DEVELOPMENT OF A FIXED, PERMANENT MOORING SYSTEM ON THE PINNACLE OF COBB SEAMOUNT

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DEVELOPMENT OF A FIXED, PERMANENT MOORING SYSTEM ON THE PINNACLE OF COBB SEAMOUNT

FINAL REPORT
BY THE
OCEANOGRAPHIC INSTITUTE OF WASHINGTON

25 April 1971

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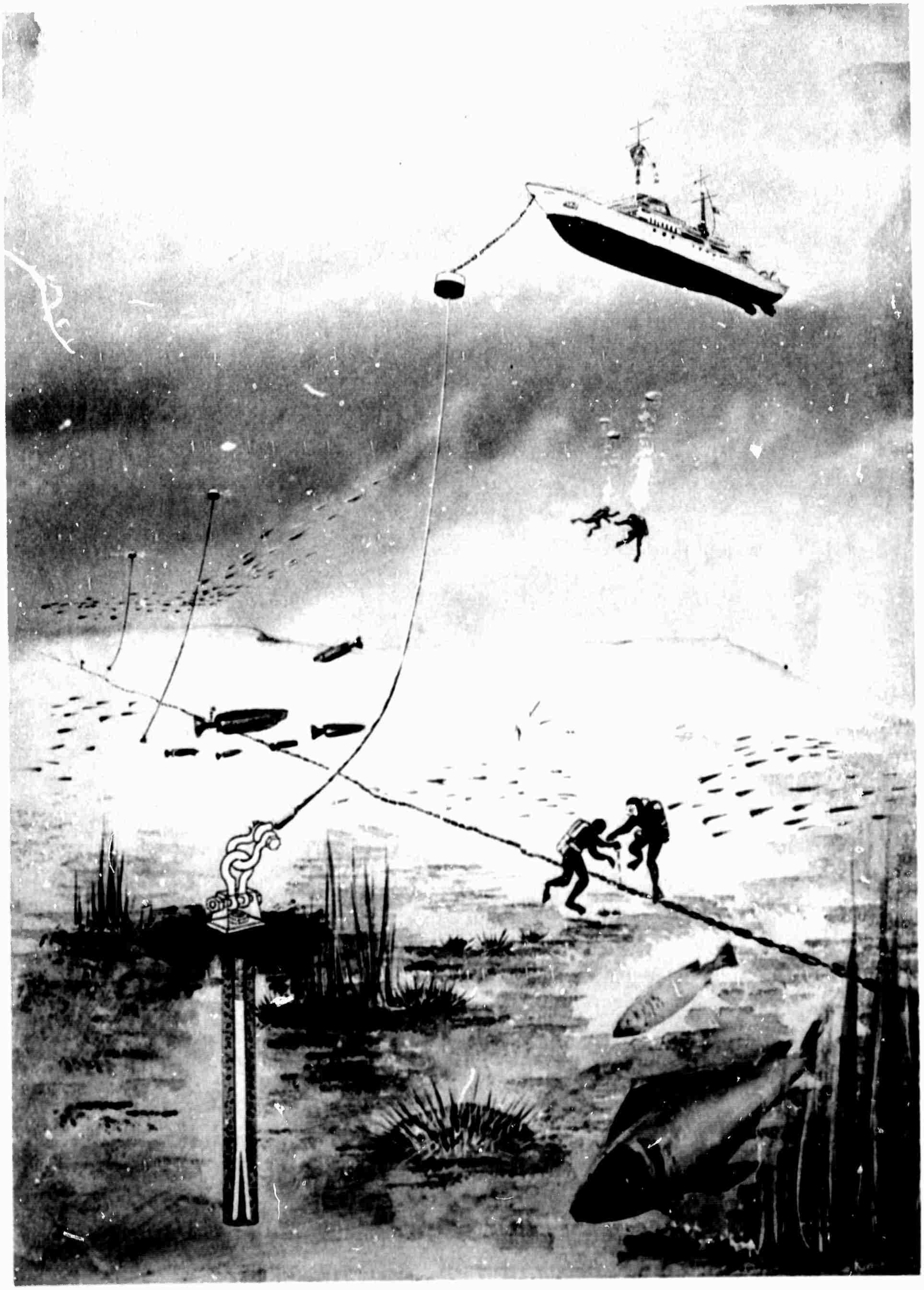

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THE OCEANOGRAPHIC COMMISSION OF WASHINGTON

Washington State Senate Bill 49, Chapter 243, Laws of 1967 (RCW 43.94.020) created the Oceanographic Commission of Washington (OCW). An independent agency, the OCW is composed of twelve commissioners representing the state legislature and administration, industry, labor and education. A permanent staff of four state employees administers the functions of this agency. The OCW is an advisory, promotional, coordinating organization with no regulatory powers and responds directly to the legislature of the state.

THE OCEANOGRAPHIC INSTITUTE OF WASHINGTON

The same legislation which created the OCW also permitted that body to incorporate an action arm to be known as the Oceanographic Institute of Washington (OIW). The OIW is a non-profit, tax-exempt research and educational corporation, incorporated in the state of Washington and King County. RCW 43.94.020 further requires that all members of the Commission must serve as Trustees to the corporation and that they may elect not less than one or more than eight additional members to the Board of Trustees. At the present time the OCW permanent staff additionally provides the entire administrative as well as some of the action support to the OIW. At the present time there are nineteen Trustees, a number of whom are scientists from several academic and industrial organizations.

HISTORY OF THE SEA USE PROGRAM

Cobb Seamount is an extinct volcanic mountain rising from an ocean floor 9000 feet deep, with an 18-mile diameter base, approximately 270 miles due west of Grays Harbor, Washington, at 46°45'N latitude and 130°50' W longitude. It is of conical shape, rising through a series of terraces to finial basalt plug--steep-walled, flat-topped, coming within 120 feet of the surface. The surface area of this plug, at 120 feet, is approximately 850 x 550 yards.

Discovered in 1950 by the Bureau of Commercial Fisheries Research Vessel, JOHN N. COBB, the underwater mountain had been the scene of several one-shot, uncorrelated explorations of the University of Washington, Oregon State University, NOAA (then ESSA) and the National Marine Fisheries Service (then BCF). Various Canadian institutions had also conducted observations there. In April 1968, the Oceanographic Commission of Washington was approached by a group consisting of Battelle Northwest, the University of Washington, Honeywell Marine Systems and the Oceanic Foundation of Hawaii, to sponsor a continuing program of scientific exploration of Cobb. The Commission agreed to do so and the SEA USE Program was thus initiated.

Within the first six months it became obvious that major funding for a large-scale assault upon the objective would not soon be forthcoming, so the earlier, ambitiously planned operations were set aside and more modest attempts were programmed, using donated services and equipment from the expanding number of participants. Thus in October 1968, the first expedition under the SEA USE Program was mounted in NOAA's OCEANOGRAPHER and was to be limited to scuba diver reconnaissance of the pinnacle for purposes of bathymetry, and an attempt was to be made to locate some NOAA instrumentation left there the previous year. While this operation aborted early due to increasingly deteriorating weather, a start was made on developing badly needed information on the surface of the pinnacle.

In August 1969, a more ambitious expedition was mounted in USCGC IVY from Astoria, Oregon. Many of the same divers were involved, thus giving a slight advantage in terms of familiarity, and most of them were retained for the 1970 efforts. Three underwater transmitting beacons were stapled to the pinnacle as was a surge meter developed by the Nereus Corp., the latter in an attempt to measure and record the severity of forces exerted upon the pinnacle during coming winter storms. Additionally, an attempt was made at gaining a toe-hold on the mountain by implanting an explosive anchor developed by the Naval Civil Engineering Laboratory, Port Hueneme, California. The basaltic composition of the pinnacle was so hard that the anchor blade made only slight penetration at an oblique angle, and the blade itself suffered a series of hairline cracks, so that shortly after, while IVY was riding at that anchor in mounting seas, a portion of the blade sheared off, and the remainder of the anchor pulled free. Finally, during that operation, the scuba divers conducted further reconnaissance to improve bathymetric data, and a small beginning at recording the operations through underwater color photography was made. The failure of the explosive anchor emphasized the need for the development of a permanent mooring system of Cobb to increase chances of success in ongoing operations. This led to an immediate review of techniques, industrial capabilities and prices for the mooring system which was envisaged, and ultimate application was made on 26 March 1970 to the Advanced Research Projects Agency for funds to develop a fixed, permanent mooring system.

Early in May 1970 the third SEA USE expedition arrived at Cobb, mounted in USCGC CACTUS. This operation was aimed at recovery of the instrumentation implanted the preceding summer. Although hampered initially by a prolific plankton bloom which seriously impaired underwater visibility, conditions improved toward the end of the on-station time, and the mission was successfully accomplished. Unfortunately, all three underwater beacons and the surge meter were badly damaged by what were believed to be the nets of foreign trawlers, the meter so seriously that no useful data was obtained from it. None of the instruments were in their original positions, and the meter had been completely pulled free from its holding staples. This indicated why other instrumentation placed at Cobb in previous years was never found.

Nonetheless, the experience gained from the foregoing operations provided the experience and tactical expertise which resulted in the success of the rock coring and anchor bolt implants, which were funded by this contract. Improved bathymetric and photographic pictures were obtained, making it possible to predetermine the optimum locations for the anchor bolt emplacements.

As the operations which have just been described were being conducted over the period from 1968 to 1970, the organisation for planning and executing the assaults upon Cobb was evolving. By the end of 1968, it was apparent that this particular seamount held significant regional interest, and that the region should have a voice in the goals and methods of achieving these goals. Action was initiated by the Oceanographic Commission of Washington to develop a body to determine the long-range program, the group later becoming known as the SEA USE

Council. Delegates, each holding his appointment from his respective governor, were named to the Council from Oregon, Alaska, Hawaii and Washington. At about the same time the Secretary of the Navy, the Commandant of the Coast Guard and the Administrator of NOAA (the Director of ESSA) each named an official delegate. The Council has functioned ably in this manner ever since, and thus the Commission withdrew from the actual involvement other than to support operations financially and with administrative assistance, leaving the operations management to its action arm, the Oceanographic Institute of Washington. The Council and Institute have been assisted by a Scientific and Technical Board, largely drawn from participating organizations, and a Planning Committee, whose membership fluctuates and is comprised of representatives from those organizations directly involved in any particular expedition.

The success of the permanent mooring system conducted under this contract enables continuing planning for the long-range objectives envisioned by the SEA USE Council. Most immediately efforts will be concentrated on the design of an instrumented mast, followed by its erection at Cobb, after which such projects as an observation platform and an underwater laboratory will be reviewed.

ANALYSIS OF IMPLANT OF ROCK BOLTS ON COBB SEAMOUNT

Military Application

- Ultra-stable positioning for surface platforms in shallow water
- Fundamental to seamount occupation, surface and sub-surface
- New surveillance sensor embedment capability
- Provides toe-hold for ongoing projects having future military applications

Experimental Uniqueness

- Never done before
- Shallow, unstable sea state
- Unusually hard base material and no sediment overburdens
- Excellent test recording possible

SUMMARY OF RESULTS AND FUTURE IMPLICATIONS

The operation at Cobb Seamount was successful from the point of view of the results desired by the Oceanographic Institute of Washington as well as results sought for the Department of Defense. Three rock bolts were implanted on the pinnacle of Cobb, and one rock bolt was tested to failure. (Details covering the installation of the rock bolts are contained in Appendix I.) Specifically, however, the results are:

1. Retrieval of three oriented cores approximately 55 inches long by 2-1/8 inches and one oriented core 24 inches by 2-1/8 inches from the basalt pinnacle of Cobb Seamount. These cores are being analyzed by the expedition's geologist, Dr. David Pavear, at Western Washington State College.

2. Implantment of three anchor bolt assemblies in the core holes. Each of the rock bolts was inserted to a depth of approximately 55 inches and grouted into place. The foot of the first bolt was not separated; however, the foot of the second bolt was separated ¼ inch and that of the third was separated 3/8 inch (see Figure 1).

3. Information relating to the effort required to drill cores in basalt. The average penetration rate for the diamond bit was approximately one inch/minute at 120 rpm with 2000 pounds of vertical force, and 75 foot pounds of torque on the bit.

