116

DRAFT REPORT

HAWAII DEEP WATER CABLE PROGRAM
(HDWCP)

CABLE REPAIR RATIONALE

Prepared for:

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CABLE REPAIR RATIONALE

I. INTRODUCTION

A. Purpose

The Hawaii Deep Water Cable (HDWC) program has a major objective of determining the technical feasibility of deploying and operating, over a service life of thirty years, a submarine power transmission cable between Kohala on the island of Hawaii and the Makapuu area of Oahu. To this end the (HDWC) program has incorporated work elements to: 1) build and laboratory test a prototype cable that is designed to meet a wide range of environmental conditions expected in the route between the islands; 2) conduct at-sea tests to determine the feasibility of accurately laying a commercial cable with the proper tensions; and 3) perform bottom roughness surveys to establish the existence of acceptable cable laying routes and determine the laying requirements.

Another task, which this report addresses, is assessing the requirements for repairing the submarine portion of an inter-island cable system should damage occur during its operating life. Currently the (HDWC) program does not envision any field test demonstrations of repair procedures because the field splicing and test procedures which will be developed in the factory will establish the techniques of welding, wrapping, and sealing. Extrapolating these procedures to the field is a matter of equipment design and training and not a question of feasibility. Consequently this report is directed to reviewing existing repair techniques as they could apply to an interisland cable system and to confirm there are no further developments required to determine the technical feasibility of a commercial cable system insofar as its repair is concerned.

B. Outline of Tasks

The tasks associated with developing a cable repair rationale for the interisland cable system include the following (ref: HECO/Parsons Aug 85 Proposal to DOE, p. 11):

1. Defining cable failure and causes
2. Describing cable protection methods
3. Describing techniques and equipment required to locate and assess cable failure
4. Evaluating the necessity of uncovering buried cables
5. Evaluating use of remote operated and manned submersible vehicles
6. Identifying cable repair vessel equipment and personnel requirements
7. Formulating cable recovery, repair, and redeployment scenarios

The sections which follow discuss first the report prepared by Pirelli Cable Corporation, titled HDWC Program Repair Rationale which is included as Appendix A, and then develop a baseline approach to a repair scenario and a conceptual arrangement of equipment requirements integrated into the expected cable laying concept developed on other tasks of the HDWC program.

II. SUMMARY OF PCC REPORT

Appendix A was prepared by Pirelli Cable Corporation (PCC) under subcontract to Parsons Hawaii. This report provides the basic information upon which the concepts covered in later sections of this report are based. The following summarizes the detail contained in the PCC report covering cable failure modes and protection, basic repair methodology, and equipment requirements.

A. Cable Failure Modes

have resulted? reference?

Eighty percent of cable failures result from mechanical damage due to anchors and other objects dragged into the cable, laying the cable over sharp obstructions, or during cable handling. The natural phenomena of tides and currents and sea bed movement also contribute to the mechanical failure of submarine cables but to a far lesser degree. Cable faults due to insulation failure are also rare and account for perhaps 5% of all failures. The last category of failures is due to unknown causes and accounts for about 12%.

how many cable operations have been used in this failure evaluation?

B. Cable Protection

The most effective method of protecting the cable from external damage is by embedment. The technique used to embed the cable depends on the depth and type of soil and may involve dredging, plowing or blasting. Covering the cable with protective pipes or rocks may also be employed. The objective of such protection is to guard against damage for dragged items such as anchors. Protection may be required up to a water depth of 100-150 meters generally near cable shore landing sites.

Damage due to tidal oscillations or ~~strumming~~ is eliminated by proper placement of the cable on the sea bed such that the span between supports does not result in motions of the cable that could lead to fatigue failure.

C. Classification of Cable Repair Sites and Methodology

Pirelli's report considers two types of sites where damage can occur:

Case I - Damage at Depth less than 600 Meters and Moderate or No Slope (less than 1 to 4)

Case II - Damage at Depth greater than 600 Meters or in Vicinity of Escarpments Where Slope is Steep (greater than 1 to 4)

Page 9 of Appendix A indicates areas along the proposed cable route where these two cases occur.

