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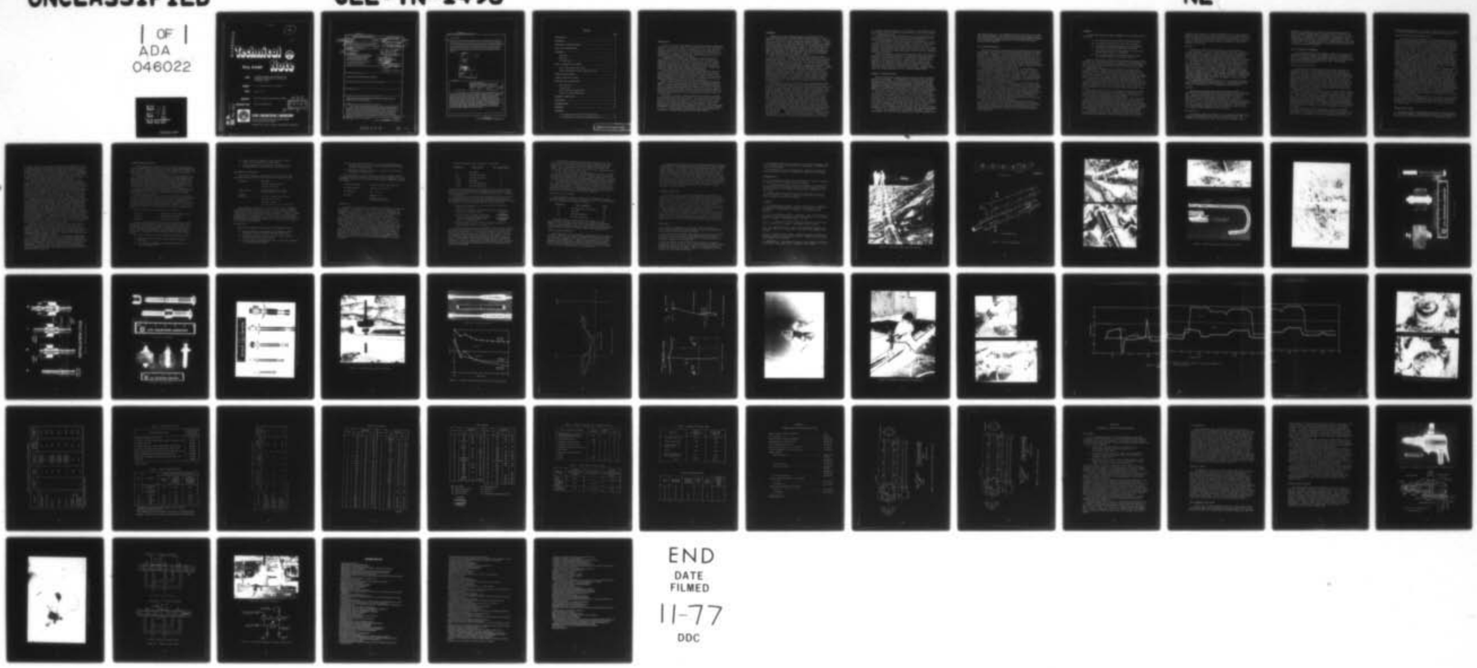

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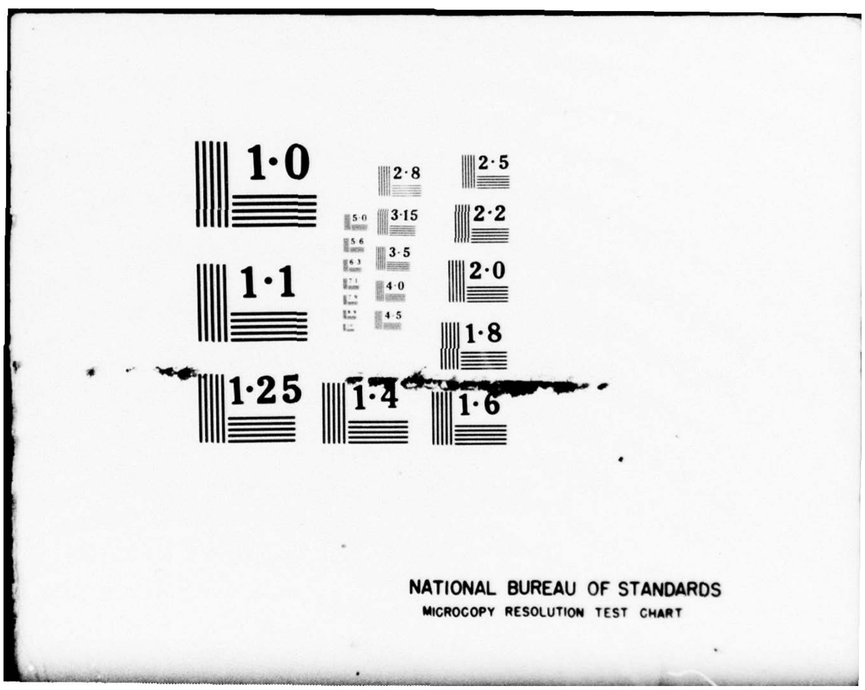
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author: R. L. Brackett and W. R. Tausig

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The U. S. Navy currently maintains and operates numerous underwater power and signal cables. Most of these cables utilize split pipe systems to protect the cable from damage in the surf zone and when crossing exposed rocky seafloors. Past experience has shown that the hardware used to install the split pipe system lacks the reliability and maintenance-free operation required for the life of these cables. Based on previous experience with cable failures, the areas determined to be in greatest need of investigation

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The U. S. Navy currently maintains and operates numerous underwater power and signal cables. Most of these cables utilize split pipe systems to protect the cable from damage in the surf zone and when crossing exposed rocky seafloors. Past experience has shown that the hardware used to install the split pipe system lacks the reliability and maintenance-free operation required for the life of these cables. Based on previous experience with cable failures, the areas determined to be in greatest need of investigation are fasteners for holding the split pipe halves together, immobilization of the pipe, and cathodic protection for the entire system. This report presents the results of laboratory tests of both prototype and commercially available hardware components which appeared to be suitable replacements for the existing split pipe hardware. Also described is the installation of a 300-ft-long test section of split pipe at Anacapa Island which will be inspected during a 5 year period to determine the long-term performance of selected hardware.

CONTENTS

INTRODUCTION

The U. S. Navy currently maintains and operates numerous underwater power and signal cables. Most of these cables utilize split pipe systems (Figure 1) to protect the cable from damage in the surf zone and when crossing exposed, rocky seafloors. Past experience has shown that the hardware used to install the split pipe system lacks the reliability and maintenance-free operation required for the operational life of these cable protection systems (up to 20 years).

Documentation of failures and subsequent repairs has helped to define a few, but not all of modes of failure of ocean cables due to inadequate or inefficient cable protection systems. The most common causes of failure appear to be lack of adequate fasteners to hold the split pipe protectors on the cables, and lack of proper stabilization systems to prevent excessive vibration and movement of the cable as a result of extreme wave forces caused by adverse weather.

Previous investigations into hardware requirements for support of existing nearshore cable systems have been mainly confined to in-the-field trial-and-error procedures of using off-the-shelf hardware that appears adequate at the time of installation. However, split pipe cable protection systems have continued to fail, which indicates that these in-the-field modifications are not entirely successful.

Under the sponsorship of the Naval Facilities Engineering Command (NAVFAC), a project was undertaken by the Civil Engineering Laboratory (CEL) to develop improved hardware and methods for the maintenance and repair of existing split-pipe-protected inshore ocean cables. Based on previous experience with cable failures, the areas in greatest need of investigation were determined to be fasteners for holding the split pipe together, immobilization of the pipe, and cathodic protection for the entire system.

This effort is directed toward maintenance and repair of existing split-pipe-protected cables; the subject of protecting new cable installations has been treated elsewhere [1]. Only those portions of split-pipe-protected cables accessible by divers are treated in this report. Because of the limitations imposed by no decompression diving, the maximum depth of protected cable considered is 120 ft. Also, the minimum incremental length of cable protection that could be replaced is limited to 3 ft (i.e., replacement of one section of split pipe) because of a requirement to maintain existing split pipe/cable systems.

BACKGROUND

Communication cables passing through the nearshore zone are generally protected with two spiral wraps of heavy armor wire. These cables are set in place on the ocean floor and then encased in cast iron split pipe sections for added armoring and weighting (Figure 2). Cables crossing rock and coral seafloors generally require additional protection, which is provided by placing them in a trench or by anchoring the cable to the seafloor with grouted U-rods (Figure 3). The U-rods, which are made from 4-ft-long, 1-in.-diameter round stock bent into a tight U-shape, are placed over the split pipe with the rod ends extending down into holes pre-drilled into the seafloor. The rods are then grouted into place with a fast-setting hydraulic cement.

Eight fasteners are required to secure the two halves of each section of split pipe. Initially mild steel nuts and bolts were used to assemble the split pipe. No significant difficulty was experienced with this system, unless sections of pipe had to be removed to make repairs to the cable damaged by some other cause. In this case, the corrosion of the nut and bolthead caused problems in removing the fasteners. They generally had to be ground off in order to disassemble the pipe. Stainless steel nuts, bolts, and lockwashers have been used more recently in an attempt to eliminate this problem. Although the fastener corrosion problem was greatly reduced, the corrosion of the cast iron split pipe flange was accelerated due to the galvanic couple formed by the cast iron and stainless steel. The reduction in flange thickness caused by this corrosion relieves the compression on the lock washer, thereby allowing the nut to be unscrewed by wave-induced motion of the cable system (Figure 4).

The assembly of split pipe with nuts, bolts, and washers by divers is the most time-consuming phase of the cable installation operation, especially in cold water where divers have very little tactile sensitivity. A typical operation requires two divers to install each fastener. One diver is required to assemble and hold the bolt from spinning, while the other diver torques down on the nut with a hand or impact wrench. The bolt must be inserted up through the hole from the underside of the pipe. In many cases, this side of the pipe is difficult to reach in sandy or rocky bottom conditions. Average installation times under ideal conditions require 4 minutes per pipe section using two divers.

Several problems have been identified with the use of U-rods for immobilization of split-pipe-protected cables. U-rods do not provide any positive clamping load, and, thus, the split pipe is able to move slightly. This movement contributes to abrasion of both the pipe and U-rod. If the pipe under the U-rod becomes disconnected, the abrasion of the cable on the rod can result in a critical failure (Figure 5). U-rods require large-diameter drilled holes (2-1/2 in. in diameter), which necessitates the use of heavy rock drilling equipment. U-rods made of stainless steel suffer from crevice and pitting corrosion at and below the seafloor interface (Figure 6). U-rods made of copper nickel alloys do not suffer from the same corrosion problems, but the initial material cost is prohibitively high.

Problems have also been identified with the grout-dispensing techniques currently used. These problems and the development of a diver-operated grout-dispensing system are discussed in Reference 2.

As discussed above, one of the major factors contributing to deterioration and failure of split pipe systems is corrosion. This problem is made even worse when the split pipe/cable system is subjected to rapidly moving waterborne sand, which produces an effect much like sandblasting. The waterborne sand removes the protective layer of corrosion products, exposing fresh metal, thus greatly accelerating the consumption of metal by corrosion.

Large-scale movement of the split pipe/cable system caused by wave-induced forces has been responsible for considerable amount of damage to the system. Wave-induced motion of a nonstabilized, suspended cable resulted in failure of the cable at a water depth of 120 ft where the midpoint of the suspension came in contact with the seafloor rock. Abrasion of the split pipe fasteners creates problems when trying to remove the nuts and bolts for maintenance and repair. A special nut splitting tool has been developed [3] to minimize this problem; however, removal of damaged fasteners is still a time-consuming project.

APPROACH TO PROBLEM SOLUTION

Based on the previous problem analysis four main areas of investigation were identified: (1) modification of materials and/or design of the split pipe sections, (2) evaluation of new fastener material and configurations, (3) development and evaluation of immobilization techniques that eliminate the grouting requirement and provide a positive clamping action between the split pipe and the seafloor, and (4) development of a cathodic protection system if the improved cable protection system could not readily be fabricated from corrosion-resistant materials.

Literature was reviewed to determine if commercial hardware was available to meet the improved criteria. Where no commercial hardware was available, performance specifications were written for procurement of prototype items. These commercial and prototype components were then investigated in the laboratory and subjected to short saltwater exposure tests (6 months) in Port Hueneme harbor to identify unsuitable candidates. The hardware components that showed promise were used in a 300-ft-long open ocean test installation on the south side of Anacapa Island (offshore from Port Hueneme, California), where they are being inspected semi-annually for a 5-year period to determine their long-term performance.

Prior to the investigation of new hardware components, currently used hardware was tested to obtain baseline data (tensile strength, cost, installation time, etc.) for comparison with the test data of the candidate improved hardware. The expected wave and current loading on split pipe and associated hardware was then theoretically analyzed to determine if the structural/strength properties of the existing and improved system would be adequate.

SPLIT PIPE MODIFICATIONS

Most of the problems associated with the deterioration of split pipe and fasteners can be traced to the electrochemical interaction of these two dissimilar components. By fabricating the split pipe out of inert material (i.e., concrete, plastics, glass reinforced epoxies, etc.) or metallic alloys compatible with the existing fasteners, a majority of the corrosion and deterioration problems could be solved without the use of a cathodic protection system. At the same time, new configurations for the pipe could be considered that would reduce the number of fasteners, thus making the diver construction operation simpler. Appendix A contains technical information on cast iron split pipe.

A preliminary investigation revealed that, of the nonmetallic materials under consideration, concrete was the only one to provide sufficient abrasion resistance to be acceptable. However, it also had to be discarded as a candidate because it required such a large cross section to obtain strength properties comparable to cast iron pipe that it would not be compatible with the existing pipe. Corrosion-resistant metallic alloys were determined to be undesirable also because of the extremely high cost of the raw materials.

The simpliest and lowest cost alternative to cast iron split pipe was to use no split pipe at all. It is possible that an armored cable could be secured to the seafloor with rock bolts or some other anchoring system and suffer less from wave and current action than a split-pipe-protected cable. This technique has been used to protect four cables in the Hawaii area (Figure 7); to date, no significant deterioration has been found. However, before this technique can be recommended as a general solution to the problem, additional work must be conducted to determine the relative abrasion resistance of split pipe and bare cable on various types of seafloor rock and coral.

Because of lack of a more appropriate material from which to fabricate a new form of split pipe, and the uncertainty of performance of bare cable anchored to the seafloor, the remainder of the effort to develop improved hardware was conducted with the constraint that all components must be compatible with the existing split pipe material and configuration.

FASTENERS

In selecting potential fastener candidates, the following criteria were used:

(1) The installation process should be quick and simple.

(2) The fastener should have as few parts as possible.

(3) The fastener should be designed so that installation requires access from only one side of the pipe.

(4) The fastener should be strong enough to hold the pipe halves together under all conditions.

(5) The fastener should resist vibration loosening even if the pipe partially corrodes away under it.

Among the alternatives considered for replacing the presently used stainless steel nuts and bolts were: (1) adhesives, (2) nonmetallic nuts and bolts, (3) clamps, (4) one-piece fasteners, and (5) self-locking nuts. Stainless steel and mild steel nuts and bolts were also tested to obtain baseline data.

Adhesives for joining split pipe underwater are commercially available; however, several deficiencies for joining split pipe were identified: (1) the surfaces to be joined must be clean and free from any corrosion product; (2) the sections of pipe must be bolted or clamped together until the epoxy hardens; and (3) presently available adhesives have an unacceptably low bonding strength (approximately 200 psi).

Commercially available clamps for joining split pipe were investigated, and none were found that appeared to offer any advantage over the currently used mechanical fasteners. Their higher initial cost and more complex configuration (with the resultant greater risk of failure) also contributed to the decision to exclude clamps from further consideration.

Self-locking nuts have been used previously on a split pipe cable repair operation. Since this cable is periodically inspected, it was felt that sufficient information on the performance of this type of fastener could be obtained without further testing.

Previous tests with nonmetallic fasteners (nylon, PVC, and glass-reinforced plastic) yielded unsatisfactory results. In all cases, the fasteners had been fabricated one at a time from round or hex stock. This resulted in very high costs and lower-than-predicted failure loads. Since those tests, PVC nuts and bolts have become commercially available. This significantly reduces the unit cost per fastener, and, according to vendor literature, better tensile strength properties are promised.

A preliminary study [4] was conducted in 1971 of some special purpose fasteners for split pipe. This study consisted of a survey of the commercial availability of blind bolts, pop rivets, and spring fasteners that could meet the size requirements for split pipe fasteners. Based on this analysis and an updated review of vendor capabilities, the BOM bolt, Huck bolt, and Hi Shear torque bolt were selected for evaluation. The BOM bolt and Huck bolt are both off-the-shelf items, while the Hi Shear torque bolt is a special order item, designed to CEL specifications for split pipe.