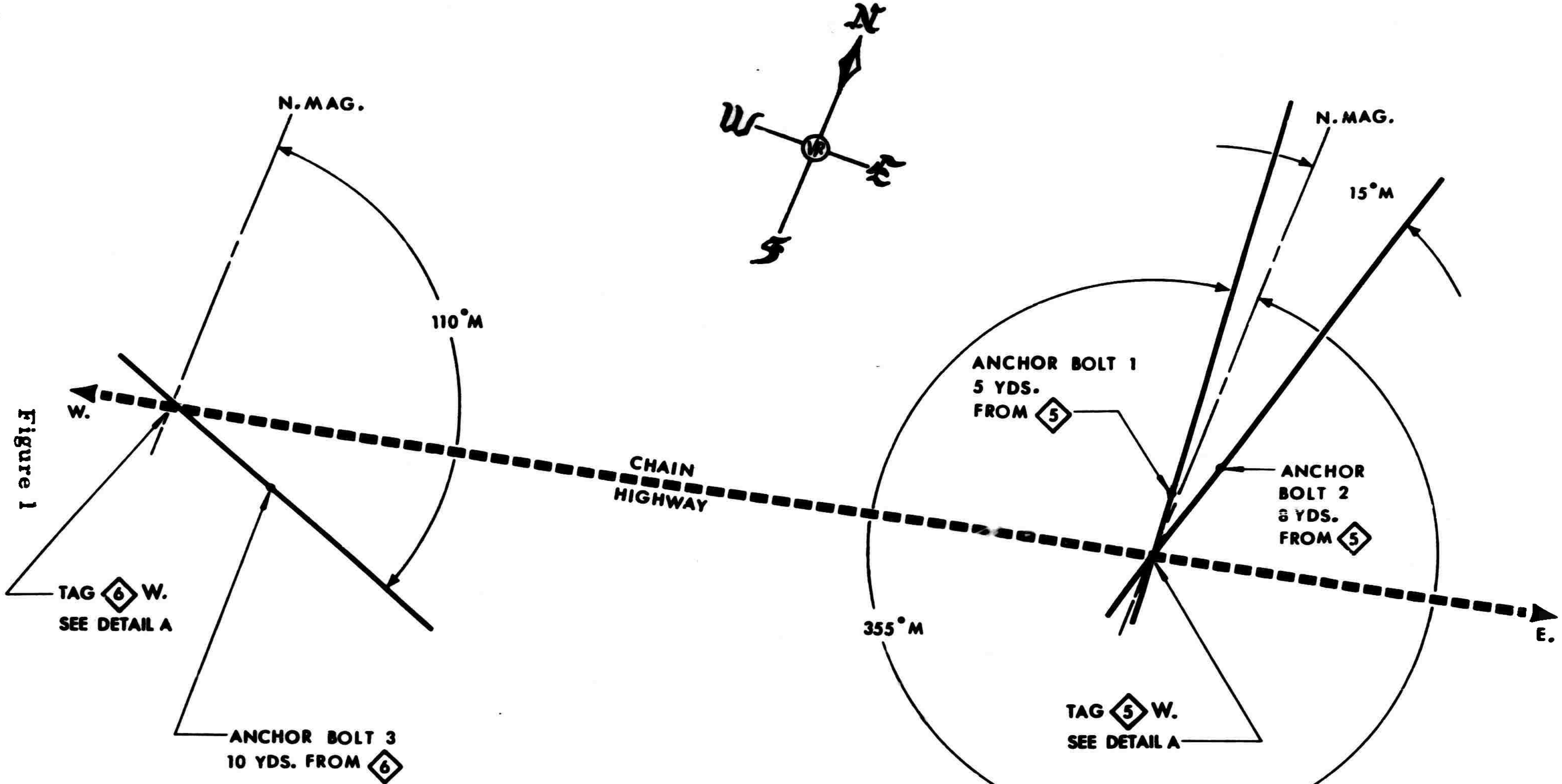
4. A permanent toe-hold for mooring on Cobb's pinnacle, thus facilitating future operations.

In testing the bolts to failure (see Appendix II for specific information) the following results were obtained:

1. Failure of the moorage between the rock bolt and the grout.

2. A non-creep load of the tested moorage about 20 tons, the ultimate load about 110 tons, the yield load about 50 tons, and safe load about 35 tons, and the system modulus of deformation at 2×10^5 psi. These load strengths were based on vertical pull.

3. The possibility of applications to a wide variety of bottom conditions, including soft rock beds through this system and method.



ENGINEER		NORTHWEST DIVING INST. 11522-21ST NE BELLEVUE WASH. 98004
APPROVED		
DRAWING Vince Rainier	2-26-71	TITLE ANCHOR ROCK BOLT POSITION
DRAWING NO. 12-00-03	4 HAS.	

Figure 1

In addition to the foregoing, extensive motion picture coverage of the entire operation was obtained, using 16 mm color film.

The most immediate implication with respect to Cobb is the gaining of a permanent mooring which may be used by any group or organization. Repeatedly past anchoring efforts were hampered by being dependent upon clumps or ships' anchors, most of the latter failing to hold or else, having lodged in a crevice, were sacrificed to the operation. Conducting diving operations directly from a free floating platform was either hazardous or impossible; however, this problem was solved by the permanent moors. With respect to the SEA USE operations, the moors not only provide this toe-hold, they also can be used for marker or instrumented buoy moors, and the failure tests are being employed in the design criteria for guying and anchoring an instrumented mast, which is the next logical step in developing Cobb as a national seamount station. Any and all of the foregoing are available for use by the Department of Defense as their needs may require.

The mooring techniques as they are developed, particularly if improved upon as indicated in the section of this report covering recommendations, should prove to be useful to the Department of Defense in all types of rocky bottoms in that they would:

1. Improve moored bottom-lay fueling lines and buoys

2. Facilitate amphibious assault over the beach

3. Provide berthing for close support vessels

4. Provide a holding point or mooring system for all types of approaches to oceanography through ocean engineering

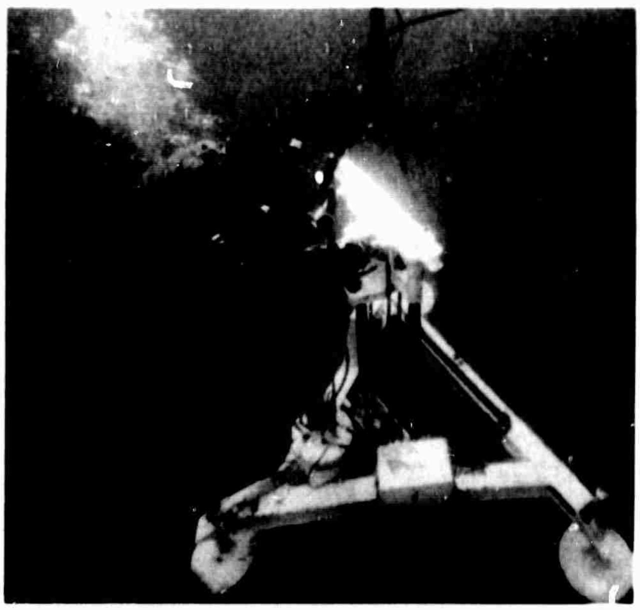
5. Provide a stable mooring for floating platforms

6. Permit a large step forward in terms of in-ocean techniques

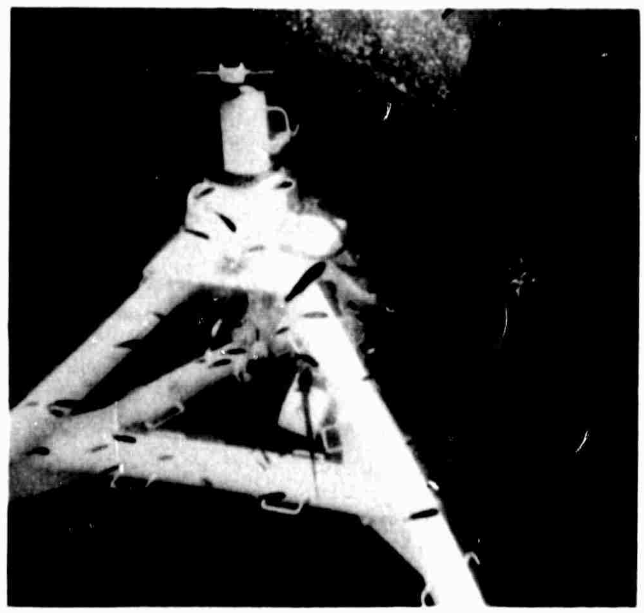
REHEARSAL OPERATION

The unsolicited proposal to the Advanced Research Projects Agency contained budget provisions for a rehearsal of the operation. This was deemed necessary as both the Ocean Systems, Inc. (OSI) coring rig and the Foundation Sciences, Inc. (FSI) hydraulic pulling rig were new and had been designed and built with operations at Cobb particularly in mind. Moreover three different groups of divers would be working together at Cobb--OSI, FSI, and Northwest Diving Institute (NDI, acting as the SEA USE Diving Team)--none of whom had worked with these rigs under water before (see Figure 2).

In view of the foregoing, personnel from Ocean Systems, Inc. began arriving in Seattle on 18 June for pre-rehearsal conferences and by the afternoon of 22 June, 1970, all OSI personnel and equipment had been loaded on board USS TATNUCK (ATA-195) at Pier 91, and TATNUCK was underway by 1830. In line with the Institute's PROGRAM PLAN, copies dated 23 June 1970, which were furnished to ARPA, the site selected for the rehearsal was a reef running north from Bare Rock, north of Orcas Island, in the San Juan Islands in Puget Sound. This site was selected because the rock formation was of similar composition to basalt and was in relatively protected waters. However, the entire day of 23 June was spent in attempting to moor the ship in strong tidal currents, and finally by that evening the site was abandoned. On the morning of 24 June, 1970, an attempt was again made at the Bare Rock site in calm water, but by the time the core drilling rig was readied for positioning on the bottom, strong tides again jeopardized the safety of the ship and coring rig, and TATNUCK moved into Echo Bay at Succia Island. NDI divers had by this time joined the expedition; both NDI and OSI divers found a sandstone outcrop at the bottom of the bay, and it was decided that the rehearsal would be conducted at that site. By mid-afternoon the drilling rig was on the bottom and after diver familiarization with its operation, a test core was made using remote control of the core drilling rig from the ship. An actual core was taken at 1630, and ten minutes later the rock bolt had been grouted in place and the rig had been recovered. A second coring attempt was made immediately thereafter, but the ship was unable to hold her position due to the change in tidal current, so that by 1830 the rig was recovered and TATNUCK departed for Seattle. All equipment and personnel were removed from TATNUCK on arrival at Pier 91 on 25 June, with the equipment being transferred to storage and most of the personnel returning to their points of origin. A critique was held with the OSI Project Manager on 26 June and it was determined that aspect of the



A diver from Ocean Systems, Inc. descends with the coring rig to the pinnacle. With a diamond bit, OSI drilled and extracted three basalt cores. Divers then pneumatically forced cement grout into the holes and inserted the 2½" x 5' steel bolts. Marked with arrows to indicate magnetic north, the cores are now under study by geologists.



A diver from Foundation Sciences, Inc. of Portland, Oregon, operates the hydraulic test rig during tests of one bolt assembly. At about 110 tons of vertical pull, failure occurred between the bolt and the grout. The yield strength was 50 tons and the safe load 35 tons. Although it withdrew about one and a half inches, the bolt still had some 20 tons of residual strength.

Figure 2

rehearsal was sufficiently successful to warrant the attempt at Cobb Seamount.

Foundation Sciences personnel tested the hydraulic pulling rig during the period 2, 3, and 4 August 1970. Essentially this was a familiarization operation in which FSI divers were checked out procedurally by the Project SEA USE chief aquanaut. The pulling rig was emplaced on the bottom at Echo Bay and attached to the rock bolt in order to insure that vertical clearances and positioning of the rig could be carried out by scuba divers. Additionally, experiments were made using styrofoam floats to bring the rig to just under negative buoyancy in order that it could be manually positioned on the scene. These tests were completely successful and the hydraulic rig was then removed to Pier 91 in readiness for the Cobb operations.

The end results of both rehearsals clearly indicated that mooring in basaltic rock at Cobb should be a successful operation, and it also reflected that advance rehearsal for personnel who are familiar with such equipments was not only desirable, but in fact most necessary.

