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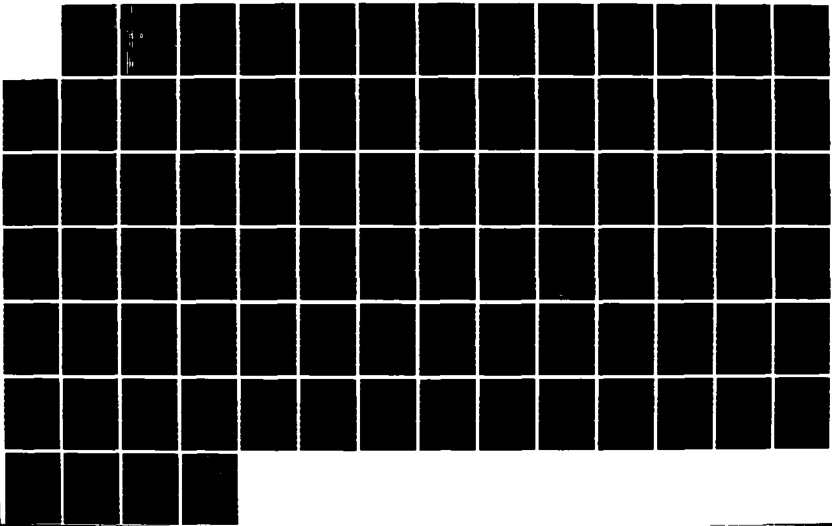

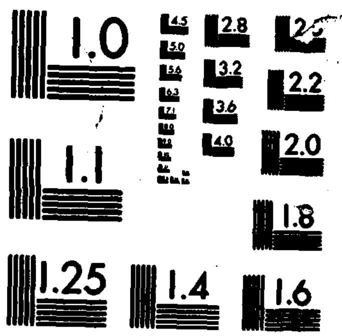

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OCEAN THERMAL CONVERSION (OTEC) PROJECT
BOTTOM CABLE PROTECTION STUDY

ANALYSIS AND SELECTION OF PROTECTION TECHNIQUES

BY

BESIER, GIBBLE & QUIRIN
CONSULTING ENGINEERS INC.

FPO-1-81-(20)
OCTOBER 1981

OCEAN ENGINEERING AND CONSTRUCTION PROJECT OFFICE
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Guideline methods and procedures for cable protection are given in general for the four proposed OTEC plant sites and cable routes, together with Seafloor Scenarios and Protection Strategies for each of the four sites. Burial of the cable below the seafloor is recommended and best method (Con't)

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of protecting the OTEC cables from the hazards existing at all sites, namely, a) chafe and corrosion, b) hydrodynamic forces, c) trawler/dredge, and d) ship anchor. For landslides and earthquakes the only feasible method of protection, although limited is to provide slack in the cable, namely to lay extra length.

Trenches for burial of the cable are recommend to be constructed a) by blasting through hard bottom at Hawaii for the first nautical mile (n.m.) and at Puerto Rico for the first 0.9 n.m., b) by a plowing machine at Hawaii for the next 0.5 n.m., c) by a trenching machine at Guam for the first 0.55 n.m., d) by a trenching/laying machine at Florida for 110 n.m., and e) by a conventional floating dredge for 15 n.m. For the outshore segments of the cable routes it is recommended to lay the cable on the seafloor because bottom sediments are soft enough to permit the cable to bury itself. Except for the Florida route, a normal cable laying vessel is recommended for laying the cable from plant site to landfall and for performing the protection details which are tremie concrete cover over the cable at Hawaii for 0.5 n.m. and split pipe and rock anchor at Puerto Rico for 0.2 n.m. At the Florida route it is recommended to use a machine which can dig a trench and lay the cable in the same operation. Some modification to vessels existing or development of new devices are recommended for the trencher at Guam and for the trencher at Florida to accommodate greater water depth and greater burial.

Estimated costs for complete installation are as follows: Hawaii $7,070,500, Puerto Rico $5,278,700, Guam $7,400,000 and Florida $11,370,000.

A specific site survey (at all four sites) is recommended in order to obtain more accurate cost estimates and to plan the actual construction methods.

EXCUTIVE SUMMARY

Guideline methods and procedures for cable protection are given in general for the four proposed (OTEC) plant sites and cable routes, together with Seafloor Scenarios and Protection Strategies for each of the four sites.

Burial of the cable below the seafloor is the recommended and best method of protecting the OTEC cables from the hazards existing at all sites, namely, a) chafe and corrosion, b) hydrodynamic forces, c) trawler/dredge, and d) ship anchor. For landslides and earthquakes the only feasible method of protection, although limited, is to provide slack in the cable, namely to lay extra length.

Trenches for burial of the cable are recommended to be constructed a) by blasting through hard bottom at Hawaii for the first nautical mile (n.m.) and at Puerto Rico for the first 0.9 n.m.; b) by a plowing machine at Hawaii for the next 0.5 n.m.; c) by a trenching machine at Guam for the first 0.55 n.m.; d) by a trenching/laying machine at Florida for 110 n.m.; and e) by a conventional floating dredge for 15 n.m. For the outshore segments of the cable routes it is recommended to lay the cable on the seafloor because bottom sediments are soft enough to permit the cable to bury itself. Except for the Florida route, a normal cable laying vessel is recommended for laying the cable from plant site to landfall and for performing the protection details which are tremie concrete cover over the cable at Hawaii for 0.5 n.m. and split pipe and rock anchor at Puerto Rico for 0.2 n.m. At the Florida route it is recommended to use a machine which can dig a trench and lay the cable in the same operation. Some modification to vessels existing or development of new devices are recommended for the trencher at Guam and for the trencher at Florida to accomodate greater water depth and greater burial.

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INTRODUCTION

Modification P00003 to Contract N62477-80-C-0163 required Besier Gibble & Quirin, Consulting Engineers, Inc. to analyze and select protection techniques for the power cables to be laid from shore to proposed OTEC plant sites at four locations, namely,

Kahe Point, Oahu, Hawaii

Punta Yeguas, Puerto Rico

Cabras Island, Guam

West Coast of Florida - Tampa

Specific guideline methods and procedures were to be selected for providing the necessary protection to the seafloor cables at each of the four proposed OTEC sites. These guidelines were to be based on the data from Chapter 3 of the report "OTEC Project Bottom Cable Protection Study - Environmental Characteristics and Hazard Analysis", reference (1) herein, and of the Brown and Root report on cable protection requirements and techniques, reference (4) herein. Where the cables should be protected and why was also to be indicated.

A seafloor scenario was to be developed for each of the four cable routes. One or more routes were to be described and one or more protection methods were to be proposed with explanations in detail.

A protection strategy for each site was to be developed by looking at the hazards at each site vs. water depth, environment, seafloor composition, and cable protection system.

ANALYSIS AND SELECTION
OF PROTECTION TECHNIQUES

CHAPTER 1. GUIDELINE METHODS AND PROCEDURES FOR CABLE PROTECTION

1.1 SUMMARY OF ENVIRONMENT, SEABED CONDITIONS AND HAZARDS

All four proposed OTEC plant sites are located in warm tropical climates and in exposed ocean waters. Cable routes between landfall and plant are generally normal to the coast line and have varying lengths in nautical miles as follows: Hawaii 4.6, Puerto Rico 4.4, Guam 1.1 and Florida 145.0.

For the Guam site the bottom profile is fairly flat at the shore for only about 300 feet from which point it slopes gradually to the plant site with a maximum slope of one vertical to two horizontal. For the other cable routes the flat beach section extends outshore about 1 nautical mile at Hawaii and Puerto Rico and about 90 nautical miles at Florida at which points the slopes become greater for the remainder of the route to the plant site. The steepest slope occurs at Puerto Rico about one nautical mile from shore where for a distance of 0.1 nautical mile the slope reaches approximately two vertical to one horizontal. Beyond this the slope quickly flattens to one vertical to two horizontal and thence almost flat at the plant site. Slopes at the other sites namely Hawaii and Florida do not exceed one vertical to 2 horizontal.

Very high winds are likely to occur at all sites generating 50 feet high waves. These waves can create hydrodynamic forces on the cable laying on the sea bottom from shore outwards to the places where water depth is about 75 fathoms. The distance out from shore to the 75 fathom mark is about as follows (in nautical miles): Hawaii 1.0, Puerto Rico 1.0, Guam 0.3 and Florida 90.0. Tide is generally small, not over 2 and one-half feet and mostly semi diurnal at all sites. Surface currents are generally small except for

Guam where it can reach 4 knots and for Florida 5 knots during storms.

In Hawaii and Puerto Rico the inshore length of the cable route for a distance of slightly over 1 nautical mile the sea floor bottom is expected to be hard. For the other two sites sand is expected to be found in the inshore lengths, as much as 10 nautical miles in the case of Florida. For the outshore lengths soft bottoms of sediments, clay, silt, ooze or mud are expected to be found.

Because of wave action and currents on the sea floor the hazards of chafing and corrosion exists at all sites along the inshore reaches of the cable route for cables laid on the seafloor without protection.

Erosion and scour can be expected offshore Hawaii and Puerto Rico along the steepest parts of their slopes, again exposing cables to the hazards of chafing and corrosion when they are laid without protection. Submarine landslides can also be expected offshore Hawaii and Puerto Rico, somewhat outshore of the areas where there exists the possibility of erosion and scour.

Ship and trawler activity are generally present to some extent at all sites. The hazards of anchor dragging and snagging the cable and of the action of trawling therefore exist over most of the lengths of the cable routes at all four OTEC sites except for a low probability at Guam and Puerto Rico. The probability of damage from these hazards however becomes very small in the deep water segments of the cable where water depths are over 350 fathoms and where trawling becomes very difficult to perform.

Earthquakes are possible to occur and affect the seabottom cables at all OTEC sites with the possible exception of Florida.

Refer to figures 3.1, 3.3, 3.5, 3.7 which show the profiles in true scale, seabed conditions, hazards likely to be encountered and probabilities of hazard damage. Reference (1) gives more detailed information regarding environmental characteristics and hazards.

1.2 PROTECTION METHODS

There are a number of methods or techniques for providing protection to the OTEC undersea power cables. For the purposes of guide line methods for the four OTEC sites and cable routes these techniques are presented under three main groups, according to the type of protection provided, namely, (1) mass anchors, (2) tie-downs, (3) burial. The technique of tensioning cables is not included here because of a) the great lengths of cables involved, b) the great depths of water involved and c) the high cost involved in the four OTEC sites. Tensioning cables would probably not provide the cables with sufficient strength to withstand the forces imposed (a) by large sized dragging anchors of major size ships at all of the sites, or (b) by the extensive trawler action at the Hawaii and Florida sites. Included in the discussion which follows are a description of major components and equipment, and estimates of production rates.

1.2.1 MASS ANCHORS

Mass anchoring is a procedure or method of providing the undersea cable with weight thus developing friction between the seafloor bottom and the cable protection system components to resist the horizontal forces resulting from hydrodynamic action on the sea floor and ship anchors snagged on the cable. Mass Anchoring might be called a stabilization technique and can be considered a protection system if it succeeds in resisting the environmental influences (hydrodynamics, anchor drag forces, etc.). However, when the environmental forces exceed the friction forces the mass anchor becomes part of the cable system and may itself require additional protection. Mass anchors include (a) cable armor, (b) split pipe, and (c) concrete.

(a) Cable armor is usually comprised of galvanized steel wires, of a given size and strength, usually coated for corrosion protection. Wires are added during the manufacturing process of the cable. The use of armoring as the only stabilization means is not common except in calm waters where cable hazards are non-existent or minimal. If some of the seafloor at the several sites is found to consist of a deep enough sand layer to prevent exposure of the rock through scour and erosion, and soft enough to allow the cable to imbed itself due to wave action, then armoring of a cable will help through the added weight to hasten the burial process.

The design of protective armor, namely size and strength of wire and extent of coating, can be varied by developing the requirements with a cable manufacturer.

(b) Split Pipe is the method of placing a cable within a pipe for the purpose of stabilization and protection. The procedure usually involves the use of sections of heavy nodular cast-iron pipe split longitudinally and placed below and above the previously laid cable with bolting to hold in place. Sections of pipe are joined and held together by an interlocking joint. See Fig. 1.1.

A split-pipe protective system performs two basic functions: (1) it provides abrasion protection for the cable, thus increases cable resistance to chafing and corrosion, and (2) increases the system density and therefore increases the cable system's capacity to withstand hydrodynamic forces due to wave action and bottom currents. The first function is performed extremely well when the cable system passes over a rocky bottom. There is some doubt however that the added weight of the split pipe will be sufficient to adequately resist the actual hydrodynamic forces expected to be experienced at the four proposed OTEC sites.

The usual method of applying this technique of split-pipe to a cable is by the use of divers doing the work underwater after the cable has been laid. This method usually becomes very costly because of the use of considerable

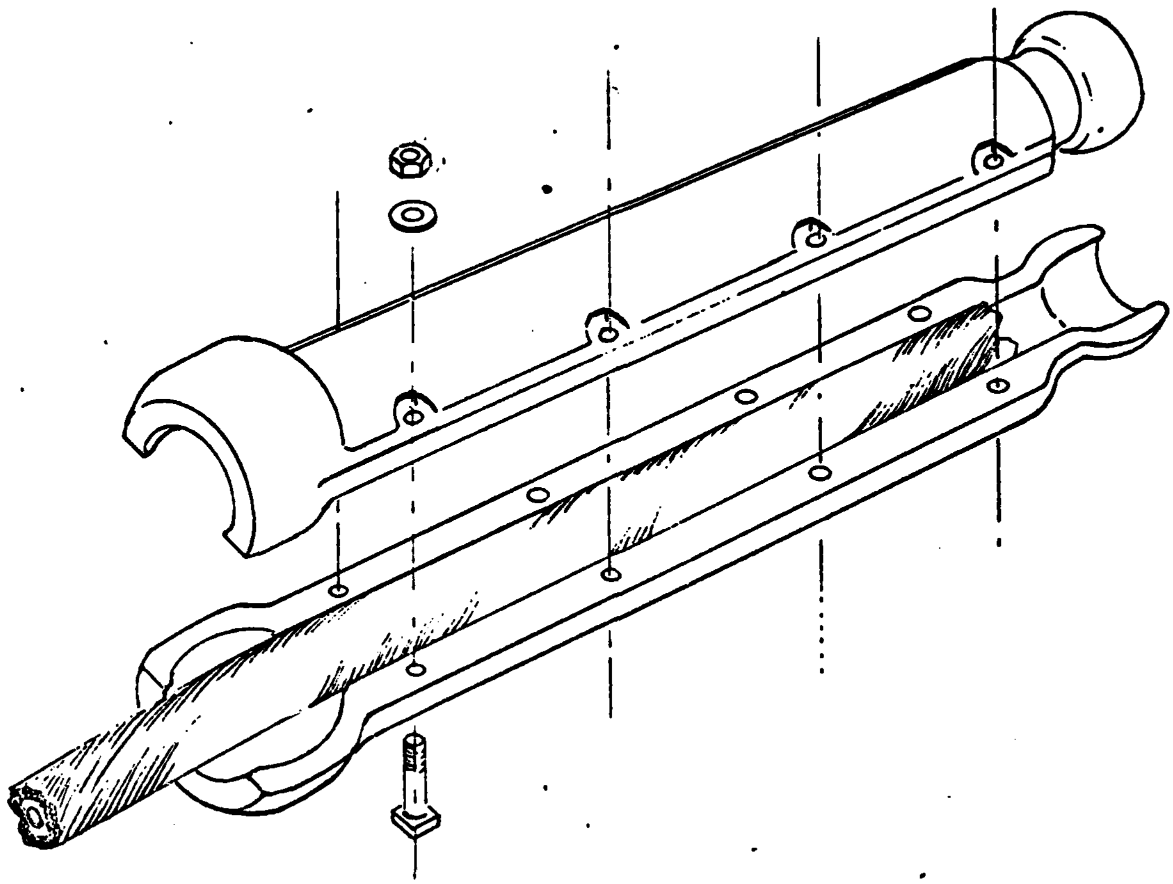


Figure 1.1 Split Pipe

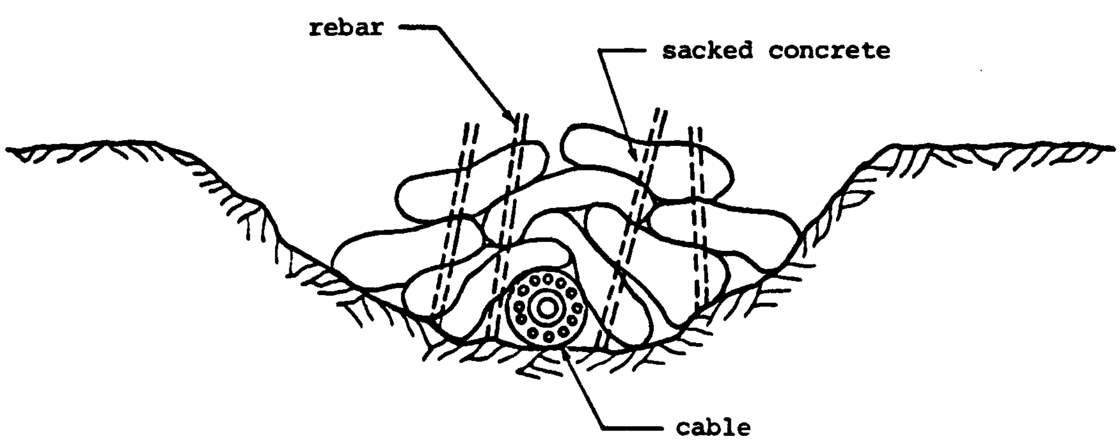


Figure 1.2 Sacked Concrete

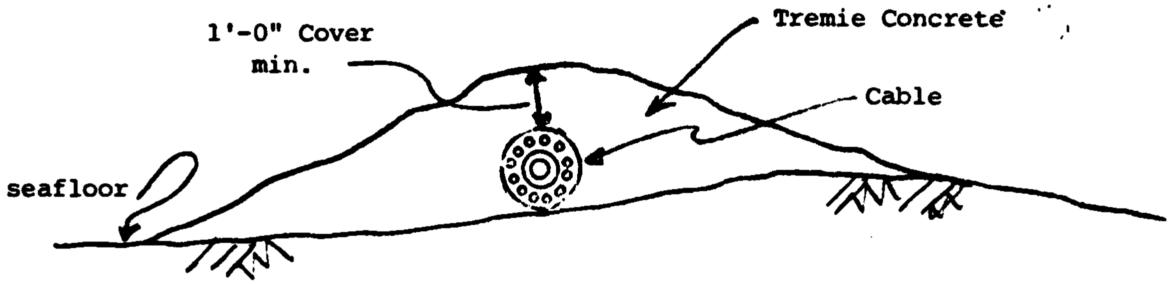


Figure 1.3 Cast-in-Place Concrete

time in the underwater hand work involved and in the interruptions due to sea conditions. Besides the method of applying this technique of split-pipe underwater by the use of divers there have been devloped three other techniques of installation. These are (1) applying the split-pipe to the cable on the beach and then dragging the piped cable to sea; (2) applying the split pipe to a floating cable from an under-running vessel; and (3) applying short lengths of split-pipe to the cable on the beach and then dragging the split-pipe over the cable to sea. Each of these techniques is appropriate at different times and perhaps a combination of all may be the best solution. The last technique appears to be of questionable value because of its inherent difficulty of installation. Reference (2) gives a much more detailed description and explanation of the materials, installation techniques, support requirements and selection factors for this method of providing protection by the use of split pipe. Ten diving hours should produce 100 ft of protected cable.

