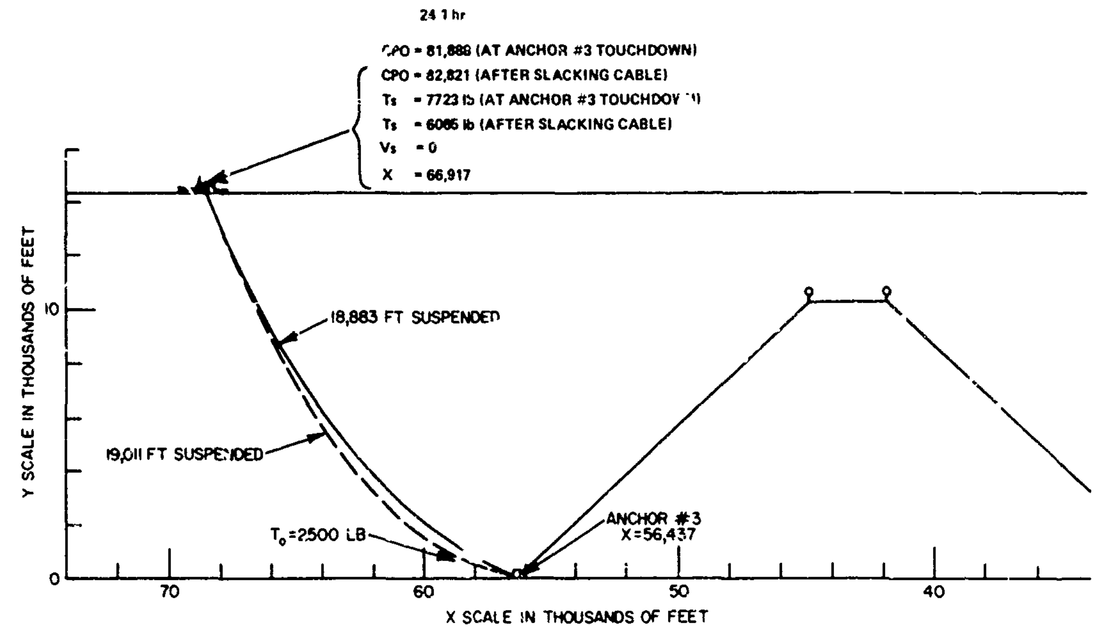
(C) Fig. B1—Touchdown of anchor 1



(C) Fig. B2—Touchdown of anchor 2



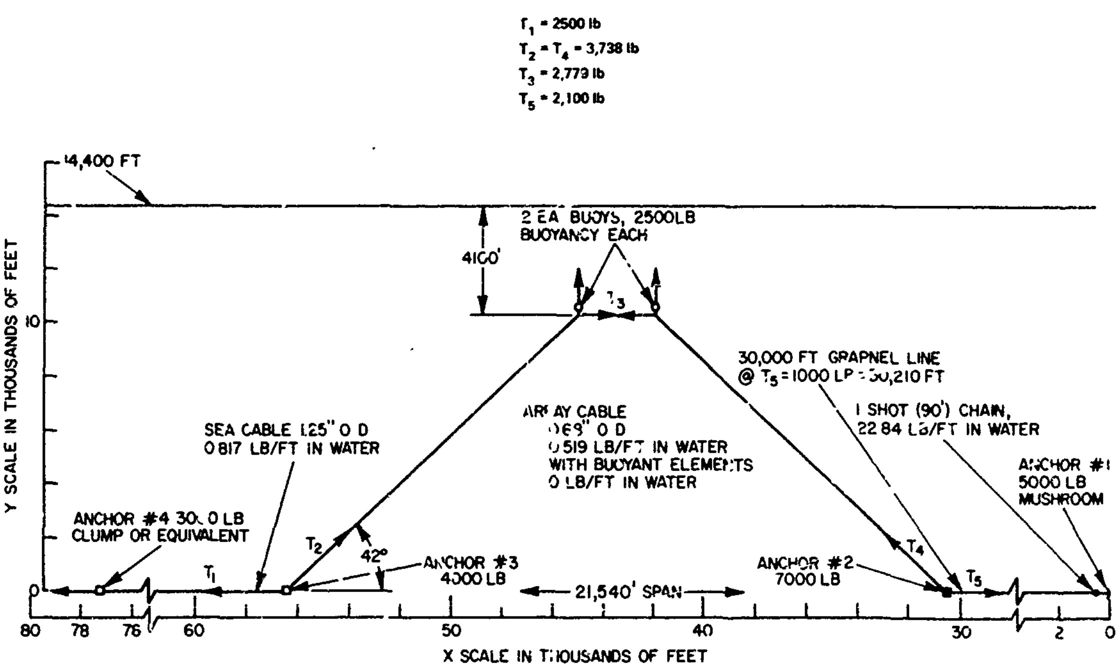
(C) Fig. B3—Lowering of anchor 3



PROCEDURE (CONT.)

11. SHIP PROCEED FROM X = 54,669 TO X = 66,917 AT ½ Kt, NOT PAYING OUT CABLE
12. STOP SHIP AT X = 54,669 AND PAY OUT 4598 FT OF CABLE WHEN ANCHOR #3 TOUCHES DOWN
13. PAY OUT AN ADDITIONAL 933 FT OF CABLE.
14. SHIP ATTACH #4 ANCHOR SYSTEM AND PROCEED TOWARD THE SHORE LAYING CABLE WITH T_0 = 1500 - 2000 LB UNTIL THIS FINAL ANCHOR HAS BOTTOMED. SHIP CONTINUE TOWARD SHORE LAYING CABLE AT PROPER RATE TO BE DETERMINED ON SCENE

(C) Fig. B4—Touchdown of anchor 3



(C) Fig. B5—Final configuration

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13 ABSTRACT

The LRAPP (Long-Range Acoustic Propagation Project) Test Bed represented the first successful deep-ocean implantment of an instrumented stable suspended array. Though the array short-circuited 5 days after implantment, 14 months later acoustic means verified it to be in the installed position. The Test Bed was an instrumented, tensioned structural system composed of many general-purpose marine components and subsystems, but its overall design concept was a system comprising three major subsystems: the hydromechanical subsystem, the sensor and electronic subsystem, and the implantment subsystem. In optimizing the system, compromises were required in the subsystems because of schedule limitations, available funding, and restriction to existing technology. The first two of these limitations were clearly required, but the restriction to existing technology is not always so clear. Whereas the subsystems and components of the Test Bed appeared to be within the bounds of technology and were satisfactorily tested ashore, a fully successful installation was not forthcoming without incorporating technological gains. This report discusses the technology used in the Test Bed and identifies the areas wherein technological gains either have since been made or need to be implemented. Successful implantments in the deep ocean can be achieved by designing lightweight structures and performing research and development of such moors from the systems viewpoint.

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LRAPP Test Bed						
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WHOI-72-87	Daubin, S. C., et al.	THE ACODAC SYSTEM	Woods Hole Oceanographic Institution	721101	AD0756628; ND	U
NRLR7516	Fleming, H. S., et al.	PROJECT NEAT 1 ENVIRONMENTAL DATA REPORT (U) (USNS J.W. GIBBS)	Naval Research Laboratory	721129	NS; ND AD523746	U