Case I repairs can be accomplished by existing techniques which have been demonstrated to depths of 200 meters. The technique is to grapple, cut and seal the cable, retrieve one end and splice it to a spare cable (length equal to about twice the depth of water), retrieve other end of cut cable and splice it to the remaining end of the spare cable. Finally the repaired cable (now with extra length) is laid over by rotating from vertical to horizontal onto the seabed where it is referred to as a bight.

For Case II a more complex and time consuming procedure must be followed. After grappling, cutting, and sealing the cable at the fault location, one end is retrieved to an area away from the escarpment where the water depth is acceptable for laying the bight and there it is cut and sealed. The other end of the cable is retrieved from the area of the fault to an area of water depth less than 600 meters where it is cut and sealed. The two retrieved cable lengths are then inspected, tested, rewound on the turntable, and spliced together. This connected length of retrieved cable is then spliced to a spare length of cable on the vessel. The end of the cable left on the seabed at depth less than 600 meters is now recovered and spliced to the other end of the spare cable. The cable is then laid up to the position of the other end of the cable at the selected bight site. This end is then recovered and spliced to the end of the re-laid cable. As in Case I, the final step is to remove the cable from the laying machine and carefully lay the bight .

D. Vessel, Equipment, Operations

1. Repair Vessel

Appendix A recommends that a dynamically positioned cable vessel be used as repair vessel to provide the requisite sea keeping performance and for protection of the jointing operation. The vessel must therefore be of sufficient size to accommodate the machinery needed to handle the cable bight and spare cable in addition to that required for retrieving and laying the cable. This will include two cable sheaves, two laying machines, turntable with pick up arm and cable tension(?) compensator. In addition to the cable machinery, space will be required on the vessel for the jointing tools and equipment and the jointing-on-board operation. Drawings are included with Appendix A which show

I don't find these.

typical equipment layouts aboard a cable vessel for the repair operations.

2. Support Equipment and Services

Appendix A identifies support craft, equipment, and facilities that will be required during a repair operation, and types of personnel that will be needed both on board the ship and at the shore-based support facilities. The report also emphasizes the importance and significance of setting up special safety and emergency systems for the operation.

3. Repair Operation Time Estimate

Estimates of the repair operation duration are provided from the time an interruption of electric service is experienced until service is re-established and the repair force is demobilized. Estimates are provided for the situation in which there is a dedicated cable laying vessel in Hawaii, and for one where there is no dedicated vessel available. It is estimated that an additional 50 days will be required for mobilization in the latter situation due to the time needed to obtain a vessel and prepare it for the special operation. The estimates for the at-sea portion of the repair operation are 35 days for a repair site classified as Case I and 50 days for Case II.

III. ASSESSMENT OF DAMAGE POTENTIAL ALONG ROUTE

The main cause of damage to undersea cables has been through external forces such as fishing gear and anchors. The Pirelli report states that these two causes are responsible for over 50% of all submarine cable failures. Except for areas in the vicinity of the shore landing sites, most of the interisland cable route, although in a heavily traveled area, is located where potential for cable damage from these causes will be non-existent or minimal.

Figures 1 and 2 provide information on the preferred cable route including data on distance and water depth for each of the undersea segments. These figures indicate 51 percent of the route is submerged, of which 80% is in water depth of less than 300 fathoms (547m). wouldn't 600 meters be a more appropriate criterion?

A. Shore Take Off and Landing Points

The most likely locations for mechanically induced cable damage are in the vicinity of the four shore take off and landing points. These are located in the general areas of Mahukona Harbor, Hawaii; Huakini Bay, Maui; Ahihi Bay, Maui; and Waimanalo Bay, Oahu. In addition to the environmental factors which must be considered, there is marine activity at each of these locations in varying degrees. Suitable ship anchorages are available in both Mahukona Harbor and Ahihi Bay; Waimanalo Bay offers all-weather protection for small craft due to its location inside a barrier reef; there is bottom fishing and other activity in the vicinity of Huakini Bay.