(c) Mass anchoring by concrete is a method of placing concrete on the cable on the sea floor by using sacked concrete, cast-in-place concrete and precast concrete elements. See Figure 1.2 and 1.3.

Sacked concrete consists of numerous flexible containers such as burlap, nylon, canvas, or rubber bags filled with concrete on the surface and positioned over the cable on the seafloor. Cast-in-place concrete consists of large masses of concrete delivered to the seafloor as a wet mix from the surface and either allowed to flow as an unconfined mass over the cable and seafloor or pumped into flexible forms (bags) which have been prepositioned over the cable. Precast elements are monolithic blocks of reinforced concrete which have been poured into forms and allowed to cure on land before positioning over the cable on the seafloor.

The use of sacked concrete is feasible only on rock or coral seafloors where self burial of the sacks or scouring of the soil under the sacks is not possible. No actual bond will exist between the sacks of concrete and the cable. Sacked concrete provides little or no protection against the various hazards except for hydrodynamics forces and then only if maximum wave conditions are expected to be less than 20 feet wave height during the life of the installation. Small waves can cause problems during the installation by causing the cement to leach out of the concrete resulting in no bonding between the sacks.

Cast-in-place concrete is accomplished by utilizing one of the four techniques used in underwater concrete construction, namely, (1) underwater bucket, (2) tremie, (3) preplaced aggregage and pumping grout, and (4) pumping concrete.

The use of cast-in-place concrete has advantages over other methods of cable stabilization when environmental conditions allow this method to be utilized. Very little site preparation is necessary, underwater work by divers is minimized, concrete conforms to bottom irregularities thus increasing its holding power and corrosion problems are reduced. One disadvantage with this method is that retrival of damaged cables for repair is very difficult.

Waves and current have minimal effect on the concrete once it has set. This technique produces a low profile mass of concrete that conforms to and locks into the seafloor. However, during placement of the concrete and prior to set, excessive water particle motion caused by waves and currents can have a disastrous effect on the installation. Any water motion will tend to wash the cement out of the concrete leaving a weak, crumbling mass composed mainly of aggregate.

Discrete masses of concrete placed at intervals along the cable provide little protection against any of the hazards. A continuous pour along the entire length of the cable would be effective against anchor drag and fouling. Pumped concrete appears to be the only feasible method of completely encasing the cable in concrete.

Although a great deal of literature exists on methods of placing concrete under water, virtually nothing could be found which documented the results of actual cable stabilization installations or how successful concrete was at immobilizing the cable for any extended period of time.

Reference (2) gives a much more detailed explanation and description of the materials, procedures, support requirements, installation time estimates, selection factors for the method of protecting an undersea cable with the use of concrete.

Reference (2) includes two other forms of stabilization of an undersea cable by the use of mass, namely, oil well drill pipe and chain. Neither of these methods are appropriate for the proposed OTEC sites. The use of oil well drill pipe actually decreases the cable system density making the system more sensitive to hydrodynamic forces. Chain is appropriate for cable runs having a limited life requirement or in areas of minimal hydrodynamic forces.

1.2.2 TIE-DOWNS

Ties-downs are immobilization techniques which mechanically couple the cable to the seafloor at discrete points along the length of cable. This type of protection technique is generally used when the cable or cable/mass-anchor system is not sufficiently heavy to remain stable under the influence of maximum anticipated hydrodynamic loads. Tie-downs can be categorized into 3 groups namely, (1) Pin Anchors, (b) Grouted Fasteners and (c) Rockbolts.

(a) Pin Anchors of the steel bar type jackhammered into coral have not proven successful and is considered obsolete for coral seafloors. Pin Anchors using a disk shaped in the form of a screw and working on the auger principle have been used in sand or clay seafloor materials but primarily to stabilize large diameter pipelines. See Figure 1.4.

Reference 2 describes this type of tie-down in greater detail together with a discussion of procedure and selection factors.

(b) Grouted Fasteners are usually of U-shaped rods grouted into previously drilled holes in the rock bottom. Properly installed, namely, tight fitting over the cable system, and when used in conjunction with split-pipe covered cable U-rods provide a formidable immobilization technique but require fairly good diving conditions and considerable time. See reference 2 for more detailed information. See Figure 1.5.

(c) Rock Bolts are the same as used in the construction industry for anchoring to rock and utilize for purposes of developing their anchoring strength the principle of mechanically expanding the downhole end of the bolt to develop friction and adhesion between the anchor and the rock together with sufficient penetration of the anchor into the rock. See Figures 1.6 and 1.7.

Rockbolts are classified into two types, the drive-set fastener and

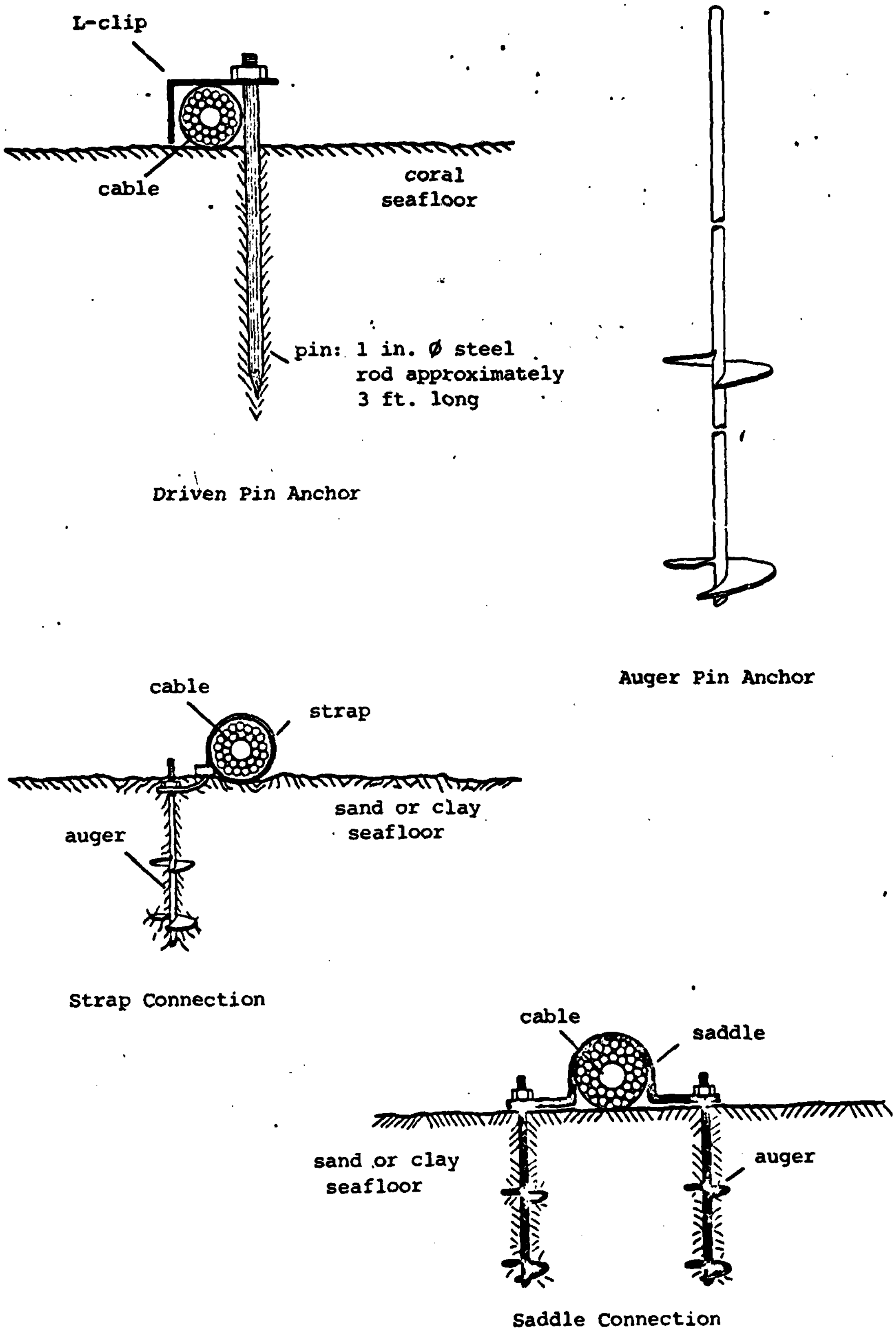


Figure 1.4 Tie Downs - Pin Anchors and Augers

the torque-set fastener. They are commercially available in a variety of designs and sizes together with hand power tools for their installation. Cables are immobilized by installing the rockbolts in pairs at intervals along the cable with a saddle spanning the cable at each pair of bolts. Some existing standard rockbolts have corroded in 3 to 4 years at which time protection is

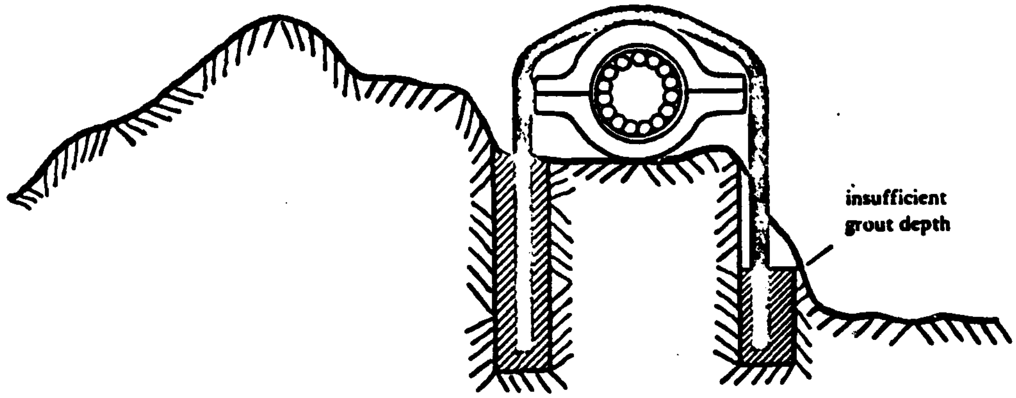
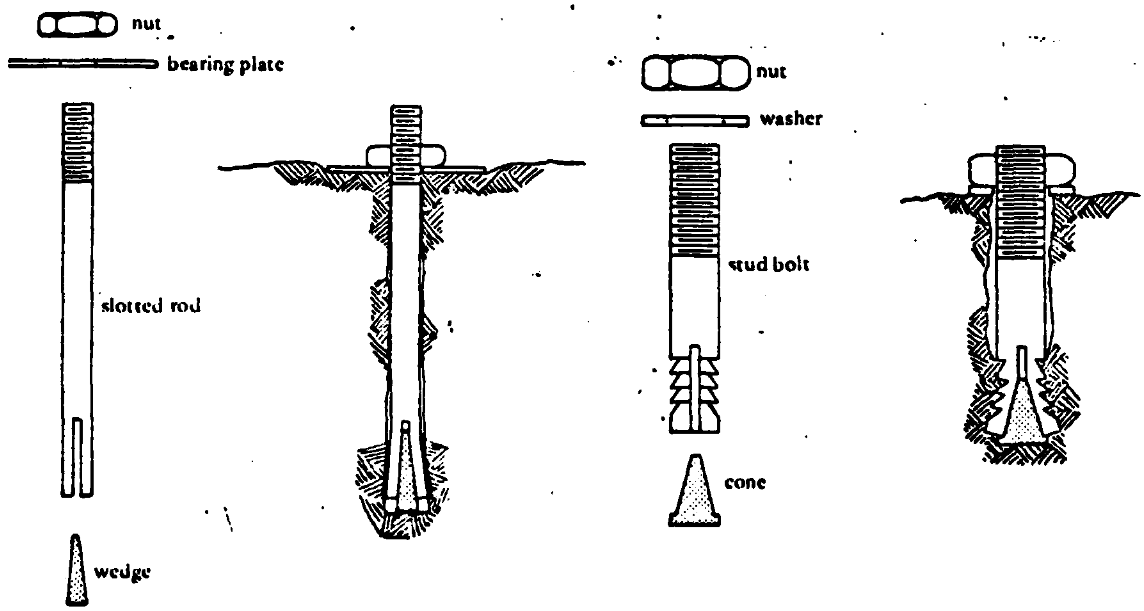


Figure 1.5 Grouted Fasteners



Slot and Wedge Bolt

Cone and Stud Anchor

Figure 1.6 Rock Bolts

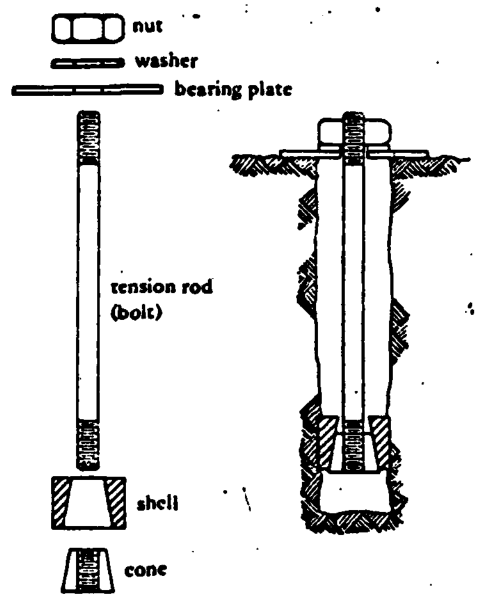


Figure 1.7 Torque Set Anchor

greatly decreased. Therefore, these bolts must be made of exotic material (not stainless steel) or otherwise cathodically protected. Sizing and spacing can be determined by design to withstand static and dynamic forces.

1.2.3 BURIAL

Burial provides protection by allowing the cable to be placed below the surface of the seafloor. The effectiveness of this technique depends on the depth of the burial and consequently the removal of the cable from the environmental hazards expected to be encountered. Since burial eliminates the influence of the environmental hazards rather than providing a means to resist them, design theories are not applicable as they are with mass anchors and tie-downs. The selection and implementation of the several techniques available for burial depends, therefore, on economics and the ability of the available equipment to bury the cable to the required depth. The techniques for burial can be classified as follows: (a) self burial, (b) plowing, (c) jetting, (d) dredging, (e) explosive excavation, (f) mechanical trenching and (g) drilled hole.

(a) Self burial occurs because of the high unit weight of the cable and the strength reduction and scour of the underlying seafloor sediments caused by waves and currents in cases where the cable is laid on sand, silts and soft clays. Self burial may sometimes occur very rapidly, the same day as it is laid. When laid, sufficient slack must be provided to allow the cable to follow the natural seafloor profile without restraint. An experiment or test section would be needed in each case to ascertain the probable depth of self burial.

(b) Plowing is a technique workable only for soft soil conditions, where depth of embedment is not critical. Plowing equipment is usually designed for high production rates and for deep water where hazards are few. Of the equipment surveyed by reference (4) all are effective in fine sand, silt and soft mud. Cable plowing has an inherent cost advantage because the plowing is done at the same time as the cable lay operation. As shown in Table 1.1 several models have high production rates, compared with other protection techniques.

(c) Jetting is a technique workable in most noncohesive materials (except those with large gravel not movable by jets) and in many cohesive soils (except for those too highly consolidated to erode with low pressure jets).

Table 1.1

SUBSEA CABLE PLOW CAPABILITIES

Company/Machine Name	During/ Post-Lay Burial	Maximum Production Speed (m/h)	Maximum Burial Depth (cm)	Maximum Water Depth (m)
Flexservice/Plow	During	200	180	200
KDD/KS-1	During	3700-5500	70	*
Sumitomo Elect. Ind./MARK III	During	3700-5500	150	200
A.T.&T/Sea Plow IV	During	1100	60	914
Sumitomo/Plow	During	2000	150	100
Harmstorf Corp./VIBRO-HYDROJET	During	*	610	300

*Unknown

Note: Information for this table was obtained from OTEC Subsea Electrical Cable Protection Systems and Technology Survey, BARDI, January 1981.

Jetting is primarily a post-lay operation. Two quite different mechanisms can be used. The first involves using large jets to erode and displace sea-floor material, leaving an open trench into which the cable is inserted. The second involves using many small jets to fluidize the soil in a narrow silt formation allowing the cable to follow immediately behind by feeding the cable to the jetting machine as it advances. In the first case the trench is allowed to fill naturally.

Table 1.2 lists the capabilities of several commercial jetting machines. Two machines of note are the SCARAB II and the SOFIE. SCARAB II is a second generation vehicle with exceptional depth capability. Reasonable production rates can be achieved with this machine, although it was designed primarily as a salvage, repair and exploration vehicle. On the other hand, the SOFIE is designed as a production vehicle and achieves a very respectable burial depth. It has had extensive field experience.

(d) Dredging is usually reserved for the stronger, cohesive soils, for soils containing gravel or cobble and for those soils not easily excavated by plain jetting. Burial of the cable by a dredge-type trencher usually requires laying the cable first along the proposed route followed by trench excavation and cable insertion by the self-propelled dredge trencher, usually accomplished by starting out at sea and working toward the beach.

(e) Explosive Excavation is used in very hard materials or in extremely rugged topography in softer materials where it is the most viable means of route preparation. Involved here is sufficient background information and capability to handle the various blasting techniques. The most common basic techniques range from simple contact blasting through complex drilled and delayed charge principles.

(f) Mechanical Trenching is a modern developing technique available for

TABLE 1.2

SUBSEA CABLE JETTING CAPABILITIES

Company/Machine Name	During/ Post-Lay Burial	Maximum Production Speed (m/h)	Maximum Burial Depth (cm)	Maximum Water Depth (m)
Balfour Beatty/CLEM 2	During	960-1200	150	45
Balfour Beatty/CLEM 3&4	During	1200	200	120
Norges Vassdrags/Organ	Post	*	100	150
Cables & Wireless, Ltd/SCARAB I	Post	150	60	1800
Ocean Search, Inc./SCARAB II	Post	150	40	1800
UDI Group, Ltd./Sea Bug	During	600-900	160	300
Suspect Slingsby Engr./Sea Cat	Post	120	*	200
British Telecom/Sea Dog	Post	80-300	100	274
Elsam-Svitzer/SOFIE	Post	120	120	300
Hoad, Ltd./STV (1)	Post	920	30	1000
Sumitomo/	During	100	20	100

*Unknown

Note: Information for this table was obtained from OTEC Subsea Electrical Cable Protection Systems and Technology Survey, BARDI, January 1981.

deep water and for deep trenching through a great number of existing devices manufactured by many companies. Use of this type of trencher has been rather extensive for underwater oil pipe lines for the offshore oil drilling industry. The capabilities of several trenchers are compared in Table 1.3. There are actually two classes of trenchers at the present time. One class, represented by machines such as the Sumitomo Trencher TM402 and the UWAG1 are designed merely to dig through soil, sand and clay more efficiently than jets or plows. These machines are equipped with chain cutters, which are limited in the amount of normal force which they can exert on the soil.

The premier class of trenchers are the rock trenchers, because these are designed to excavate material up to an unconfined compressure strength of 20,000 KN/m^2, which corresponds to a shear strength of about 8,000 KN/m^2. Unlike the soil trenchers, these machines, such as the BM-1, Flexservice Drum Cutter, Travocean Trencher, and the RTMII are equiped with toothed wheels which can apply considerable force to the forward trench wall. All of the four aforementioned machines have undergone extensive testing lending credibility to their production claims.