BOM Bolt

The BOM bolt (Blind Oversized Mechanically locking fastener) is shown in Figure 8. It is a one-piece fastener that can be installed from one side of the workpiece. This fastener functions by pulling a central mandrel up through and crimping the bottom of the fastener's outer sleeves. The mandrel is pulled using a special hydraulic tool. The fastener and tool are both manufactured by Huck Manufacturing Company.

To install this fastener (Figure 9), the diver inserts the blind bolt into the hole in the split pipe flange, and then engages the tool onto the fastener. The jaws in the nosepiece of the tool lock onto the grooves at the top of the fastener. When the tool is activated, a piston pulls the mandrel up through the sleeve, which crimps the lower end of the fastener into a strong bulbed head. Continued pull causes the anvil to swage the collar material against the mandrel, mechanically locking the fastener assembly. The fastening operation is completed when the central mandrel breaks off inside the nose of the tool. An ejector inside the nosepiece ejects the broken off mandrel. The tool is then ready for the next installation.

The BOM fastener has the advantage that it is one piece and can be easily installed from one side of the pipe. It also resists loosening caused by vibration because of its mechanically locking feature.

Huck Bolt

The Huck bolt, manufactured by Huck Manufacturing Company, is installed in the same manner and with the same hydraulic tool as the BOM bolt. However, the Huck bolt is a two-piece fastener (Figure 10) and requires access to both sides of the split pipe. The central mandrel is inserted up through the underside of the split pipe. The locking collar is then placed over the mandrel, similar to placing a nut onto a bolt. The tool is then inserted over the mandrel/collar, and the bolt is swaged in the same manner as the BOM bolt. The Huck bolt has a higher preload clamping force than the BOM bolt, which is useful for closing any gaps between the split pipe halves.

Hi Shear Bolt

The Hi Shear torque bolt (Figure 11) is a specially designed blind fastener made by Hi Shear Corporation to CEL specifications. The fastener is installed as one unit, using a hydraulic impact wrench to tighten it. Torquing the nut causes the central threaded mandrel to pull up through the outer sleeve. A square collar at the top of the sleeve keeps the fastener from rotating on the split pipe as the nut is tightened. As the mandrel is pulled tighter, it expands the sleeve bottom against the work piece, locking the fastener in place. The top of the installation nut then breaks off at a predetermined torque of 800 to 900 in.-lb. The completed fastener installation becomes essentially a one-piece nut and bolt assembly.

TESTS OF PROSPECTIVE FASTENERS

A preliminary analysis of the fasteners chosen for evaluation was conducted to establish hardware performance criteria for a long-term test and to identify fasteners that showed promise for further development. The preliminary tests consisted of a split pipe tensile pull test and a diver shallow-water ocean simulation test. The candidate fasteners are given in Table 1.

Split Pipe Tensile Pull Test

The objective of the split pipe pull test was to determine the comparative strengths of the different fasteners when installed on assembled split pipe. If the assembled pipe is pulled longitudinally along the ocean bottom, either during installation or afterwards by wave action, the individual pipe sections are loaded in tension. When the pipe joints are pulled in tension, the bell end tends to spread and separate, allowing the socket to pull out. This places the fasteners nearest the bell in tension. The strength integrity of each pipe joint depends on the fastener's ability to keep the two pipe halves tightly clamped. To obtain this comparative data, two assembled sections of split pipe were loaded in a special jig and pulled in tension using a 400,000-lb Baldwin Testing Machine.

Results of a similar test conducted at CEL in 1972 showed the split pipe bell, using class 5 bolts, to fail under a tensile load of 70,000 lb. Failure occurred when the bell spread, allowing the socket to pull out. The 1972 tests established 35,000 lb as the safe working tensile load for the bell joint of the split pipe. Initial tests on the BOM fastener and Huck bolt were inconclusive. A clearance problem between the split pipe flange and the Huck installation tool prevented proper installation of the fastener. As a result, an entirely new installation tool was developed. Details of this tool development are presented in Appendix B.

Table 2 shows the results of the split pipe pull test. When installed with the CEL tool, the BOM fastener was the strongest of all the fasteners. The results of the test also showed the strength of the pipe joint to be dependent only upon the holding capacity of the two fasteners nearest the joint. Loosening or tightening the bolts elsewhere on the pipe flange had no effect on the strength of the pipe joint.

Diver Shallow-Water Ocean Simulation Tests

The objective of the shallow-water ocean simulation test was to compare diver installation techniques and times for different fasteners under simulated ocean conditions, and to determine any human factors or mechanical problems with the tools or fasteners under controlled conditions. Table 3 shows the results of the four different tests that were conducted. In the first test, a single diver was timed as he assembled three sections of split pipe with threaded nuts and bolts by using a hydraulic impact wrench. The second test was identical, except two divers were used. The third test was conducted using Hi Shear one-piece bolts and a hydraulic impact wrench. The Hi Shear bolt installation test experienced problems with the bolts spinning on the pipe flange. The test was repeated using a crescent wrench to help hold the bolts in place. The fourth test was conducted using the BOM bolt and the newly designed CEL installation tool. This test experienced difficulty when the gripping jaws of the installation tool began to slip. As a result, some of the BOM fasteners had to be pulled twice.

The results of these initial tests show the BOM fastening system to be the fastest and easiest method of installation. To prevent any further spinning problems, the next generation of Hi Shear fasteners was modified by enlarging the square collar at the top of the sleeve. The BOM test was inconclusive. The clearance between the pipe flange and CEL installation tool was so small that the gripping jaws inside the tool nosepiece could not fully engage on the fastener. Later modifications to the nosepiece, discussed in Appendix B, solved this problem.

The diver installation tests were repeated in the simulation tank after the required modifications were made to the CEL tool nosepiece and the Hi Shear fastener collars. These test results are shown in Table 3 as tests 3b and 4b. The major difference in complete installation times for the two fasteners (BOM and Hi Shear) is in the torque-down times. The BOM fastener averages 10 seconds each to be crimped with the CEL tool, while the Hi Shear fastener averages 16 seconds each to be torqued down with the impact wrench.

The Huck bolt was eliminated from these tests since its installation method is identical to the BOM method. Also, having to insert the bolt up through the underside of the pipe and hold it in place until the installation tool was engaged made the Huck bolt system too difficult for divers to use.

IMMOBILIZATION SYSTEMS

Four basic types of immobilization systems were considered during the preliminary analysis: (1) explosively driven studs, (2) wedge-type rock bolts, (3) grouted rock bolts, and (4) oversized driven pins.

Land tests conducted with explosively driven studs revealed the stud to either richochet or spall all rock other than sedimentary rock (such as sandstone) to the extent that no holding force could be developed. Even when penetration was achieved in sedimentary rock, the development of useful holding strength levels depended heavily on a prior knowledge of the hardness of the rock so that the proper size charge could be selected. The percussion and noise caused by the explosive charge (a 38 caliber shell) presented potential problems to the diver.

A literature review revealed grouted rock bolts and oversized driven pins to be unacceptable because of deficiencies in equipment or techniques to install them or poor reliability with previous installations. In contrast, it was found that a considerable amount of work [5] has been done in the development and evaluation of hardware and techniques for fastening objects to rock and coral seafloors using expansion-type rock bolts. Commercially available rock bolts (Figure 12) have been found to be quicker, less expensive, and easier to install than grouted fasteners and are superior in holding capacity in all but the weakest seafloor materials (less than 5,000 psi compressive strength).

Although data are available [5] on the holding capacity of rock bolts in various seafloor materials, very little is known about the rate of deterioration due to the galvanic corrosion couple formed between steel rock bolts and cast iron split pipe. During one underwater construction project conducted in 1973, 5/8-in.-diameter rock bolts were used to secure a short length (≈500 ft) of split pipe to the seafloor. The installation was accomplished by drilling 5/8-in.-diameter holes into the seafloor rock, using the holes in the pipe flange as a template. After the bolts were installed, two zinc anodes were secured to the top of each bolt (Figure 13). A subsequent inspection revealed the anodes had been consumed within 6 months, since they were protecting the pipe as well as the rock bolt. In the 2-1/2 years since the anodes were depleted, some deterioration of the rock bolts has occurred, but not enough data are available to predict how long they will last.

A special rock bolt (Figure 14) was developed at CEL in 1974 for anchoring cables to very weak coral seafloors. These bolts are not especially well suited for use with split pipe since the 1-1/4-in.-diameter anchor portion of the bolt will not fit through the hole in the split pipe flange. The use of these bolts with existing split pipe installations would require a clamp to be placed over the pipe with the rock bolts passing through the clamp.

The success of wedge-type rock bolts in producing reliable high-capacity seafloor anchors, plus the ease of installation compared to grouted fasteners, suggests that they would be an ideal solution to the split pipe immobilization problem if an adequate service life could be established. Therefore, the 5/8-in.-diameter masonry stud anchors manufactured by Phillips Drill were selected for further evaluation during the long-term testing to determine life expectancy both with and without cathodic protection.

CATHODIC PROTECTION SYSTEM

The development of a cathodic protection system became essential when no suitable substitute for cast iron split pipe could be identified and alloy steel fasteners and rock bolts were selected for testing. Two basic types of cathodic protection were considered: (1) sacrificial anodes, and (2) impressed current systems.

A preliminary analysis of the advantages and disadvantages of each type of system indicated sacrificial anodes would be more suitable for repairs to existing installations and impressed current would be more appropriate for new installations. This conclusion was based on the fact that the impressed current system would require conductors to be run from shore; these would be susceptible to damage unless they were enclosed in the split pipe during the original installation.

A test was conducted in Port Hueneme harbor to determine the anode consumption rate and electrical current requirement for a cathodic protection system. The effect of painting the pipe and installing jumper cables was also tested.

Three 30-ft-long strings of split pipe were installed in water 10 ft deep near the entrance to the harbor. A 25-lb zinc anode was attached to each of the three test sections. A 0.01-ohm precision resistor was placed in series with the anode to allow current measurements to be obtained. The split pipe was sandblasted to clean metal, and one string was painted with black coal tar epoxy (Porter C 200™). Two of the strings were assembled with jumper cables to provide electrical continuity.

The test condition of each of the three sections was:

Section 1. . . . . .Sandblasted without jumper cables

Section 2. . . . . .Sandblasted with jumpers

Section 3. . . . . .Painted with jumpers

The test installation was left in place for a period of 6 months. During this time the galvanic potential of the anodes and pipe was measured with an underwater voltmeter to determine the extent of protection the pipe was receiving. The voltage drop across the resistor was also measured to determine the current flowing from the anode to the pipe. The results of these tests are shown in Figure 15 and Table 4.

As a result of this test, the following conclusions were drawn:

(1) Split pipe must be painted to make cathodic protection practical.

(2) The current requirement for painted pipe averages 0.4 A for 10 sections (30 ft).

(3) Jumper cables are required if more than one section of pipe is to be protected by a single anode.

(4) Anode consumption for painted pipe is relatively low, averaging about 0.2 lb of zinc per section per year.

LONG-TERM TEST INSTALLATION

Based on the results of the Laboratory and harbor tests, the following hardware components were selected for long-term testing:

Fasteners. . . . . .Huck BOM
Hi Shear Stainless Steel
Hi Shear Mild Steel

Immobilization. . . . . . Philips Wedge Masonry Anchor, 5/8-in. diam. x 12 in. long.

Cathodic protection. . . . . Sacrificial anode consisting of:
five 75-lb zinc anodes
99 jumper cables
Coal tar epoxy coating on split pipe

To determine the suitability of these candidate system components to perform effectively in an actual split pipe installation, a 300-ft-long test section was installed that will be inspected semiannually for a 5-yr period. This installation serves two purposes. First, it provides an opportunity for military divers to install split pipe using the new hardware and tools, and second, it provides an opportunity to observe the condition of the candidate hardware over a long period when subjected to the open ocean environment.

Site Selection

The test site selection was based on the following criteria.

(1) The site should be close enough to Port Hueneme to allow semiannual inspections without high deployment costs.

(2) Because of the short length of the test section (300 ft), a steep depth gradient is desirable.

(3) The area should be predominantly rock to allow full evaluation of the immobilization system.

(4) The site should be protected to allow for installation and inspection by divers, but it should be subject to the effects of winter storm conditions.

(5) Underwater visibility should be at least 30 ft to allow for photographic documentation.

The selected site is located on the south side of Anacapa Island at coordinates 34°0'15"N latitude, 119°23'30"W longitude (Figure 16). After preliminary selection, the site was surveyed, and the following conditions were found:

- Bottom material . . . . . Vesicular Basalt, 80%; Sand, 20%
- Depth gradient . . . . . 14% Slope (0 to -42 ft)
- Visibility . . . . 30 to 90 ft
- Swell . . . . Minimum, 1/2 ft
  Maximum, 8 to 10 ft
  (late summer and fall)

Installation

The actual installation was accomplished in six phases: (1) mooring installation, (2) assembly of 75 ft of split pipe on warping tug, (3) deployment of cable and first 75 ft of split pipe, (4) deployment and assembly of remaining 225 ft of split pipe by divers, (5) installation of rock bolts and anodes, and (6) inspection and documentation.

The mooring installation consisted of two rock bolt anchors to which 3-ft-diameter mooring buoys were attached. The location and configuration of the moorings are shown in Figures 17a and 17b. The anchors consisted of 2-1/2-in.-diameter by 2-ft-long Williams rock bolts. The holes into which the bolts were inserted were drilled using a hydraulic rock drill (Figure 18) currently under development at CEL.

Because of the heavy surge conditions that exist near shore, the first 75 ft (25 sections) of pipe were assembled around the cable on board the CEL warping tug. A 12-in. H-beam was first tack-welded to the deck, and the pipe and cable were assembled in the upper channel (Figure 19). This served to stabilize the pipe during transit to the test site, and it also acted as a guide during deployment of the pipe and cable.

The bolting sequence for the first 25 sections was:

Section No.	Type of Bolt	No. of Rock Bolts
1	Mild Steel	2
2-5	Hi Shear Stainless	4
6-10	Hi Shear Mild Steel	0
11-15	Huck BOM	2
16-20	Hi Shear Stainless	0
21-25	Hi Shear Mild Steel	0

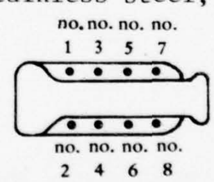
This phase of the installation also allowed all of the tools and power sources to be checked out prior to deployment and the divers to familiarize themselves with the tools and their operation prior to using them in the open ocean.

After the split pipe and cable had been deployed at the test site, the remaining 225 ft of split pipe were assembled on the seafloor by divers using the three types of blind bolt fasteners discussed previously. The procedures used for assembling the test installation were:

(1) One type of fastener was to be used for five consecutive split pipe sections.

(2) Sequence of fasteners: Huck BOM, Hi Shear Stainless Steel, and then Hi Shear Mild Steel.

(3) Bolt holes no. 5 and no. 6 would not contain fasteners (Rock bolts would be installed during the immobilization phase of the installation)



(4) Jumper cables were to be connected between sections of pipe using bolt holes no. 1 and no. 7.

The divers reported only minor problems with the tools and fasteners, and most of these occurred in the heavy surge area near the shore end. Positioning the BOM tool on to the fastener tended to slow the installation process when the divers were working in shallow water, but this was minimized as they became more familiar with the operation of the tool. Hole misalignment between half sections and lack of sufficient clamp-up force were the major problems encountered with the Hi Shear fasteners. It was also found that all of the fasteners had to be inserted into the holes before tightening the first one to assure that the holes could be aligned.

A hydraulically powered rotary percussion rock drill was used to drill the holes for installation of the 5/8-in.-diameter rock bolts (Figure 20). The bolts were inserted through the pipe flange and pounded into the predrilled hole in the seafloor rock with a 3-lb hammer. The nut was then torqued to about 60 ft-lb to expand the anchor and securely clamp the pipe to the rock.

The rock bolts were always installed in pairs in holes no. 5 and no. 6 in the split pipe flange. This prevented the pipe from twisting and applying a bending load to the bolt. The bolt pairs were to be installed in every sixth section of pipe; however, the presence of sand and loose rocks in some areas precluded absolute adherence to this spacing.

Five anodes were attached, one each to sections 10, 30, 50, 70, and 90. A 20-ft-long cable connected each 75-lb zinc anode to the pipe. The anodes were placed as far from the pipe as possible and in a rocky area where they wouldn't be covered with sand. After the rock bolts and anodes were installed, all of the remaining flange holes were filled with mild steel nuts and bolts and Hi Shear fasteners.