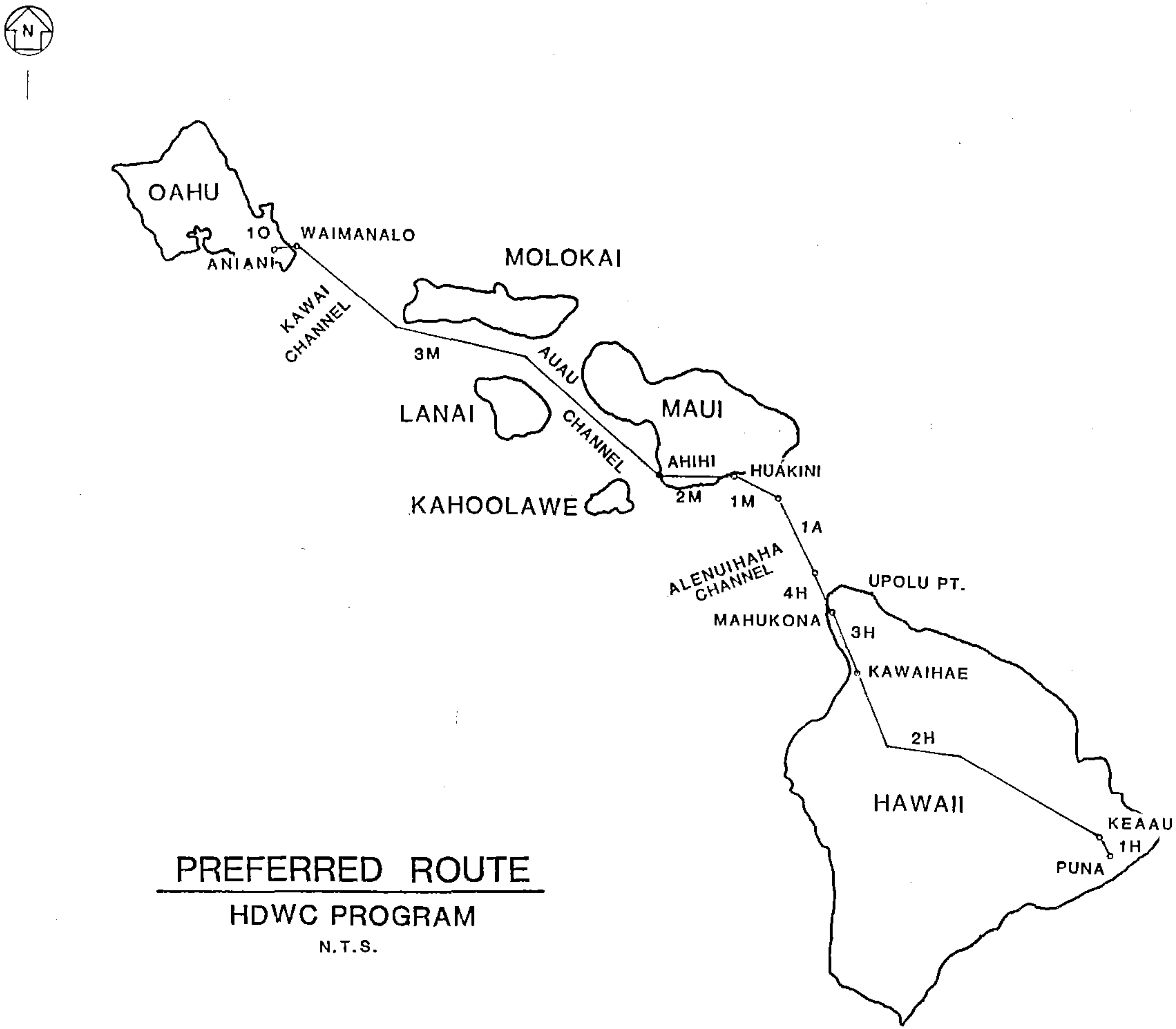

N
OAHU
1O
WAIMANALO
ANIANI
KAWAI CHANNEL
MOLOKAI
3M
AUAU CHANNEL
LANAI
MAUI
AHIHI
HUAKINI
KAHOOLAWE
2M
1M
1A
ALENUIHAHA CHANNEL
4H
UPOLU PT.
MAHUKONA
3H
KAWAIHAE
2H
HAWAII
KEAAU
1H
PUNA
PREFERRED ROUTE
HDWC PROGRAM
N.T.S.

Figure 1

DISTANCE AND DEPTH CHARACTERISTICS
OF PREFERRED ROUTE, April, 86

Hawaii to Maui to Oahu

FROM	TO	SEGMENT	OH/SUB	LENGTH KM	LENGTH MI
Puna	Keaau	1H	OH	23	14
Keaau	Kawaihae	2H	OH	129	80
Kawaihae	Mahukona	3H	OH	23	14
Mahukona	Alenuihaha	4H	SUB	32	20
Alenuihaha	Alenuihaha	1A	SUB	19	12
Alenuihaha	Huakini Bay	1M	SUB	16	10
Huakini Bay	Ahihi Bay	2M	OH	32	20
Ahihi Bay	Waimanalo	3M	SUB	154	96
Waimanalo	Aniani	10	OH	5	3
		TOTAL OVERHEAD		212	131
		TOTAL SUBMARINE		221	138

PERCENTAGE SUBMARINE = 51%

LONGEST SUBMARINE RUN = 154 km

APPROXIMATE DISTANCE WITHIN DEPTH RANGES
FOR SUBMARINE PORTIONS (KM)

SEGMENT	DEPTH 0-1800 / 0-547 / 0-300	1800-3600 / 547-1094 / 300-600	3600-5400 / 1094-1641 / 600-900	5400-7200 / 1641-2188 / 900-1200	Feet / Meters / Fathoms
4H	27	5	-	-	
1A	-	10	1	8	
1M	7	2	7	-	
3M	144	10	-	-	
TOTAL	178	27	8	8	
PERCENT	80.5%	12.2%	3.62%	3.62%	

Figure 2

B. Potential Damage Due to Trawler

Due to the typically rough bottom conditions in Hawaiian waters, bottom trawls are seldom used. Recent attempts at trawling for bottom fish (uku, opakapaka, ehu, onaga) have proven to be very uneconomical due to fishing gear damage and losses. There are, however, three trawlable bottom areas in the vicinity of the proposed cable route segment 3M where penaeid shrimp ("Hawaiian Red Shrimp") have been located.

- Penguin Bank

  An 8-mile (14.8 km) long area of about 3.0 square miles (10.3 km^2), centered on the 100 fathom depth curve (185 m) between long. 157°22'W and 157°30'W. This is on the north edge of the bank west of Molokai (Figure 3).

- Kalohi Channel

  A small portion of the western channel between Molokai and Lanai bounded on the north, east, and south by the base of the shelf break at about 125 fathoms (230 m) (Figure 3).

- Pailolo Channel

  A 7-mile (13 km) long area of about 3 square miles (10.2 km^2) extending from about lat. 21°03'N, long. 156°41'W to lat. 20°58'N, long. 156°46'W. This is on the southeast edge of the channel near Maui (Figure 4).