The Flexservice Drum Cutter warrants special note because of its unique features and outstanding capabilities. Unlike some competing models, this machine performs simultaneous lay/burial which reduces overall construction costs. In addition, the production statistics are based on actual performance rather than engineering estimates. See Figures 1.8 and 1.9.

(g) Drilled Hole technique has been used in a few cases to prevent grounding icebergs from crushing undersea cables. Here the technique is to drill a hole in a straight or curved line by the use of a rig of the type used in mining, construction exploration and oil drilling and then threading the cable. This method has thus far appeared economically justified only in very

TABLE 1.3

SUBSEA CABLE TRENCHER CAPABILITIES

Company/Machine Name	During/ Post-Lay Burial	Maximum Production Speed (m/h)	Maximum Burial Depth (cm)	Maximum Water Depth (m)
COMEX/BM-1	Post	90	170	180
Flexservice/Drum Cutter	During	300	120	*
Lyntech Corp./Gopher MK-2	During	460	140	120
Lyntech Corp./Mud Bug 6	During	150	180	60
Land & Marine Engr./RTM II	Pre	420	150	100
Sumitomo/	During	*	170	200
TECNOMARE/TM-402	Post	10-400	160	160
Travocean/Trencher	Post	80-150	150	60
Deutsche Babcock Anlagen/UWAG I	During	225	250	100

*Unknown

Note: Information for this table was obtained from OTEC Subsea Electrical Cable Protection Systems and Technology Survey, BARDI, January 1981.

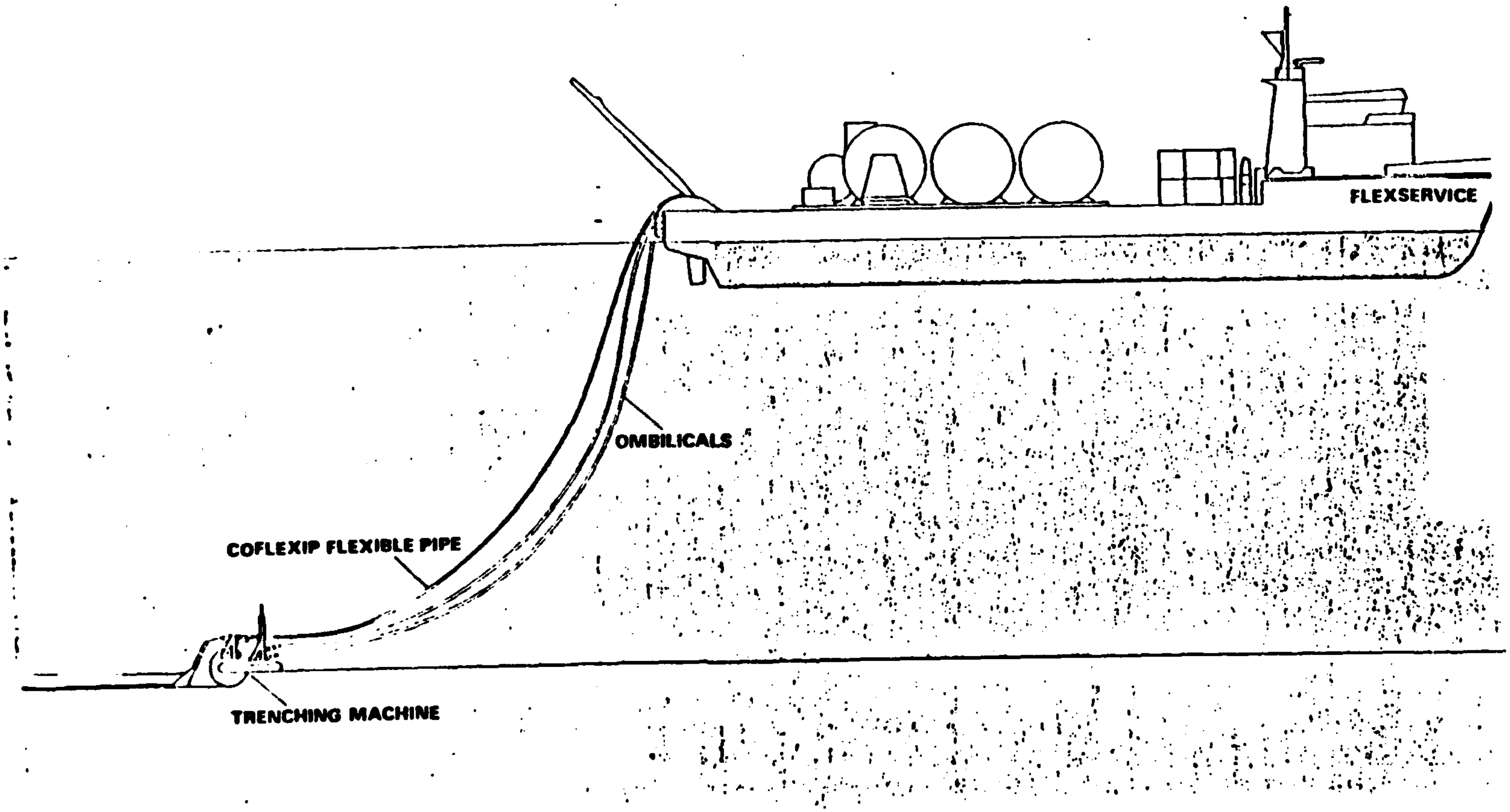


Figure 1.8 Laying and Trenching Operation

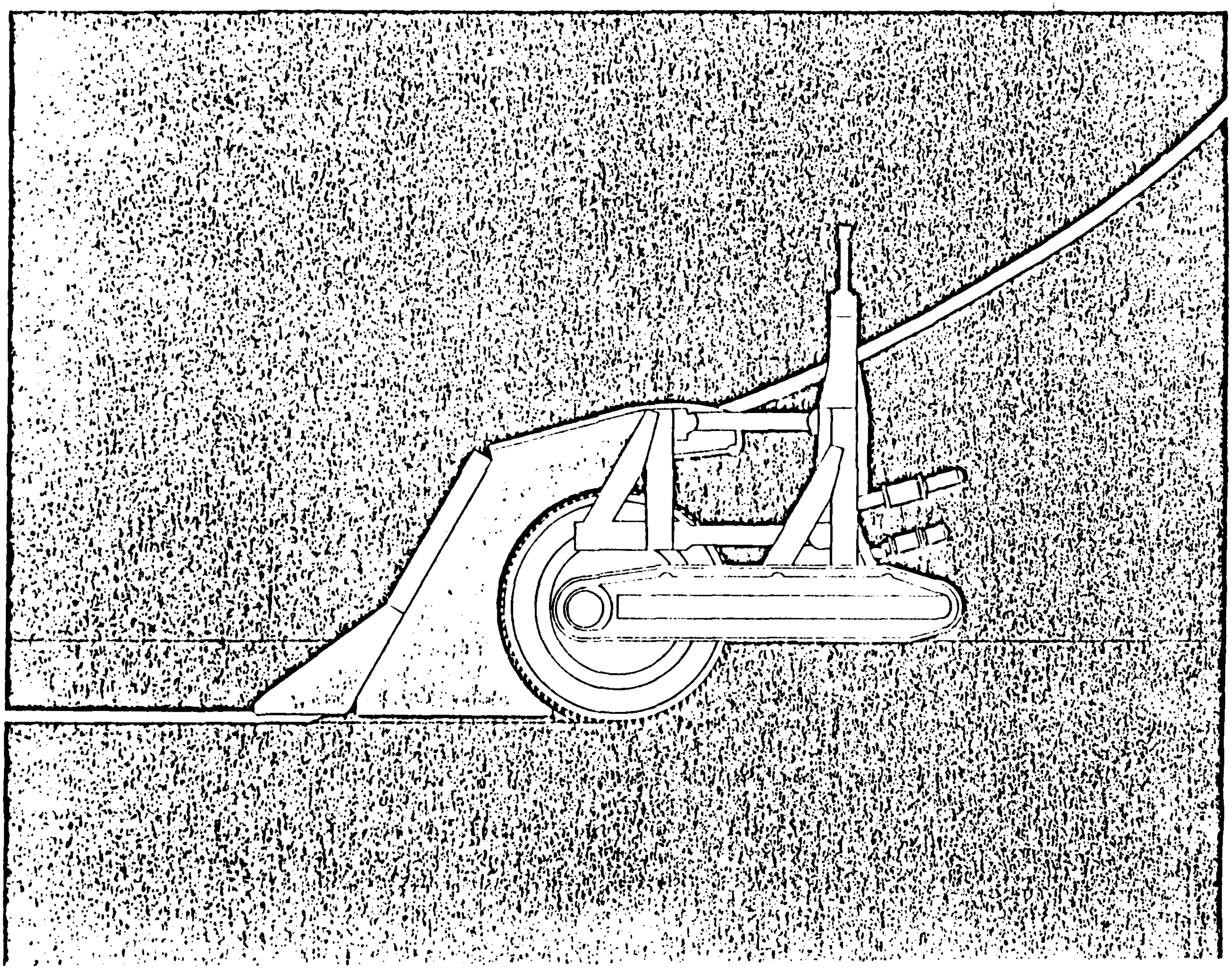


Figure 1.9 Trenching Machine

special circumstances.

1.3 EFFECT OF SITE AND HAZARD PARAMETERS ON PROTECTION METHODS

It would appear that in consideration of all the hazards present at all OTEC sites and cable routes, both the environmental and man-made, the best protection method would be to bury the cable in the sea bottom. Depth of burial can be varied dependent upon the degree of the hazards present in any given length of cable. Depth of burial may be limited due to the difficulty of being able to create a trench within reasonable cost factors. For the out-shore length of cable runs in all sites it is expected that burial will occur naturally. Depth of burial here of course will depend on the actual site conditions. Using a length of cable for a test, actual observance may be made before embarking on the final actual laying of the cable. The equipment used in each case will also determine depth of burial.

Diver support for any protective method is possible only to about 220 fathoms water depth. Many of the machines used for plowing, jetting or trenching reach their operating limit before they reach this water depth, thus narrowing the choice of using trenching equipment, remotely controlled beyond the 220 fathom mark to only a few.

In the surf zone, namely, that length of cable line to the 10 feet depth mark is actually too shallow for many of the plow, jet and trencher machines but the cable may be buried by conventional dredging methods. Alternates such as mass anchoring with concrete may be used effectively in the shelf zone. Down to a water depth of about 100 fathoms jetting, plowing, and trenching are all viable protection techniques.

Where the bottom is hard and maybe costly to excavate an alternate solution would be to use the mass anchor technique of split pipe tied down to the seafloor with rockbolts. An exposed cable in all cases where the bottom is hard is subjected to abrasion and if held in place the hazards of chafing and erosion can be overcome. In these cases however, anchor snagging and trawler action can still exert severe forces on the cable and therefore tie downs must be carefully and conservatively designed.

1.4 PROCEDURE FOR PROTECTION

All of the discussion hereinbefore concerning the environment, sea bed conditions and hazard is based upon available literature and publications. They are general in nature and not site specific. To properly analyze each site in order to determine the degree of protection, the method and procedure to use and an estimate of cost it would be necessary to adopt a procedure somewhat as follows:

1.4.1 SITE SURVEY

The environmental factors, seafloor soil conditions and hazards existing at the four proposed OTEC sites and the discussions hereinbefore were all based upon a thorough investigation of available literature. In order to (a) establish a precise cable route line, (b) design in precise detail the protection system, (c) plan the installation and construction and (d) make an estimate of cost there is needed more specific and precise data concerning the seafloor at each proposed site.

This is accomplished by a specific oceanographic site survey over the proposed routes at the four sites. The site survey should cover a sufficient width over the cable route to permit a thorough study of route deviations to take advantage of the seafloor characteristics and to avoid physical hazards of either man-made or naturally existing. In other words the site survey should be conducted by systematically covering the area in broad sweeps to insure that all underwater obstacles have been disclosed. A site survey would include topography of the seafloor, bottom soil types and strength properties and a measurement of underwater current velocities and turbidity.

The topographic features of the seafloor essential to designing and laying a cable system can be considered in three broad catergories, (1) macrotopography, (2) microtopography, and (3) surface roughness. The major topographical features of the seafloor are the continental shelf, the continental slope, the continental rise, oceanic ridges, trenches and volcanic cones. Superimposed upon these major features are numerous hills, ridges, basins and valleys that are classed macrotopographic features. Superimposed also upon the major features of the seafloor are small features which are termed microtopography and surface roughness. These small features, ranging in size from less than an inch to 60 feet in vertical relief, include ripple marks, sand waves, rock outcrops, the trails and mounds of small seafloor animals and small-scale, shallow, discontinuous depressions.

Bottom soil samples should be taken at sufficient points to define the geological structure and bearing strength. This data is essential for the selection of the cable routes in detail,for the selection of trenching and other equipment needed for the cable installation, and for use during installation to determine anchoring positions for construction vessels. The ultimate bearing capacity of a sediment depends on cohesion, angle of internal friction, density, depth on the sediment and other properties all of which are determined in a test laboratory from actual core sample taken in the ocean bottom.

Turbidity currents are those great moving masses of water containing suspended sand, pebbles and wind which are likely to occur in deep ocean channels or marine canyons after a seismic disturbance. These flows can generate tremendous forces and it would be prudent to avoid sites where they are likely to occur. Water currents existing along the bottom at the four sites should be measured to verify their existence and to determine to what extent a cable needs to be protected to resist current forces.

1.4.2 ROUTE SELECTION

On the topographic chart produced in the site survey the probable cable path can be then located. The route should be arranged to provide the maximum possible conservation in the overall distance from the land fall to the OTEC plant site. The identification of a probable route will depend on the following factors:

(1) Avoiding the possibility of cable suspension or avoiding unstable seafloor material.

(2) Avoiding existing facilities or obstructions, such as another previously installed cable or pipeline, dumping areas, fish havens, wrecks, etc.

(3) Assessment of the capability to create a trench for burial of the cable or to create the protective devices on the cable if trenching is too costly or impossible.

(4) Assessment of the capability to install the cable along the specified path. This includes such factors as the type of ships to be used, their ability to maintain position during the laying operations and the length of time the ship must remain on station. The possibility of large catenaries developing due to current before the cable is positioned on the seafloor and the capability of repositioning the cable once it is installed must also be considered.

(5) Hydrodynamic factors, such as the direction of maximum current and waves that can influence the selection of a cable path. Since the magnitude of the hydrodynamic forces is influenced by the angle of incidence of the impinging water particles, the combined effects of current and surge can

sometimes be used to indicate an optimum cable path along which the maximum water particle velocity will always be parallel to the cable.

The evaluation of these five factors can be used to identify both a best and worst case cable path. A conservative design is achieved if the cable installation is based on a best path and the stabilization/immobilization system is designed on a worst case path.

1.4.3 STORM WAVE

The selection of design waves (height, length, period and direction) will have a large economic impact during the installation of the cables. Specifying unrealistic large wave parameters will result in unwarranted expenditure of funds, while too moderate a wave environment will most often result in premature failure. The selection of the design wave must be based on the probability of exceeding the design hydrodynamic forces being acceptably small.

The design wave parameters are, for the four proposed OTEC sites, best obtained using forecasting techniques. At the Florida site where a predominance of shipping and fishing activity exists, consultations with local interests can prove very helpful. Refer to reference (2) for more detailed explanations on the subject of forecasting wave parameters.

Since none of the wave theories are valid for waves once they are broken, a breaking wave analysis must be undertaken. Likewise there is needed to take into account the effects of shoaling and refraction which is done by an analysis of these two factors. See reference (2).

1.4.4 COMPUTATION OF FORCES

Cables for the four proposed OTEC plant sites are subject to both static and dynamic forces. Static loads are produced by the reaction of the weight of the cable resting on or suspended above the seafloor and by the hydrostatic pressure. Dynamic loads consist of forces produced by currents and waves as water particles move past the cable. Reference (2) gives a dissertation on these forces and how to compute them.

Forces produced by dragging anchors and trawling gear do not lend themselves to generalized analytical solutions. They generally relate to the power of the vessel on the surface of the sea whose anchor may be dragging or who is pulling the trawling gear.

1.4.5 DESIGN OF PROTECTION SYSTEM

Having studied the various protection methods in relation to the site survey, and having selected the probable route, it is now possible to select the system for particular lengths of the cable route. The stability of the selected method can then be ascertained by applying the forces computed in section 1.4.4. The first selection should probably be a cable/mass anchor system and if found to be unstable under the influence of the hydrodynamic forces a new selection can be made and the process repeated or a feasible immobilization technique can be selected and analyzed for stability.

A protective system of burial of the cable does not need to be analyzed for stability as does a mass anchor or stabilization system and an immobilization system. The criteria here is basically the type of soil to be encountered and the depth to which a dragged anchor may imbed itself and become snagged on a buried cable. It is obvious that the softer the subsoil the deeper the burial. Anchors have been known to bury themselves as much as twenty five feet in mud. A burial of ten feet in coarse sands would normally be adequate.

1.4.6 SELECT CONSTRUCTION METHODS

Having completed a site survey, selected a probable route, computed static and hydrodynamic forces and designed the necessary protection systems with alternates the final step is to select the construction and installation vessels and equipment and plan the construction operation all of this is necessary to perform prior to commencing the actual construction and installation operations. Reference (3) gives a detailed dissertation on the various aspects of construction and installation planning.

Because of the hazards expected to be encountered at all four proposed OTEC sites it appears that the best protection method is to bury the cable for its entire lengths. For the extreme outshore portion of the cable route at all four sites it appears that the bottom consists of soft soil of sufficient depth which would allow the cable to bury itself. It would therefore be necessary to utilize only cable laying equipment for these lengths. Natural burial for the outshore reaches where water depth is great, over 350 fathoms deep (220 fathoms in Guam), should prove to be adequate because most of the hazards will be minimal or non-existent. The lengths of these outshore reaches in nautical mile where self burial is expected to take place are: Hawaii 2.6, Puerto Rico 3.3, Guam 0.5, and Florida 20.0.

From these points towards shore to the 10 fathom depth mark, at the Guam and Florida sites, deep sea ocean vessels and equipment will be needed to create a trench of the required depth and to lay the cable. At the Hawaii and Puerto Rico sites in addition to the trenching and cable laying vessels there will be needed other vessels and equipment to perform the stabilization work for a portion of their routes. This latter type of work requires extensive use of divers in water depths up to 220 fathoms.

Inshore of the 10 fathom line, the water depth will be too shallow for the vessels used outshore. Consequently for this area the vessels and equipment will be of the more conventional type used for marine construction such as cargo barges, derrick barges and small work boats.