OPERATIONS AT COBB SEAMOUNT

The operation to Cobb Seamount involved obtaining three oriented cores; implanting three rock bolts in the core holes, and fail testing one of the rock bolts. Last minute personnel changes, as outlined in the Program Plan dated 23 June 1970, reflected that Mr. Vincent Ranier replaced Mr. James Washburn as Assistnat Diving Supervisor, Mr. Washburn having to cancel. Also Mr. Donald Dodds replaced Mr. Kenneth Dodds as Chief Engineer Diver from Foundation Sciences, and Mr. Harry Lambert replaced Mr. Donald Hanberg as the Ocean Systems Equipment Technician. Captain Griffith C. Evans, Jr., USN (Ret), Executive Director of the Oceanographic Institute of Washington, did sail as SEA USE Liaison Officer and in this capacity controlled the operations conducted by both ships and was responsible for the final preparation of this report.

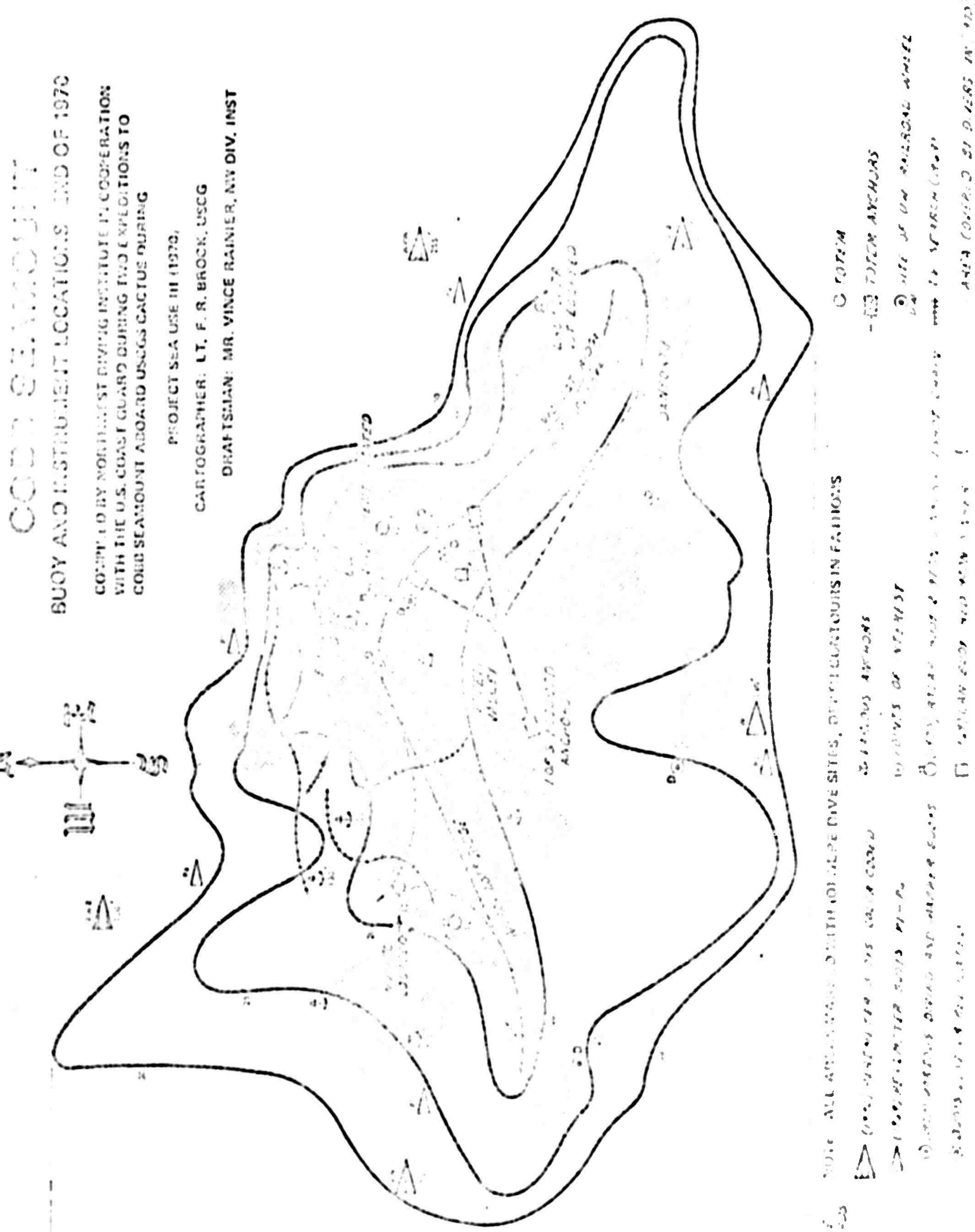
Personnel and equipment began loading on board USCGC CACTUS in Astoria, Oregon on July 24, 1970, those personnel and equipments being strictly in accordance with the Program Plan. CACTUS, with the SEA USE diving team, departed Astoria at 0800 on 27 July 1970, for Cobb Seamount, arriving at approximately 1200, 28 July 1970. Upon arrival at the Seamount CACTUS commenced operations, which involved deploying a type-A mooring buoy approximately 500 yards due east of the reflector buoy which had been implanted in May 1970. In addition to implanting the buoy, CACTUS also laid the chain highway along the east-west axis, and along the entire length of the pinnacle. This "chain highway" was further marked off at 100-foot intervals and served superbly throughout the operation for diver orientation. Indeed, this chain highway may well prove to be one of the major assets for future operations at Cobb.

The Washington State National Guard Coastal Freighter, FS-313, arrived at Pier 91 Seattle at 0830 on the morning of July 27, 1970. Immediately upon arrival, both the Ocean Systems, Inc. hydraulically operated coring rig, the Foundation Sciences, Inc. hydraulic test pulling rig and other associated equipments were loaded and stowed in the number two cargo hold. New 7/8 inch wire cable was picked up and wound on the winch serving the FS-313 jumbo cargo boom, and additional nylon hawsers were stowed on board. By 2000, 27 July 1970, FS-313 with all equipment and personnel as outlined in the Program Plan on board, departed Pier 91 for Cobb Seamount, arriving at first light on 29 July 1970.

Shortly after rendezvous at Cobb Seamount between CACTUS and FS-313, a conference on board the latter ship revealed that the chain highway and the Class A buoy were in position, but that CACTUS would require an additional 24 hours to implant a third buoy on a clump which would provide a three-point moor. In view of the extremely mild weather with a light easterly breeze prevailing, and in view of the fact that an additional 24 hours would be required for the third mooring buoy's implacement, the Project Liaison Officer decided to commence operations immediately using the reflector buoy and the Class A buoy for a two-point moor. FS-313 moored accordingly, the initial position being as close at the eastern end of the pinnacle and to the Class A buoy as could safely be achieved without risk of fouling the ship's propellers or rudder in the buoy assembly. By 1700, 29 July the ship was in position, but recognizing that extensive preparations would be required before actual coring could be undertaken, all further operations for the remainder of the day were terminated. CACTUS steamed in the immediate vicinity until the evening of 1 August, offering berthing, messing and logistic support to the SEA USE diving team and Foundation Sciences personnel.

On the morning of 30 July 1970 at first light, FS-313 and OSI personnel began operations by hoisting the coring rig out of the ship's number two hold, testing and rigging the hydraulic assembly, and preparing the drill for on the bottom operations. All tests were completed by mid-afternoon with the rig implaced on the seamount pinnacle and coring using the remote controls on board FS-313, commenced. Due to the failure of the remote penetration indicator on the instrument panel on board the ship, indications were that coring was going extremely slowly. After approximately two hours with a surface indication by instruments of only about 1½ inches penetration, one of the Ocean Systems, hard hat divers descended to inspect the rig and try and determine the reasons for the very slow progress. It was then discovered that the indicator was defective, and that the drilling had already penetrated the basalt to a depth of about 4½ feet. Accordingly, the remainder of the core was completed in very short order, the coring drill was removed, grouting was exhaled into the core hole using a specially designed cement injector, a rock bolt implanted, the collar and shackle on the rock bolt screwed into place, and operations were terminated for the day with the first oriented core retrieved and on board FS-313. The drilling rig was left in place on Cobb's pinnacle and connected to the ship by the lifting cable.

By daylight, 31 July 1970, the wind had shifted around to becoming a fresh breeze from the north, which moved FS-313 far enough out of position to the south that recovery of the coring drill was considered to be hazardous to the rig. After watching the fitful weather in hopes of a further wind shift until noon, a review of the bathymetry of the top of the pinnacle indicated the possibility of rigging a hawser from the ship to one of the Totem 2 clumps (see Figure 3), thus enabling



COBB SEAMOUNT
BUOY AND INSTRUMENT LOCATIONS END OF 1970
COMPILED BY NORTHWEST DIVING INSTITUTE IN COOPERATION
WITH THE U.S. COAST GUARD DURING TWO EXPEDITIONS TO
COBB SEAMOUNT ABOARD USCGS CACTUS DURING
PROJECT SEA USE III 1970,
CARTOGRAPHER: LT. F. R. BROCK, USCG
DRAFTSMAN: MR. VINCE RAINIER, NW DIV. INST

Figure 3

the ship to kedge herself up wind. Using the SEA USE aquanauts, this third point moor was achieved, and FS-313 was able to resume a position sufficiently in line with the Class A and reflector buoys to permit lifting and re-implanting the Ocean Systems coring rig. A second core was promptly begun and successfully completed by day's end, and this included the implant of the second rock bolt, complete with collar assembly. In the remaining daylight, FS-313 kedged up to within 20 feet of the reflector buoy, remaining in a three-point moor, and obtaining approximately a 250-foot separation between the first two rock bolts and that point (see Figure 1).

On the morning of 1 August 1970 operations were promptly resumed, and by noon the third core had been completed along with the successful implant of the third rock bolt and assembly. During this operation the sole operation's accident throughout the entire time occurred when the winch operator on board FS-313 maintained a strain on the cable to the coring rig, and a sudden surge of the ship lifted the coring machine free of the pinnacle. Fortunately, the only result of this casualty was an unexpected and happily welcomed additional two-foot, oriented core. All operations were completed by noon, and the ship's and the Ocean Systems' personnel worked for most of the remainder of the afternoon retrieving the coring rig, which had become fouled by the hydraulic, actuating hoses, due to rotation of the rig while it was suspended over the side. At about 1700, the rig had been recovered and was stowed in the number two cargo hold, and the hydraulic puller had been implanted adjacent to the number two rock bolt, tested for buoyancy and maneuverability with scuba divers, and CACTUS was directed to assume the three-point moor on which the FS-313 lay. FS-313 immediately broke her moor, buoying the mooring hawsers, and sailed for Seattle, arriving at Pier 91, 1030, 3 August 1970.

CACTUS was successful in picking up the three-point moor in the face of a freshening wind and the onset of darkness that evening. Thus dives by the SEA USE aquanauts and the FSI scuba divers began promptly on 2 August, beginning with the correct positioning of the hydraulic ram over number two anchor bolt. By the time the ram was connected to the anchor bolt shackle, the cement grout had set for 72 hours. Repeated dives continued in order to conduct the anchor bolt failure test, and these tests were successfully completed by evening of 3 August. In all, twelve dive missions were involved in the failure tests over the two-day period, requiring 28 separate dives, although six of the dives were for photographic recording purposes. All diving was secured by noon, 4 August and CACTUS spent the remainder of that day retrieving both the Class A and reflector buoys and associated clumps, departing Cobb on the evening of 5 August 1970, and arriving in Astoria, Oregon on 6 August 1970. No problems of significance were encountered while conducting the failure tests.

PROBLEMS ENCOUNTERED

When the initial project was submitted to the Advanced Research Projects Agency, it was considered an add-on to an ongoing expedition under the SEA USE Program. As the primary objective of the August expedition had originally been to upgrade bathymetry and photography of the pinnacle of Cobb Seamount and possibly implant new instruments, the add-on of the development of a fixed, permanent mooring system on the pinnacle of Cobb Seamount greatly complicated the program. Initially, the work under SEA USE would have required only one ship and SEA USE aquanauts, operating as scuba divers. The new program required an additional ship, both for berthing and cargo area, and it posed further complications in the effective direction of the operation. The end result was an operation involving two ships' captains, each from a different service, a project manager and a chief diver from OSI, a project engineer from FSI, the SEA USE chief aquanaut and the project liaison officer from the Oceanographic Institute of Washington. That the operation was so successful is testimony to the cooperative effort and can-do spirit put forth by all hands. This is not, however, the most ideal command or executive relationship. In part the preponderance of managers arose from the fact that it was not feasible to re-train our aquanauts to handle all of the technical equipments that would be required, and thus the proposal had to envision inclusion of a separate team of hard hat divers from OSI to handle the core drilling rig, and another team of scuba divers from FSI to operate and observe the hydraulic tests on an implanted rock bolt. With three different teams of divers involved, the problems in coordinating their efforts, and above all, obtaining quick diver orientation on the pinnacle for the OSI and FSI divers at Cobb, the decision was made just prior to sailing to add the laying of a marked chain highway across the pinnacle of Cobb.