Control Section Installation

Four individual sections of split pipe were installed to provide isolated specimens that could be compared to the 300-ft-long installation. The four sections were configured as follows:

Section No.	Type of Fastener	Anode
C1	Stainless Steel Nut and Bolt	No
C2	Huck BOM	No
C3	Hi Shear Stainless	Yes
C4	Hi Shear Mild Steel	Yes

The anodes for the control sections each weighed 7 lb and were attached to the pipe section with a steel spider strap shown in Figure 21. Four fasteners in the center four holes of the pipe were used to connect the anode to the pipe. Each control section was immobilized with two rock bolts using the procedure discussed previously.

Inspection and Documentation

After completion of the installation, inspection dives were made to document (1) the type and number of fasteners in each section of pipe, (2) the galvanic potential of each section of pipe, and (3) the depth profile of the installed pipe. Tables 5 and 6 summarize the types of fasteners used and indicate the relative success of installing them. Figure 22 shows the galvanic potential of each pipe section, and Figure 23 is a plot of the depth profile of the installation.

An underwater television system was utilized during the installation to determine the average time per pipe section and total time to complete various phases of the installation. The data presented in Tables 7 and 8 when compared to the results of the diving tank tests (Table 3) show almost a doubling of the average installation time per pipe section. This can be attributed to the irregular seafloor, thick kelp, surge, and cold water conditions that did not exist during the controlled (diving tank) tests. The elapsed time data are presented to give a more accurate total picture of the time involved in this type of operation, and include the time required to change dive teams, move from one section of pipe to the next, and change from one tool to another. With all of these factors, the average time to lay and fasten each of the 75 sections of pipe increased to 9.9 min/section.

SEMIANNUAL INSPECTIONS

In November 1976, the first of ten semiannual inspections was conducted. Visual inspection of the installation revealed that numerous jumper cables had been broken. All the jumpers were broken or missing between sections 1 and 35. Additional broken jumpers were found between sections 44 and 45, 60 and 61, and 77 and 78. The wires connecting the anodes to the pipe at sections 10, 30, and 90 were broken, and the anodes connected to sections 10 and 30 could not be located. The three anodes that were found were weighed in the water to determine the amount of anode consumption. These data are presented in Table 9.

Galvanic potential readings were obtained with an underwater voltmeter; the results are presented in Figure 22. Because of the numerous broken jumpers and disconnected anodes, only sections 45 through 78 are being protected. Figures 24 and 25 are representative closeup photos taken of fasteners in the protected and unprotected areas, respectively.

CONCLUSIONS

1. No suitable replacement for split pipe could be identified that would be compatible with existing installation repair requirements and still provide acceptable abrasion resistance.

2. All results to date indicate that expansion-type rock bolts are well suited to solving the problem of immobilizing split pipe systems in rocky areas. Tools for installing this type of seafloor fastener are currently available to Navy diving units.

3. Both the BOM and Hi Shear fastener were successful in reducing installation time of the split pipe. The BOM fastener provided a higher strength pipe assembly, and it was reported to be slightly easier to install than the Hi Shear fastener. However, a noncommercial tool is required for underwater installation.

4. The hardware selected for attaching the zinc anodes and jumper cables to the long-term split pipe installation is inadequate to withstand the open ocean environment.

5. The suitability of the test hardware for long-term installations will be updated as results of the semiannual inspections are obtained.

RECOMMENDATIONS

1. A tool should be developed that allows divers to remove the one-piece fasteners in the event future repairs are required.

2. If subsequent inspections confirm the requirement for cathodic protection of the pipe and hardware, additional work is required to assure the survivability of the cathodic protection system components in the open ocean.

3. Relative abrasion tests of bare cable and split pipe on various types of seafloor rock should be conducted to determine if split pipe can be eliminated in certain environments.

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2.————. Technical Note N-1347: Development, test, and evaluation of an underwater grout-dispensing system for use by divers, by A. M. Parisi, and R. L. Brackett. Port Hueneme, Calif, Jul 1974.

3.————. Technical Note N-1483: Manual nut splitters for diver use, by S. A. Black and S. S. Sergev. Port Hueneme, Calif, May 1977.

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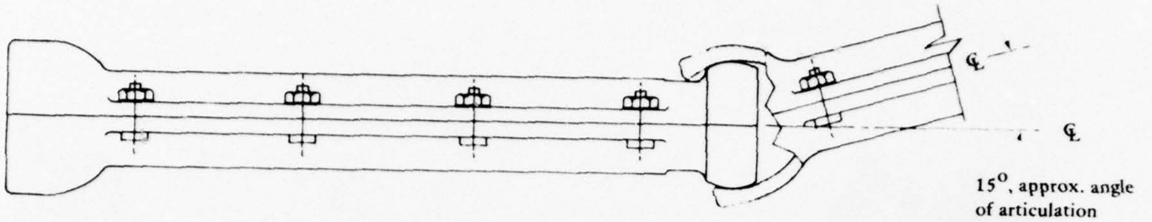
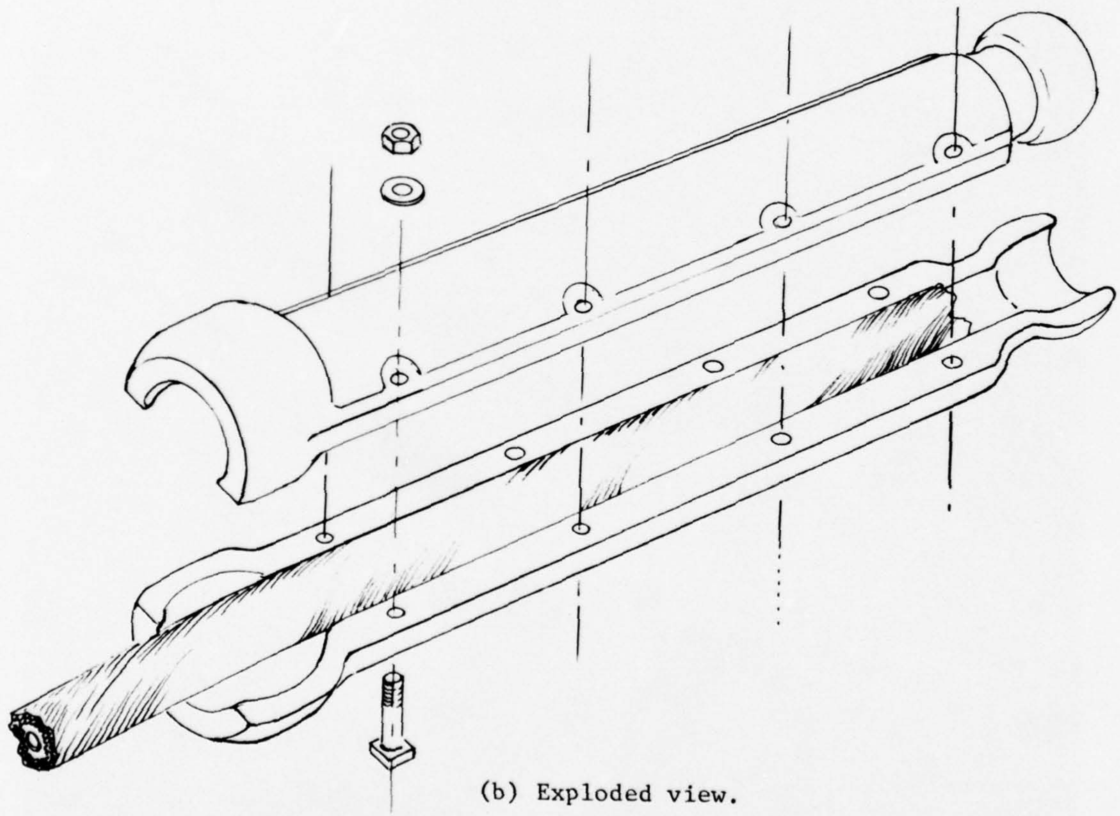
5.————. Technical Report R-824: Hand-held hydraulic rock drill and seafloor fasteners for use by divers, by R. L. Brackett and A. M. Parisi. Port Hueneme, Calif, Aug 1975.

6. CHESDIVNAVFAC. "Test program to evaluate cable stresses and behavior during EastPac cable ops," by J. F. Thibeaux. Apr 6, 1972.

Figure 1. Split pipe cable protection system.



(a) Side view.



(b) Exploded view.

Figure 2. Cast iron split pipe.

Figure 3. Grouted U-rod.

Figure 4. Damaged pipe due to failure of fasteners.

Figure 5. Damaged cable due to abrading on U-rod.

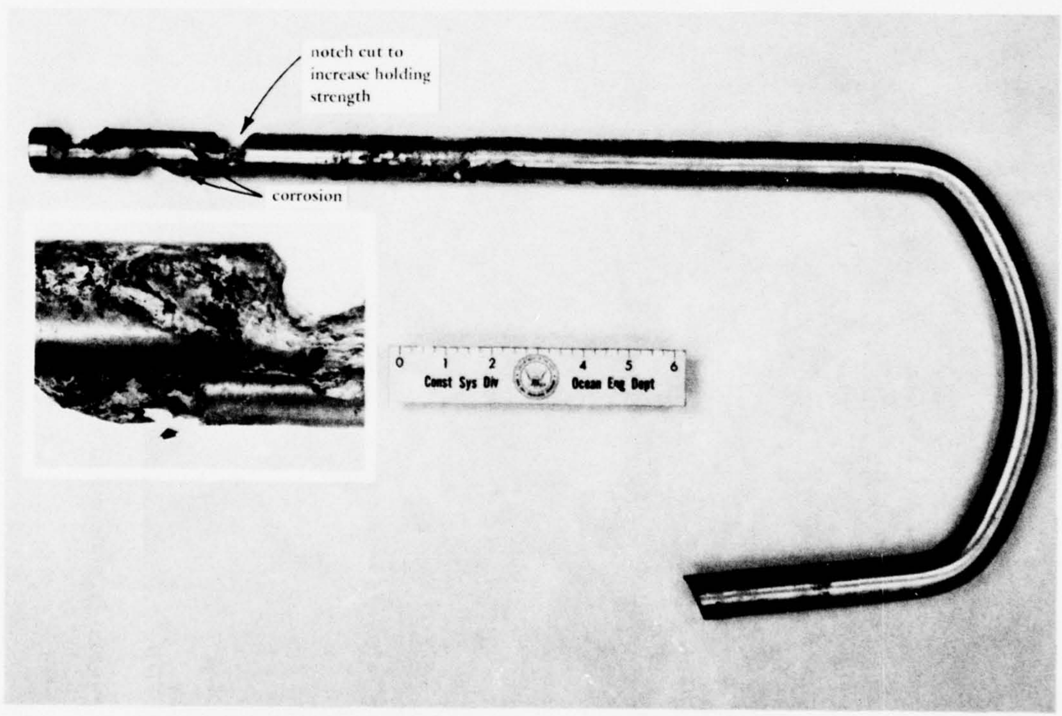


Figure 6. Crevice corrosion of stainless steel U-rod.

Figure 7. Armored cable immobilized with rock bolts.

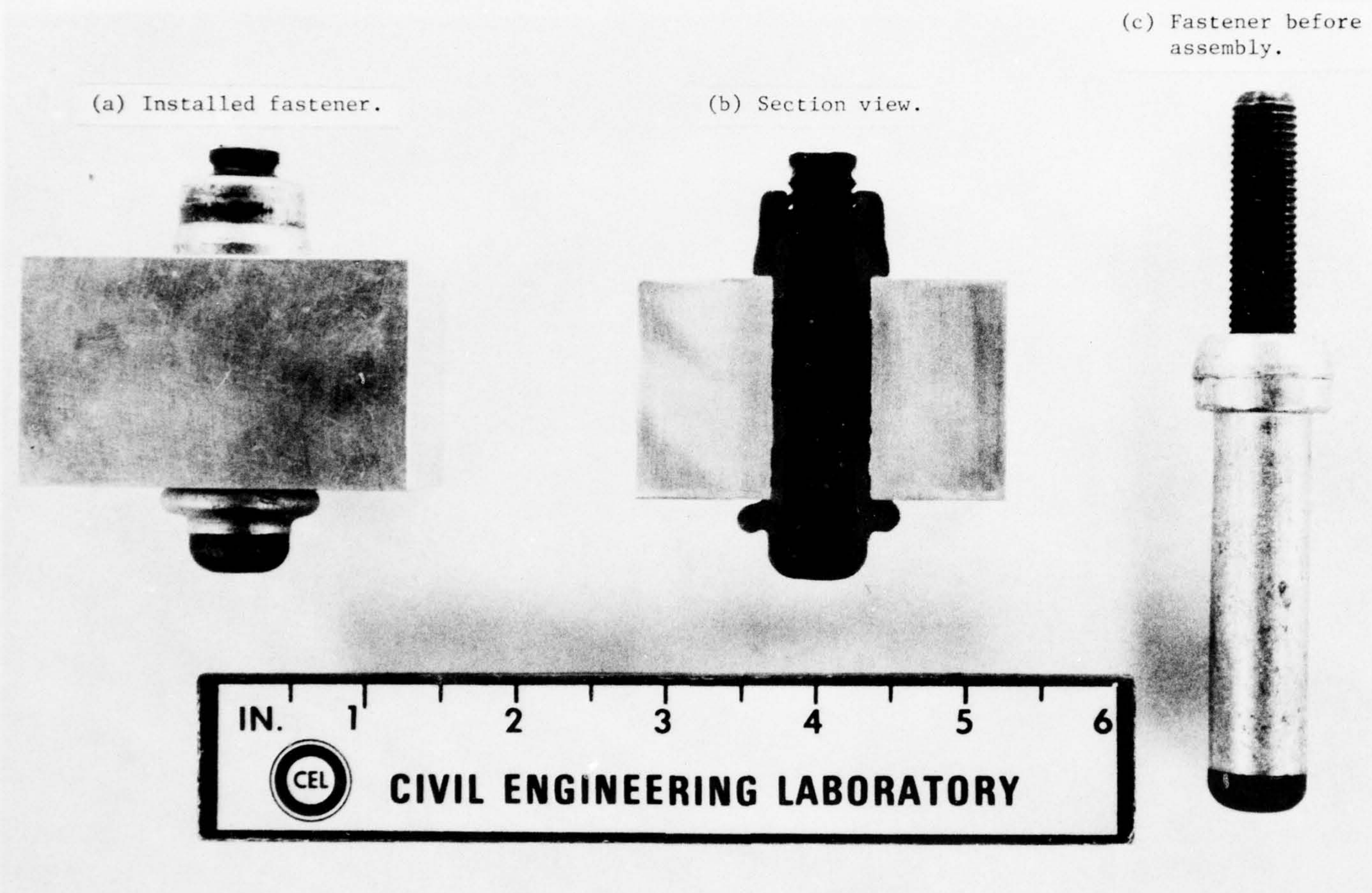


Figure 8. BOM bolt.

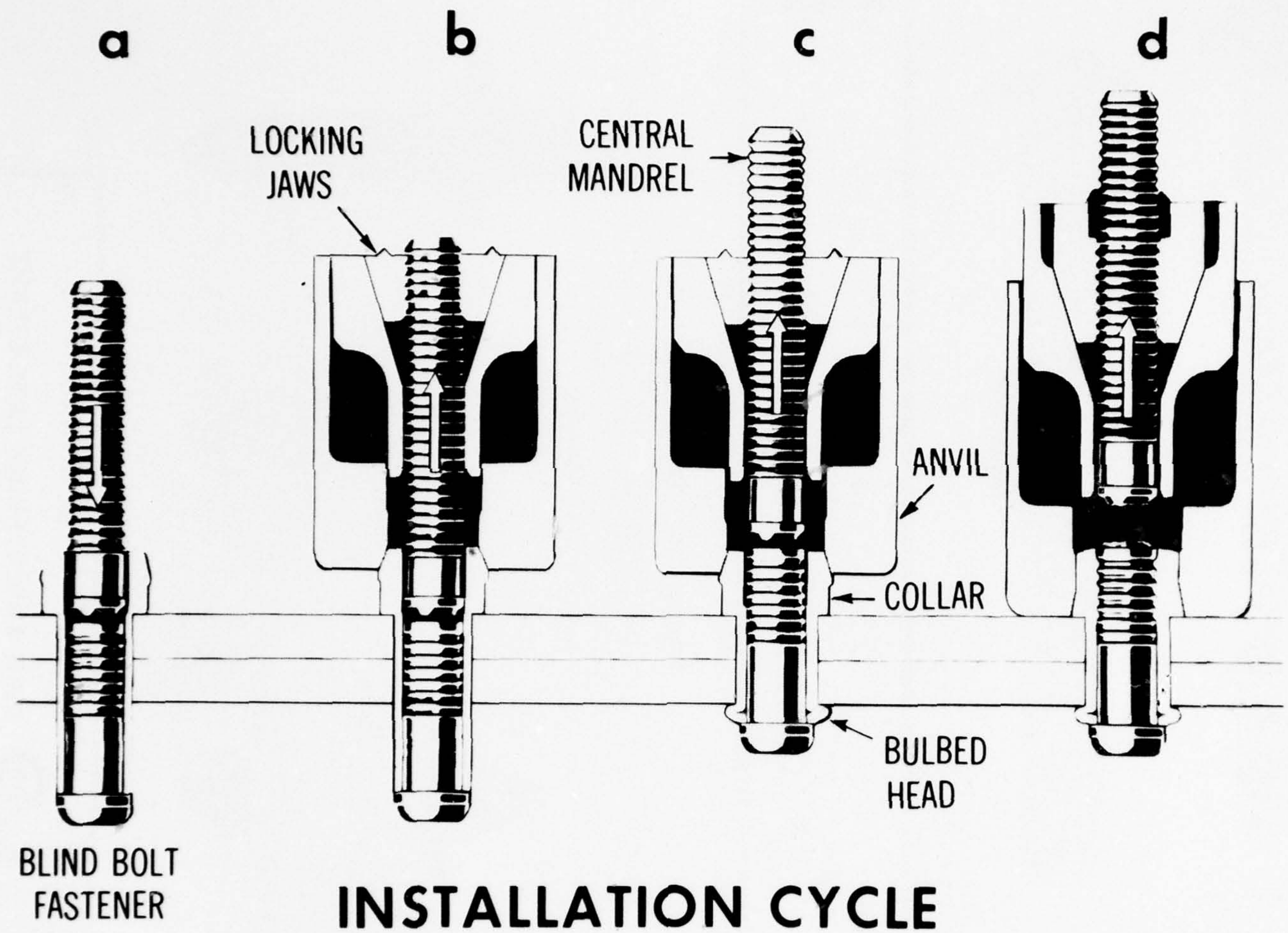


Figure 9. BOM installation cycle.