The following is an outline of the process to follow:

1. List of equipment requirements
    a) Offshore
        1. Cable laying vessels with machinery and auxiliary propulsion and navigation and positioning instruments
        2. Derrick barge
        3. Ocean going tugs
    b) Nearshore
        1. Shallow draft cable barge
        2. Cargo Barge
        3. Samll work boats
        4. Crew boat
        5. Vessel for performing sea end to shore end cable splicing
    c) Nearshore marine construction work
        1. Dredges
        2. Cargo Barge
        3. Derrick barge
        4. Cable laying and recovery machinery
        5. Work barge - diving equipment
    d) Onshore
        1. Testing equipment and instruments
2. List the labor requirements
    a) Project management
    b) Work crews
    c) Divers
    d) Vessel, boat crews

e) Onshore personnel

3. List construction tasks

   a) Planning

      1. Facility layout

      2. On-site inspection and survey

   b) Site preparation

   c) Vessel mobilization and loading

   d) Cable laying

   e) Offshore construction

4. Estimate costs

5. Evaluate alternates and decide

6. Set up training and testing procedures

7. Mobilize

8. Do the work

9. Demobilize

CHAPTER 2. SEAFLOOR SCENARIO

2.1 KAHE POINT, OHAU, HAWAII (Refer to Figure 3.1)

In general, the bottom offshore of Kahe Point has a very flat slope of about 1 vertical to 40 horizontal for a distance of about 0.5 nautical miles and then gradually the slope increases to 1 vertical to 3.75 horizontal in the zone between 1 nautical mile and 2.4 nautical miles from shore where the slope begins to flatten and becomes 1 vertical to 25 horizontal at the plant site. This profile extends up and down the coast from Kahe Point. A straight line route from Kahe Point to the plant site is approximately normal to the contours representing the bottom as described hereinbefore. Any minor change in alignment would not materially affect the slopes expected to be found along such route.

For 1.0 nautical mile from the shore line the bottom is expected to be coral, coralline reef facies and some sand. For the next 0.45 nautical miles the bottom is expected to be coralline reef material overlain by sand deposits. For the next 3.15 nautical miles the bottom is expected to consist of loose sediments from 250 feet to 350 feet thick. In this area it is expected that the cable will bury itself. Landslides may be possible in the sand deposits where the slopes are greatest, in the 1.0 to 1.45 nautical mile range.

Maximum storm waves can create bottom currents and hydrodynamic forces from shore outward about 1.0 nautical mile. Bottom water currents outshore of the 1.0 nautical mile line are not known precisely.

Trawler action on the seafloor and ship anchor dragging are considered real hazards out to the 2.0 nautical mile line where the depth is about 350 fathoms and outshore of which the probability of damage due to trawler and anchor actions is about 4 and 8 percent respectively. Earthquake movement is possible with the highest probability of disturbance to the cable occuring inshore where the bottom is hard.

Because of the existence of a privately maintained light near the landfall site it may be necessary to carefully route the cable to avoid this light. About 500 to 1,000 feet from the OTEC plant site lies the Oahu Submarine Tie Cable which would have to be crossed by the OTEC cable. A relocation of the plant site towards shore about 500 feet would avoid the crossing.

2.2 PUNTA YEGUAS, PUERTO RICO (Refer to Figure 3.3)

In general the bottom offshore of Punta Yeguas has a very low slope of about 1 vertical to 60 horizontal for a distance of about 0.1 nautical mile to a depth of 10 feet and then flattens for a distance of about 0.7 nautical mile to a depth of 30 feet. Thence the bottom begins a steeper slope of 1 vertical to 2-1/2 horizontal to a depth of 100 fathoms about 1 nautical mile from shore. At this point the slope continues to become steeper to about 2 vertical to 1 horizontal to a depth of 220 fathoms about 1.12 nautical miles out. The bottom then begins to flatten out with the slope being 1 vertical to 30 horizontal at the plant site. This profile extends up and down the coast from Punta Yeguas. A straight line route from the landfall to the plant is approximately normal to the bottom contours described hereinbefore. Any minor change in alignment would not result in any material change in slopes over which the cable will be laid. For the portion of the route which has the steepest slope (2 vertical to 1 horizontal) care should be taken to ensure that the cable line is normal to the contour lines.

Coarse rock, shell fragments and coral is expected to be found in the bottom for a distance of 1.12 nautical miles. From here outshore the bottom is expected to consist of calcareous ooze, clay and silt. Landslides may be possible in this area where slopes are greatest, in the 1.1 to 1.5 nautical mile range.

Maximum storm waves can create bottom currents and hydrodynamic forces on the cable from shore outward about 1.0 nautical mile. Bottom water currents outshore of the 1.0 nautical mile line are not known precisely. Based on the cable failure study the probability of chafing and corrosion occurring outshore of this point is about 50%.

Trawler action is not considered a real hazard but ship anchor dragging is a real hazard out to the 1.12 nautical mile line where depth is about 150 fathoms and outshore of which the probability of damage due to anchor dragging is about 8 percent.

Earthquake movement is possible with the most disturbance to the cable occurring inshore where the bottom is hard.

2.3 CABRAS ISLAND, GUAM (Refer to Figure 3.5)

The bottom offshore Cabras Island has a short flat beach slope for about 0.1 nautical mile from which the bottom slopes more or less uniformly to the plant site at about 1 vertical to 2.5 horizontal. This profile extends to either side of the cable route line. A straight line route from Cabras Island to the plant site appears to be normal to the contours representing the bottom as described hereinbefore. Any minor change in alignment would not materially affect the slopes expected to be found along such route.

The bottom soil is expected to consist of white calcareous beach sand for a distance of about 0.2 nautical mile, followed by sediments of coral, mud, and sand for the next 0.2 to 0.3 nautical mile and finally globigerina ooze for the remaining 0.5 to 0.6 nautical mile to the plant site. The globegerina ooze appears soft and deep enough to permit the cable to bury itself. No landslides are expected to occur along the route off Cabras Island.

Maximum storm waves can create bottom currents and hydrodynamic forces from shore outwards about 0.3 nautical miles. Bottom water currents outshore of the 0.3 nautical mile line are not known precisely, but based upon the cable failure study the probability of chafing and corrosion occurring outshore of this point is about 50 percent.

Trawler action is not considered a real hazard but ship anchor dragging is a real hazard out to the 0.6 nautical mile line where depth is about 220 fathoms and outshore of which the probability of damage is about 8 percent. Earthquake movement is possible with the most disturbance to the cable occurring inshore of the globigerina ooze.

2.4 TAMPA, FLORIDA (Refer to Figure 3.7)

The bottom is a very flat slope for 70 nautical miles from shore. Beyond this the bottom slope increases gradually to about 1 in 10 at the plant site. This profile is typical up and down the coast from the cable route. A straight line route between the landfall and plant site lies normal to the contours. Any realignment or deviation from the straight line would not materially affect the degree of slope expected to be found.

The bottom is expected to consist of white sand for 10 nautical miles and then 10 feet of mud thickness over shells, sand, quartz and feldspar out to the 100 nautical mile line where the sediments are of carbonated clay. No landslides are likely but soil particle movement can be anticipated.

Maximum storm waves can create bottom currents and hydrodynamic forces from shore for a distance of about 90 nautical miles. It is likely there are bottom currents beyond 90 nautical miles but they are not precisely known. Based on the cable failure study the probability of chafing and corrosion occurring outshore of this point is about 50 percent.

Trawler action and ship anchor snagging are considered real hazards out to the 124 nautical mile line where depth is about 350 fathoms. Earthquake movement is not likely to occur.

There is a fish haven obstruction at about the 10 nautical mile line and an unusued explosive dump site at about the 120 nautical mile line. The routing should be deviated from the straight line to avoid going over these obstructions. It is also expected that a sea lane with heavy ship traffic exists at about the 90 nautical mile line.

CHAPTER 3. PROTECTION STRATEGY

3.1 GENERAL

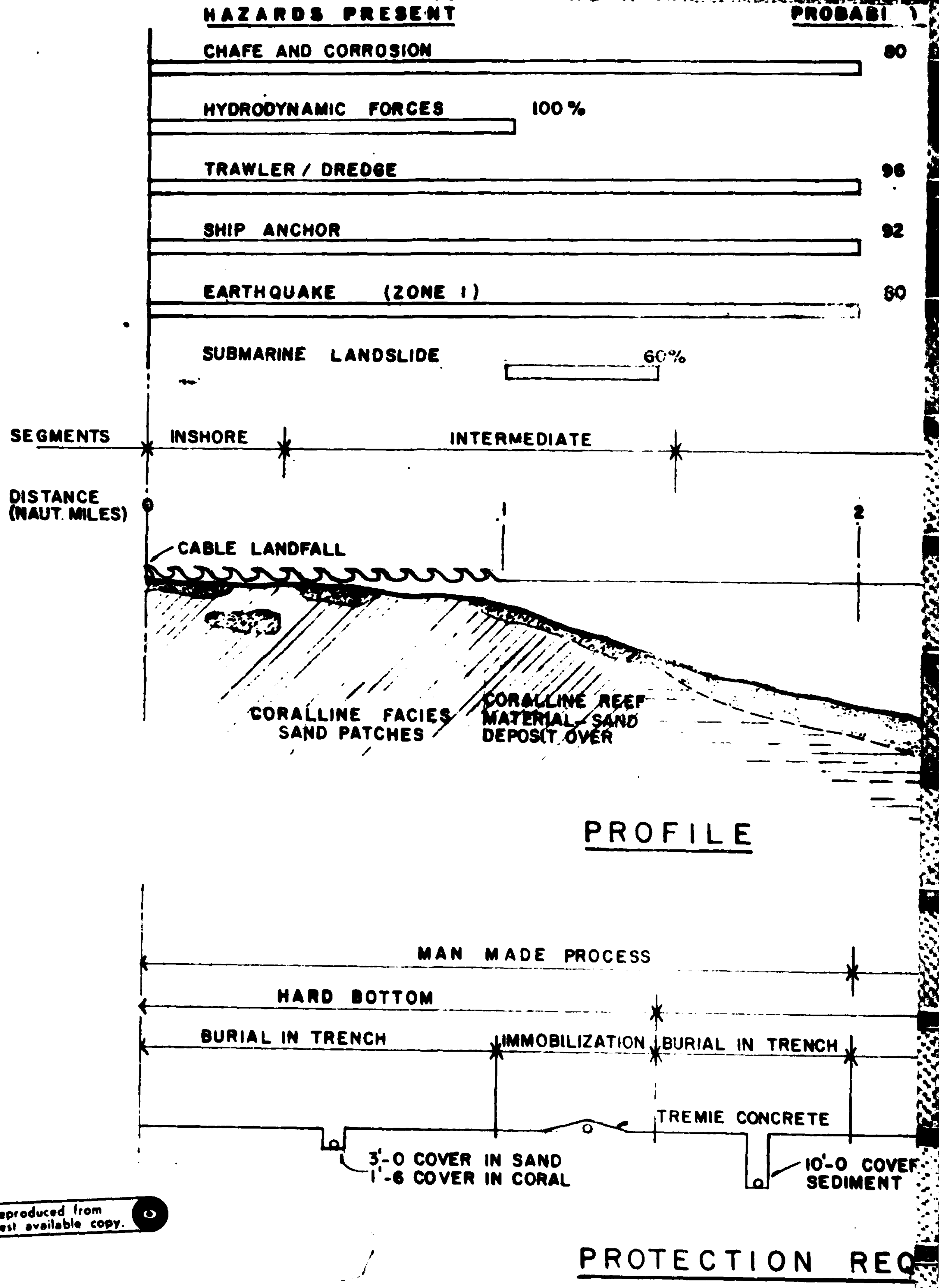
For purposes of this report it has been assumed that only a single electric cable extends from the OTEC plant site to the landfall site at each of the four proposed sites. It may be advisable to lay a multiple cable network to ensure the integrity of the power cable line. To obtain maximum protection cables should be laid out apart from one another a considerable distance. However, in areas which require unusual protection techniques such as blasting a trench through rock it may be possible to lay several cables in the same trench and thereby reduce protection costs. It is not possible to protect against earthquakes or landslides except to allow slack in the cable, namely to lay extra length.

Scheduling for each site includes approximately two days at each end of the cable line for the plant and shore tie-ins. Mobilization and demobilization time and costs are quite variably being dependent upon the availability and locality of the required equipment. Weather downtime, too, could greatly affect the schedules time and cost.

3.2 KAHE POINT, HAWAII

3.2.1 GENERAL (Refer to Figure 3.1)

For convenience the cable route from Kahe Point to the plant site is divided into three segments. The first, designated inshore segment, in which the water depth goes from zero (beachhead) to 10 fathoms, is the length, in this case about 0.4 n.m., over which conventional dredging and construction equipment can operate. Diver work is relatively easy in this length. The second, designated intermediate segment, in which the water depth is 10 fathoms and deeper to 220 fathoms, is the length (1.1 n.m.) over which modern deep ocean


HAZARDS PRESENT
PROBABI
CHAFE AND CORROSION
80
HYDRODYNAMIC FORCES
100 %
TRAWLER / DREDGE
96
SHIP ANCHOR
92
EARTHQUAKE (ZONE 1)
80
SUBMARINE LANDSLIDE
60%
SEGMENTS
INSHORE
INTERMEDIATE
DISTANCE (NAUT. MILES)
0
1
2
CABLE LANDFALL
CORALLINE FACIES SAND PATCHES
CORALLINE REEF MATERIAL-SAND DEPOSIT OVER
PROFILE
MAN MADE PROCESS
HARD BOTTOM
BURIAL IN TRENCH
IMMOBILIZATION
BURIAL IN TRENCH
TREMIE CONCRETE
3'-0 COVER IN SAND
1'-6 COVER IN CORAL
10'-0 COVER SEDIMENT
PROTECTION REQ

ROBABILITY %   SEE NOTE 2

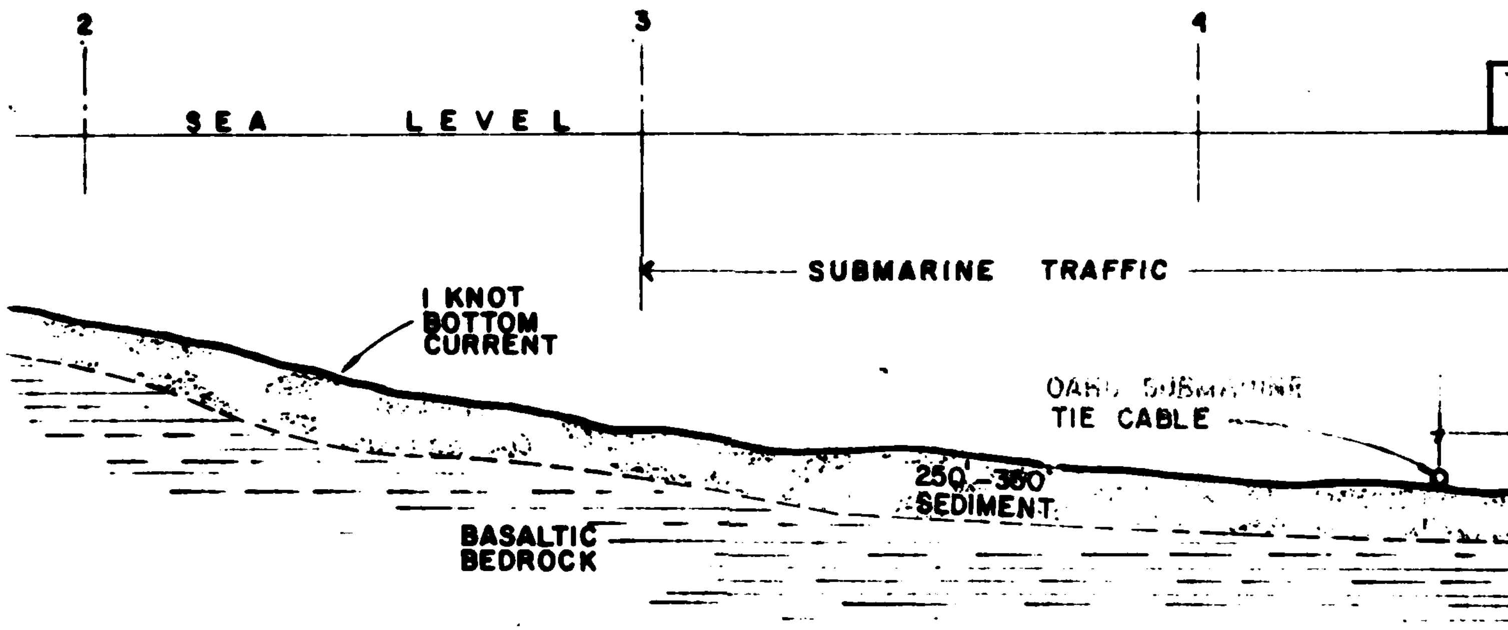
80

96

92

80

OUTSHORE



NATURAL PROCESS

SOFT BOTTOM

NCH   BOTTOM LAY – NATURAL BURIAL

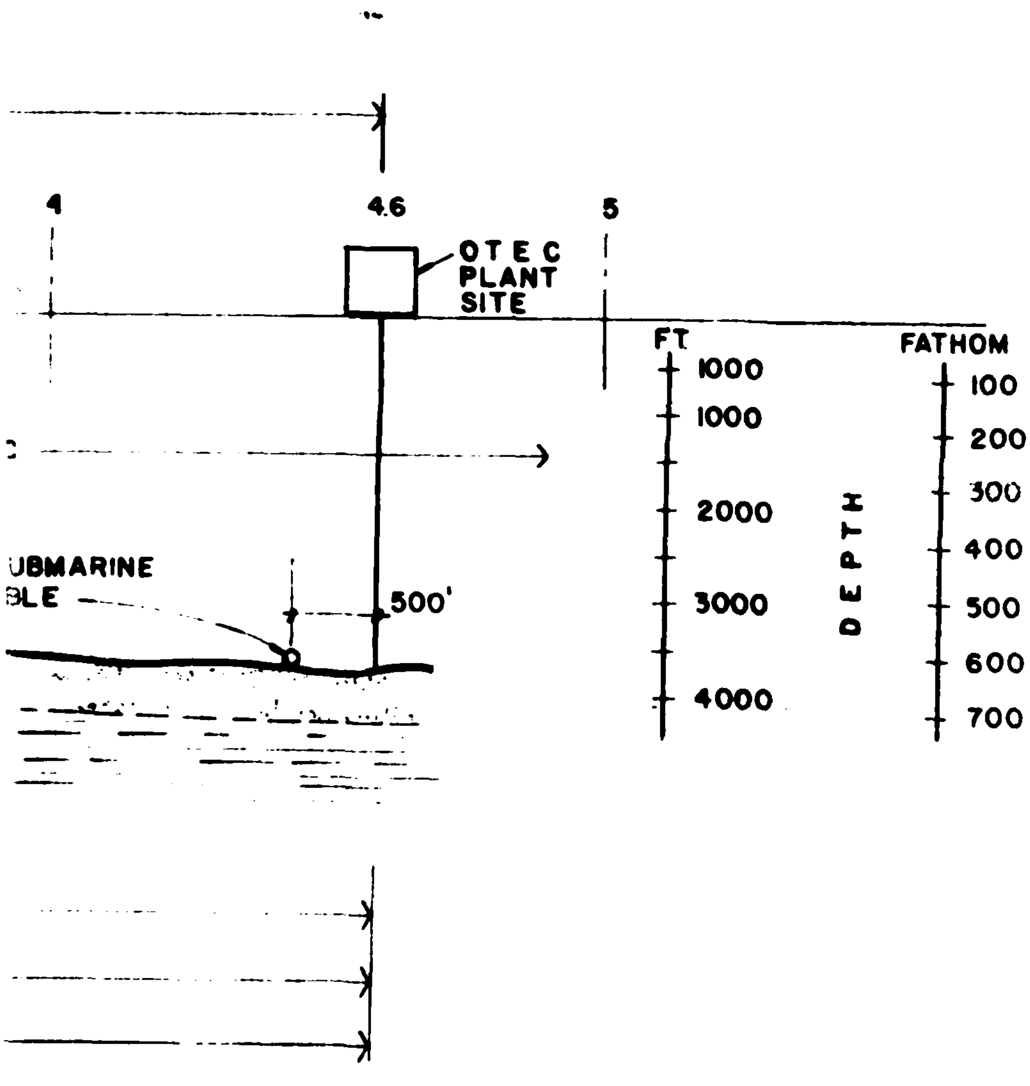
TE

10'-0 COVER IN SEDIMENT

N REQUIREMENTS

NOTE

1. PROTECTION IS REQUIRED TO PROTECT AGAINST THE HAZARDS LISTED.
2. PERCENTAGE PROBABILITY GIVEN IS THE CUMMULATIVE PROBABILITY OF OCCURANCE FROM SHORE TO THE POINT OUTSHORE INDICATED.
3. NO GUARANTEE OF PROTECTION CAN BE GIVEN TO EARTHQUAKE OR SUBMARINE LANDSLIDE.
4. AFTER NATURAL EMBEDMENT TAKES PLACE OUTSHORE, FULL PROTECTION WILL BE AFFORDED TO CHAFE AND CORROSION, BUT ONLY PARTIAL PROTECTION TO SHIP ANCHOR DEPENDENT ON NATURAL DEPTH OF EMBEDMENT.