From experience and data collected it appears that the shrimp stocks in the vicinity of the Hawaiian Islands are capable of supporting only one trawler at best. It is very seldom that a

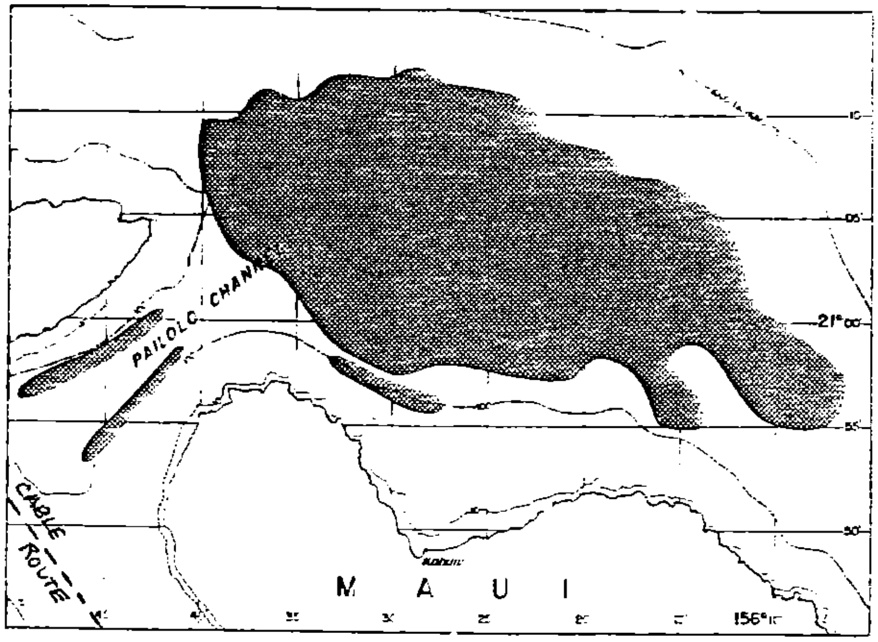


Figure 4. Trawlable areas (hatched) in Pailolo Channel and north of Maui.

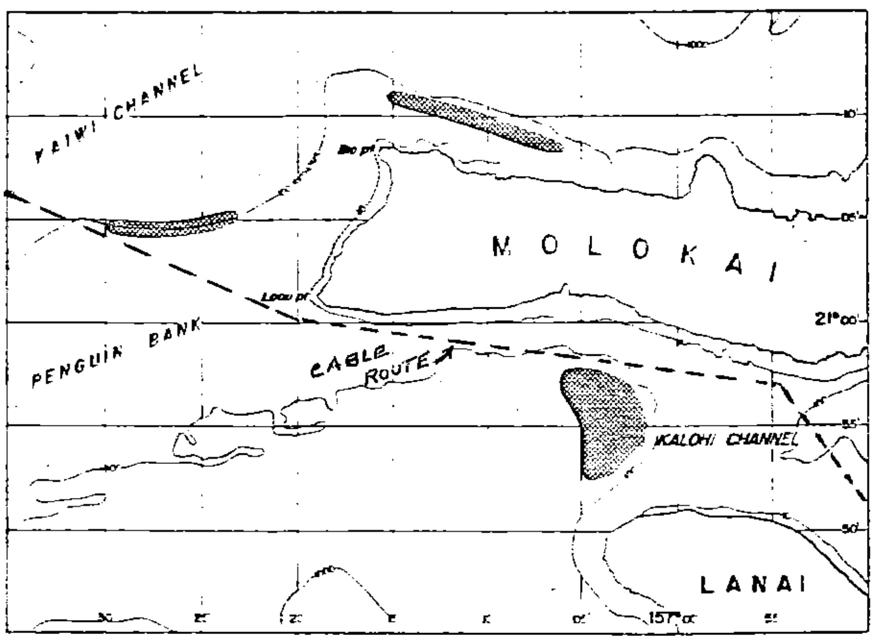


Figure 3. Trawlable areas (hatched) in the vicinity of west Molokai.

trawler operates in these waters.

Damage due to trawling is unlikely along the cable route because the route avoids trawlable areas and the activity is sparse.