A second unanticipated problem was in the use of the coring drill, which was essentially a new and experimental tool. Minor mechanical problems did occur on site, and with only two hard hat divers available through OSI, serious delays on station would have had to be accepted as their maximum dive time was used up each day of the operation. Accordingly, the project liaison officer authorized a sub-contract on scene between OSI and the SEA USE aquanauts to provide the additional dive time required in handling the rigs, clearing fouled lines, providing labor on Cobb in support of the hard hat divers and for the many extra night hours added on for recharging scuba bottles and refurbishing scuba gear for dives the following days. Probably the most recurring problem resulted from the unusual clarity of the water, the whitish surface of the pinnacle causing extensive photic reflection, and the abundant biotic life. The OSI and FSI divers repeatedly referred to an "intoxicating effect" from this situation, and even our own divers, with considerable experience already at Cobb, had occasional trouble with this situation. The chain highway thus proved to be invaluable in minimizing this sense of dislocation. A final problem was in the efficient use of diving time. In taking advantage of the prevailing good weather, the hard hat divers, as has been previously noted, were used to their maximum extent. This led to the decision, in the interest of safety, that no recompression dives would be made by the scuba divers, thus severely limiting the bottom time for each and requiring constant relays of new divers, with a resulting loss in operational continuum.

RECOMMENDATIONS FOR FUTURE ROCK BOLT IMPLANT OPERATIONS

In practical application, particularly where failure tests are not required, the following recommendations for improving the operation in terms of cost reductions and performance efficiency are recommended:

1. The drilling platform should have a self-positioning capability in order to remain within an acceptable radius of the drilling rig while it's on the bottom, and thus not being dependent upon temporary bottom moors.

2. The coring machine should be hooked onto the ship using non-rotating wire with a swivel on top of the rig.

3. A hydraulic hammer should be used for seating the rock bolts.

4. The core drilling machine could be improved for leveling capabilities by having all three legs adjustable, and larger hydraulic rams on the legs would be desirable.

5. The hydraulic hose reel should have hydraulic controls, and slip rings should be mounted for all hydraulic and electrical connections.

6. Extra core barrel racks should be mounted on the core drilling machine.

7. The anchor bolt should have a swivel type top rather than a simple shackle.

8. The anchor points should have anodes mounted to resist corrosion.

9. A large, well-trained diver team would expedite the operations.

10. The drilling rig could be mounted on a sled for quick diver repositioning.

11. The drilling rig should have an underwater TV camera mount as back-up for the rig's surface, sensor instruments.

12. Forms should be made so that the cement grout could be poured around and underneath the bolt collar to compensate for bottom irregularities.

13. If cores are not important, a different bit might be more efficient.

14. Drill bits themselves could be used as anchor points. A small grout mixing machine for use on the bottom might expedite the operation.

15. It would be a definite advantage to conduct the entire operation using a single organization.

16. Engineering stress should be conducted to determine if irregularities on the anchor bolt surfaces would add to better cement holding strengths.

17. For increased holding strength, future moorage systems of this type should have a minimum of 60 rod diameters of embedment in the grout.

18. The use of a resin grout in place of the cement grout should be considered for quick holding strength. It should, however, be noted that the holding strength of the cement grout (Lumnite) used would increase by approximately 50% at the end of three months after implant.

TECHNICAL REPORT

ANCHOR BOLT INSTALLATION ON COBB SEAMOUNT

By

Ocean Systems, Inc.
11440 Isaac Newton Industrial Square North
Reston, Virginia 22070
September 22, 1970

Appendix I

INTRODUCTION

This report concerns work completed by Ocean Systems, Inc., under Contract No. 61807 for the Oceanographic Institute of Washington in connection with the unsolicited proposal dated March 25, 1970, to the Advanced Research Projects Agency. The work performed by Ocean Systems, Inc., included drilling three holes in the basalt pinnacle of Cobb Seamount, removing three rock cores from these holes, and installing three anchor bolt assemblies in the holes.

The holes were drilled with a specially designed submersible rotary coring/drilling machine. Ocean Systems, Inc., divers inserted cement grout and anchor bolts into the holes to complete the anchorages.

Two days after installation one of the anchors was tested for vertical holding power by Foundation Sciences, Inc. The results of the test indicated that the anchor had an ultimate strength in excess of 100 tons and a safe working load of about 35 tons.

Ocean Systems, Inc., believes that the strength of similar type anchorages can be improved with minimal effort.

DESCRIPTION OF EQUIPMENT AND MATERIALS

Coring Machine

A specially designed, hydraulic powered, rotary coring machine was used to drill the anchor holes in the rock and retrieve the cores. The machine is completely submersible and can be operated remotely from the surface or by divers on the bottom. The machine will accept standard drill rod and core barrels and can be adjusted to drill 5 ft., 10 ft., or 20 ft. cores.

For this particular job the machine was set up for 5 ft. cores and was fitted with a small diamond, light matrix diamond bit. The core barrel used is designed to drill a 3 inch nominal diameter hole and remove a 2-1/8 inch nominal diameter core. The core is removed from the hole by a core catcher located in the core barrel. The core catcher grips and breaks off the core when the core barrel is retracted from the hole.

Additional information covering the coring machine and core barrel may be found in the Appendix.

Anchor Bolt Assembly

The anchor bolt assembly consists of a steel rock bolt and a shackle on a special pad which is bolted on the rock bolt once it is in place in the bottom. The assembly is designed to have a minimum yield strength of 160, 000 lbs. when pulled on in the vertical direction. (This, of course, is predicated on the rock bolt holding fast in the bottom.) Additional information on this assembly is located in the Appendix.

The rock bolt is designed to be inserted in a hole which is slightly larger than the bolt in diameter and has been filled with cement grout. Once the bolt has bottomed-out in the hole, it is hammered down on a steel wedge that has been pre-inserted in a slit cut in the foot of the bolt. The hammering forces the bolt down on the wedge, which spreads the foot apart making the bolt fast in the hole once the cement grout has hardened.

Cement Injector

A specially designed cement injector was used for injecting cement grout into bottom of each drilled hole. It is very important that the cement grout be injected into the bottom of the hole and allowed to fill the hole from the bottom up. If the cement was poured into the top of the hole it would be washed out, and thus rendered weaker, as it settled to the bottom.

The cement injector consists of an aluminum tube (slightly smaller in diameter than the hole) to which is fitted a traveling piston and an air flask with a valve. The injector is loaded by filling the barrel with cement and putting a light covering of tape over the end to prevent the cement from washing out. The injector is then transported to the bottom and inserted in the hole by a diver. The diver opens the valve to the air flask, thus forcing the cement out of the injector and the injector out of the hole. A relief valve is employed to prevent overpressurization of the barrel once the piston reaches a stop at the end of the barrel.

Cement Grout

The cement grout used was made from Lumnite calcium--aluminate cement. This cement reacts with water to develop a hydraulic strength much in the same manner as portland cements do in structual concrete. The rate of this chemical reaction is rather fast, so that for practical purposes Lumnite mixes will develop full working strength in 24 hours. These strengths will compare favorably with portland cement mixes a month old.

The particular grout used consisted of pure Lumnite cement mixed at a ratio of 5¼ gallons of potable water per bag (94 lbs.) of cement. This ratio will result in a cement with a 2 day compressive strength of approximately 5,100 psi and a three month strength of approximately 7,500 psi.

PROCEDURE FOR BOLT EMPLANTMENT

The following procedure was employed to drill the anchor holes and install the anchors. Although the procedure did vary slightly between the three holes it was essentially the same.

1. Rig coring machine on deck and lower to sea bottom.

   Actually the coring machine was lowered from the ship for the first hole, and was lifted off of the bottom and suspended from the ship while the ship was repositioned for the second and third holes.

2. Level coring machine by adjusting hydraulic legs.

   This was accomplished using the remote control and level indicators.

3. Using remote controls lower core barrel until drill bit touches bottom. Take initial penetration reading and begin drilling.

   Actually the remote penetration indicator failed due to a water leak in an electrical resistance pot and a diver was employed to take an initial reading from a visual indicator located on the coring machine.

4. Turn on rotary drive and begin drilling. Continue drilling until penetration is within a few inches of desired hole depth.

   Because of the penetration indicator failure, a diver was employed to take an intermediate penetration reading from which a penetration rate was calculated, and a time-to-finish estimated. This worked quite well in that the desired penetration was approached within ¼ to 1 inch.

5. Diver descends and completes hole to desired depth using diver controls on coring machine.

6. Core barrel is retracted and core broke off using remote controls.

7. Diver removes core barrel from machine and sends to surface via line.

8. Loaded cement injector is lowered to diver via line and diver injects cement grout into hole.

9. Diver inserts rock bolt into hole.

   After the rock bolt was inserted into the first hole, the diver attempted to use a pneumatic hammer to drive the bolt down on the wedge. At this point the air compressor stopped running and 20 minutes elapsed before it was running again. Once the air compressor was running a second diver tried to drive the bolt but was unsuccessful. This failure to drive the bolt was probably due to the cement having partially set and also to insufficient air pressure (100 psi in 120 feet of water) from the compressor. It is estimated that at least 200 psi pressure is needed to operate the hammer adequately in 120 feet of water.

   The pneumatic hammer was not used for the remaining two holes, but instead the bolts were pre-spread before insertion in the holes.

10. Diver makes up anchor shackle assembly on bolt and returns to surface.

11. Coring machine is retrieved.

RESULTS

The specific results of the portion of the Cobb Seamount Operation that involved Ocean Systems, Inc., are:

1. Retrieval of three cores approximately 55 inches long by 2-1/8 inches in diameter from the basalt pinnacle of Cobb Seamount.

2. Emplantment of three anchor bolt assemblies in the core holes. Each of the rock bolts was inserted to a depth of approximately 55 inches and grouted into place. The foot of the first bolt was not spread; however, the foot of the second bolt was spread ¼ inch, and that of the third was spread 3/8 inch.

3. Information was obtained relating to the effort required to drill cores from basalt. The average penetration rate for the diamond bit was approximately 1 inch/minute at 120 rpm and 2,000 lbs. force on the bit.

COMMENTS

The anchor bolt pull test report states that at 220,000 lbs. of pull the anchor bolt was "withdrawing as fast as they could pump and extend the ram." Because the anchor bolt has a 164,000 lb. minimum yield strength it is possible that at 220,000 lbs. pull the bolt was not only withdrawing, but also yielding.

It is believed that there was bond failure between the cement grout and bolt, and that after this mode of failure much of the load was transferred to the spread foot of the bolt, which accepted the load. Thus, failure continued as the foot of the bolt crushed the cement above.

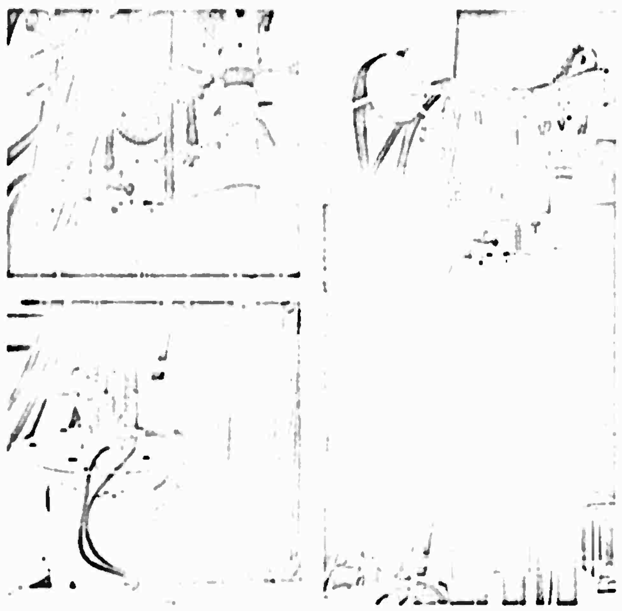
Since the bolt tested had been chipped free of scale and washed, it is doubtful that the bond strength can be increased except by deforming the bolt. However, the total pullout strength can be increased by deeper embedment of the bolt. There is, of course, a point of diminishing returns where no load is transferred to the lower section of the bolt until the upper section has slipped.