KAHE POINT, OAHU, HAWAII

OTEC

BOTTOM CABLE PROTECTION STUDY

BESIER GIBBLE QUIRIN	CONSULTING ENGINEERS INC. 130 ELM STREET OLD SAYBROOK CONN. 06475	DATE 10/9/81	FIG. 3.1

trenchers can operate and over which diver work can still be accomplished. The third, designated outshore segment, in which the water depth is 220 fathoms and greater, is the length (3.1 n.m.) where diver underwater work is impossible and where any underwater work would have to be performed by machines remotely controlled.

3.2.2 PROTECTION REQUIREMENTS

Along the inshore and intermediate segments, the hazards to protect against are those listed in Table 3.1. Along the outshore segment hydrodynamic forces no longer have any effect on the seafloor cable nor are landslides likely to occur. Furthermore, along the outshore segment, the probability of damage from the hazards of chafing and corrosion, trawler and/or dredge action ship anchors and earthquakes are reduced to a degree where the risks associated with each hazard can be accepted without special protection. In the column under "Outshore" the figures represent the probability percentage for damage in the outshore segment, based on the cable damage study in reference (1).

Table 3.1 Hazards

Kahe Point, Hawaii

	Cable Segments		
	Inshore	Intermediate	Outshore
Chafing and Corrosion	Yes	Yes	30 to 5%
Hydrodynamics	Yes	Yes	No
Trawler/Dredge	Yes	Yes	15 to 2%
Ship Anchor	Yes	Yes	8 to 2%
Landslide	No	Yes	No
Earthquakc	Yes	Yes	28 to 12%

3.2.3 PROTECTION STRATEGY

Embedment of the cable into the sea bottom is the best method of protection against the hazards expected to be encountered. As stated in reference

(1) a shallow embedment would provide protection against the hazards of chafe and corrosion, hydrodynamic forces, and trawler action. To protect against snagging ship anchors, there would be required deeper embedment dependent upon the type of soil. The softest soils require the greatest depth.

(a) Along the inshore segment an attempt should be made, after a specific site survey has been completed, to route the cable so that it would lie within the sand patches. This would allow a conventional dredge to be used to dig a trench in the sand. The depth in sand in this segment should be at least 3 feet.

It may be that a route cannot be found which would be all sand but that coralline facies would be encountered. A cutter dredge then may be able to cut a trench in the coral bottom. An investigation of equipment available locally and of prior experience in dredging would reveal the feasibility of this method. Subsoil exploration during the specific site survey would also reveal the hardness of the coral or rock to be encountered. If the cutter dredge operation is not feasible then blasting may be necessary. This of course necessitates the use of divers. A depth of embedment of 1.5 feet would be satisfactory in hard coral or rock.

The ideal procedure for blasting would be to use rod charges (long flexible tubes of high explosive) which may be laid on the bottom much like cable. When detonated, these rod charges can excavate a trench up to 1'-6" deep. This trench would have rounded, sloping sides of about 45 degrees depending upon the material's natural angle of repose. In coral the rod charges would likely liquify the surrounding material. In hard rock the rod charges break the rock into rubble, which can be dredged later. A remote operated vehicle (ROV) can be used effectively to monitor the condition of the trench.

The length of this inshore segment is approximately 0.4 nautical miles or

2,500 feet. It would appear that only two days time would be needed for a cutter dredge to cut through a 2,500 feet long trench for one cable. Blasting a trench would require about one week.

The support vessel for the blasting operation must have at least 50 feet by 100 feet of deck space for the 75 feet long shaped charge frame and storage for the charges, at least a 50 ton crane to lift and set the shaped charge frame, and a clamshell bucket so that blasting can be conducted during the day and dredging the trench at night. Since anchoring in deep water becomes difficult, dynamic positioning is a necessity. Since a cable lay ship is needed to lay the cable over the entire length it does not appear economical to mobilize a second vessel to support only the blasting operation. Consequently it is suggested that the cable lay ship conduct the blasting operation, then return to the OTEC plant site to begin laying the cable. For the purpose of estimating time and cost it is assumed that blasting a trench in this segment is the most feasible method.

(b) Along the intermediate segment the same bottom conditions exist as in the inshore segment and the same procedure should be used of finding a route through the sand patches. If this is possible then a jetting machine could be used such as the Elsam - Svitzer/Sofie which can operate up to 160 fathoms water depth at a speed of 400 feet per hour and requires the cable to be laid after the trench has been dug. It would not be able to dig a trench in the outer 0.2 n.m. or 1200 feet of the intermediate segment.

Again in this intermediate segment is may not be possible to find a path consisting of sand only but more likely coral will have to be cut. This could be accomplished by the use of a subsea cable trencher such as Comex/BM-1 listed and described in reference (4). This machine can operate up to 90 fathoms water depth at a speed of 300 ft. per hour and requires the cable to be laid after the trench has been dug. It would not be able to dig a trench in the outer 0.4 n.m. or 2500 feet of the intermediate segment.

Since the maximum burial depth of this vessel is only about 2 feet the full protection requirement of 10 feet cannot be achieved. However, since many burial vehicles are designed and built specifically for a particular job, it is likely that one or more existing vehicles can be modified to meet both the water and burial depth requirements. An alternative method, depending upon rock hardness and final detailed cost estimates, would be to use blasting of the rock utilizing diver work.

For the outer 0.5 nautical mile of this intermediate segment where the danger still exists of the cable encountering ship anchors and trawler/dredge action although with a lesser probability of damage if the bottom is found too hard to permit trenching by reasonable means and costs become high, a means of stabilization without trenching is considered adequate. Water depth ranges from 70 to 220 fathoms.

One method would be to cover the cable with a mass of concrete somewhat as shown on Figure 1.3 using tremie concrete. Concrete of the order of 3000 cubic yards would be required over this 3,000 feet stretch and pouring would have to be continuous over less than a weeks time for one cable. This could be feasible if calm weather can be predicted for such a length of time. However one or two breaks in the pouring because of weather could be acceptable. This scheme would result in an effective means of protection against trawler and dredge action on the seafloor and against dragging ship anchors. Some diving is of course necessary to check and inspect tremie pipes when they are first placed into position and to inspect the finished concrete pour.

The length of the intermediate segment is approximately 1.1 nautical mile or 6,700 feet and if blasting by diver is the method used for digging a trench the time required would be about three weeks. Either of the two machines mentioned above would complete excavation in one day's time. Using the tremie concrete method of protection over 0.5 n.m would require about two weeks time and would be done after all other work has been completed. For the purpose of estimating time and cost it is assumed that blasting a trench for 0.6 n.m. and protecting the cable with tremie concrete for 0.5 n.m. in this segment is the most feasible method.

(c) Along the outshore segment the bottom is expected to consist of sediments soft enough and deep enough to permit the cable to bury itself. The unknown of course is to what depth the cable will go under a natural process. By laying a short section of cable on the bottom for a short period of time, the depth to which the cable will bury itself can be ascertained. In any event for the first 0.5 n.m. length of this segment it is felt that an embedment of 10 feet should be achieved for protection against the hazards of trawler/dredge and ship anchors. A vessel capable of operating in 330 fathoms would be necessary. The choice is very few, such as the plowing vessel AT&T Sea Plow IV. Refer to reference (4). Along the remainder of the route out to the plant site namely 3.1 n.m., the only need is to lay the cable on the bottom with a cable laying vessel.

The transition between the 10 feet embedment requirement in the outshore segment and the 1.5 feet embedment or the stabilization scheme of the intermediate segment must be given consideration. Since the deeper section should have higher priority at the transition a sloping trench down from 1.5 feet to 10.0 feet must be dug in the coral bottom. If the alternate method of stabilization is used it should be extended out over the softer bottom until the point where the cable is laying 10 feet below the surface. This same strategy applies of course to any transition which may be needed in the actual installation.

3.2.4 CABLE LAYING

The best procedure would be to lay the cable after the trenches were dug. The actual laying of the cable should not be too far behind the digging of the trench, consequently the scheduled plan must be carefully workd out to coordinate the various elements, (a) the inshore vessesls, the seagoing trenching equipment, and the cable laying vessel. In all cases the cable trenches would be filled by natural process. There would be not need to backfill by machine.

3.2.5 CONSTRUCTION TIME AND COST

Actual laying of the cable should be accomplished within 1 week after the trenches have been completed which requires about 2 weeks time. Cable protection requires about 2 weeks. Mobilization, including testing and training of personnel would require a little more than 2 weeks. The entire operation requires about 10 weeks. See Table 3.2 for estimated construction times for the various construction elements. Figure 3.2 gives the same information in the form of a time schedule.

Based on the construction costs given in Reference (5), Table 3.3 gives the estimated cost for the scenario given herein. It covers the use of a cable lay and support vessel, a plowing machine, barges, work boats, tremie pipes and concrete pumping equipment and an ROV for the entire schedules time of 67 days. The total cost for the cable installation at Hawaii is estimated at $7,070,000.

3.3 PUNTA YEGUAS, PUERTO RICO (Refer to Figure 3.3)

3.3.1 GENERAL

For convenience the cable route from Punta Yeguas to the OTEC plant site is divided into three segments. The first, designated inshore segment, in

TABLE 3.2

Estimated Construction Time

Kahe Point, Oahu, Hawaii

Construction	Cable Segments				
	Inshore	Intermediate		Outshore	
	0.4 n.m.	0.6 n.m.	0.5 n.m.	0.5 n.m.	2.6 n.m.
Blast Trench & Dredge	6d.	8d.			
Plowing Machine				1d.	
Cable Lay	1/2d.	1-1/2d.		4d.	
Protection - Tremie Concrete			14d.		
Alternate - Dredge Trench	2d.				
Alternate - Trenching Machine		1d.			
Cable Tie-in	2d.			2d.	
Mobilization		16d.			
Demobilization		12d.			

d. = days

Figure 3.2

Estimated Construction Time Schedule

Kahe Point, Oahu, Hawaii

		0 10 20 30 40 50 60 70 80 days
Mobilize	16d.	
Blast Trench	14d.	
Plow Trench	1d.	
Lay Cable	6d.	
Protection - Tremie	14d.	
Cable Tie-in	4d.	
Demobilize	12d.	
Total	67d.	

TABLE 3.3

Estimated Construction Costs

Kahe Point, Oahu, Hawaii

Construction Element	Days	Cost Per Day	Cost
Mobilization	16	$ 79,500	$1,272,000
Blast & Dredge Trench	14	143,000	2,002,000
Plow Trench	1	94,500	94,500
Lay Cable	6	114,500	687,000
Protection - Tremie	14	114,500	1,603,000
Cable Tie-in	4	114,500	458,000
Demobilization	12	79,500	954,000
Total	67	$103,440	$7,070,500

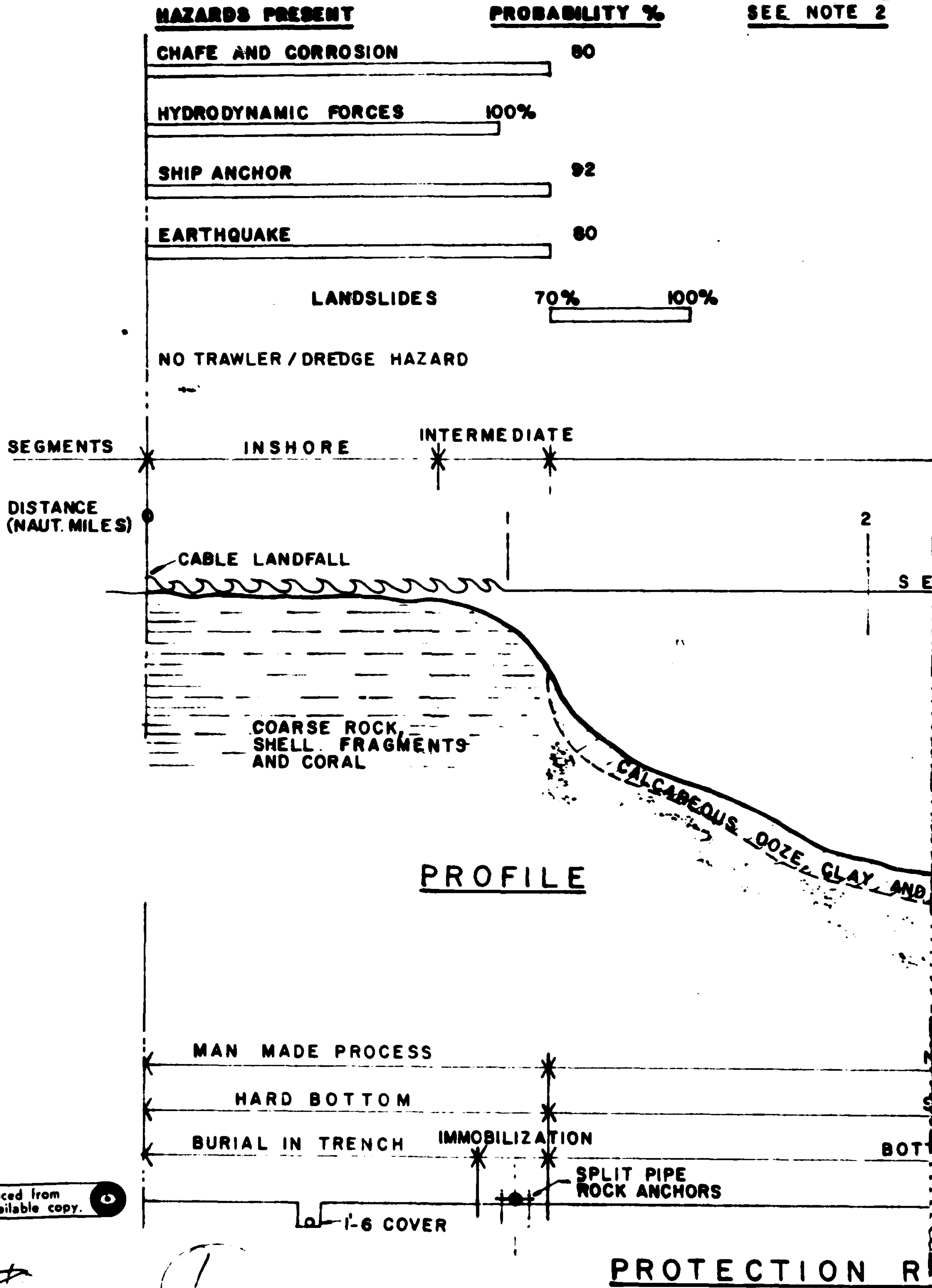
which the water depth is zero to 10 fathoms, is the length (0.8 n.m.) over which conventional dredging equipment can operate. Diver work is relatively easy in this segment. The second, designated intermediate segment, in which water depth is 10 fathoms to 220 fathoms, is the length (0.32 n.m.) over which the bottom is still very hard. The third, designated outshore segment, in which the water depth is 220 fathoms and greater, is the length (3.28 n.m.) over which the bottom is expected to consist of soft sediments.

3.3.2 PROTECTION REQUIREMENTS

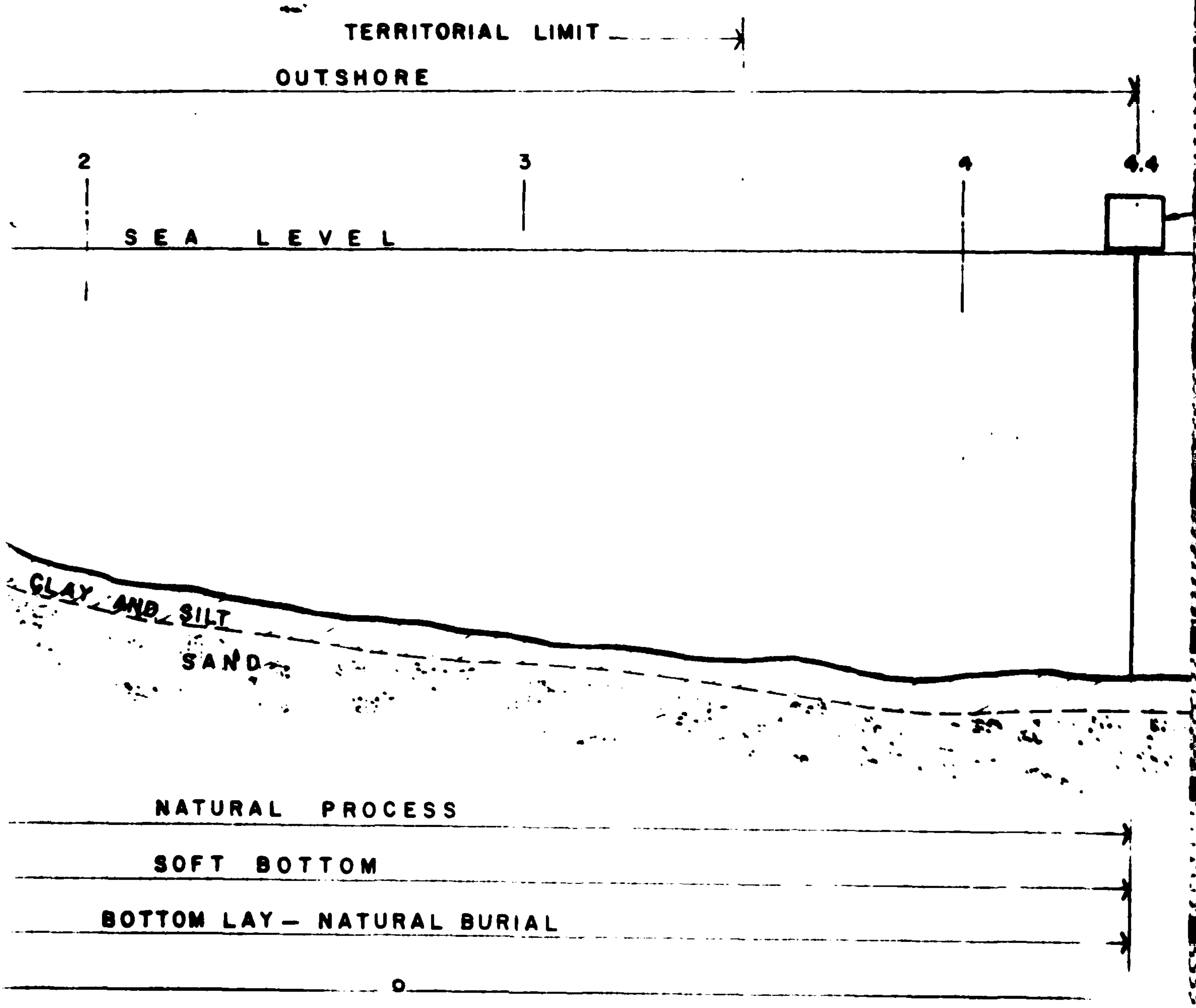
Along the inshore and intermediate segments the hazards to protect against are chafing and corrosion, hydrodynamic forces (except for the outer 0.15 n.m. of the intermediate segment), ship anchors, and earthquakes. Along the outshore segment hydrodynamic forces no longer have any effect on the seafloor but landslides are a possiblility in the inner portions of this segment where slopes are greatest. Furthermore, along the outshore segment, the probability of damage from the hazards of chafing and corrosion, ship anchors, landslides and earthquakes are reduced to a degree where the risks associated with each hazard can be accepted without special protection. See Table 3.4 for a listing of the hazards likely to cause damage. The figures under "Outshore" represents the percentage of probability of damage occurring in the outshore segment due to the various hazards, as given in reference (1).