C. Potential Offshore Damage Due to Anchors

The use of anchors while fishing in Hawaiian waters is limited primarily to bottom ~~fish fishery~~ fishing handline operations in waters less than 15 fathoms (27m) deep. Bottom ~~fish~~ fishing in the vicinity of cable route segment 3M is concentrated in the Penguin Bank area and in the Auau Channel. Handline fishing is also conducted in the vicinity of Alenuihaha Channel cable route segments 4H and 1M. This ~~fishery~~ fishing is limited to depths less than 150 fathoms (274m).

Navy submarine and surface ships routinely anchor off Lahaina, Maui in the Auau Channel, and therefore there is a relatively short area in the vicinity of route Segment 3M where there is potential for cable damage in depths of less than approximately 20 fathoms (37m).

Avoiding potential damage due to anchors is discussed in Section IV.

IV. EMBEDMENT REQUIREMENTS FOR HDWC

Section III makes note of the fact that the selected route is very heavily traveled although the damage potential is minimal. Consequently the trade-off between cost and the added reliability afforded by burying the cable favors installing the cable on the seabed without trenching or other protection. This conclusion does not suggest it is unnecessary to embed the cable in certain areas. There remains the question, therefore, as to where, ~~and~~ over what length, ~~how extensive~~ and how deep the embedment should be.

Appendix B presents a general discussion on the subject of submarine cable embedment and considerations relative to the Hawaii interisland route.

A. Protection From Trawlers and Anchors

Pirelli has advised that submarine cables should be protected against external damage only along sections of the cable route where the relevant risk is high (A. Morello and G. Davini, Comments of August, 1983, in response to W. Engelmann, W. Searle, A Von Alt, "A Different Approach to the Repair and Protection of Submarine Cable Systems"). The assessment presented in Section III suggests that trawling is not a significant factor in submarine cable damage in Hawaiian waters. In fact it should be feasible to avoid potential cable damage from any trawler activity along the route by selecting cable paths that avoid the known trawlable areas.

Appendix B discusses the considerations relative to protecting the cable from anchor damage, and concludes that embedment should be provided out to a depth of 12 fathoms (22m) at take-off and landing points. To avoid anchors along the route, the cable should not be laid along any portion of route segment 3M which approaches within 3km distance of Lahaina, Maui, and within about .6 km of the Molokai coastline on the Penguin Banks.

Table I provides an assessment of Hawaii cable embedment requirements based on the above discussion and Appendix B.

B. Additional Protection at Shore Take-Off and Landing Sites

In addition to burial of the cable below the ocean bottom at the shore take-off and landing sites, other measures will be required for protection from environmental forces due to wave motion. Appendix B discusses this requirement and outlines various methods that have been successfully employed. Appendix B concludes that effective methods for Hawaii coastline conditions would include surrounding the cable with split cast iron protectors or a concrete duct from the shoreline out to approximately the 10 fathom curve (18m) at each shore site.

TABLE I

Embedment Requirements At Shore Landings

Embedment Requirements	Mahukona Harbor, Hawaii Take Off Zone	Huakini Bay, Maui Landing Zone	Ahihi Bay, Maui Take Off Zone	Waimanalo Bay, Oahu Landing Zone
Embedment Distance Out From Shore	365m	731m	915m	2744m
Depth of Water	0-22m	0-22m	0-22m	0-22m
Sea Bottom Condition	Cobbles, small boulders. Soft with sand deposits below 10m.	Cobble beach. Sand channel with rock out-crops below 20m.	Hard with sand spots.	Sand channel mixed with boulders.
Burial Depth	2m	2m	2m	2m

V. ASSESSMENT OF REPAIR METHODOLOGY

The overview provided in the PCC report provides a basis on which to project the repair scenario(s) for the commercial operation of the interisland cable system. Since there are some uncertainties regarding the exact configuration the cable system will have, i.e. number of cables, spacing, and embedment depth, it is necessary to develop a conceptual repair rationale based on the best assumptions available to the program.