It is believed that additional spreading of the foot of the bolt will result in a considerable increase in holding power. The bolt is probably just as effective if the foot is spread before the bolt is inserted in the hole, rather than after it is inserted.

Because of the strength of concrete in tension, shear and bond are proportional to compressive strength, the strength of the anchor bolt after three months would be approximately 50% greater than that at 2 days.

Finally, it must be remembered the first bolt was emplanted in homogenous basalt, one of the strongest rocks known to man (compressive strength between 30,000 and 60,000 psi), and the same bolt emplanted in a weaker rock, or one that had been throughly fractured, could fail in a different mode such as diagonal tension where a large portion of rock would be torn from the bottom.

APPENDIX



CORING EQUIPMENT

HYDRAULIC ROTARY CORING MACHINE

In order to provide the capability to core hard formations including igneous rock, or to drill anchor holes in hard material, Ocean Systems has designed a bottom-standing hydraulically driven rotary core drill. When lowered to rest on the ocean bottom it is isolated from movement of the support vessel. Hydraulic power control and monitoring is provided from the surface.

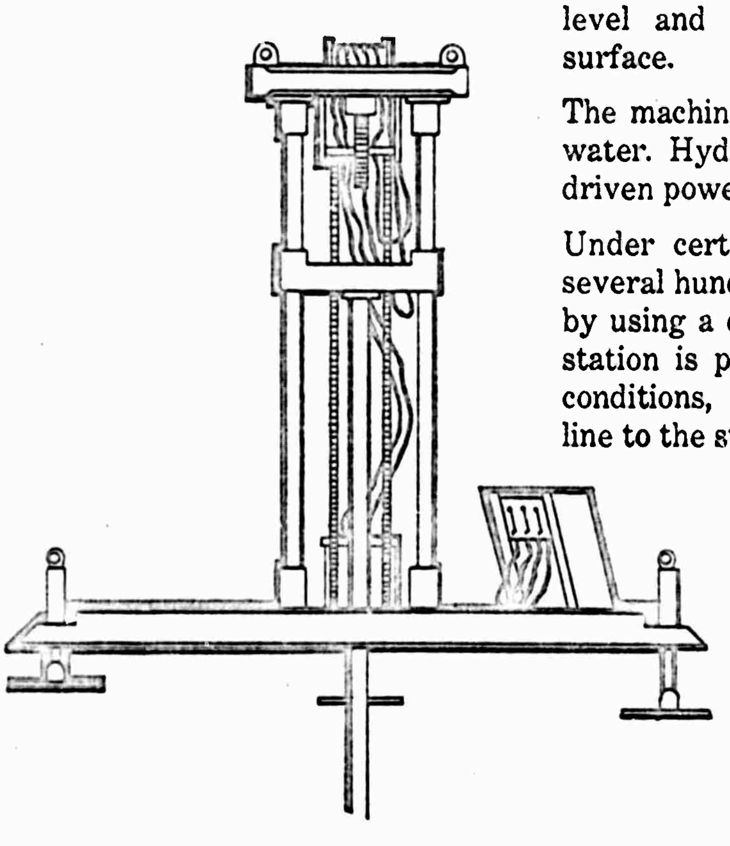
The corer is capable of penetrating up to 20 feet of bottom material in one continuous core. The system includes electrically operated hydraulic valves on the machine which control level and cross level, right and left hand rotation, and up and down feed. Bit pressure, rotary RPM, penetration depth and level and cross-level are all monitored at the surface.

The machine is capable of operation in 600 feet of water. Hydraulic power is furnished by a diesel-driven power unit at the surface.

Under certain circumstances, repetitive cores to several hundred feet below the bottom can be taken by using a diver to add drill rod. A diver's control station is provided for this purpose. Under these conditions, cores are retrieved by means of wire line to the surface.

SPECIFICATIONS

Height: 9' (for 5 foot cores)
Height: 14' (for 10 foot cores)
Height: 24' (for 20 foot cores)
Base Triangular: 11' on a side
Weight: 3800 lbs. (weight of corer in air)
1500 lbs. (hydraulic power supply)
Core Depth: 20' max.
Core Diameter: up to 4½"
Depth Rating: 600 ft. max.



Price List Effective August 15, 1969
Replaces List Effective June 1, 1966

"L" Design Double Tube Swivel Type

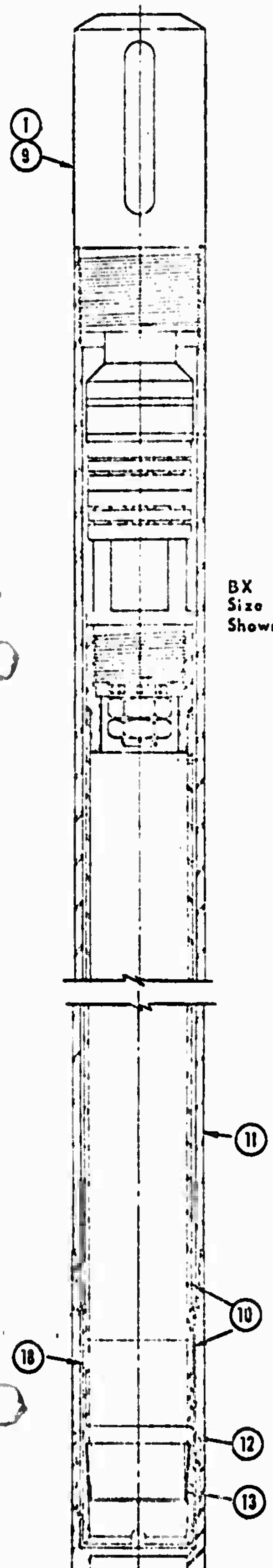
The "L" Design Core Barrel is an exclusive patented Longyear Design, available in EX, AX, BX, and NX sizes, with "old standard" or "W" group threads. It is a high recovery double tube swivel type barrel, designed to increase core recovery in formations difficult to core—friable, broken or unconsolidated.

World wide use of the "L" Barrel since 1950 has proven core recovery effectiveness challenged by no other core barrel. Contributing features are: (1) A non-rotating inner tube resulting in little, if any, abrading of the core. (2) The drilling fluid passes between the inner tube and outer tube leaving only the core at the face of the bit exposed to washing. (3) A patented Water Shut-off Valve which expands against the outer tube when a core block puts upward pressure on the inner tube. This restricts the flow of circulating water. An increase in gauge pressure warns the driller of the block and permits him to stop drilling before grinding core. (4) All Longyear "L" Design Core Barrel heads are furnished standard with hard facing. The hard facing provides for longer wear and better stabilization in the drill hole. (5) Slip fit connection of core lifter case transfers upward force to outer tube when breaking core.

The standard assembly includes a split ring core lifter, sliding core lifter case and thread protector. Accessory equipment includes blank reaming shell, blank bit, inner tube extension and a basket type core lifter. The basket type core lifter is recommended when drilling in clay or badly broken formations.

Price List Effective August 15, 1969
Replaces List Effective June 1, 1966

"L" Design Double Tube Swivel Type (cont'd)



BX Size Shown

SIZE OF BARREL		BXL, BWL	NXL, NWL
Nominal Dimensions	Core and Hole Diameter	1-5/8" x 2-3/8" 41.3 x 60.3 mm	2-1/8" x 3" 54.0 x 76.2 mm
	Outer Tube, ID and OD	2" x 2-9/32" 50.8 x 57.9 mm	2-5/8" x 2-29/32" 66.7 x 73.8 mm
	Inner Tube, ID and OD	1-23/32" x 1-7/8" 43.7 x 47.6 mm	2-1/4" x 2-1/2" 57.2 x 63.5 mm
	Blank Bit, ID and OD	1-11/16" x 2-19/64" 42.8 x 58.3 mm	2-3/16" x 2-59/64" 55.6 x 74.2 mm

ITEM	NAME OF PART	BXL, BWL PART NUMBER	UNIT WT. LBS.	UNIT WT. KG.	UNIT PRICE	NXL, NWL PART NUMBER	UNIT WT. LBS.	UNIT WT. KG.	UNIT PRICE
	"X" GROUP (For B and N Connections)								
1-14	CORE BARREL ASSEMBLY								
	5-Ft. (1.52 m)	22612	37.3	16.9	$173.00	22618	61.5	27.9	$220.00
	10-Ft. (3.05 m)	22613	62.8	28.5	181.00	22619	99.8	45.4	233.00
	"W" GROUP (For BW and NW Connections)								
	5-Ft. (1.52 m)	22615	37.3	17.0	173.00	22621	61.5	27.9	220.00
	10-Ft. (3.05 m)	22616	62.8	28.5	181.00	22622	99.8	45.2	233.00
1-9	HEAD, COMPLETE "X" GROUP	12388	8.1	3.7	95.00	12389	16.9	7.7	114.30
1-9	HEAD, COMPLETE "W" GROUP	16445	8.1	3.7	95.00	16470	16.9	7.7	114.30
10	Inner Tube Ass'y, 5-ft. (1.52 m)	22593	8.5	3.9	30.20	22596	17.3	7.9	38.80
or 10	Inner Tube Ass'y, 10-ft. (3.05 m)	22594	16.5	7.5	36.85	22597	33.2	15.1	44.60
11	Outer Tube, 5-ft. (1.52 m)	12370	18.5	8.4	32.55	12372	23.7	10.6	49.85
or 11	Outer Tube, 10-ft. (3.05 m)	12277	36.0	16.4	37.75	12129	46.1	21.	57.45
12	Core Lifter Case	12281	**	**	7.25	12133	**	**	9.75
13	Core Lifter	12280	**	**	5.00	12132	**	**	5.30
	Thread Protector (not shown)	18293	1.8	.8	3.70	18294	2.8	1.3	4.65

OPTIONAL ACCESSORY EQUIPMENT

ITEM	NAME OF PART	BXL, BWL PART NUMBER	UNIT WT. LBS.	UNIT WT. KG.	UNIT PRICE	NXL, NWL PART NUMBER	UNIT WT. LBS.	UNIT WT. KG.	UNIT PRICE
	Core Lifter, Basket Type (not shown)	12283	**	**	32.95	12135	**	**	33.10
18	Inner Tube Extension*	12278	**	**	4.50	12130	**	**	4.60

*Item 18 for replacement only included in Item 10 (Inner Tube Assembly). Item 10 includes Inner Tube with Inner Tube Extension brazed on.
**Weighs less than one pound (.4 kg)

CHROME PLATING. Hardness is 9 Moh's scale. To order, add "CP" to Core Barrel part number and specify "chrome plated" with:
A 21372 OUTER TUBE. 18" (.46m) on outer surface at both ends, 1/16" (1.6mm) from each end, .004" (.1mm) thick. Price: $20.00 for 5 and 10-foot (1.52 and 3.05m) tubes, $46.25 for 20 foot (6.10m) tubes.
A 21833 INNER TUBE. Entire inner surface, .002" - .004" (.05-.1mm) thick. Price: $25 for 5 and 10-foot (1.52 and 3.05m) tubes. Price for 20-foot (6.10m) tubes on request.

CONTENTS

The array of diamond bits shown in this picture illustrates some of the factors that complicate modern diamond bit design. Diamond bit experts combine years of study and field experience to completely understand all of these factors.

INTRODUCTION

E. J. Longyear Company has engaged in world-wide diamond core drilling operations in all varieties of rock and mineral formations for over 70 years. Resulting experience makes it possible to design diamond bits and reaming shells with long life, high drilling speed, and low diamond cost per foot of hole drilled.

To obtain optimum performance diamond bits must be designed for the work to be done. No two formations drill exactly the same. The designing of diamond bits may be likened to the alloying of metals. Different alloys are made to serve different purposes – some hard, some soft, some tough, some malleable, some brittle. The same alloy would not serve all uses.

The proper design of diamond bits blends diamonds of the right size and quality with a matrix that has the correct hardness and resistance to abrasion. Crown shape, waterways, diamond exposure and diamond distribution are other factors that influence diamond bit performance.

The effect, as well as necessity, of proper and experienced use of these factors in diamond bit design is understood by Longyear engineers. Their expert understanding gained through world-wide experience in bit design has been fully utilized in compiling the Diamond Bit Selector-Chart on pages 4 and 5 of this booklet. We believe your examination will verify the assistance this Chart offers as a reliable guide to proper selection of diamond bits. In a like manner, we know you will find the Reaming Shell Selector-Chart on page 7 very useful.