3.3.3 PROTECTION STRATEGY

Embedment of the cable into the sea bottom is the best method of protection against the hazards expected to be encountered. The depth of embedment will vary dependent upon the seafloor conditions, methods of construction, the kind of equipment used and the need for a specific depth. See comment on landslide and earthquake protection in Section 3.1 hereinbefore.


HAZARDS PRESENT
PROBABILITY %
SEE NOTE 2
CHAFE AND CORROSION
80
HYDRODYNAMIC FORCES
100%
SHIP ANCHOR
92
EARTHQUAKE
80
LANDSLIDES
70%
100%
NO TRAWLER / DREDGE HAZARD
SEGMENTS
INSHORE
INTERMEDIATE
DISTANCE (NAUT. MILES)
0
2
CABLE LANDFALL
COARSE ROCK, SHELL FRAGMENTS AND CORAL
CALCAREOUS OOZE, CLAY, AND
PROFILE
MAN MADE PROCESS
HARD BOTTOM
BURIAL IN TRENCH
IMMOBILIZATION
SPLIT PIPE
ROCK ANCHORS
1'-6 COVER
BOT
PROTECTION R

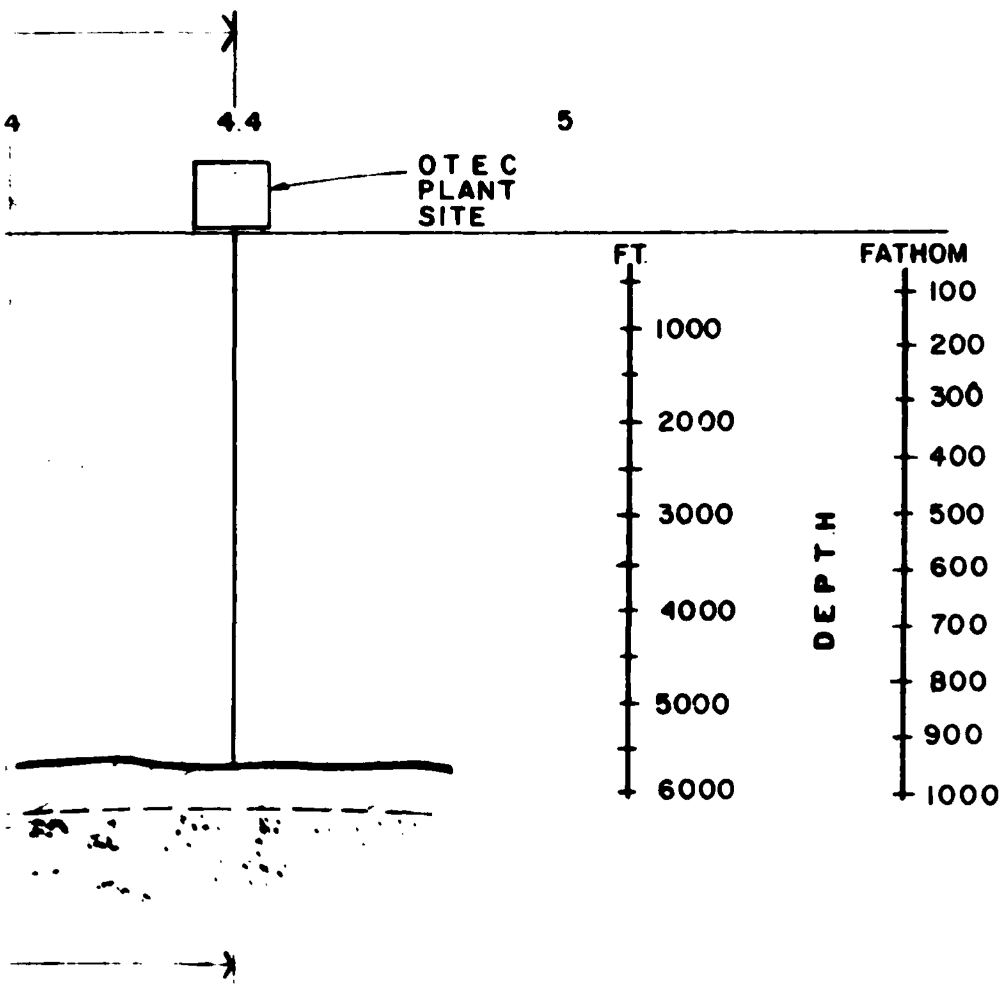
NOTE 2



ION REQUIREMENTS

NOTES

1. PROTECTION IS REQUIRED TO PROTECT AGAINST THE HAZARDS LISTED.
2. PERCENTAGE PROBABILITY GIVEN IS THE CUMMULATIVE PROBABILITY OF OCCURANCE FROM SHORE TO THE POINT OUTSHORE INDICATED.
3. NO GUARANTEE OR PROTECTION CAN BE GIVEN TO EARTHQUAKE OR SUBMARINE LANDSLIDE.
4. AFTER NATURAL EMBEDMENT TAKES PLACE OUTSHORE, FULL PROTECTION WILL BE AFFORDED TO CHAFE AND CORROSION, BUT ONLY PARTIAL PROTECTION TO SHIP ANCHOR DEPENDENT ON NATURAL DEPTH OF EMBEDMENT.



PUNTA YEGUAS, PUERTO RICO		
OTEC BOTTOM CABLE PROTECTION STUDY		
BESIER GIBBLE Q' !RIN — CONSULTING ENGINEERS INC. 130 ELM STREET SAYBROOK CONN. 06475	DATE 10/9/81	FIG. 3.3

Table 3.4 Hazards

Punta Yeguas, Puerto Rico

	Cable Segments		
	Inshore	Intermediate	Outshore
Chafing and Corrosion	Yes	Yes	30 to 2%
Hydrodynamics	Yes	Yes	No
Trawler/Dredge	No	No	No
Ship Anchor	Yes	Yes	15 to 0%
Landslide	No	No	30 to 0%
Earthquake	Yes	Yes	28 to 10%

(a) To embed the cable along the inshore segment would require digging a trench with a conventional cutter dredge to a depth of 1.5 feet since the bottom appears to be essentially rock and coral. Rock cores taken during a specific site survey would reveal the hardness of the rock and coral. From this information the feasibility can be determined for a cutter dredge being able to cut the required trench. If the hardness of the rock and coral proves to be too great then blasting would be required similar to that described for Hawaii. It is important that a relatively smooth route be provided to prevent the cable from being bent beyond its limits and to avoid long suspensions. Since the bottom consists of coarse rock and shell fragments, rod charges alone may successfully clear the trench, elimininating the need for shaped charges or dredging.

The length of the inshore segment is approximately 0.8 n.m. or approximately 5,000 feet. It is in the surf zone where wave action is prevalent and work is dependent upon a sufficiently long period of time of calm waters. It would appear that about a week would be needed in the case of a cutter dredge to cut a 5,000 feet long trench. Using the blasting technique would require about ten days time because of the extensive use of divers, a slow process. The same procedure would be followed as described for Hawaii hereinbefore. For purposes of estimating time and cost it is assumed that blasting a trench is the most feasible method for this segment.

(b) Along the intermediate segment the bottom conditions are the same as along the inshore segment except that the slope becomes very great. Water depth reaches 220 fathoms at the outshore end. In this segment there would be needed a subsea cable trencher such as Comex/BM-1 or Flexiservice Drum Cutter. See reference (4). The depth of water in which they can operate however is limited to about 180 fathoms. This depth is reached at 1.08 n.m. or 0.04 n.m. from the outer end of this segment. In this 0.04 n.m. length the bottom is expected to be rather steep, 2 vertical to 1 horizontal, which might prove too steep for any subsea cable trencher.

If the rock core borings taken during the specific site survey show the rock to be too hard for a subsea cable trencher then blasting would be required. All of the blasting techniques involve the use of divers and therefore blasting may also not be possible as a feasible means for the outer 0.04 n.m. stretch of this segment.

It therefore may be that no feasible means exists for digging a trench in this outer 0.04 n.m. length of the intermediate segment unless the ongoing research and development in the manufacture and use of trenchers produces a machine with the required capabilities.

A scheme of immobilizing the cable could be adopted as an alternative, such as concrete placed by tremie or bucket. In either case this may prove difficult because the steep slope would not hold freshly laid concrete and the concrete would run down the slope and dissolve into the sea water. A scheme of tie-down may be the only viable solution for this 0.04 n.m. stretch of the intermediate segment. An unmanned submersible, fitted with rock drills can be used to anchor the cable. Protecting the cable with split pipe by the use of divers before anchoring to the rock is insurance against the hazard of chafing and dragging anchors. The split pipe protection should extend into the area of soft sediment seafloor about 20 feet to insure protection in the transition zone between the anchored segment and the self embedment segment.

The length of the intermediate segment is 0.32 n.m. or approximately 1,800 feet out to the depth where present trenching equipment or divers can no longer operate. This segment is in deep ocean water subject to constant wave action and work depends upon good weather conditions. A trencher would require only a day or two of continuous operation to cut a trench 1,800 feet long. Tying down the cable with split pipe and anchors would take about 6 days by utilizing the cable lay vessel as was recommended for the Hawaii site.

For purposes of estimating time and cost it is assumed that the most feasible method is to blast a trench 0.28 n.m. and using split pipe and rock anchors for the outer 0.04 n.m.

(c) Along the outshore segment the bottom is expected to consist of sediments soft enough and deep enough to permit the cable to bury itself. The only need then is to lay the cable on the bottom with a cable laying vessel.

3.3.4 CABLE LAYING

The best procedure would be to lay the cable after the trench had been dug. The actual laying of the cable should not be too fat behind the digging of the trench, consequently the schedule plan must be carefully worked out to coordinate the various elements, (a) the inshore vessels, and the cable laying vessel.

In all cases the cable trenches would be filled by natural process. There would be no need to backfill by machine.

3.3.5 CONSTRUCTION TIME AND COST

Actual laying of the cable should be accomplished within 1 week after the trenches have been completed which requires about 2 weeks time. Cable protection requires about 1 week. Mobilization, including testing and training of personnel, would require about 2-1/2 weeks. The entire operation requires about 9 weeks.

See Table 3.5 for estimated construction times for the various construction elements. Figure 3.4 gives the same information in the form of a time schedule.

Based upon the construction costs given in Reference (5) Table 3.6 gives the estimated cost for the scenario given herein. It covers the use of a cable lay and support vessel, barges, work boats, cable anchoring equipment and an ROV for the entire scheduled period of time of 59 days. The total cost for the cable installation at Puerto Rico is estimated at $5,300,000.

TABLE 3.5

Estimated Construction Time

Punta Yeguas, Puerto Rico

	Cable Segments		
Construction Items	Inshore 0.8 n.m.	Intermediate 0.32 n.m.	Outshore 3.28 n.m.
Blast Trench & Dredge	10d.	4d.	
Cable Lay	1d.	1/2d.	3-1/2d.
Protection - Split & Anchor		6d.	
Cable Tie-In	2d.		2d.
Mobilization		17d.	
Demobilization		13d.	

d. = days

Figure 3.4

Estimated Construction Time Schedule

Punta Yeguas, Puerto Rico

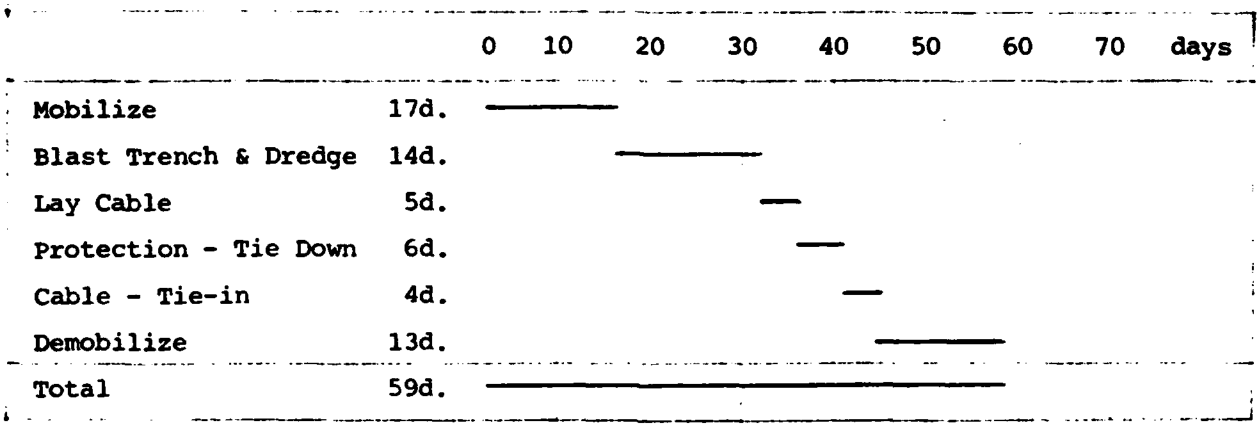


TABLE 3.6

Estimated Construction Costs

Punta Yeguas, Puerto Rico

Construction Elements	Days	Cost Per Day	Cost
Mobilization	17	$ 64,500	$1,096,500
Blast & Dredge Tench	14	128,000	1,792,000
Lay Cable	5	99,000	495,000
Protection - Tie Down	6	110,200	661,200
Cable Tie-in	4	99,000	396,000
Demobilization	13	64,500	838,500
Total	59	$ 89,470	$5,278,700

3.4 CABRAS ISLAND, GUAM (Refer to Figure 3.5)

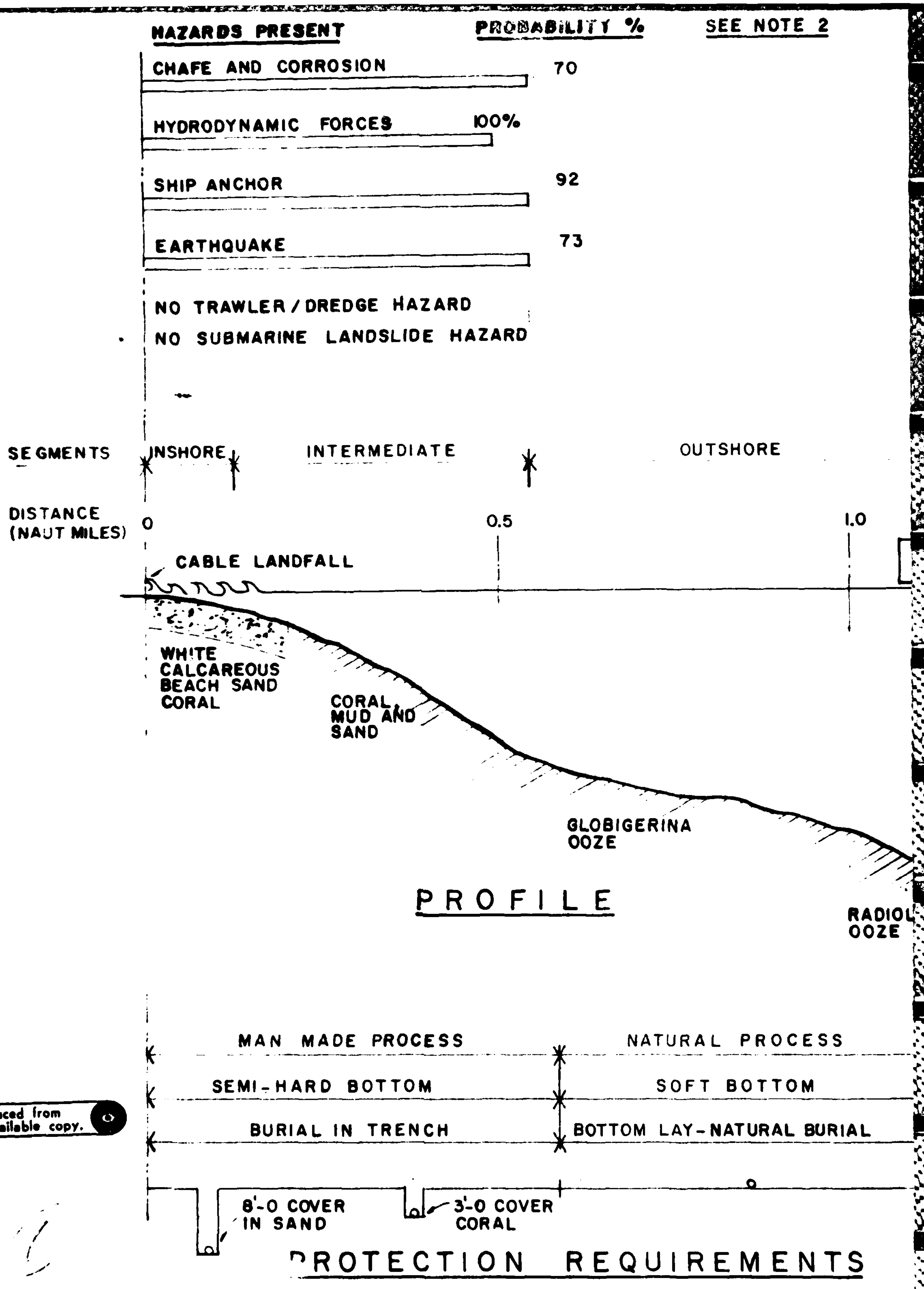
3.4.1 GENERAL

For convenience the cable route from Cabras Island to the proposed OTEC plant site is divided into three segments. The first, designated inshore segment, in which the water depth is zero to 10 fathoms, is the length (0.12 n.m.) over which conventional dredging equipment can operate. Diver work is relatively easy in this segment. The second, designated intermediate segment, in which water depth is 10 fathoms to 220 fathoms, is the length (0.43 n.m.) over which deep sea cable trenching machines can operate and over which diver work can still be accomplished. The third, designated outshore segment, in which the water depth is 220 fathoms and greater, is the length (0.55 n.m.) over which the bottom is expected to consist of soft sediments.