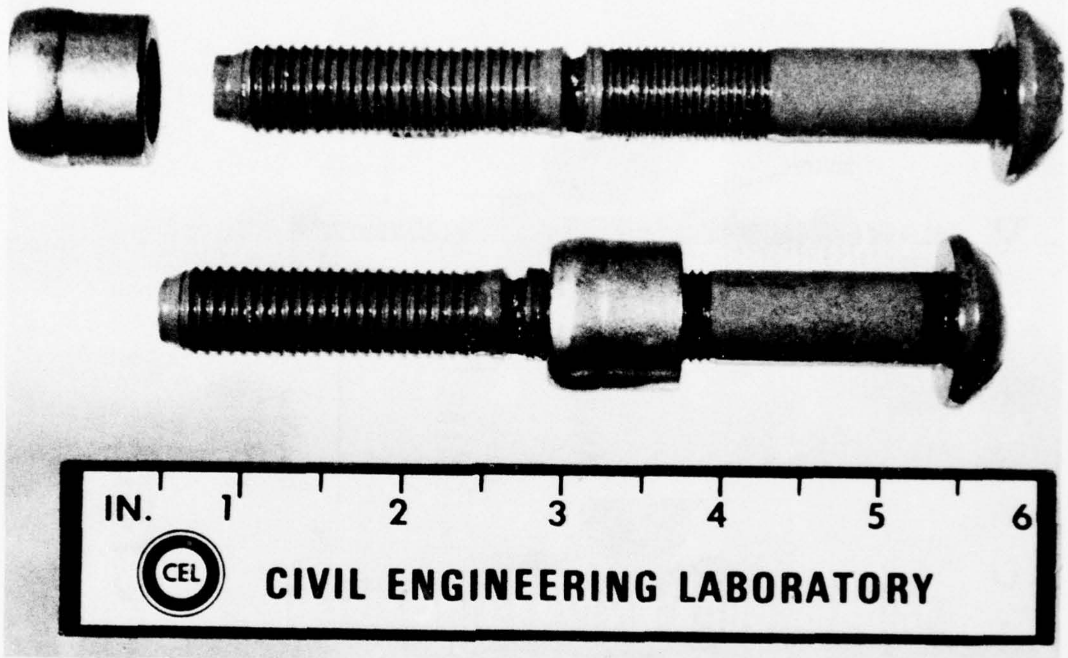


Figure 10. Huck bolt.

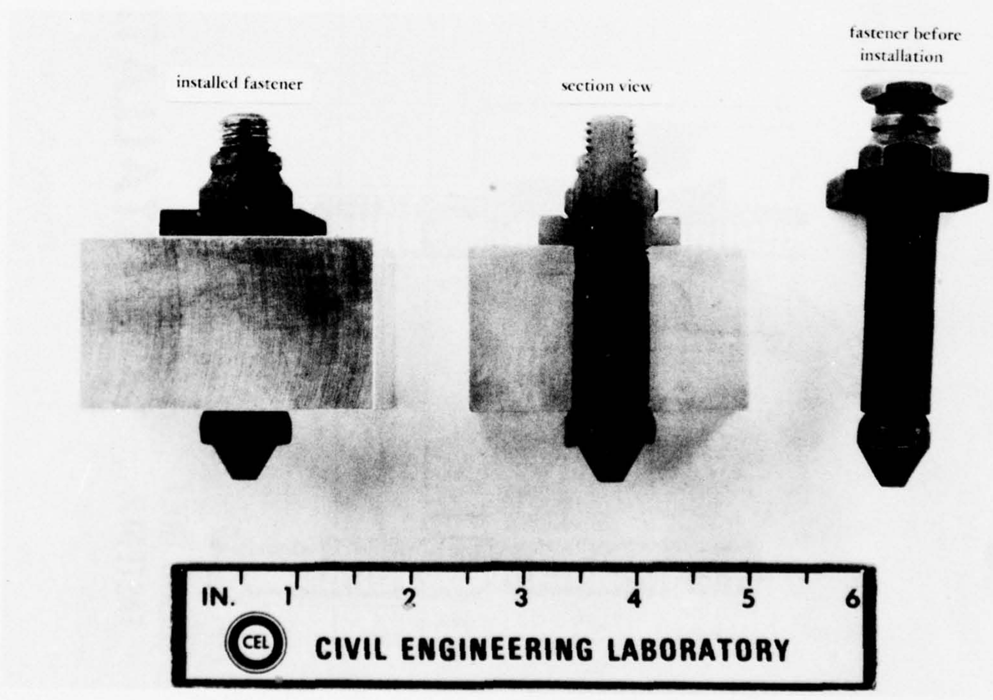


Figure 11. Hi Shear bolt.

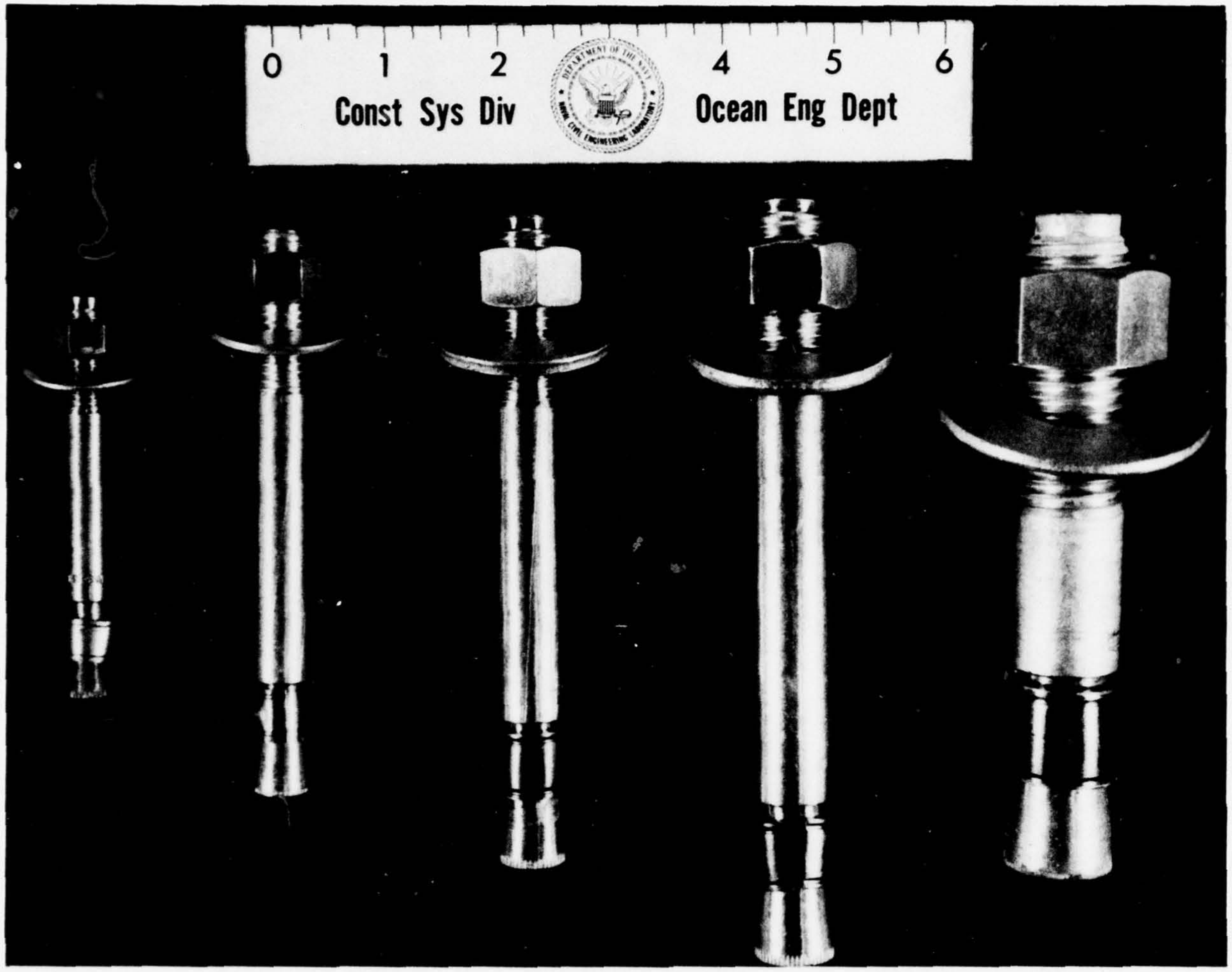


Figure 12. Commercially available expansion-type rock bolts.

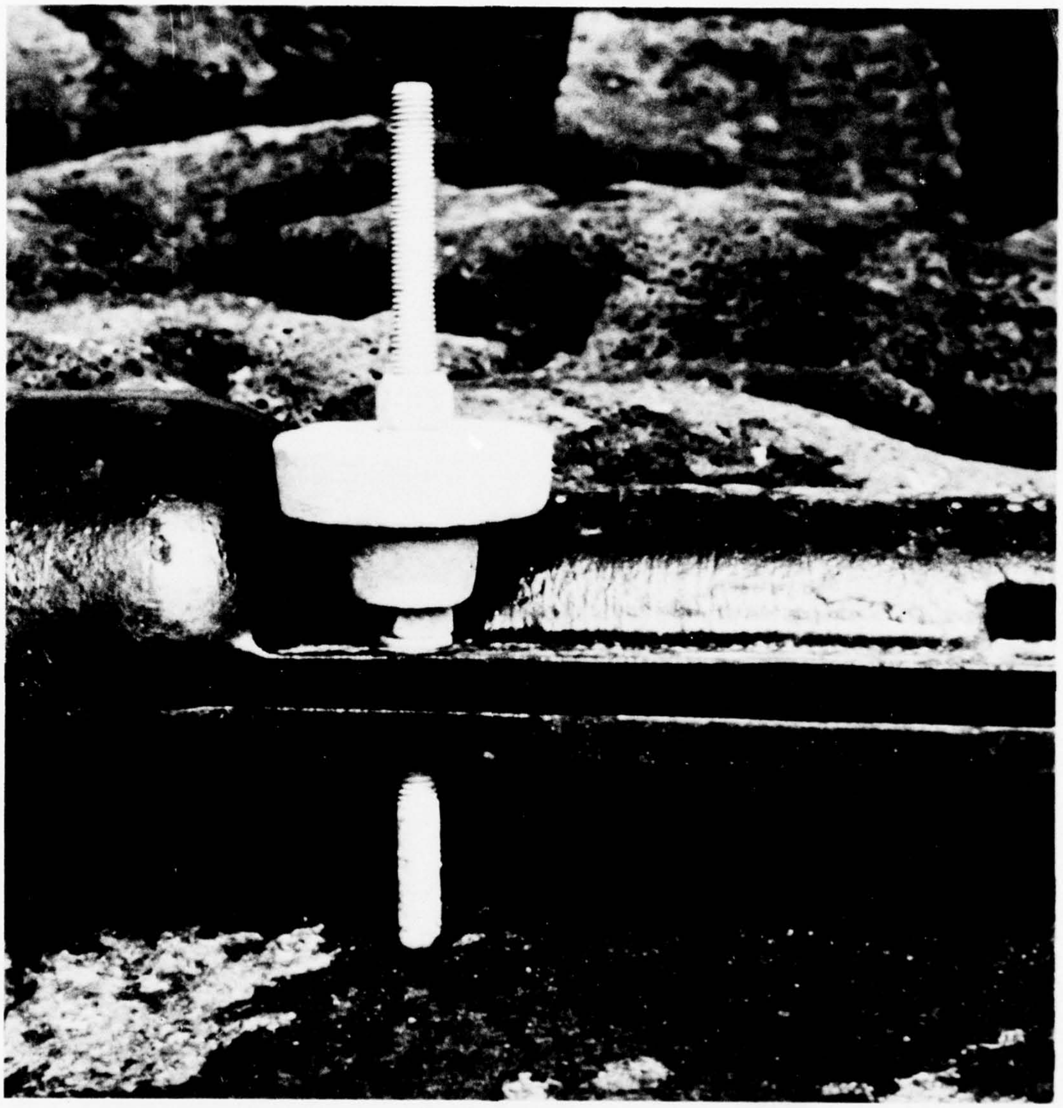


Figure 13. Rock bolt/split pipe installation.

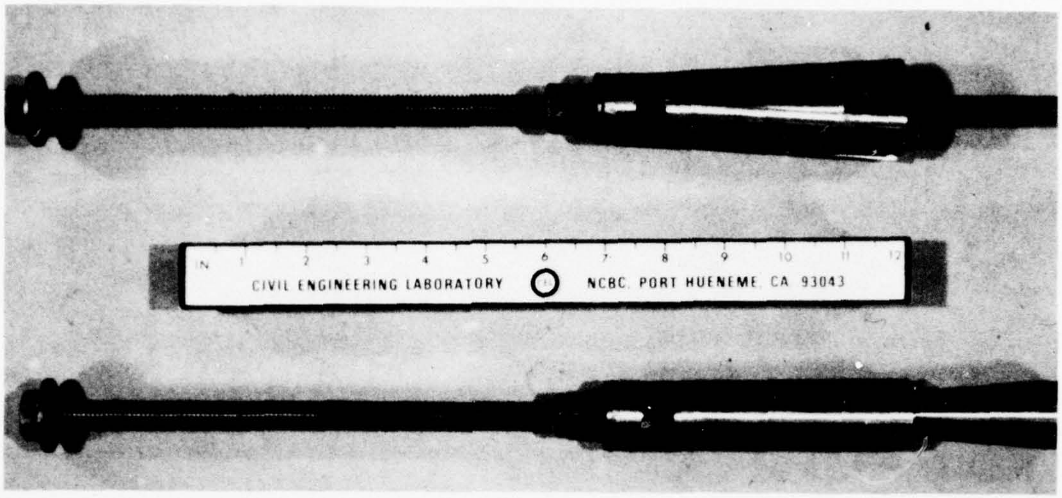


Figure 14. Titanium rock bolt.