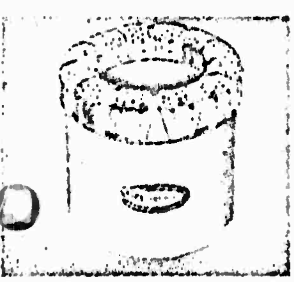
But you don't have to be a bit expert to properly select and order Longyear diamond bits. Complicated design calculations involving matrix hardness, crown shape, diamond exposure, etc., are unnecessary when you let our exclusive Diamond Bit Selector-Chart "figure the factors" for you. Use the Selector-Chart the next time you order diamond bits and see for yourself.

DIAMOND BITS

STEP CORING BIT — A most efficient style for good core recovery and fast penetration rates.

"L" SERIES BIT — Designed to be used with Longyear "L" Series core barrels for increased core recovery in difficult drilling conditions.

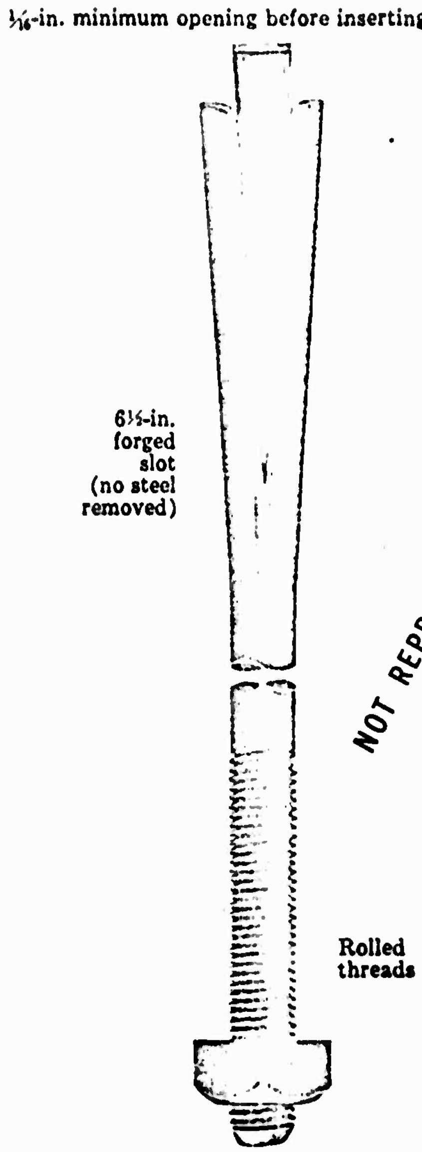
LARGE SERIES BIT — Intended for use with large series DCDMA barrels. Especially good for soft, unconsolidated formations.



SERIES "100" BIT — Fits Longyear Series "100" core barrels. Gives good results when drilling with air, water or mud.

NOT REPRODUCIBLE

SIZE AND DESIGN	GENERAL PURPOSE DESIGN — MEDIUM SIZE DIAMONDS	FOR HARD BROKEN FORMATIONS — MEDIUM TO SMALL SIZE DIAMONDS	FOR SOFT FORMATIONS — LARGE SIZE DIAMONDS	FOR [illegible] FORMATIONS [illegible] DIAMONDS	BOTTOM DISCHARGE DESIGN	CIRCLE SET DESIGN	GENERAL PURPOSE DESIGN — IMPREGNATED DIAMONDS
XRT	90002	90129	90249	90370	--	90590	90653
1¼ BLAST HOLE	90003	90130	90250	90371	--	90591	90654
EXT BEVEL WALL	90005	90132	90252	90373	--	90593	90656
EXT STRAIGHT WALL	90006	90133	90253	90374	--	90594	90657
EXK BEVEL WALL	90007	90134	90254	90375	--	90595	90658
EXK STRAIGHT WALL	90008	90135	90255	90376	--	90596	90659
EX BEVEL WALL	90009	90136	90256	90377	--	90597	90660
EX STRAIGHT WALL	90010	90137	90257	90378	--	90598	90661
EXL	90011	90138	90258	90379	90490	90599	90662
EXH (DIADRILL CONT)	90012	90139	90259	90380	90491	90600	90663
EXC	90013	90140	90260	90381	--	90601	90664
EXM	90014	90141	90261	90382	90492	90602	90665
EX-D3	90015	90142	90262	90383	90493	90603	90666
AXT BEVEL	90016	90143	90263	90384	--	90604	90667
AXT STRAIGHT WALL	90017	90144	90264	90385	--	90605	90668
AXK BEVEL WALL	90018	90145	90265	90386	--	90606	90669
AXK STRAIGHT WALL	90019	90146	90266	90387	--	90607	90670
AX BEVEL WALL	90020	90147	90267	90388	--	90608	90671
AX STRAIGHT WALL	90021	90148	90268	90389	--	90609	90672
AXL	90022	90149	90269	90390	90494	90610	90673
AXM	90023	90150	90270	90391	90495	90611	90674
AXHW (DIADRILL CONT)	90024	90151	90271	90392	90496	90612	90675
AX-C2	90025	90152	90272	90393	90497	90613	90676
AX-C3	90026	90153	90273	90394	90498	90614	90677
AX-D3	90027	90154	90274	90395	90499	90615	90678
AX SERIES 10 WIRELINE	90029	90156	90276	90397	90501	--	--
AX	90030	90157	90277	90398	90502	--	--
AQ AQ U WIRELINE	90750	90754	90758	90762	90766	--	--
BX BEVEL WALL	90031	90158	90278	90399	--	90619	90679
BX STRAIGHT WALL	90032	90159	90279	90400	--	90620	90680
BXL	90033	90160	90280	90401	90503	90621	90681
BXM	90034	90161	90281	90402	90504	90622	90682
BXHW (DIADRILL CONT)	90035	90162	90282	90403	90505	90623	90683
BX-C2	90036	90163	90283	90404	90506	90624	90684
BX-C3	90037	90164	90284	90405	90507	90625	90685
BX-D2	90038	90165	90285	90406	90508	90626	90686
BX-D3	90039	90166	90286	90407	90509	90627	90687
BX SERIES 10 WIRELINE	90041	90168	90288	90409	90511	—	—
BQ-BQ-U WIRELINE	90751	90755	90759	90763	90767	--	--
NX BEVEL WALL	90042	90169	90289	90410	--	90630	90688
NX STRAIGHT WALL	90043	90105	90290	90411	--	90631	90689
NXL	90044	90170	90291	90412	90512	90632	90690
NXM	90045	90171	90292	90413	90513	90633	90691
NXHW (DIADRILL CONT)	90046	90172	90293	90414	90514	90634	90692
NX-C2	90047	90173	90294	90415	90515	90635	90693
NX-C3	90048	90174	90295	90416	90516	90636	90694
NX-D2	90049	90175	90296	90417	90517	90637	90695
NX-D3	90050	90176	90297	90418	90518	90638	90696
NX SERIES 10 WIRELINE	90052	90178	90299	90420	90520	—	—
NQ, NQ-U WIRELINE	90752	90756	90760	90764	90768	—	—
NC	90053	90179	90300	90421	--	90641	90697
NC-D3	90054	90180	90301	90422	90521	90642	90698
HQ WIRELINE	90753	90757	90761	90765	90769	—	—
3⅞ x 2¼ DCDMA	90055	90181	90302	90423	90522	90643	90699
5½ x 4 DCDMA	90056	90182	90303	90424	90523	90644	90700
7¾ x 6 DCDMA	90057	90183	90304	90425	90524	90645	90701
6⅝ x 5⅜ EJL 3088	90058	90184	90305	90426	—	90646	90702
3⅞ x 2[11]/[32] EJL SERIES 100	90059	90185	90306	90427	90525	90647	90703
3[15]/[16] x 2[11]/[32] EJL SERIES 100	90060	90186	90307	90428	90526	90648	90704
4 x 2[11]/[32] EJL SERIES 100	90061	90187	90308	90429	90527	90649	90705
4⅛ x 2[11]/[32] EJL SERIES 100	90062	90188	90309	90430	90528	90650	90706
4¼ x 2[11]/[32] EJL SERIES 100	90063	90189	90310	90431	90529	90651	90707



The 1-in. standard slotted bolt and wedge has been used for many years in roof and rock control applications. It is especially suitable when a stoper or other driving tool is available and space permits their use.

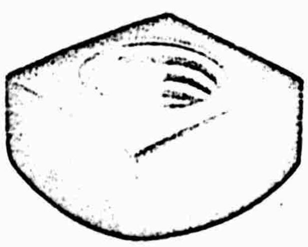
Threaded at one end, the bolt has a slot forged into the opposite end. Forging of the slot maintains the equivalent of the bar's original cross section. Because no metal is lost during the forging operation, there is no reduction in the strength of the bolt. When the bolt is driven into a predrilled hole (1⅛- to 1¼-in. diameter), the steel wedge is forced deep into the slot when the top of the hole is reached. This action expands the end of the bolt providing solid anchorage.

To minimize loss of head room in mine installation, drill hole to an exact depth, 3 in. less than the bolt's length.

On most installations, the 1-in. standard slotted bolt can be tightened to 350/400 ft-lb. Minimum yield load of the standard slotted bolt is 27,800 lb; minimum breaking load is 40,500 lb.

Bethlehem also manufactures an extra-strength slotted bolt in diameters ranging from 1 in. to 2½ in. The 1-in. extra-strength slotted bolt has a minimum yield load of 34,600 lb and a minimum breaking load of 56,000 lb. Suggested torque is 400/500 ft-lb. For more information on Bethlehem's extra-strength slotted bolts, see the following page.

Plain wedge



Nut

Wedges and Nuts

FOR 1-IN. STANDARD AND EXTRA-STRENGTH SLOTTED BOLTS

Made in three sizes:

¾ in. x 5½ in., 400 per keg
⅞ in. x 5½ in., 400 per keg
1 in. x 5½ in., 300 per keg

All wedges, tapered to a sharp point for easy installation, are shipped in wooden kegs.

A regular square nut is recommended because it is strong enough to break the 1-in. slotted bolt. However, finished hexagon, heavy square, and heavy hexagon nuts can also be furnished.

Information on wedges for larger diameter, extra-strength bolts can be found on the next page.

1-INCH SLOTTED BOLTS

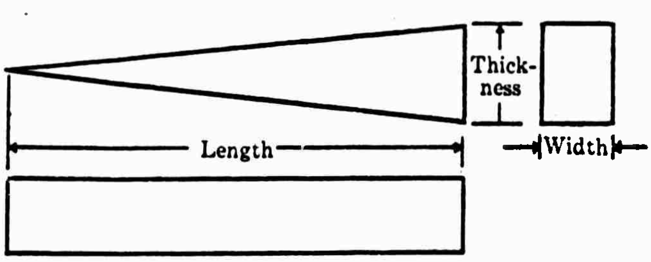
Bolt designation	Recommended hole sizes, in.	Lengths*	Bolts per bundle	Bolts per lift	Maximum weight per lift	Grade of Steel	Minimum breaking load, lb	Minimum yield load, lb	Length of slot, in.
Standard	1⅛ to 1¼	2 ft to 4 ft 6 in. 5 ft to 6 ft 6 ft 6 in. to 7 ft 7 ft 6 in. to 8 ft	10 5 5 5	400 300 250 200	4125 4052 3903 3600	A306 Grade 60	40,500	27,800	6½
Extra strength	1⅛ to 1¼	2 ft to 4 ft 6 in. 5 ft to 6 ft 6 ft 6 in. to 7 ft 7 ft 6 in. to 8 ft	10 5 5 5	400 300 250 200	4125 4052 3903 3600	A306 Grade 80	56,000	34,600	6½

*Longer lengths can be furnished to meet special needs.

Order in lifts, as shown in above table, for prompt delivery. The steel bands which strap the bundles together make each package into a lift which can be handled easily by crane or lift truck. Wood blocking, placed inside the bands, also becomes part of each lift.

LARGE-DIAMETER, EXTRA-STRENGTH SLOTTED BOLTS

Bolt diam, in.	Hole size, in.	Grade of steel	Minimum breaking load, lb	Minimum yield load, lb	Length of slot, in.
1¼	1½	A306 Grade 80	87,000	50,000	6½
1½	1¾	A306 Grade 80	130,000	70,000	8
1¾	2	A306 Grade 80	161,500	89,300	9
2	2¼	A306 Grade 80	205,000	112,500	10
2¼	2½	A306 Grade 80	260,000	140,000	11
2½	2¾	A306 Grade 80	312,000	164,000	12



WEDGES FOR LARGE-DIAMETER, EXTRA-STRENGTH SLOTTED BOLTS

Bolt diam in.	Length, in.	Thickness, in.	Width, in.
1¼	5½	¾, ⅞, 1	¾
1½	7	1¼	1
1¾	7	1¼	1
2	9	1½	1½
2¼	9	1½	1½
2½	11	1¾	1¾

Bolting Material

Steel Specification. The steel from which Bethlehem roof and rock bolts are manufactured meets the requirements of the Specification for Carbon Steel Ba... subject to Mechanical Property Requirements, ASTM A306, latest issue, Grade 60 for standard slotted bolts, and Grade 80 for headed bolts and extra-strength slotted bolts.