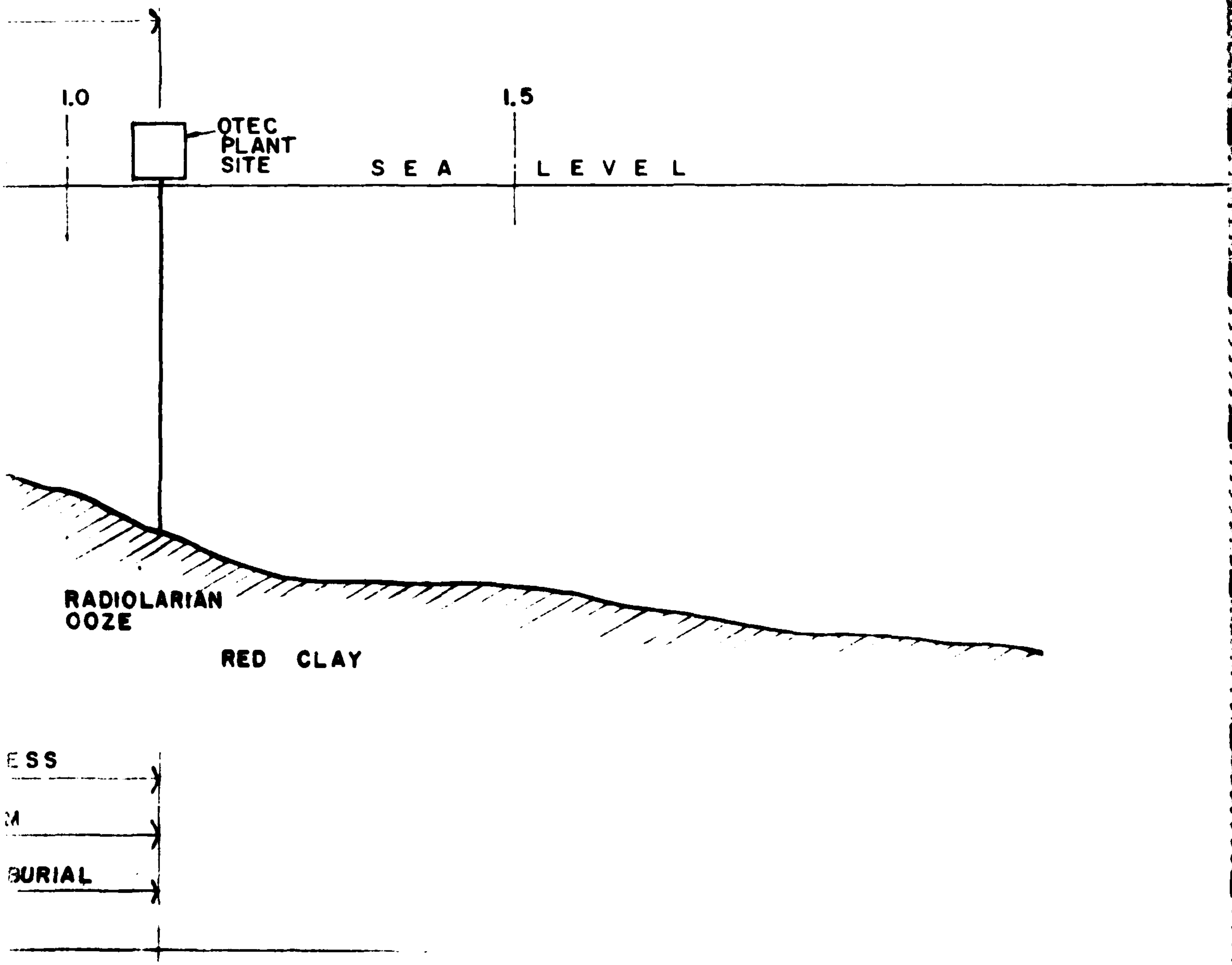
3.4.2 PROTECTION REQUIREMENTS

Along the inshore and intermediate segments the hazards to protect against are chafing and corrosion, hydrodynamic forces, and ship anchors and earthquakes. Along the outshore segment hydrodynamic forces no longer have any effect on the sea floor. Here, the probability of damage from the hazards of chafing and corrosion and ship anchors are reduced to a point where the risks can be accepted without special protection of the cable.

Embedment of the cable into the sea bottom is the best method of protection against the hazards to be expected. Depth of embedment will vary dependent upon the sea floor conditions, the method of construction, the kind of equipment used and the degree of protection required. See Table 3.7 for a listing of the hazards expected offshore Guam. In the column under "Outshore" the figures represent the probability percentage for damage in the outshore segment, based on the cable damage study in reference (1).


HAZARDS PRESENT
PROBABILITY %
SEE NOTE 2
CHAFE AND CORROSION
70
HYDRODYNAMIC FORCES
100%
SHIP ANCHOR
92
EARTHQUAKE
73
NO TRAWLER / DREDGE HAZARD
NO SUBMARINE LANDSLIDE HAZARD
SEGMENTS
INSHORE
INTERMEDIATE
OUTSHORE
DISTANCE (NAUT MILES)
0
0.5
1.0
CABLE LANDFALL
WHITE CALCAREOUS BEACH SAND CORAL
CORAL, MUD AND SAND
GLOBIGERINA OOZE
RADIOL OOZE
PROFILE
MAN MADE PROCESS
NATURAL PROCESS
SEMI-HARD BOTTOM
SOFT BOTTOM
BURIAL IN TRENCH
BOTTOM LAY-NATURAL BURIAL
8'-0 COVER IN SAND
3'-0 COVER CORAL
PROTECTION REQUIREMENTS

E 2

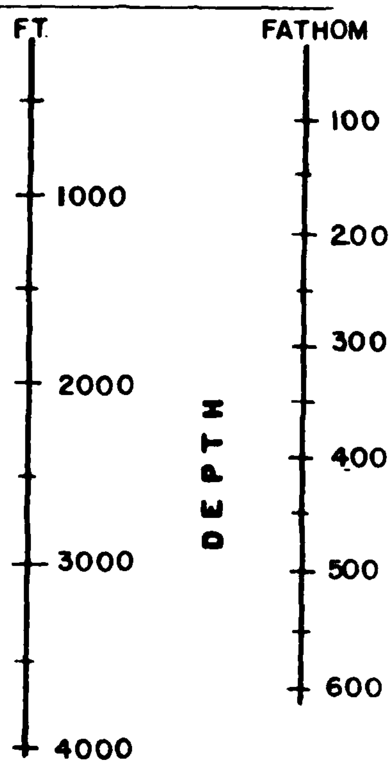


1.0
1.5
OTEC
PLANT
SITE
SEA LEVEL
RADIOLARIAN
OOZE
RED CLAY
ESS
M
BURIAL

NTS

NOTES

1. PROTECTION IS REQUIRED TO PROTECT AGAINST THE HAZARDS LISTED.
2. PERCENTAGE PROBABILITY GIVEN IS THE CUMMULATIVE PROBABILITY OF OCCURANCE FROM SHORE TO THE POINT OUTSHORE INDICATED.
3. NO GUARANTEE OR PROTECTION CAN BE GIVEN TO EARTHQUAKE OR SUBMARINE LANDSLIDE.
4. AFTER NATURAL EMBEDMENT TAKES PLACE OUTSHORE, FULL PROTECTION WILL BE AFFORDED TO CHAFE AND CORROSION, BUT ONLY PARTIAL PROTECTION TO SHIP ANCHOR DEPENDENT ON NATURAL DEPTH OF EMBEDMENT.



CABRAS ISLAND, GUAM

OTEC

BOTTOM CABLE PROTECTION STUDY

BESIER GIBBLE QUIRIN	CONSULTING ENGINEERS INC. 130 ELM STREET OLD SAYBROOK CONN. 06475	DATE 10/9/81	FIG 3.5

3.4.3 PROTECTION STRATEGY

Table 3.7 Hazards

Cabras Island, Guam

	Cable Segments		
	Inshore	Intermediate	Outshore
Chafing and Corrosion	Yes	Yes	30 to 19%
Hydrodynamics	Yes	Yes	No
Trawler/Dredge	No	No	No
Ship Anchor	Yes	Yes	8
Landslide	No	No	No
Earthquake	Yes	Yes	28 to 18%

(a) To embed the cable along the inshore segment would require digging a trench in beach sand with a conventional dredge to a depth of 8 feet. At the landfall and along the beach it is expected that coral may be found. A cutter dredge should therefore be engaged.

The length of this segment is approximately 0.12 n.m. or 750 feet. It is the surf zone where wave action is prevalent and work is dependent upon a sufficiently long period of time of calm waters. It would appear that it would require but one day to cut a 750 feet long trench. For the purpose of estimating costs it is assumed that the trenching machine used in the intermediate segment would be used in this segment, since it is not know whether a cutter dredge is available locally.

(b) Along the length of the intermediate segment the bottom conditions are the same except for some coral to be present. Water depth reaches 220 fathoms at the outshore end. In this segment there would be needed a subsea cable trencher such as the Sea Plow IV, see reference (4), a plowing machine assisted by jets, or the Scarab I or Scarab II, jetting machines, all of which can operate in 220 fathoms of water. Depth along this segment should be about 8 feet but reduced to 3 feet in the outer half.

It can be expected that any coral found in this segment may be to hard for a plow or jet machine to effectively cut through. In such cases the possibility should be explored of avoiding the coral by rerouting the cable. If not blasting can be used to remove any coral.

The length of this segment is approximately 0.55 n.m. or approximately 3,400 feet. It is in a zone where deep water waves are prevalent and work is dependent upon a sufficiently long period of time of calm water. It would appear that it would require less than 3 days to actually cut a trench 3,400 feet long.

(c) Along the outshore segment the bottom is expected to consist of sediments soft enough and deep enough to permit the cable to bury itself. The only need then is to lay the cable on the sea floor utilizing a cable laying vessel.

3.4.4 CABLE LAYING

Over the entire length of the cable route it is expected that the best procedure would be to lay the cable after the trench were dug. The trenching equipment mentioned above are all post-laying devices with the exception of the AT&T Sea Plow IV. The actual laying of the cable should not be too far behind the digging of the trench, consequently the scheduled plan must be carefully worked out to coordinate the various elements, (a) the inshore vessels, the seagoing trenching equipment, and the cable laying vessel.

In all cases the cable trenches would be filled by natural process. There would be no need to backfill by machine.

3.4.5 CONSTRUCTION TIME AND COST

Actual laying of the cable should be accomplished within 1/2 week, after the trenches have been completed which requires about 1/2 week. Mobilization including testing and training of personnel, would require about 7 weeks in this remote area of the world. The entire operation requires about 15 weeks or within 4 months.

See Table 3.8 for estimated construction times for the various construction elements. Figure 3.6 gives the same information in the form of a time schedule.

Based on the construction costs given in reference (5), Table 3.9 gives the estimated costs for the scenario given herein. The total cost for the cable installation at Guam is estimated at $7,400,000.

TABLE 3.8

Estimated Construction Time

Cabras Island, Guam

	Cable Segments		
Construction Elements	Inshore 0.12 n.m.	Intermediate 0.43 n.m.	Outshore 0.55 n.m.
Cut Trench	1d.	3d.	
Cable Lay	1/2d.	3/4d.	3/4d.
Cable Tie-in	2d.		2d.
Mobilization	40d.		
Demobilization	46d.		

Figure 3.6

Estimated Construction Schedule

Cabras Island, Guam

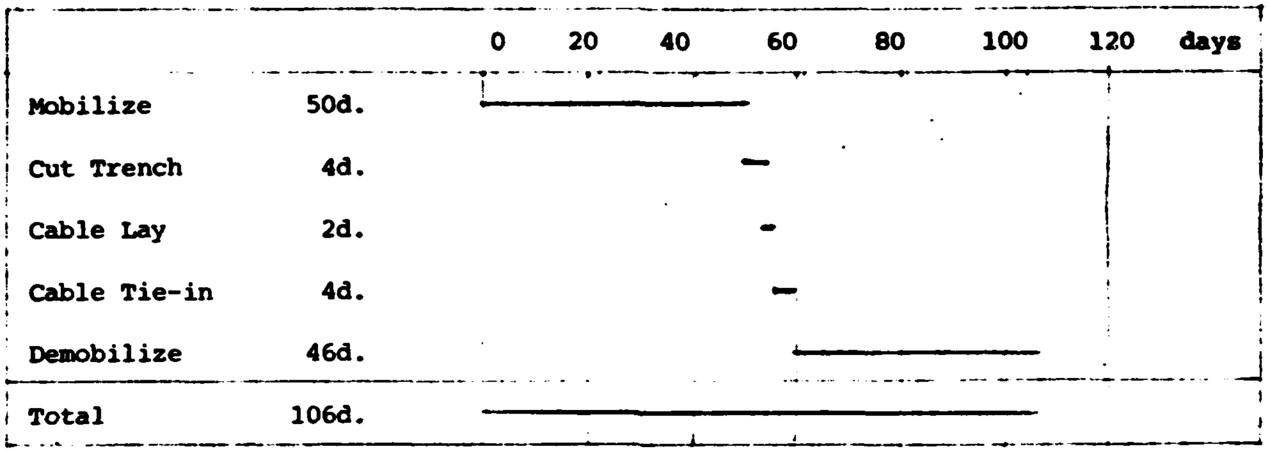


TABLE 3.9

Estimated Construction Costs

Cabras Island, Guam

Construction Element	Days	Cost Per Day	Cost
Mobilization	50	$ 63,000	$3,150,000
Cut Trench	4	116,000	464,000
Lay Cable	2	98,000	196,000
Cable Tie-in	4	98,000	392,000
Demobilize	46	63,000	2,898,000
Development Costs			300,000
Total	106	$ 69,800	$7,400,000

3.5 WEST COAST OF FLORIDA, TAMPA (Refer to Figure 3.7)

3.5.1 GENERAL

The inshore zone is approximately 15 n.m. in length with water depths of zero to 10 fathoms.

The intermediate zone is approximately 103 n.m. in length with water depth of 10 fathoms to 220 fathoms.

The outshore segment is approximately 27 n.m. in length with water greater to 220 fathoms.

3.5.2 PROTECTION REQUIREMENTS

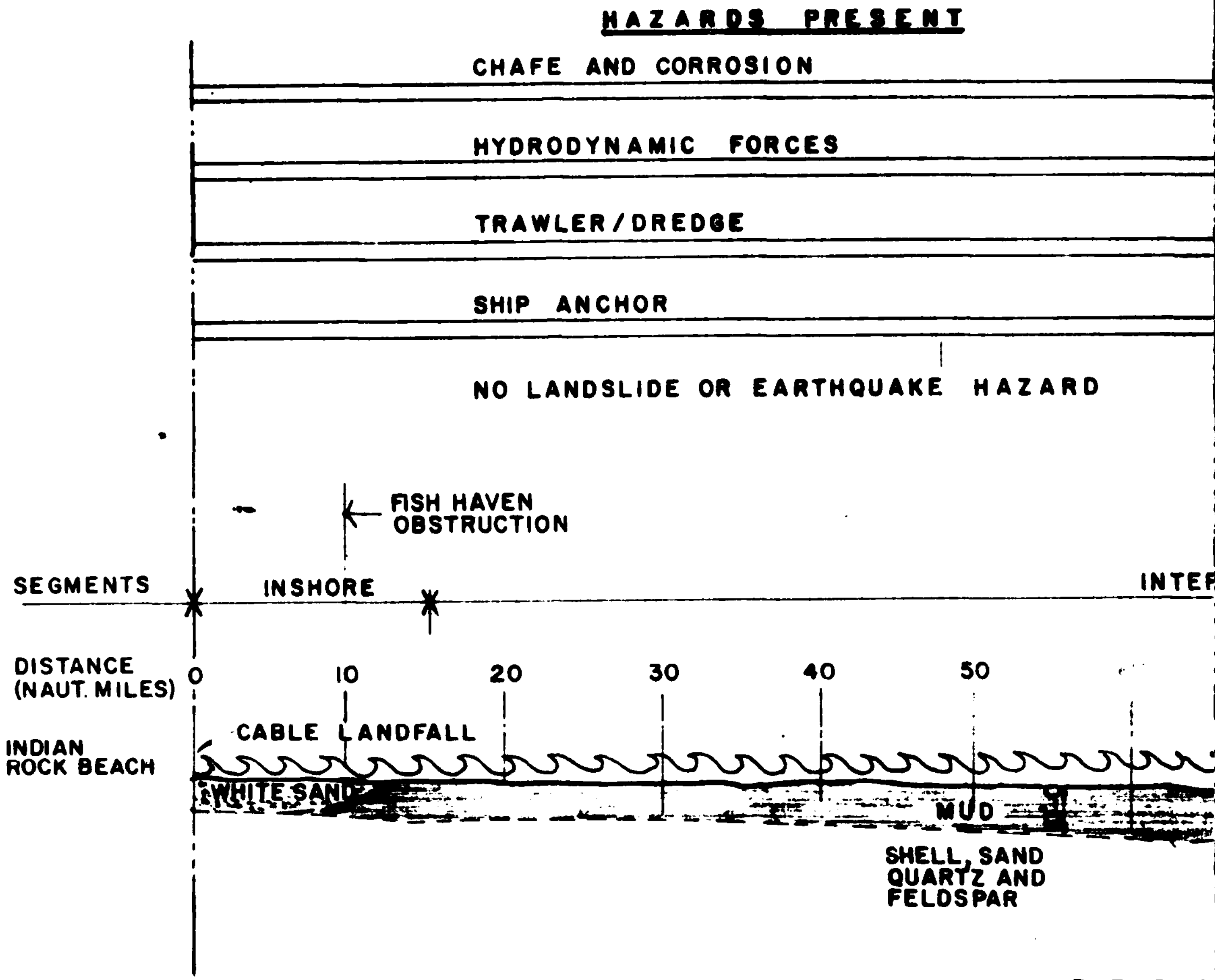
Along the inshore and intermediate segments the hazards to protect against are chafing and corrosion, hydrodynamic forces, trawler, dredge and ship anchor. The probability of landslides or earthquakes are very minimal.

Along the outshore segment the probabilities of damage from the hazards are reduced to such a low number that the risks can be accepted without special protection of the cable.

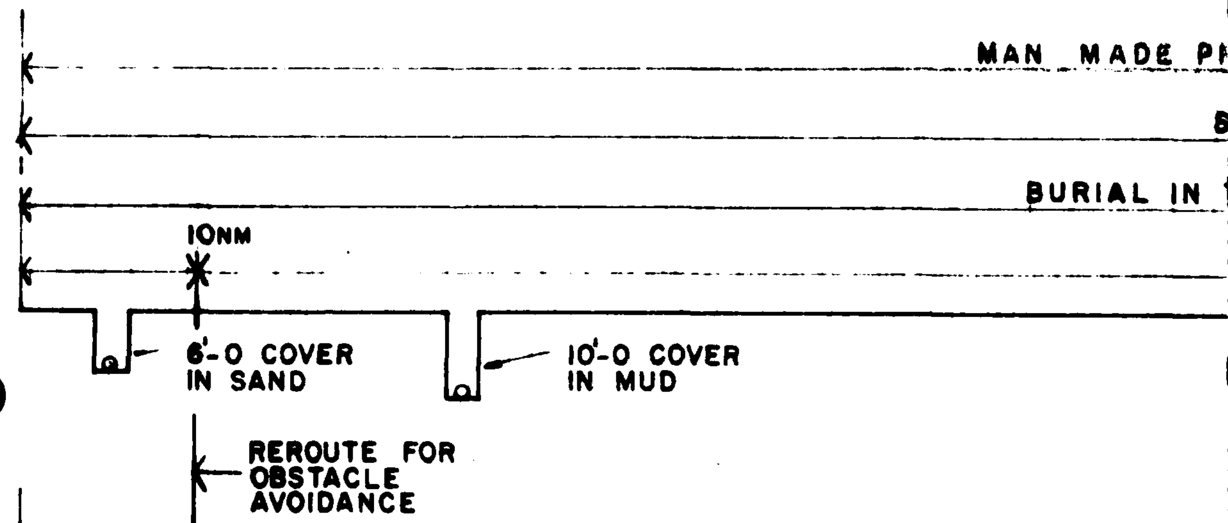
Embedment of the cable into the sea bottom is the best method of protecting against the hazards. A ten feet embedment in the mud and 6 feet in the beach sand covering the first 10 n.m. would appear adequate against anchor dragging. In the zone of heavy sea traffic, nautical mile 85 to 90,it would be prudent to obtain 20 feet embedment since this in an area of high propability of anchor dragging. See Table 3.10 for a listing of hazards likely to cause damage.