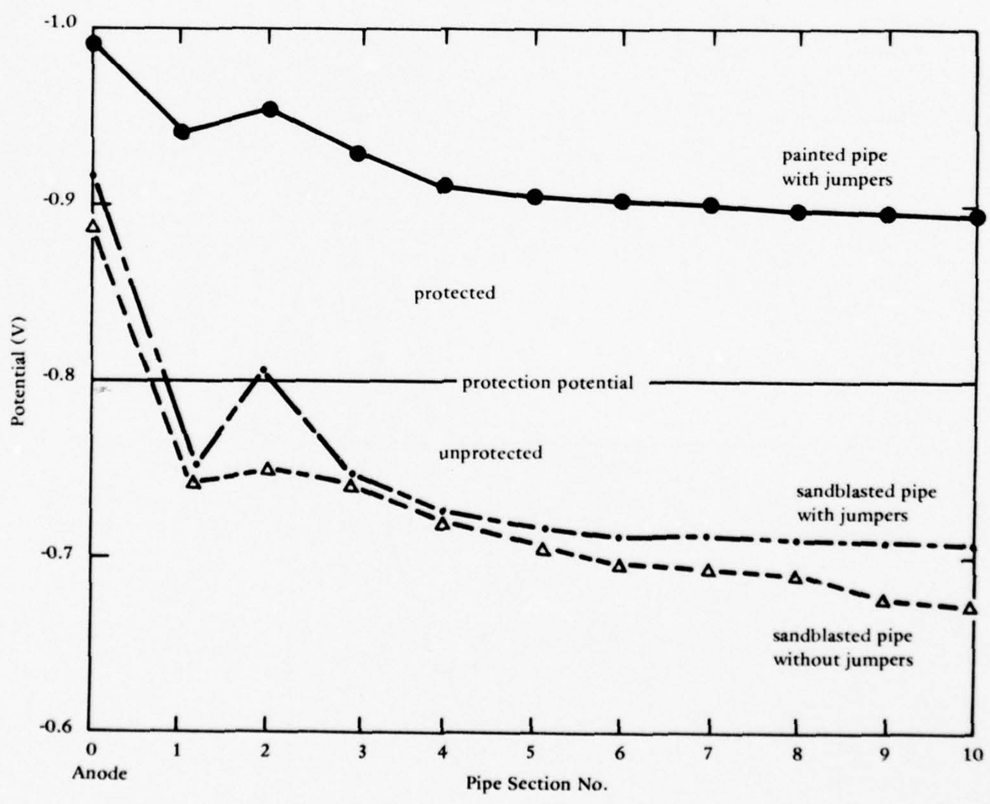


Figure 15. Cathodic protection potential of split pipe sections.

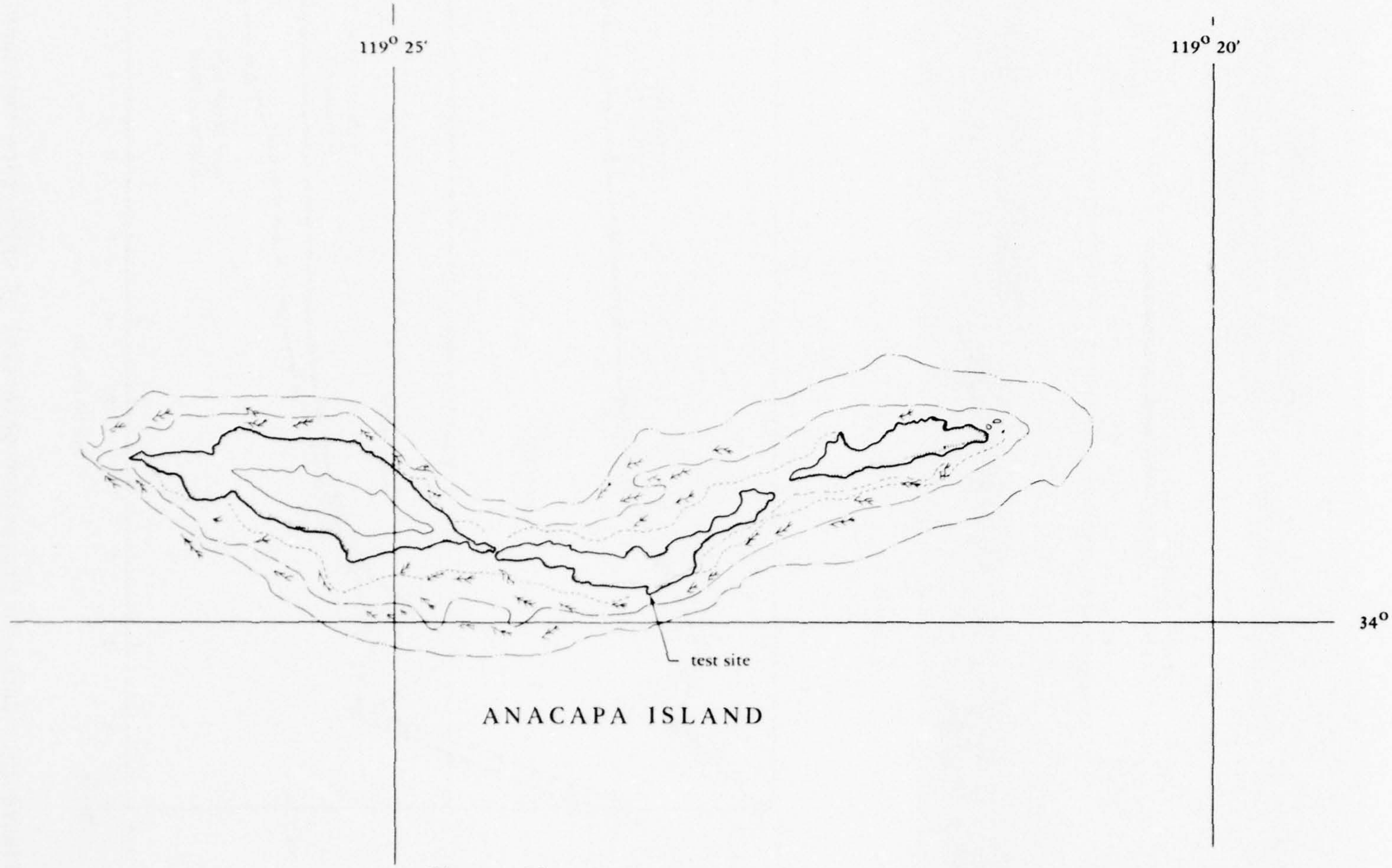


Figure 16. Anacapa test site.

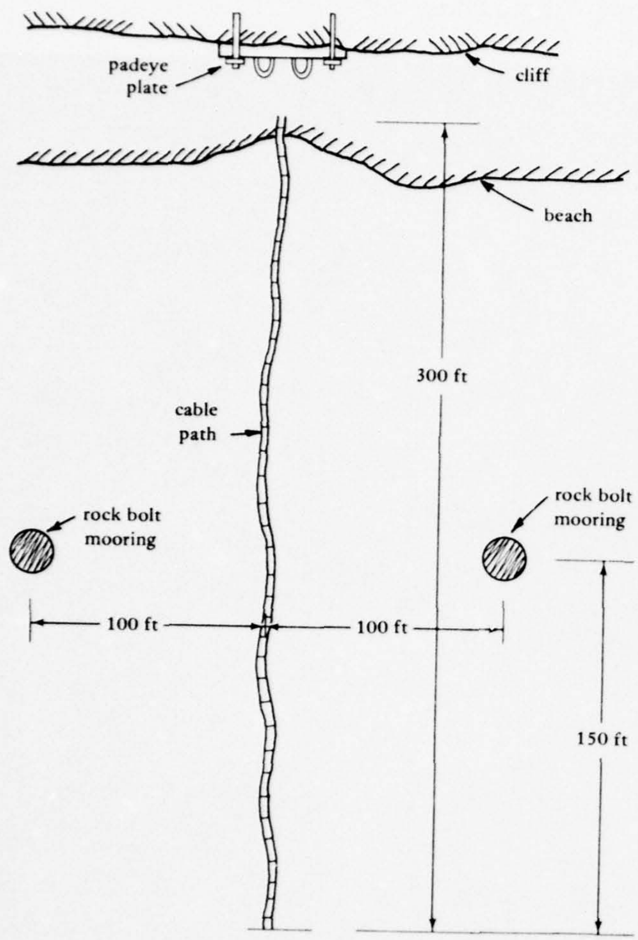


Figure 17a. Mooring location.

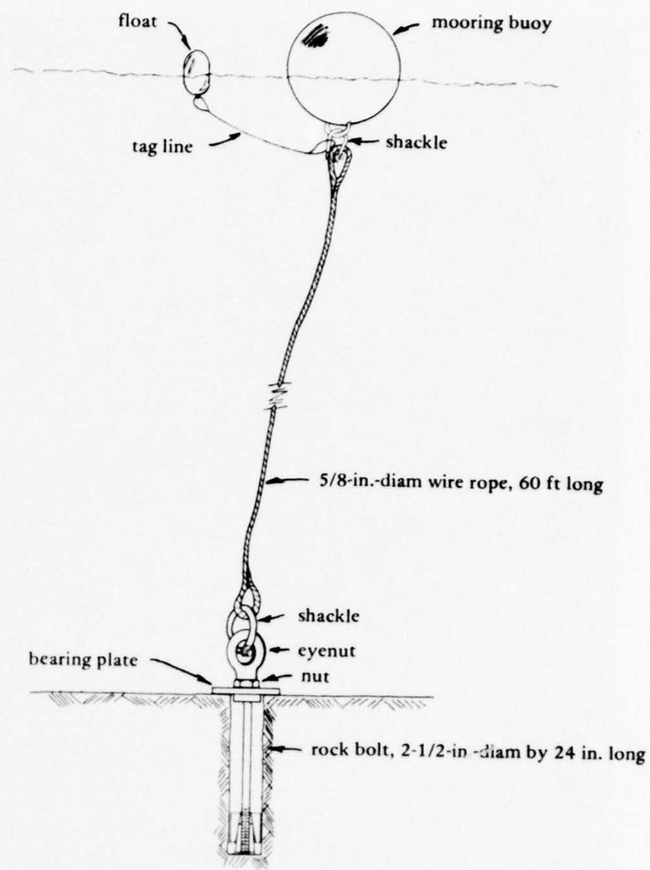


Figure 17b. Mooring configuration.

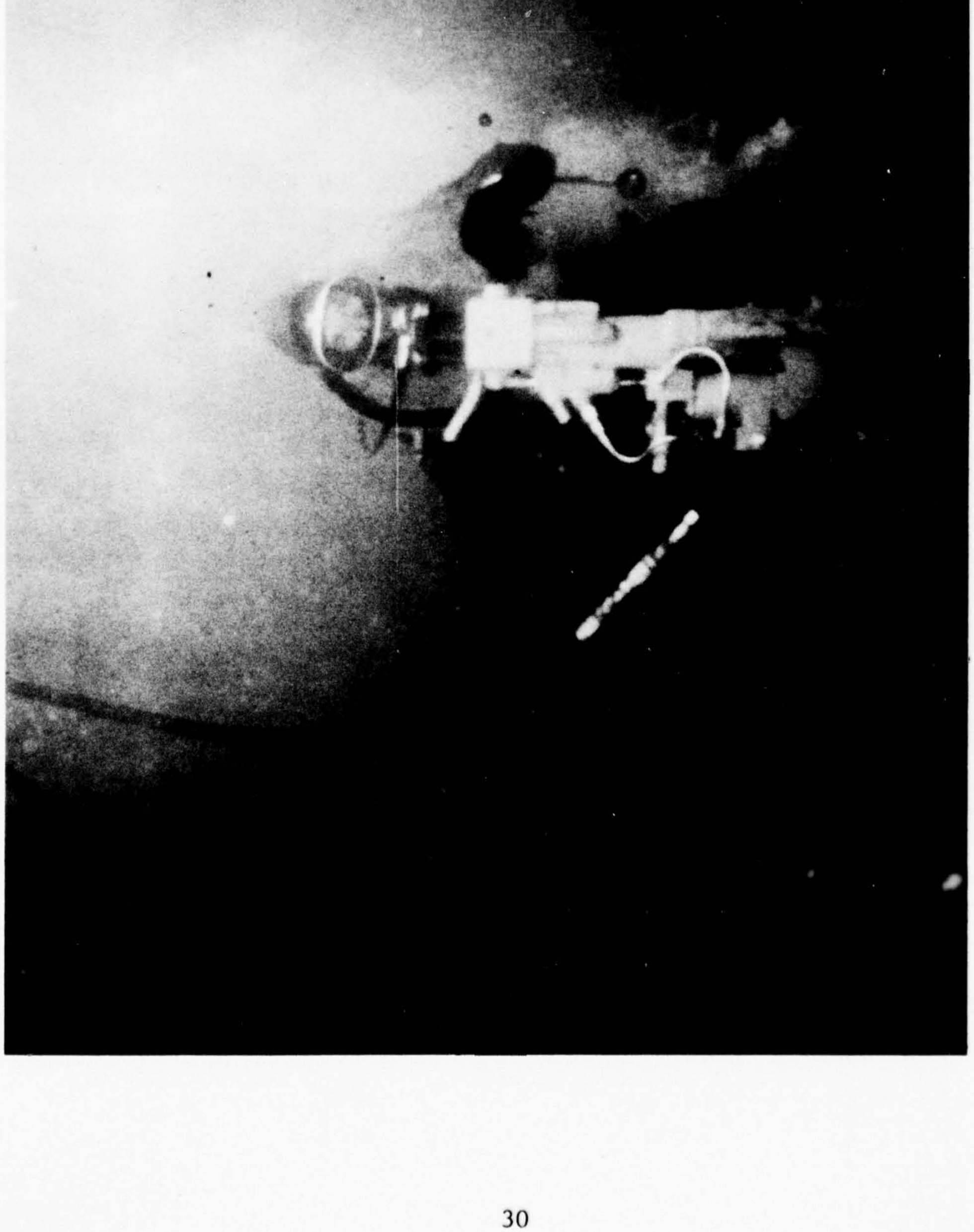


Figure 18. Large hole rock drill.

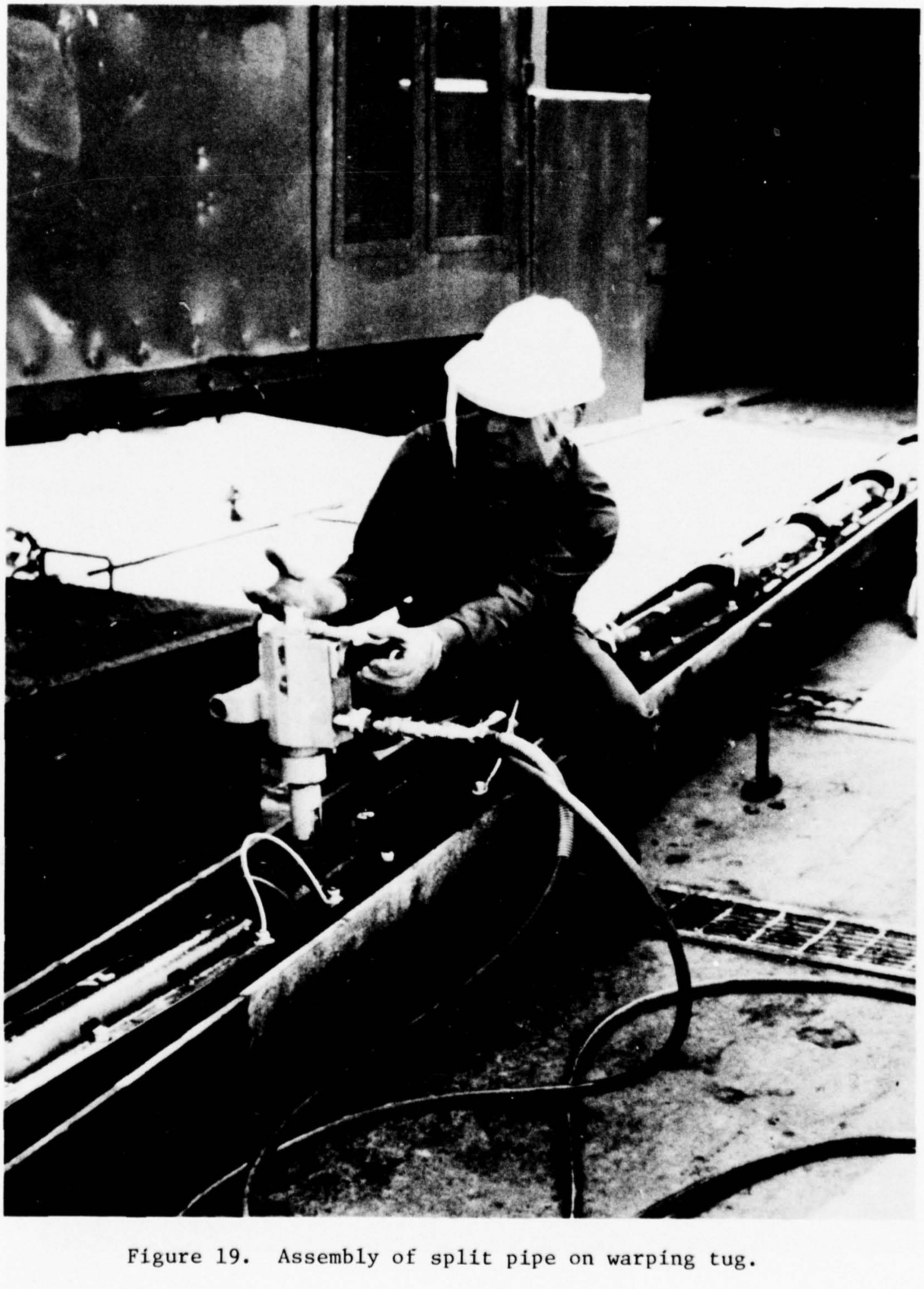


Figure 19. Assembly of split pipe on warping tug.