Strength of Finished Bolts. After fabrication, bolts have the following mechanical properties:

Diam, in.	Min yield load, lb	Min breaking load, lb
5/8-headed bolt	14,700	22,500
3/4-headed bolt	21,500	32,000
7/8-headed bolt	28,800	44,000
1-headed bolt	34,600	56,000
1-slotted bolt (standard)	27,800	40,500
1-slotted bolt (extra strength)	34,600	56,000

Thread Fits. All threads are made to accept a Class 2A "go" ring gage.

Bolt-Head Markings.
(1) The length in inches is marked on each bolt head. Example: The figure 60 indicates a 5-ft bolt.

(2) All headed bolts except the 3/4 in. are marked with a five-point star approximately 1/4 in. in diameter. All 3/4-in. bolts are ma-ked with a 1/4-in. triangle (approximate).

(3) Each bolt head is marked with the Bethlehem Steel I-Beam identification.

Expansion Shells

Steel Specification. Material for expansion shells conforms to the requirements of ASTM Specification for Malleable Iron Castings A47, latest issue, Grade 32510. Forged plugs used with expansion shells are made from steel conforming to the requirements of ASTM Specification A306, Grade 60 or 65. Cast plugs are made to ASTM Specification A47, Grade 32510 or ASTM Specification A220, Grade 45007.

Wedges for Slotted Bolts

Steel Specification. Wedges are made of open-hearth steel in accordance with the requirements of ASTM Specification A306, Grade 60 or 65.
Turn to Page 17 for basic dimensions of wedges for slotted bolts.

Roof Plate Washers and Straps

Steel Specification. Roof plate washers and straps are made from open-hearth or electric-furnace steels suitable for punching and shearing. No Bessemer steels are used.

Thickness. Optional, except that plate washers under 5/16 in., bearing directly against the rock, should be embossed.

Angle Washers, Roof Ties, and Channels

Steel Specification. These products are made of open-hearth or electric-furnace steels in which the following percentages are *not to be exceeded:*

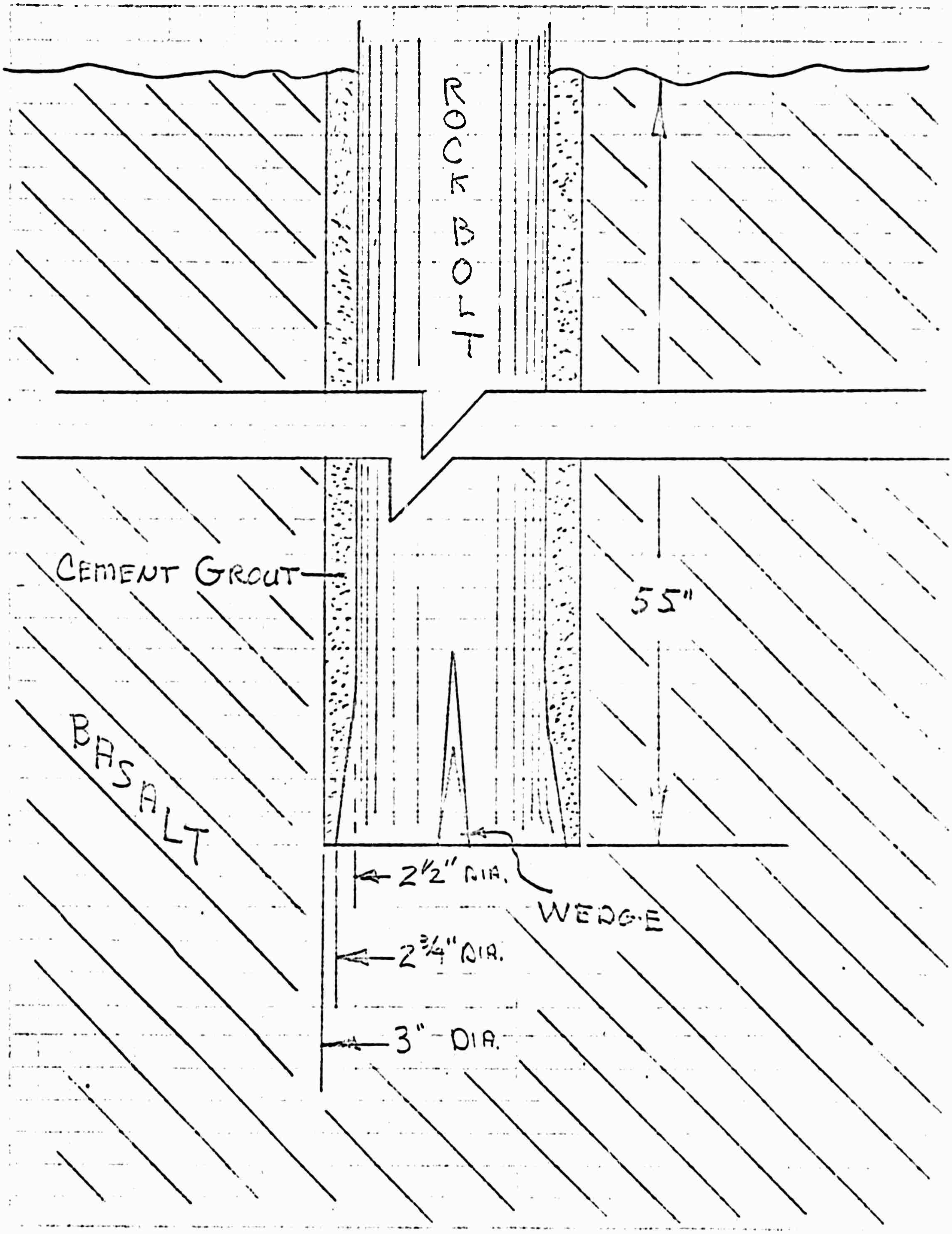
Carbon 0.40 Phosphorus 0.04 Sulphur 0.05

The Specifications equal or exceed current American Mining Congress Standards.

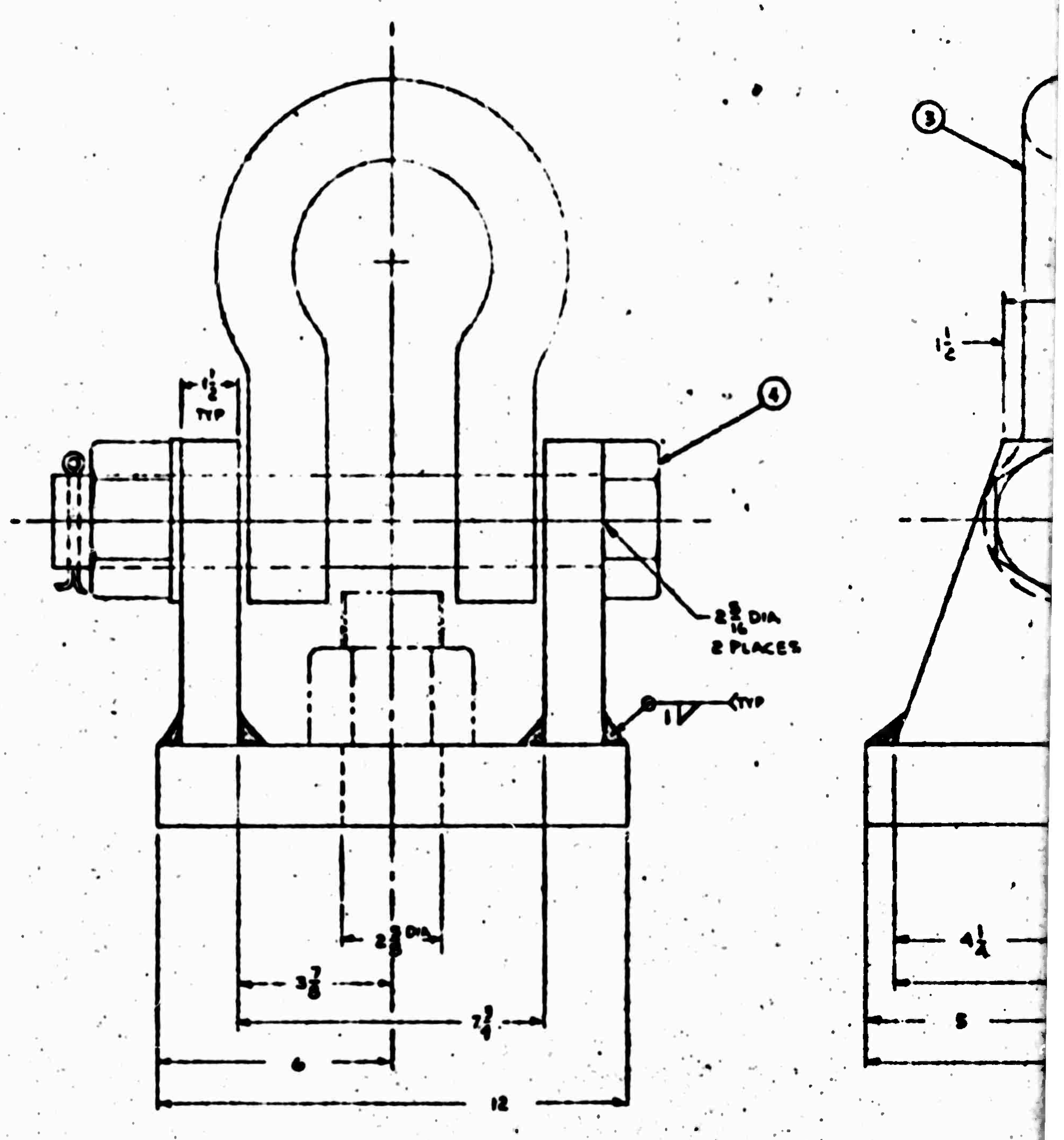
OCEAN SYSTEMS INC.
ARLINGTON, VIRGINIA

BY LSB DATE 9/17/70 SUBJECT ROCK BOLT EMPLANTMENT -TEST BOLT- SHEET NO. ... OF ...

CHKD. BY ... DATE ... JOB NO. ...

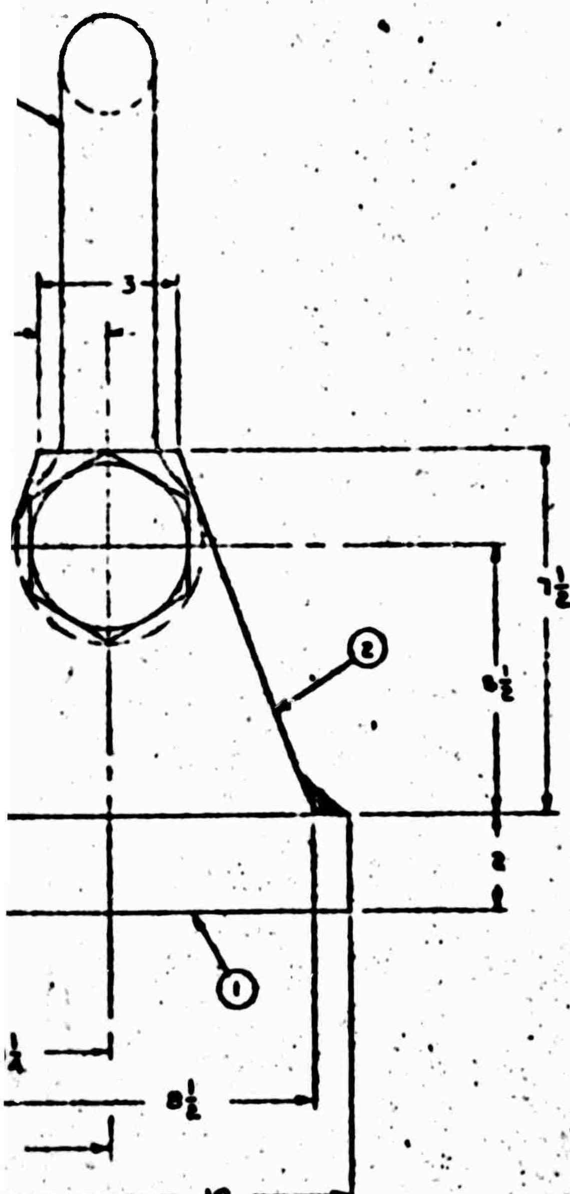


A



REVISION				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	ADDED MATERIAL TO ITEMS 1,2 & 4-6		