3.5.3 PROTECTION STRATEGY

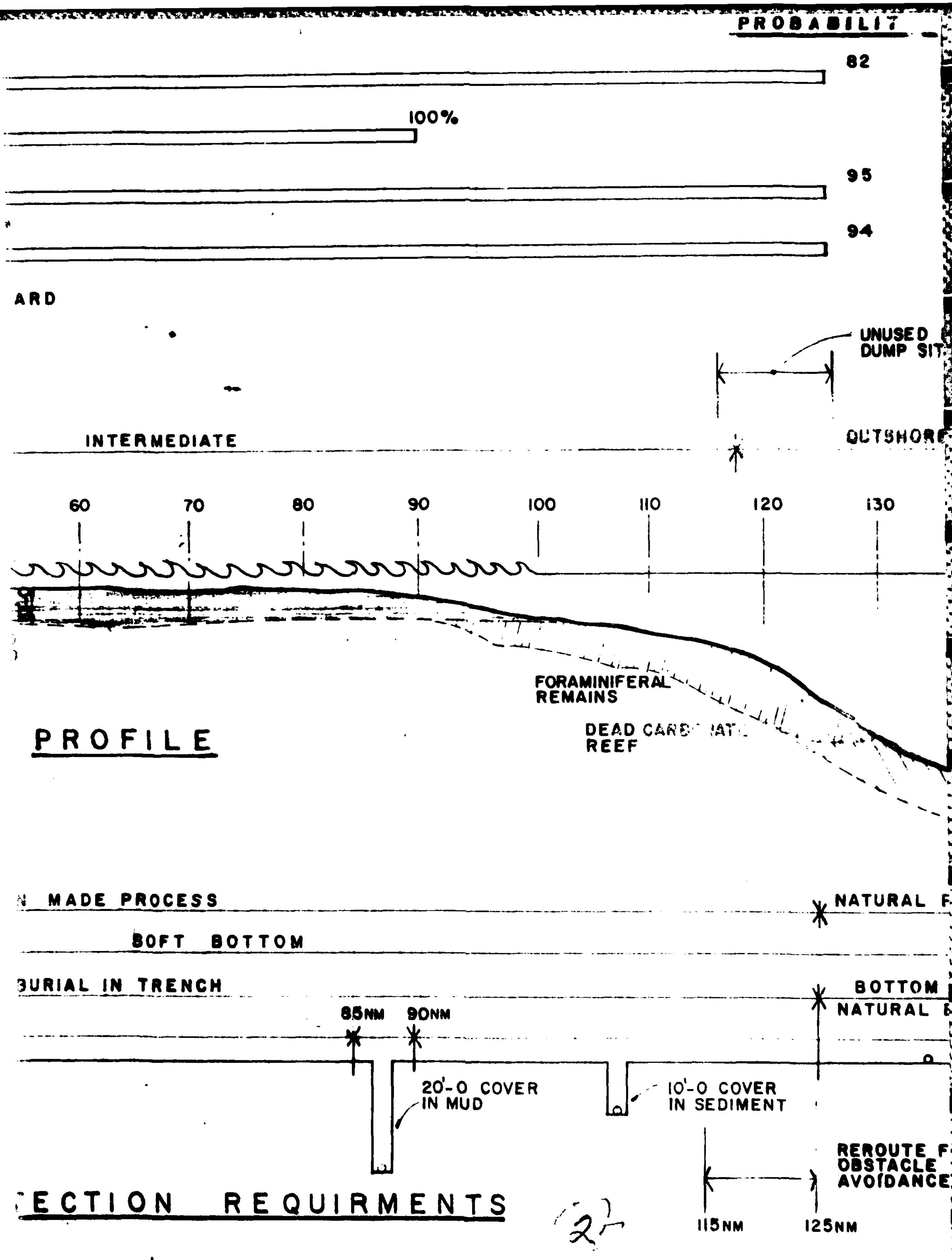
(a) Along the inshore segment a conventional dredge could be utilized to dig a trench of the required depth. A suction dredge with a cutter head would appear adequate.



PROF



PROTECTIO



PROBABILIT
82
100%
95
94
ARD
UNUSED
DUMP SIT
INTERMEDIATE
OUTSHORE
60
70
80
90
100
110
120
130
FORAMINIFERAL
REMAINS
DEAD CARB ATE
REEF
PROFILE
MADE PROCESS
NATURAL
SOFT BOTTOM
BURIAL IN TRENCH
BOTTOM
NATURAL
85NM
90NM
20'-0 COVER
IN MUD
10'-0 COVER
IN SEDIMENT
REROUTE F
OBSTACLE
AVOIDANCE
ECTION REQUIRMENTS
115NM
125NM

PROBABILITY % **SEE NOTE 2**

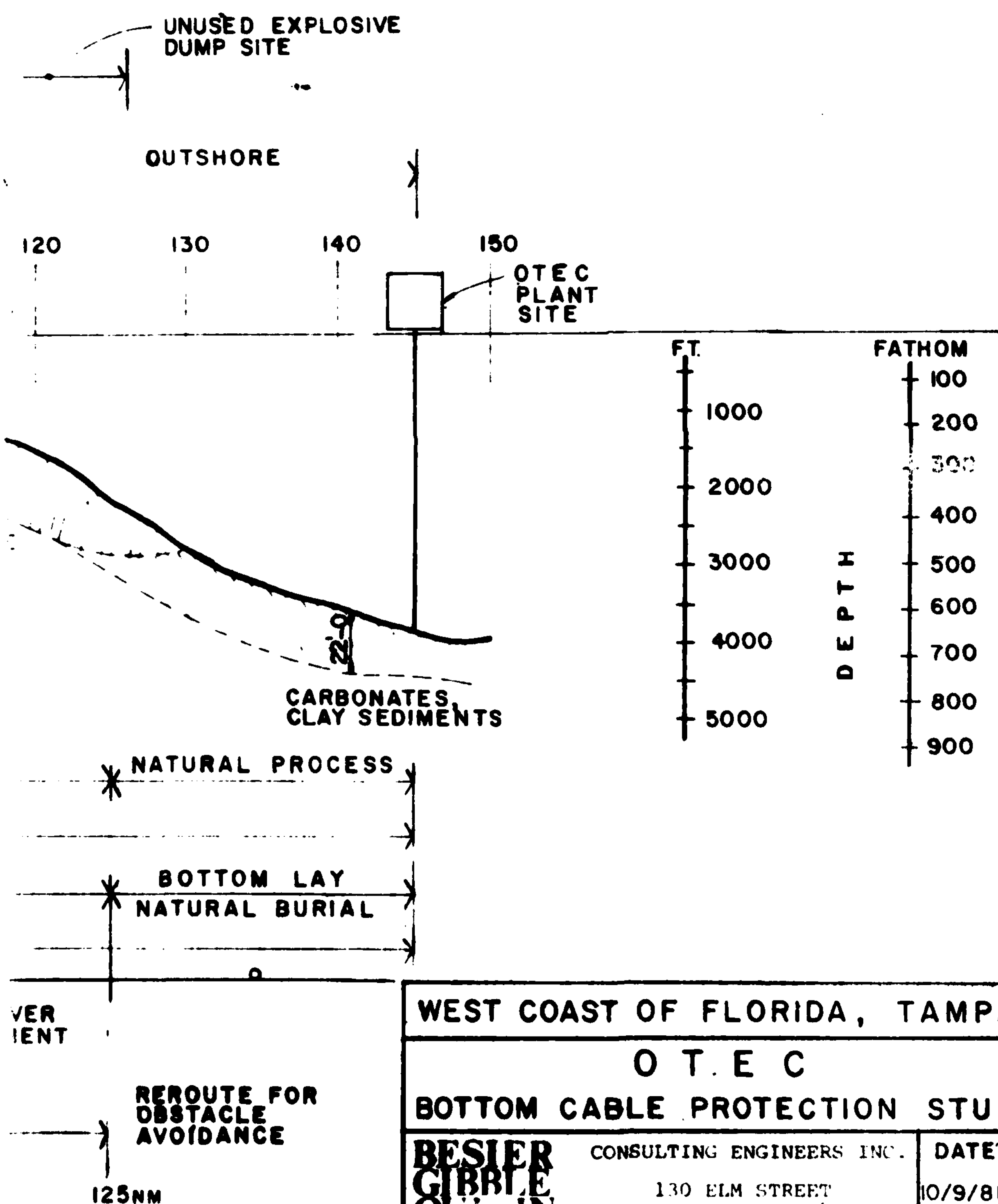
82

95

94

NOTES

1. PROTECTION IS REQUIRED TO PROTECT AGAINST THE HAZARDS LISTED.
2. PERCENTAGE PROBABILITY GIVEN IS THE CUMMULATIVE PROBABILITY OF OCCURANCE FROM SHORE TO THE POINT OUTSHORE INDICATED.
3. NO GUARANTEE OR PROTECTION CAN BE GIVEN TO EARTHQUAKE OR SUBMARINE LANDSLIDE.
4. AFTER NATURAL EMBEDMENT TAKES PLACE OUTSHORE, FULL PROTECTION WILL BE AFFORDED TO CHAFE AND CORROSION, BUT ONLY PARTIAL PROTECTION TO SHIP ANCHOR DEPENDENT ON NATURAL DEPTH OF EMBEDMENT.



WEST COAST OF FLORIDA, TAMPA			
O T E C BOTTOM CABLE PROTECTION STUDY			
BESIER GIBBLE QUIRIN	CONSULTING ENGINEERS INC. 130 ELM STREET OLD SAYBROOK CONN. 06475	DATE 10/9/81	FIG 3.7

(3)

Table 3.10 Hazards

Tampa, Florida

	Cable Segments		
	Inshore	Intermediate	Outshore
Chafing and Corrosion	Yes	Yes	30 to 5%
Hydrodynamics	Yes	Yes	No
Trawler/Drege	Yes	Yes	15 to 2%
Ship Anchor	Yes	Yes	8 to 2%
Landslide	No	No	No
Earthquake	No	No	No

A four week continuous cutting period would likely be needed to dig a trench 10 n.m. long. To reach the required depth of six feet would likely take a minimum of three passes by the dredge.

(b) Along the intermediate segment there would be needed a subsea cable trencher such as the Sea Plow IV, see reference (4), a plowing machine assisted by jets, or the Scarab II a jetting machine both of which can operate in up to 220 fathoms of water. Depth of the trench along this segment should be about 10 feet except for a five nautical mile stretch (between 85 n.m. to 90 n.m. out) where a depth of burial of 20 feet would be prudent. This is where the sea lane between Pensacola and Key West, Florida, crosses the OTEC cable route and the probability of damage from dragging anchors is considered high.

The machines mentioned above do not have the capability of reaching the required depths of protection. However, since many trenching vehicles are designed and built specifically for a particular job, it is likely that one or more existing vehicles can be modified to meet both the water and burial depth requirement, namely 10 feet. The 20'-0" cover where the sea lane crosses over the cable could be achieved by using the dredge mobilized for the inshore segment.

A five week continuous cutting period would likely be needed to dig a trench 103 nautical miles long. It is not likely to be able to predict calm weather for such a period of time. Consequently, stoppages should be anticipated due to weather during this period of time.

(c) Along the outshore segment the bottom is expected to consist of sediments soft enough and deep enough to permit the cable to bury itself. The only need then is to lay the cable on the sea floor utilizing a cable laying vessel.

3.5.4 CABLE LAYING

Along the inshore segment where a standard dredge would be used the cable will be laid after the trench has been dug by utilizing the machine used in the other cable segments.

Along the intermediate segment where a modern subsea cable trencher would be used the better method would be to utilize a machine which would lay the cable at the same time it digs the trench. The Sea Plow IV is such a machine. This would eliminate the need to operate a cable laying vessel under a common schedule with the digging machine over such a long period of time. The Sea Plow IV has a very high production rate so that the time mentioned above would be reduced.

Along the outshore segment the best procedure would be to utilize the Sea Plow IV, or equivalent, a combined trencher and cable laying vessel which should be able to lay the cable within 4 days time.

3.5.5 ESTIMATED TIME AND COST

Actual laying of the cable should be accomplished within 6 weeks time, starting at the plant site about 2-1/2 weeks after the start of the dredging of the deep trenches at 95 n.m. from shore. Mobilization for a standard dredge vessel requires less than 1 week. Mobilization for the trenching machine, including testing and training of personnel requires 2-1/2 weeks. The entire operation at the West Coast of Florida requires about three months.

See Table 3.11 for estimated construction times for the various construction elements. Figure 3.8 gives the same information in the form of a time schedule.

Based upon the construction costs given in reference (5) Table 3.12 gives the estimated cost for the scenario given herein. The total cost for the cable installation off the West Coast of Florida is estimated at $11,370,000.

TABLE 3.11

Estimated Construction Time

West Coast of Florida, Tampa

	Cable Segments		
Construction Elements	Inshore 15 n.m.	Intermediate 103 m.m.	Outshore 27 n.m.
Dredge Trench	27d. (10 n.m.)	27d. (5 n.m.)	
Trench & Lay Cable		36d.	
Lay Cable	2d.		4d.
Cable Tie-in	2d.		2d.
Mobilization - Dredge		5d.	
Demobilization - Dredge		5d.	
Mobilization - Trencher		19d.	
Demobilization - Trencher		15d.	

Figure 3.8

Estimated Construction Time Schedule

West Coast of Florida, Tampa

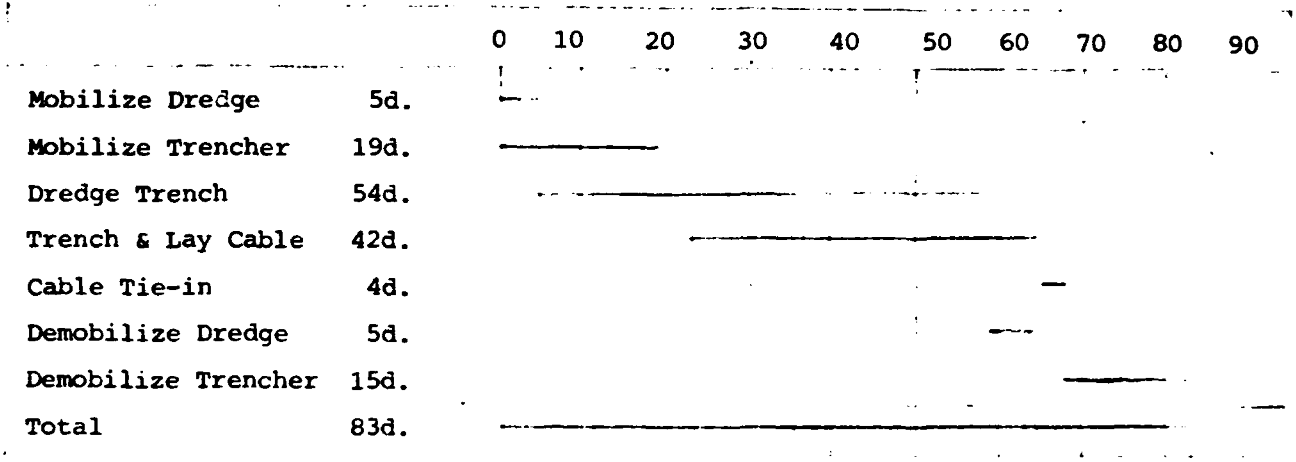


TABLE 3.12

Estimated Construction Cost

West Coast of Florida, Tampa

Construction Element	Days	Cost Per Day	Cost
Mobilization - Dredge	5	$ 30,000	$ 150,000
Mobilization - Trencher & Cable Lay	19	84,500	1,605,500
Dredge Trencher	54	50,000	2,700,000
Trench & Lay Cable	42	119,500	5,019,000
Cable Tie-in	4	119,500	476,000
Demobilization - Dredge	5	30,000	150,000
Demobilization - Trencher & Cable Lay	15	84,500	1,267,500
Total	83	$137,000	$11,370,000

CHAPTER 4 - CONCLUSIONS AND RECOMMENDATIONS

4.1 It is possible to effectively protect the OTEC power cables at all four potential sites aginst the hazards expected to be encountered and thus avoid being damaged.

4.2 At each of four plant sites the protection techniques recommended involve more than one scheme.

4.3 A dynamically positioned cable lay ship appears to be the best vessel to use due to its deck capacity and space at all sites except the West Coast of Florida. At the proposed Florida site a combined trencher and lay vessel seems to be the best solution.

4.4 There exists no machine which is capable of trenching through hard rock. Therefore the alternative techniques of blasting a trench by diver and/or of cable immobilization are needed.

4.5 Modification of existing trenching machines or development of new equipment is necessary in the case of the proposed plant site off Cabras Island, Guam.

4.6 There is of course another technique for protection that can be used at any or all sites, namely, cable redundancy.

4.7 The estimated cost figures given are based on the equipment being available but is subject to varying market conditions. Cost figures are also based upon a minimum of weather downtime.

4.8 Mobilization and demobilization costs comprise a large percentage of the total cable lay and protection costs.

4.9 In order to obtain more accurate cost estimates it would be necessary to conduct a specific site survey at all four proposed OTEC sites, including core samples of the sea floor. This site survey is also necessary before actual plans can be developed for laying and protecting the OTEC cables.

REFERENCE

1) OTEC Bottom Cable Protection Study - Environmental Characteristics and Hazard Analysis by C. Chern and W. Tudor of the Ocean Engineering and Construction Project Office, Chesapeake Division NAVFAC, Washington, D.C., FPO-1, Oct. 1981

2) Design and Installation of Nearshore Ocean Cable Protection Systems by R.L. Brackett, P.J. Valent, J.B. Ciani, R.E. Elliott and L.W. Hallinger FPO-1-78(3), Civil Engineering Laboratory, Port Hueneme, CA, 93043, Nov. 1979

3) Submarine Cabled System, Design and Installation Planning Manual; Volume I Design and Construction Orientation and Volume II Procedures for the Planning, Design, Construction and Installation of an Undersea Cabled Facility, NAVFAC, P906, April 1976

4) OTEC Subsea Electrical Cable Protection Systems and Technology Survey by Brown and Root Development, Inc., Houston, Texas, Jan. 30, 1981 for Civil Engineering Laboratory, Port Hueneme, CA 93043

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