Figure 20. Rock bolt installation using hand-held rock drill.

Figure 21. Control section with individual anode.

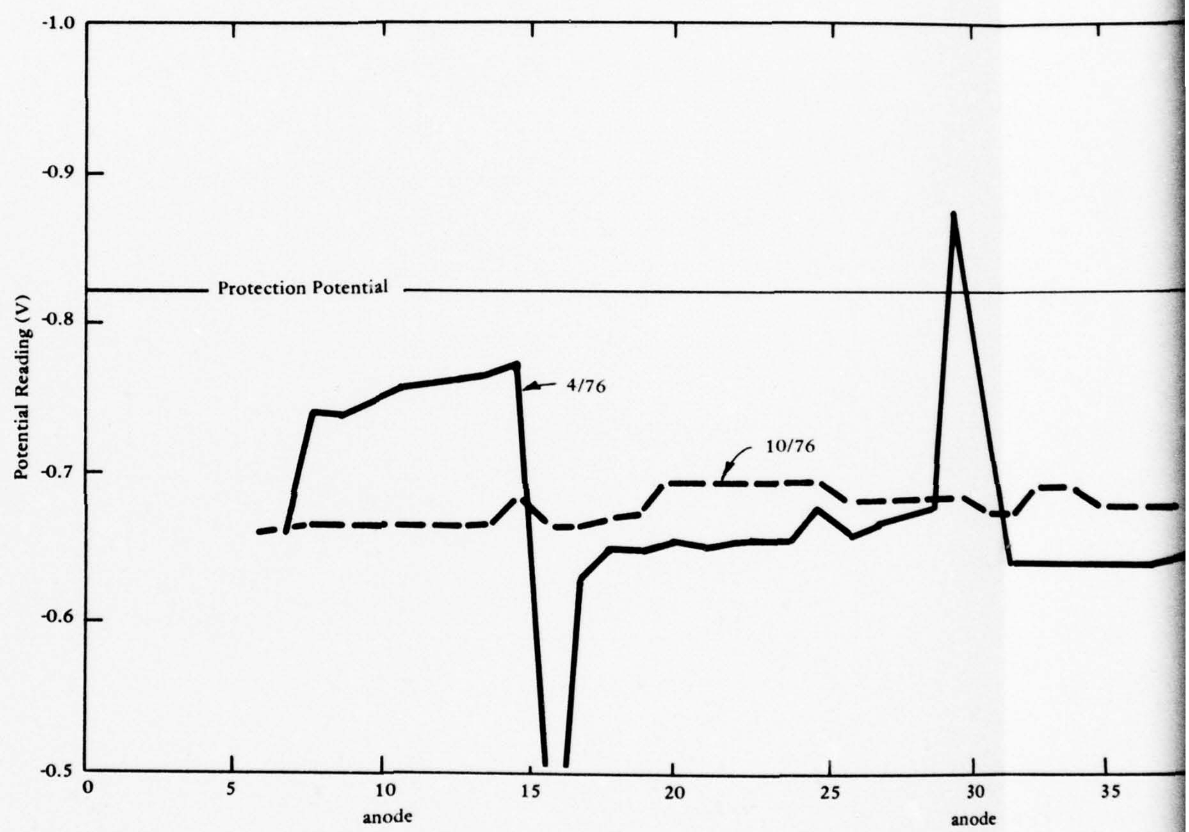
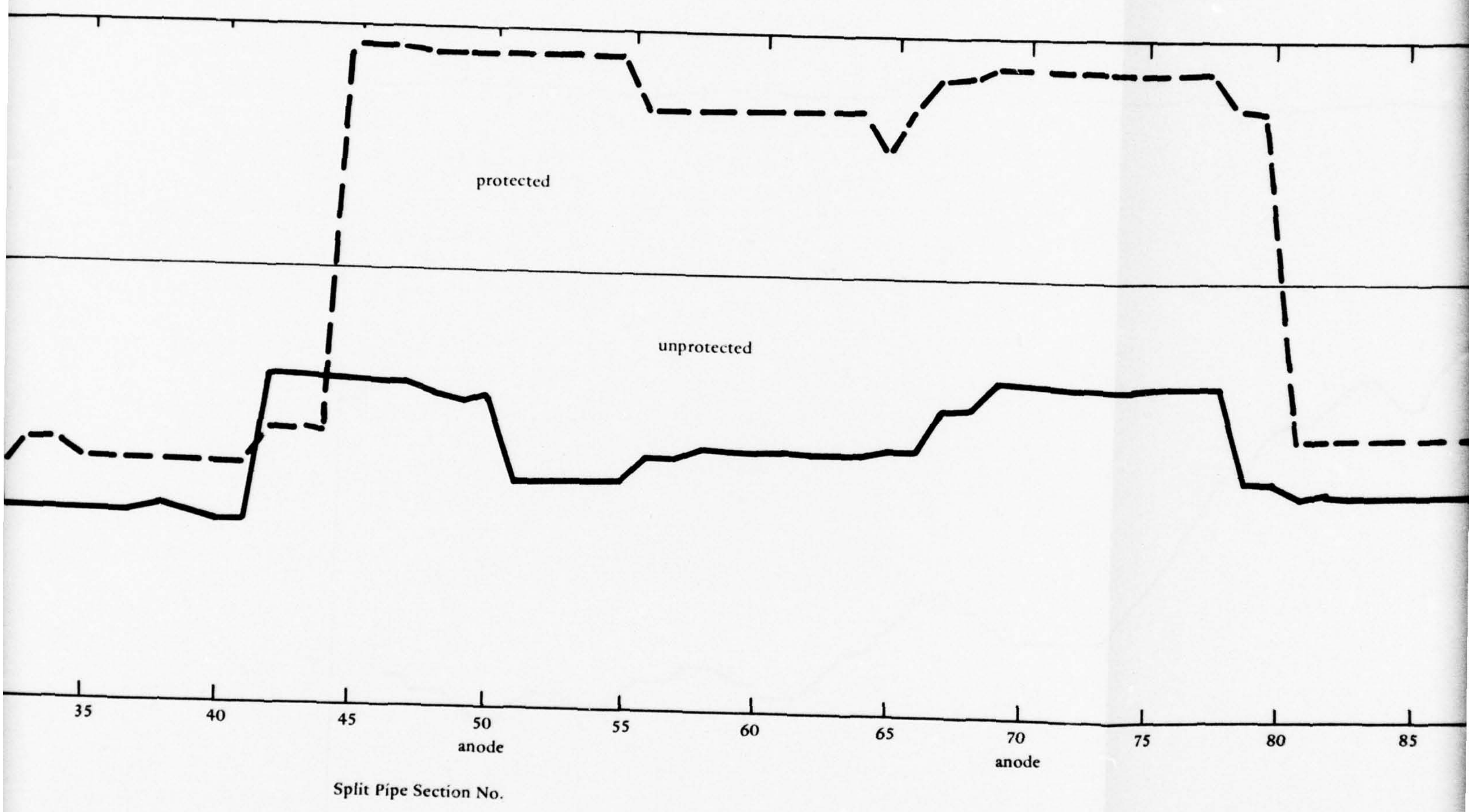


Figure 22. Catho
after



22. Cathodic protection potential of split pipe immediately after installation.

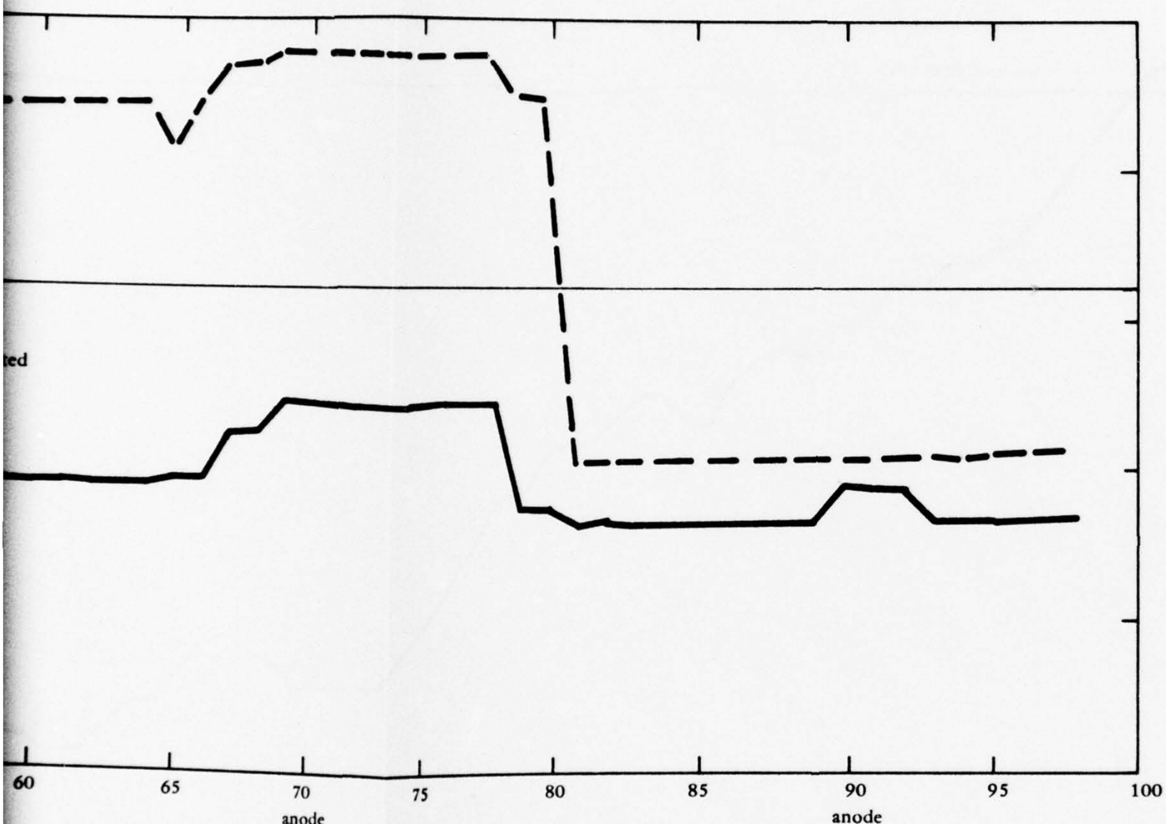


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Figure 24. Close-up photo of fasteners (protected).

Figure 25. Close-up photo of fasteners (unprotected).

Table 1. Preliminary Comparison of Candidate Fasteners

Fastener	Assembled Parts	Blind Access	Corrosion Resistance	Resists Vibration Loosening	$/Fastener[a] (1976)
Steel nut, bolt, and washer	3	no	cathodic protection required	no	0.59
PVC nut, bolt	2	no	yes	no	0.65
BOM bolt	1	yes	cathodic protection required	yes	2.20
Hi Shear	1	yes	cathodic protection required	yes	2.25
Huck bolt	2	no	cathodic protection required	yes	0.69
Hi Shear stainless steel	1	yes	yes	yes	4.10
Stainless steel nut, bolts, and washer	3	no	yes	no	6.63

[a] Depends on total number ordered.

Table 2. Split Pipe Pull Test

Fastener/Installation	Tensile Load of Pipe at Failure (lb)
BOM (installed with CEL tool)	72,400[a]
Hi Shear stainless (pre-torqued 1,200 to 1,500 in.-lb)	63,400
Carbon steel bolt	62,000
Hi Shear mild steel (pre-torqued 800 to 900 in.-lb)	53,100
Hi Shear stainless (pre-torqued 800 to 900 in.-lb)	48,500
BOM, shortened sleeve (installed with commercial tool)	47,000
BOM, unswaged (installed with commercial tool)	42,000
Huck bolt, unswaged (installed with commercial tool)	32,200
PVC bolt	16,800

[a]Bell failed.

Table 3. Diver Installation Tests

Test	Fastener	Average Time Minutes Per Section to —		
		Position Pipe	Install Fastener, Ready for Torquing	Complete Installation, Including Torquing
1	nut and bolt, 1 diver	0.72	2.46	3.95
2	nut and bolt, 2 divers	—	2.40	3.75
3a	Hi Shear	0.72	0.80	4.55[a]
4a	BOM	0.72	0.78	3.00[b]
3b[c]	Hi Shear	0.52	0.30	2.14
4b[c]	BOM	0.52	0.48	1.44

[a]Spinning of the fastener experienced; crescent wrench required to hold bolt down.
[b]Tool gripping jaws were slipping; some had to be fastened twice.
[c]Repeat of tests 3a and 4a after tool and fastener modifications.

Table 4. Test Results of Cathodic Protection Systems

Test Section	Anode Weight (lb)			Anode Consumption (lb/sect/yr)	Average Voltage Drop Across Shunt[a] (V)	Current Per Ten Sections (A)
	Original	Final	Difference			
Sandblasted pipe without jumpers (section 1)	26.0	21.3	4.7	0.94	0.34	3.4
Sandblasted pipe with jumpers (section 2)	24.8	20.2	4.6	0.92	0.24	2.4
Painted pipe with jumpers (section 3)	26.5	25.5	1.0	0.2	0.004	0.4

[a]Shunt was a 0.01-ohm resistor.

Table 5. Position of Fasteners

Section	Flange Holes			Section	Flange Holes		
	1-4,7,8	5	6		1-4,7,8	5	6
1	MB	RB	RB	31	HB(1,4L), 3MB,7MB	RB	RB
2	HB	RB	RB				
3	HB	RB	RB(L)	32	HB(7L)	SB	MB
4	HB	MB	MB	33	HB	MB	MB
5	HB	MB	MB	34	HB(3L)	MB	MB
6	HG	MB	MB	35	HB(2L)	MB	MB
7	HG	MB	MB	36	HG(2L)	SB	MB
8	HG	MB	MB	37	HG	MB	MB
9	HG(2L)	MB	MB	38	HG	MB	MB
10	HG	MB	A	39	HG(1,2L)	MB	MB
11	BOM	BOM	BOM	40	HG(1L)	MB	MB
12	BOM	MB	MB	41	BOM	MB	MB
13	BOM	MB	MB	42	BOM	MB	MB
14	BOM	MB	MB	43	BOM	RB	RB(L)
15	BOM	RB	RB	44	BOM	HB	HB
16	HB	MB	MB	45	BOM	HB	HG
17	HB	MB	MB	46	HB(1L)	RB	RB
18	HB	MB	MB	47	HB(2,7L)	HB	HB
19	HB	MB	MB	48	HB(4L)	HB	HB
20	HB	HB	MB	49	HB(7L)	HB	HB(L)
21	HG	MB	MB	50	HB	HG	AN
22	HG	MB	MB	51	HG	—	—
23	HG	MB	MB	52	HG	HB	HB
24	HG	MB	MB	53	HG	HB	HB
25	HG	MB	MB	54	HG	—	—
26	BOM	MB	MB	55	HG	HG	HB
27	BOM	MB	MB	56	BOM	HB	HG
28	BOM	RB(L)	RB	57	BOM	HB	HG
29	BOM	MB	MB	58	BOM	HB	HB
30	BOM	MB	A	59	BOM	HB	HB

continued

Table 5. Continued

Section	Flange Holes			Section	Flange Holes		
	1-4,7,8	5	6		1-4,7,8	5	6
60	BOM	HGL	HB	79	HB(4L)	RB	RB
61	HB	RB	RB	80	HB	HB	HB
62	HB(2,3,7L)	HB	HG	81	HG	HB	HB
63	HG	HG	HG	82	HG	–	–
64	HB(7L)	–	–	83	HG	HB	HB
65	HB(8L)	HG	HB	84	HG,1SB	–	–
66	HG	HG	HB(L)	85	BOM	HB	HB
67	HG	HG	HB	86	BOM	HB	HB
68	HG	HG	HG	87	BOM	RB	RB
69	HG,1MB(L)	HG	HG	88	BOM	HB	RB
70	HG,1MB(L)	–	AN	89	1,2,3,7,BOM	HB	–
71	BOM	HG	HG	90	HB	HB	AN
72	BOM	HB	HG	91	HB(1L)	HB	HB
73	BOM	HB	HG	92	HB	–	–
74	BOM	–	HG	93	HB(1L)	–	–
75	BOM	RB	HG	94	HG	–	HB
76	HB	–	HB	95	HG	HB	HB
77	HB,1MB	–	–	96	HB	HB	HB
78	HB(4,7,L)	HB	HB(L)	97	HG	MB	HB
				98	HG	RB	RB

BOM – Huck fastener
SB – Stainless steel nut and bolt
HB – Hi Shear stainless steel
HG – Hi Shear mild steel
MB – Mild steel nut and bolt
(L) – Fastener loose
RB – Rock bolt
AN – Anode attached with stainless nut and bolt