B



NOTES:

1. REMOVE BURRS AND BREAK SHARP EDGES.

7		COTTER PIN 1/4 DIA	SST
6		WASHER 4 OD × 2 1/4 ID × 1/4 THICK	STEEL, MILD
5		NUT-HEX 2 1/4 - 4 1/2 NC	STEEL, MILD
4		BOLT HEX 2 1/4 - 4 1/2 NC × 11 LONG	STEEL 4150 LEADED
3	2130-2	ANCHOR SHACKLE 35 TONS	CROSBY-LAUGHLIN FORT WAYNE, INDIANA
2		SUPPORT	STEEL, MILD
1		BASE	STEEL, CARBON 1018
ITEM	PART NO.	DESCRIPTION	MATERIAL

LIST OF MATERIAL

NAME	DATE	OCEAN SYSTEMS, INC.
[signature]	2/1/70	TITLE
[signature]	2/1/70	ROCK BOLT ANCHOR ASSEMBLY COBB SEAMOUNT

MATERIAL:

FINISH:

NEXT ASSY / USED ON

APPLICATION

CODE IDENT NO	SIZE	DWG NO.
25587	D	001097

SCALE 1:2

COBB SEAMOUNT

ROCK BOLT ANCHOR PULL TESTS
August 24, 1970

FOUNDATION SCIENCES, INC.
520 S.W. Sixth Avenue
PORTLAND, OREGON

(503) 224-4435

Appendix II

COBB SEAMOUNT

ROCK BOLT ANCHOR PULL TESTS

SUMMARY

The rock bolt moorage pull test performed on Cobb Seamount was made to determine the holding capability of the anchorage system developed by Ocean Systems, Inc. and if necessary, to indicate areas of possible design improvements in this type of a moorage system. The test was successfully completed and has established that a rock bolt type moorage system is feasible and practical under open ocean conditions. The bolt moorage tested held an ultimate load of 110 tons. Failure was along the bond between the anchor rod and the grout. Simple design improvements can increase the holding capacity to the full strength of the rock bolt. For maximum safety and reliability each rock bolt moorage system should be designed for the specific bottom condition to be encountered.

COBB SEAMOUNT

ROCK BOLT ANCHOR PULL TESTS

I. INTRODUCTION

Purpose of the Work--The work described below was performed to determine the holding capability of a rock bolt anchor system to be used for moorage and foundations on Cobb Seamount. The work is in connection with the unsolicited proposal dated March, 1970 to the Advanced Research Projects Agency by the Oceanographic Institute of Washington for the development of a fixed permanent mooring system on the pinnacle of Cobb Seamount. Field testing was accomplished August 2, 3, and 4, 1970.

Scope of the Work--The responsibilities assigned to Foundation Sciences, Inc. by the Sea Use Council are to:

1. develop a testing procedure and the required equipment which can, under open ocean conditions and at a depth of 140 feet, test to destruction a rock bolt type moorage system,

2. fabricate and check out the testing equipment and procedures,

3. perform the actual test and evaluate its results.

II. EQUIPMENT

The project requires the testing frame to be strong enough to support 400,000 pounds load, light enough to be handled by two divers when submerged, simple to operate and set up in order to minimize diver bottom time and, finally, sophisticated enough to produce the desired answers. The components of the equipment are: a pulling stand, pulling rod and shackle, hollow ram, two-stage pump and dial indicator.

The pulling stand is designed to span a 4-foot cone of possible rock withdrawal around the bolt. It is made from high-strength hollow tubes to minimize weight and add buoyancy. Minor leveling of the stand is accomplished by rotating the tripod around the pulling rod itself. The pulling rod is a specially forged 2 1/2-inch diameter hightensile steel eyebolt with a yield strength of 420,000 pounds. The shackle is a standard 2-inch hanging shackle.

The hollow ram is a 400,000 pound capacity ram with a 3-inch piston travel. The pump is a two-stage Ener-Pac pump with a pressure gauge calibrated to an accuracy of ± .2 of 1 percent. The face glass was removed from the pressure gauge to facilitate pressure equalization. The dial indicator is a standard Starrett indicator accurate to .001 inch with 1 1/2-inches of travel, mounted on a 40-pound concrete block.

III. PROCEDURE

The procedure below is used in performing the test.

1. The pulling stand is assembled on the surface, complete with pulling rod, shackle, pump and gauge.

2. A preliminary dive estimates the required length of the pulling column and the necessary adjustments are made on the surface before lowering the assembly.

3. A line is fixed to the bolt on the bottom and passed through the stand and attached firmly to the ship.

4. The pulling assembly is placed over the side and two styrofoam floatation blocks are attached to the assembly.

5. A strain is taken on the line attached to the bolt and the assembly is lowered along the line to the anchor bolt.

6. A team of two divers is dispatched to position the stand directly on the bolt, connect the shackle to the anchor bolt, remove all slack from the pulling column, level the stand to produce coaxial pull on the rock, and emplace the dial indicator.

7. A second operation by two divers was scheduled to load the bolt in 40,000-pound increments, obtaining a dial gauge reading of displacement on each increment up to 200,000 pounds, and then to relax the pull in 40,000 pound decrements and again read the dial gauge. This would produce information on energy storing capabilities, the percent of elasto-plasticity of material, and an unloading modulus.

8. A third team of two divers was scheduled to pull the bolt in 80,000 pound increments, obtaining a dial gauge reading either to 400,000 pounds or until failure occurred, with the maximum pressure to be noted.

9. The fourth team was scheduled to un-shackle the bolt and prepare for retrieval of the equipment.

In actual practice, there was some difficulty in rigging the equipment and in ship handling, but once the equipment was on the bottom the first diver teams' mission was accomplished in the prescribed time. The second dive team had trouble with the pump operation and required two more team dives to locate and correct the difficulty.

The fourth team was able to load the bolt to 100,000 pounds and read the dial gauge. The fifth team was able to load the bolt to 200,000 pounds, but the concrete block with the dial indicator lodged under one of the cross braces of the stand, negating any further deformation measurements. They reported the pressure had decreased to 40,000 pounds. The sixth team was able to pump only to 220,000 pounds because the bolt anchor was withdrawing as fast as they could pump and extend the ram. At failure, the total ram extension was 1-3/4 inches, total bolt withdrawal was 1-1/2 incnes. Divers also reported that the pressure gauge read 40,000 pounds after the anchor failed, indicating some residual holding capability after failure.

A diving team made a post-test survey to find that the stand was embedded in the bottom approximately 1/4 inch and the residual slack in the bolt was approximately 3/4 of an inch. It was impossible to examine the rod and hole because of a 2-inch anchor plate permanently affixed to the bolt.

IV. RESULTS

Figure 1 is a plot of the results of the rock bolt moorage pull test. The failure of the moorage was between the rock bolt and the grout.

Prior to failure, the bolt was loaded twice to loads in excess of 50 tons and each time, during diver team changes, the load dropped to 20 tons. This indicates that the non-creep load of the tested moorage is about 20 tons.

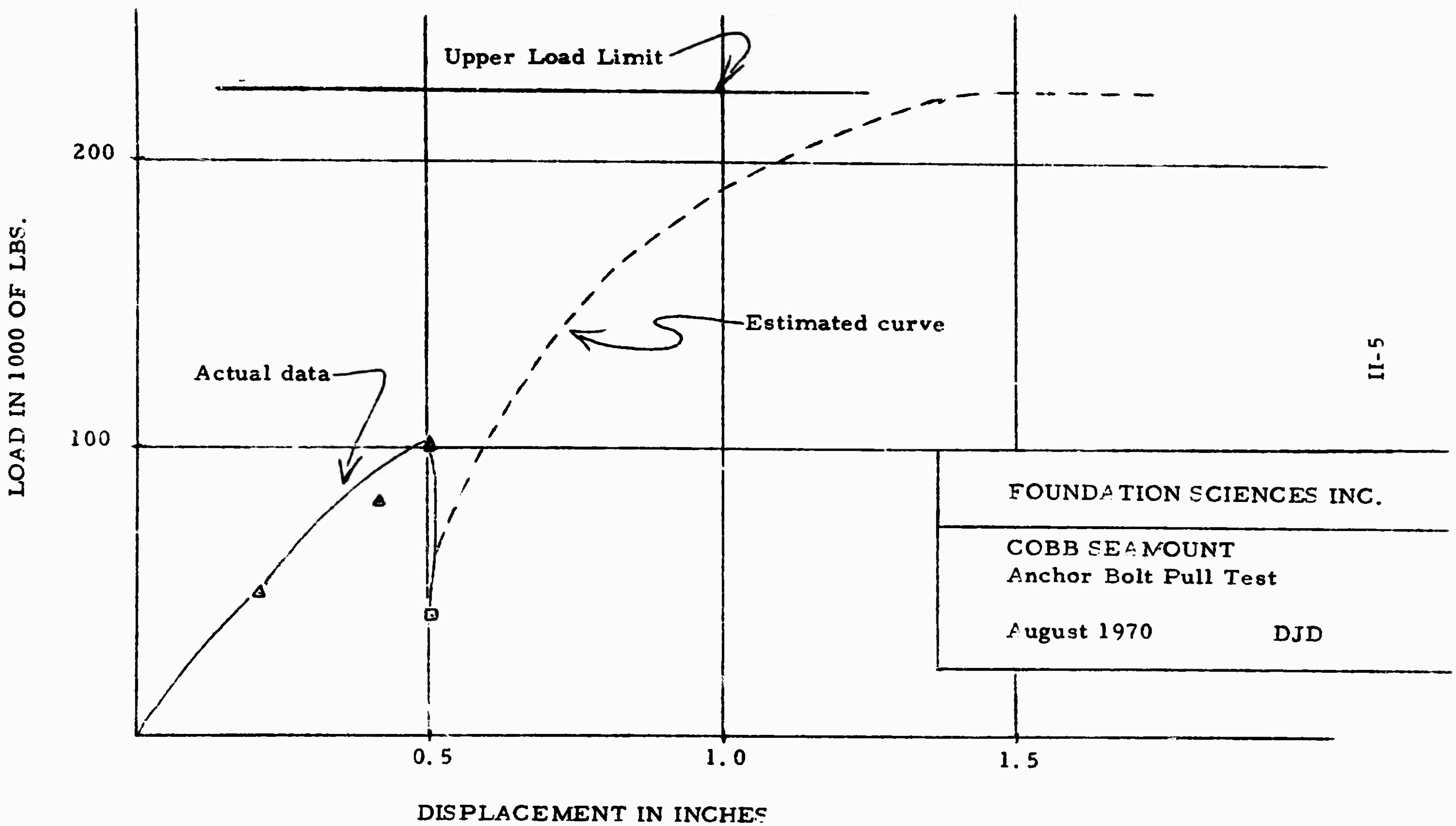

Upper Load Limit
200
100
LOAD IN 1000 OF LBS.
Actual data
Estimated curve
0.5
1.0
1.5
DISPLACEMENT IN INCHES
FOUNDATION SCIENCES INC.
COBB SEAMOUNT
Anchor Bolt Pull Test
August 1970
DJD

Figure 1

The specific results of the test are:

1.	Ultimate load	110 tons
2.	Yield load	50 tons
3.	Safe load	35 tons
4.	System modulus of deformation	2×10^5 psi

Although some improvements can be made in the bolt design, the test proved that a rock bolt type moorage system is feasible and practical.

V. RECOMMENDATIONS AND COMMENTS

1. The moorage system failed along the bond between the bolt and the grout. This was primarily due to the short depth of embedment of the bolt. Future moorage systems of this type should have a minimum of 60 rod diameters of embedment in grout.

2. Care should be taken to assure that the bolt is free from scale and oil before it is installed in the hole.

3. Deeper embedment of the bolt would also increase the non-creep load capacity of the system.

4. The use of a resin grout in place of the cement grout should be considered as it has higher earily strength and is easy to install.

5. The general system and method has possibilities of application to a wide variety of bottom conditions including soft bottoms.

Respectfully submitted this 24th day of August, 1970.

FOUNDATION SCIENCES, INC.

Donald J. Dodds
Vice-President