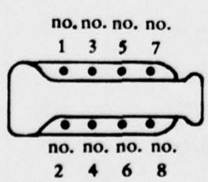


Table 6. Results of Anacapa Pipe Installation Survey

Type of Fastener Installed	Total Installed	Number Loose	% Loose
Blind mechanical fastener (installed with CEL tool)	180	1	0.5
Hi Shear Mild Steel	223	5	2.2
Hi Shear stainless steel	246	20	8.1
Mild steel nut and bolt	78	0	0
Stainless steel nuts and bolts	3	0	0
Rock bolts	26	0	0
Anode with stainless bolt	5	0	0
Voids	21	—	—
Total	782	26	—

Table 7. Split Pipe Installation Times

Type of Fastener	Average Installation Time Per Fastener (sec)	Tool Activation Cycle Per Fastener (sec)	Average Installation Time Per Pipe Section (min)
BOM	16.7	3	2.3
Hi Shear stainless steel	30.0	15 to 20	4
Hi Shear mild steel	21.5	15 to 20	2.87

Table 8. Underwater Activity Times

Function	Actual Elapsed Time (hr)	Diving Time (man-hr)
Lay and fasten pipe	12.38	33.30
Install rock bolts	4.85	9.70
Attach anodes and number pipe	1.98	3.97
Survey	1.08	3.60
Photo documentation and TV monitoring	8.17	8.17
Total	28.46	58.74

Table 9. Anode Consumption Rate

Section No.	Original Weight (lb, in water)	Weight After Six Months (lb, in water)	Weight Loss (lb)	No. of Sections Protected	Average Annual Loss Per Pipe Section (lb/yr)
10	64	–	–	–	–
30	64	–	–	–	–
50	64	57	7	15	1
70	64	53	9	19	1
90	64	62	2	–	–

Appendix A

TECHNICAL DATA FOR CAST IRON SPLIT PIPE

Length of section when assembled	3 ft
Cost estimate	$30/ft
Tensile failure (bell separated)[a]	70,000 lbf
Recommended safe working load[a]	35,000 lbf
Beach pulling load on sand[a]	30 lbf/ft
Beach pulling load in 3 ft of water[a]	34 lbf/ft
Tensile strength of cast iron material	22,000 psi
Failure modes:[a]	
Split pipe bell	40,000 lbf (yield)
	60,000 lbf (ultimate)
Bell separation	70,000 lbf
Split pipe flange	55,000 lbf (yield)
	80,000 lbf (ultimate)
Boltholes elongated	60,000 lbf
3-1/2-in.-diam pipe weight (1/2 section)	
In air	21.5 lbf/ft
In seawater	20.0 lbf/ft
5-in.-diam pipe weight (1/2 section)	
In air	30.2 lbf/ft
In seawater	28.6 lbf/ft

[a]From Reference 6.

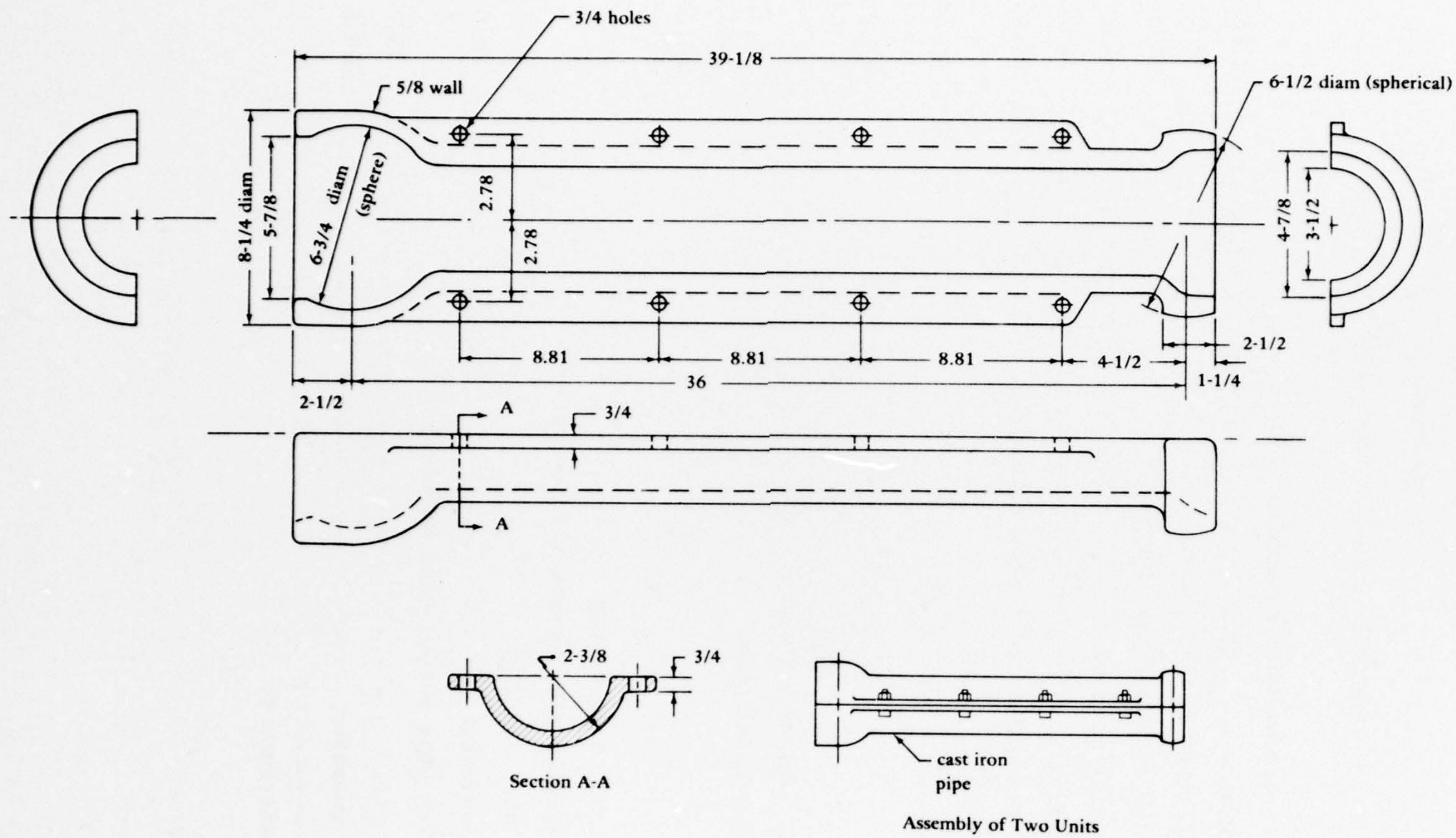


Figure A-1. Three-and-one-half-in.-diameter split pipe.

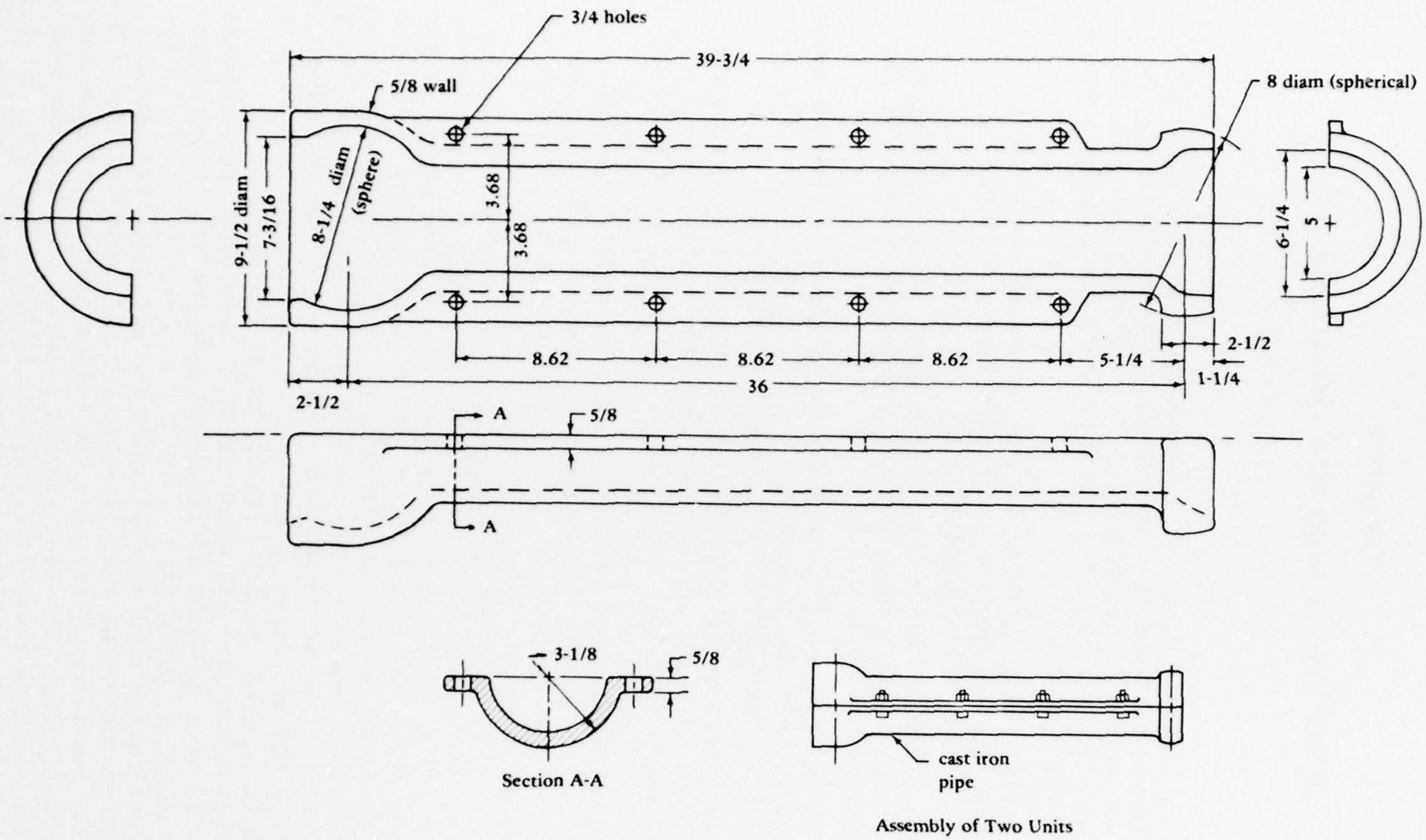


Figure A-2. Five-in.-diameter split pipe.

Appendix B

DEVELOPMENT OF BLIND BOLT INSTALLATION TOOL

TOOL DESIGN

In the preliminary stages of researching potential split pipe fasteners, it was realized that to use the Huck Manufacturing Company's fastening system (Huck bolt, BOM bolt), a completely new installation tool would have to be designed. The existing commercial Huck installation tool has several drawbacks:

(1) Insufficient clearance between the nosepiece of the existing tool and the split pipe flange will not allow proper installation.

(2) The existing tool's hydraulic control valve is triggered through an electronic solenoid, which is undesirable for underwater applications.

(3) The existing tool's ejector system, which pushes the spent mandrel out the nose of the tool, interferes with the pipe flange, again preventing proper installation.

To install fasteners using the commercial tool in early tests, the nosepiece had to be sawed off, and an extension collar had to be made for each fastener installed. The original Huck tool required 5,000 to 6,000 psi for an equivalent ram installation pull of 20 tons.

To reduce the diameter of the new tool and still retain the required 20-ton pull force, the CEL design required increasing the operating pressure to 8,000 to 10,000 psi. The configuration of the final CEL design is shown in Figure B-1.

Figure B-2 shows a scaled cutaway of the CEL experimental tool. The design had to evolve from the internal piston diameter requirements. Instead of building an ejector mechanism into the nose piece, as the Huck tool has, the CEL design has a hollow piston which allows each spent mandrel to be shoved up through and out the back of the tool. This design has two distinct advantages: (1) without the need for an ejector, the nosepiece could be shaped to fit into the recess of the split pipe flange, and (2) with a hollow piston, a BOM bolt of any length could be used, since the bolt mandrel could extend up inside the piston.

Once the piston size was established, the external and internal cylinder walls were designed according to ASME specifications for a working pressure of 10,000 psi.

The installation tool is made up of the hydraulic ram assembly, the tool adaptor assembly, and the hydraulic control assembly (Figure B-2). The hydraulic ram assembly includes the hollow piston, cylinder body, plug, and end fitting. The tool adaptor assembly includes the swaging anvil, collet, locking jaws, follower, and locking ring. The hydraulic control assembly includes the spool valve, spool fitting, and control handle.

TOOL OPERATION

When assembling a split pipe nearshore installation using the experimental tool and BOM fastener, divers first assemble the pipe halves around the cable. The holes in the pipe flanges are then lined up, and BOM bolts are inserted in them. The tool operator then positions the nosepiece of the tool over the blind bolts to be fastened (Figure B-3). As he presses the trigger on the tool, hydraulic fluid moves the piston toward the back of the housing which, in turn, pulls on the jaws and central mandrel of the fastener. At the same time, the swaging anvil reacts against the collar of the fastener. Continued pull draws the mandrel up through the sleeve of the fastener until the sleeve forms a strong bulbed head. As the pull on the mandrel continues, the anvil of the tool swages the collar material into the locking grooves of the mandrel to form a rigid, permanent lock that cannot loosen. At the completion of the fastening operation, the central mandrel automatically breaks off inside the cylinder. At this time, the operator releases the handle, and the piston returns to the initial position. Total installation time takes approximately 5 seconds. As the next fastener is inserted into the jaws, it shoves the old mandrel up through the hollow piston and is eventually ejected out the back of the tool.

HYDRAULIC CONTROL

The hydraulic control spool valve is shown schematically in Figure B-4. In Figure B-4a, the valve is shown in the "ready" position. Hydraulic fluid enters through port 3 and returns through port 2. In this position, the hydraulic circuit is open-centered through ports 3 and 2. When the tool operator presses the trigger, the spool valve is displaced to the left (Figure B-4b). This pressurizes port 1, which retracts the piston in its power stroke to the right. With the valve in this position, port 2 is blocked, and port 3 is open to the return tank. The piston continues its power stroke until the fastening procedure is completed, and the fastener mandrel breaks off. The operator then releases the handle, which allows a spring to return the spool valve to its original position. Port 3 is pressurized, and ports 1 and 2 are open to tank. This causes the piston to travel to the left until port 2 is uncovered. As the piston uncovers port 2, the hydraulic circuit becomes open-centered again (port 3 to port 2), and the piston automatically stops. The tool is then ready for the next installation cycle.

TOOL PERFORMANCE AND TESTING

Initial tests of the experimental blind bolt fastener installation tool revealed high internal leakage of the spool control valve. At high pressures (10,000 psi), standard spool clearances between the lands and port housing are too great and cause high leak rates. Spool valves lend themselves well to high flow, but relatively low pressure (2,000 psi) systems, where small internal leakage between lands is acceptable. However, in low flow, high pressure systems, internal leakage becomes critical. With the original spool valve, internal leakage was as high as 2 gpm. Under these conditions, the pressure intensifier, normally used to boost 1,600-psi pressure to 10,000 psi, could not produce sufficient flow to exceed the leakage rate and, therefore, enough pressure to complete the installation.

Two modifications were made to remedy the leak problem. First, a new spool valve was fabricated with clearances of plus or minus 0.0001 in. between spool land and valve body. And, second, a special hydraulic power converter was designed and fabricated for the tool. The hydraulic power converter is discussed in the following section.

The CEL blind bolt fastener installation tool was then tested in the shallow-water simulation facility. Four sections of split pipe were assembled by divers using the new tool and the BOM fasteners. It was found that there still existed a clearance problem between the nosepiece of the tool and the split pipe flange. The pipe flange would not allow the gripper jaws to grab completely on each fastener. As a result, during the installation process the tool slipped off of the fastener about 50% of the time. The tool nosepiece was later modified by removing 1/8 in. of material off its end, thus solving the problem.

The CEL blind bolt fastener installation tool was then tested and evaluated during the Anacapa split pipe installation. During the installation, BOM blind bolts were fastened to 30 sections of pipe. The tool performed well during the test. Divers reported that they preferred using the blind bolt installation tool over the impact wrench.

On the final sections of pipe, the nosepiece was broken due to improper tool alignment. To prevent this from occurring again, a new nosepiece was fabricated with a special handle designed to assure proper alignment.

HYDRAULIC POWER CONVERTER

The high pressure, high flow requirements of the CEL blind bolt fastener tool made it necessary to design a special power converter for the tool. The power converter, shown in Figure B-5, uses a Char-Lynn hydraulic motor to drive a Rodgers hydraulic pump. Input power requirement to the motor is 15,00 psi at 13 gpm. This requirement is well within the capability of the UCT and SUPSALV diesel-hydraulic power sources. The hydraulic motor drives the Rodger's pump at 650 rpm for an output of 1.6 gpm at 7,000 psi, which is sufficient for installing BOM fasteners. With the power converter/diesel-hydraulic power source combination, an 8,500-psi at 1.5-gpm output can be achieved. The hydraulic schematic is shown in Figure B-6.

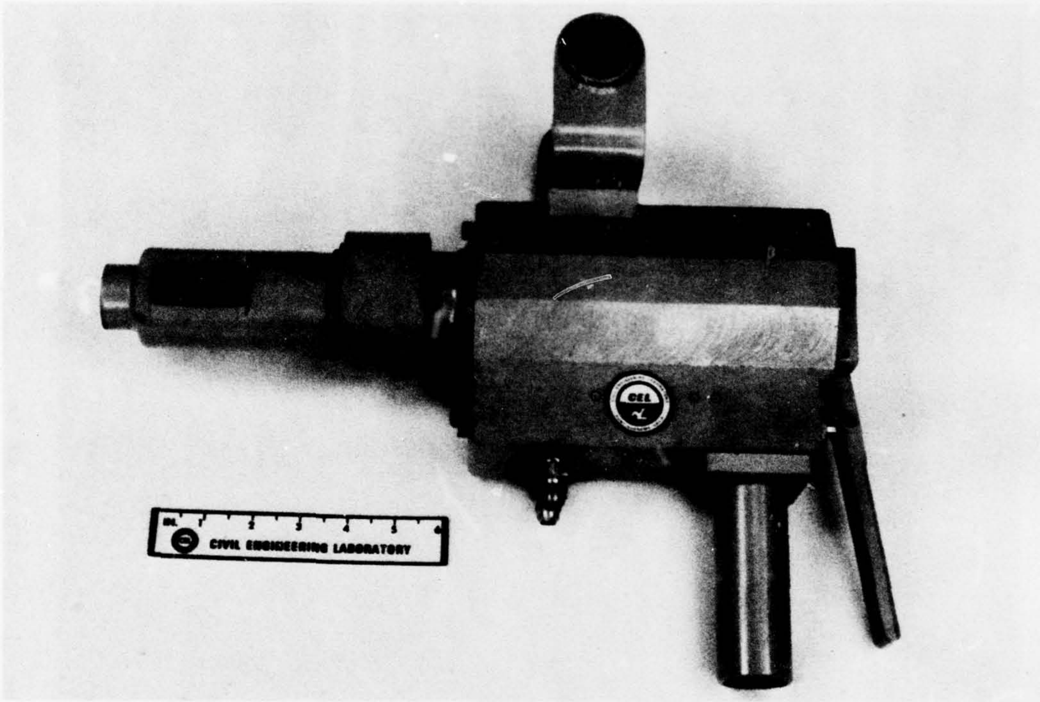


Figure B-1. *Configuration of new blind bolt installation tool.*

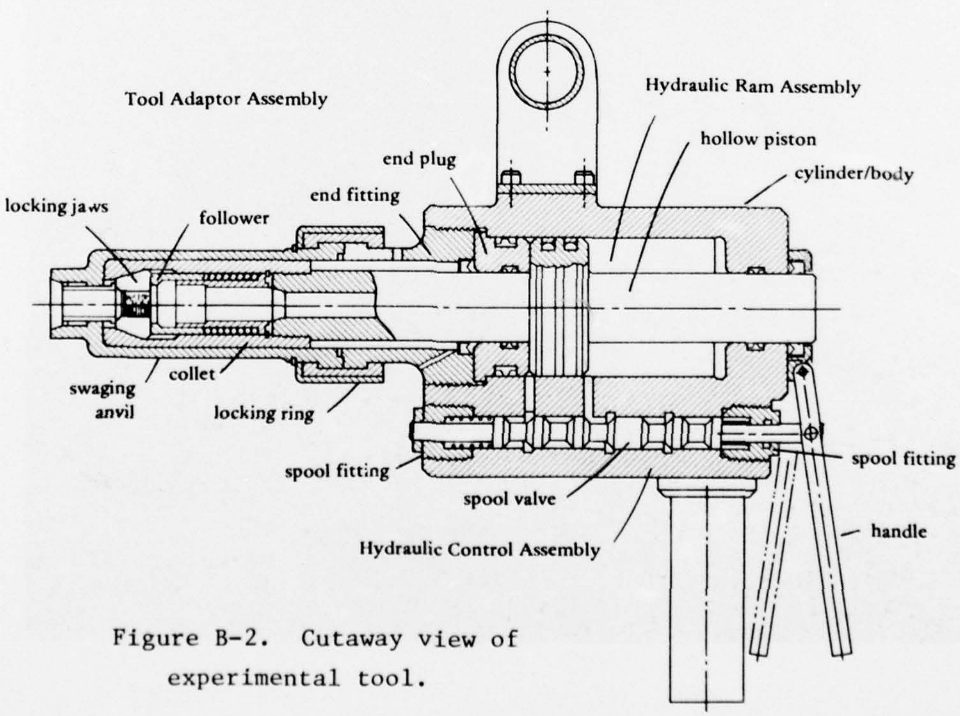


Figure B-2. Cutaway view of experimental tool.

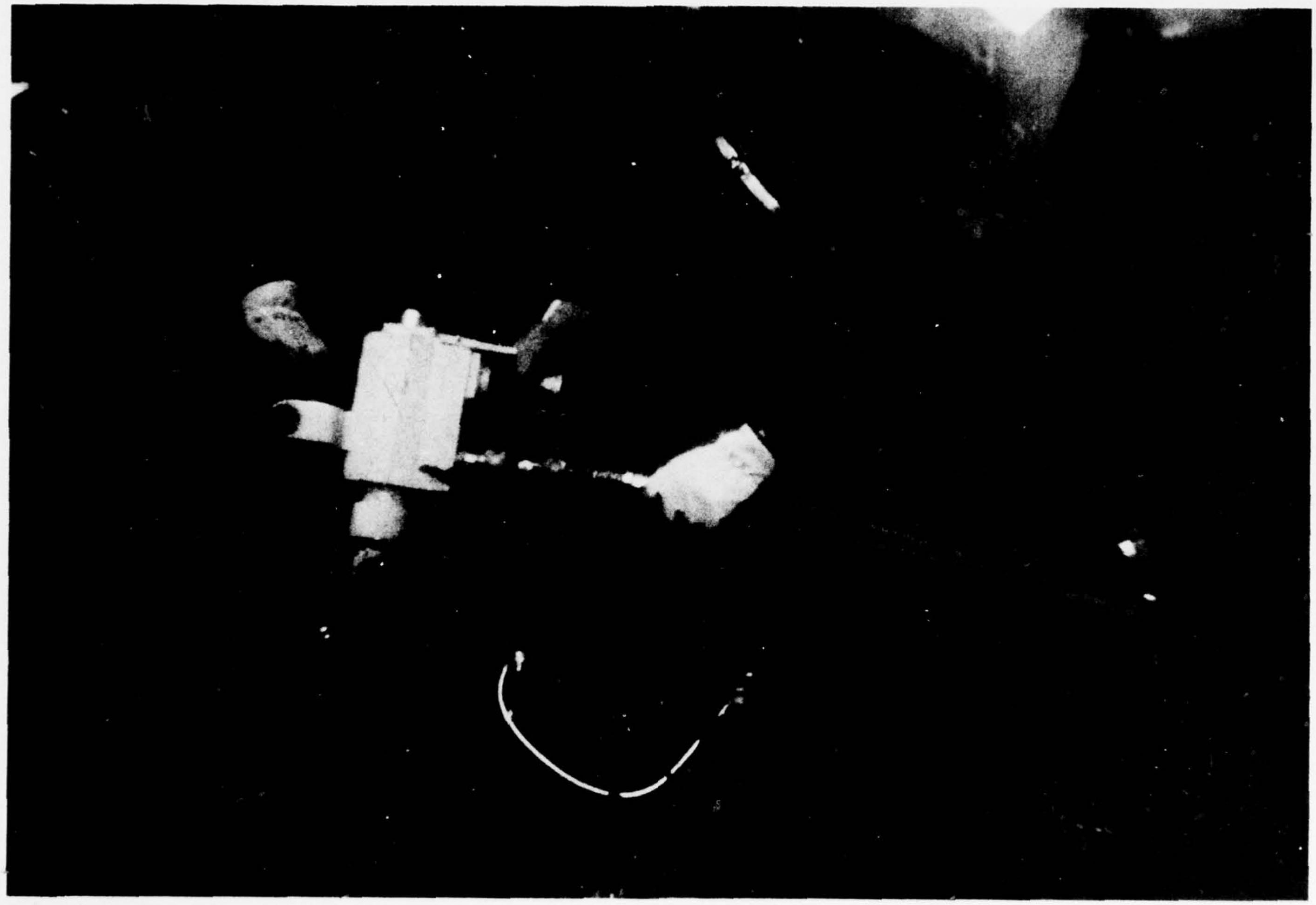
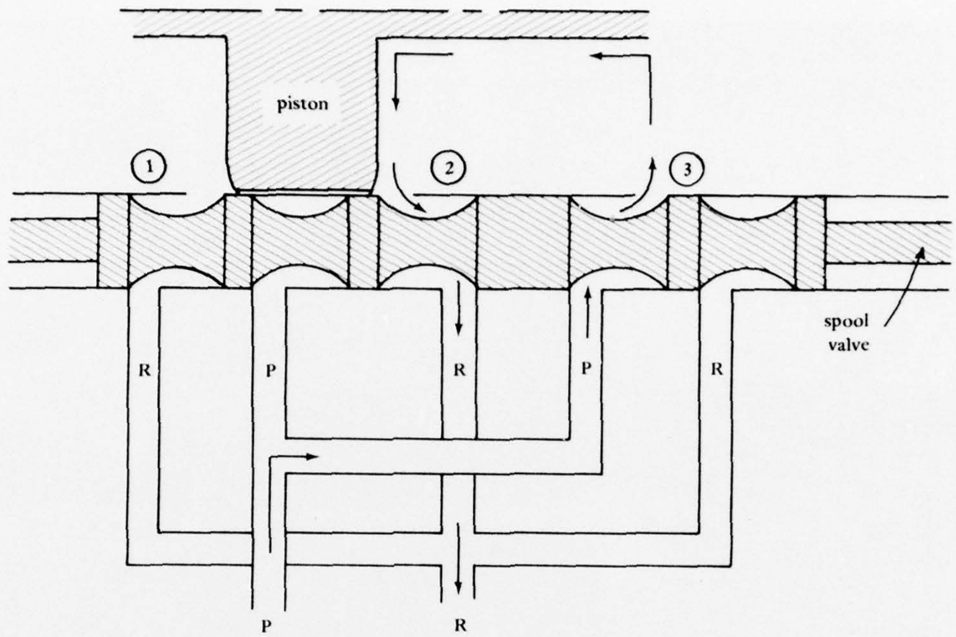
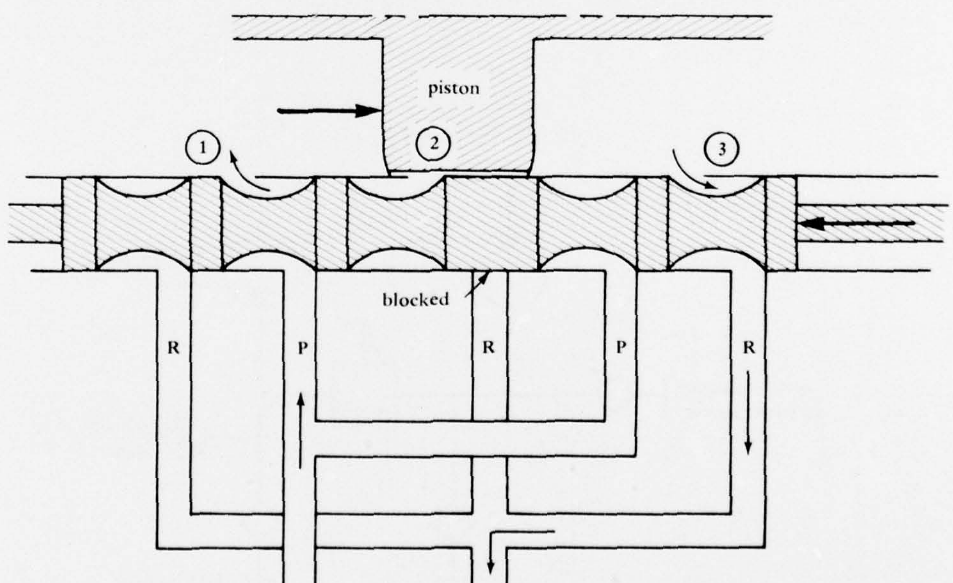


Figure B-3. Diver operation of experimental tool.



(a) Spool "at-rest" position.



(b) Valve displaced for power stroke.

Figure B-4. Hydraulic spool valve.

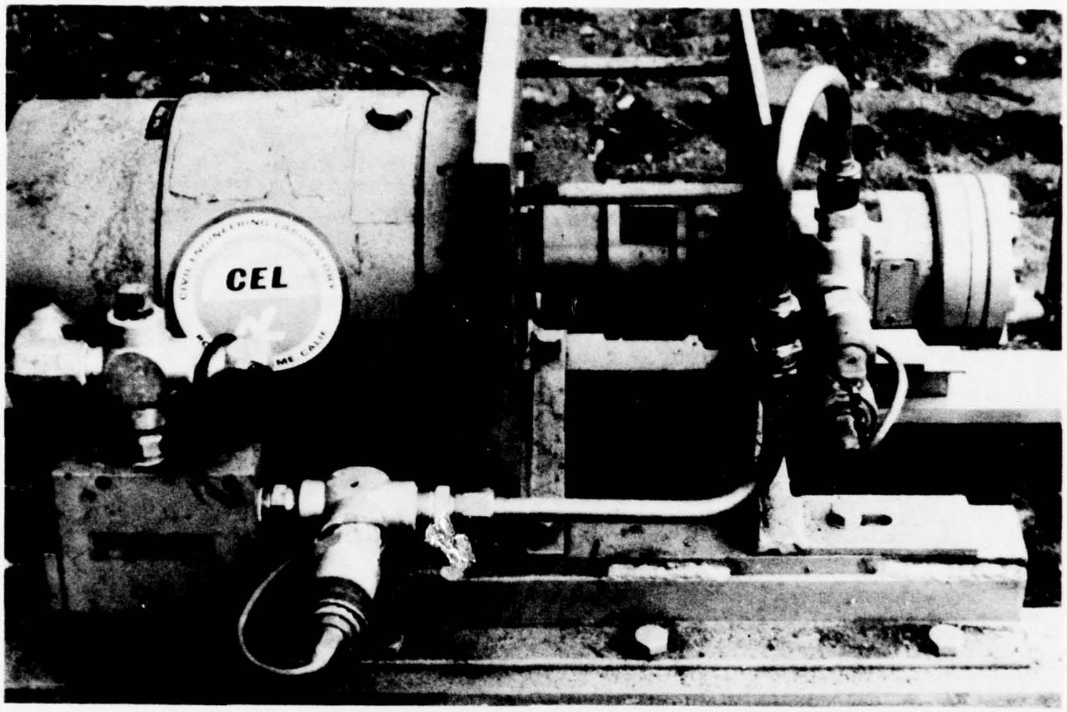


Figure B-5. Pressure intensifier.

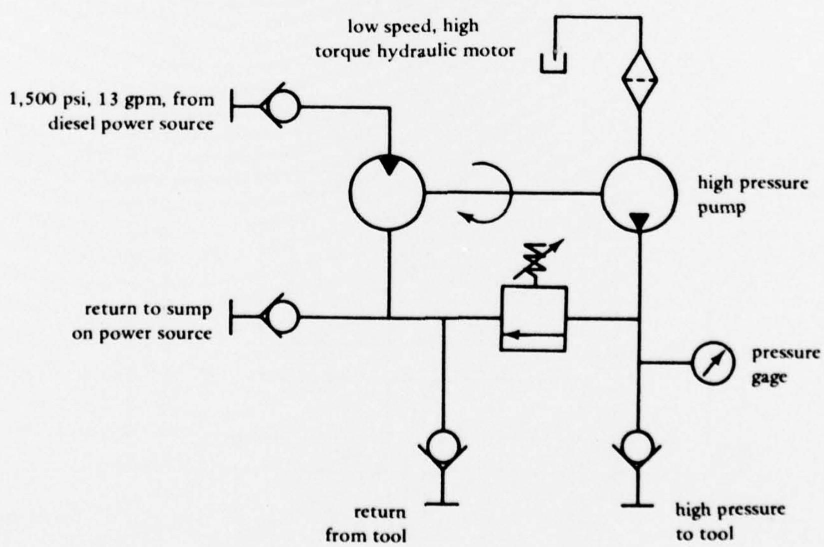


Figure B-6. Hydraulic schematic of pressure intensifier.

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