A. Repairs in Shallow Water

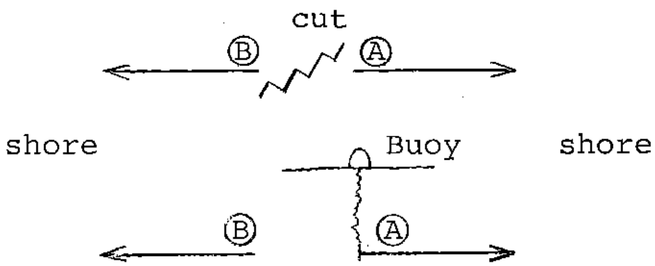
Pirelli states in the Appendix A report that the conventional repair technique has been successfully used in water depths up to 200 meters and that by controlling the laying of the bight it can be adapted to a water depth of 600 meters. The illustration on Page 9 of Appendix A shows that approximately 73% of the proposed interisland submarine cable route would be within this depth range and meet the criteria for a Case I repair situation. The repair procedure for Case I is described in Appendix A and illustrated in Figure 5. It is relatively straight forward and involves two flexible repair joints.

In Appendix A, Pirelli discusses the development of techniques for repairing the cable directly on the bottom which would save considerable time and cost compared to the out of water repair procedure. One technique is to use scuba divers; to date this has only been used for minor faults (armor or lead sheath damage resulting in oil leakage with no effect on insulation) and is limited to water depths up to 50 meters. Another technique under

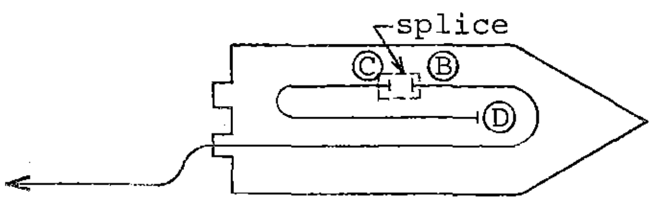
CABLE REPAIR CASE I

Damage at depths up to 600 meters and
moderate or no slope

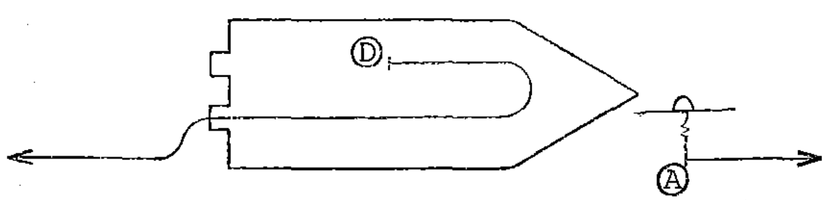
1. Grappel, cut cable at fault. Recover end A, excise damage, cap, attach to surface buoy.



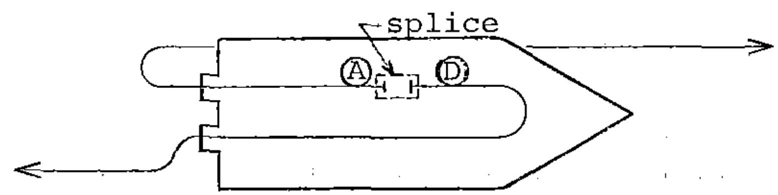
2. Recover end B, excise damaged length. Splice end B to spare cable C-D (spare length equals 2x length removed from each end plus 2x depth).



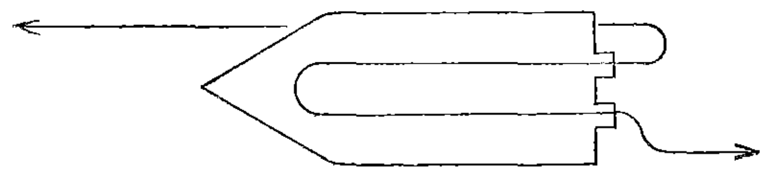
3. Lay joint and spare cable up to position of cable end A.



4. Recover end A and splice to spare cable end D.



5. Proceed toward first joint while laying the second joint through the laying machine.



6. When at area selected for laying the bight, remove cable from laying machine, support the bight and carefully lay.

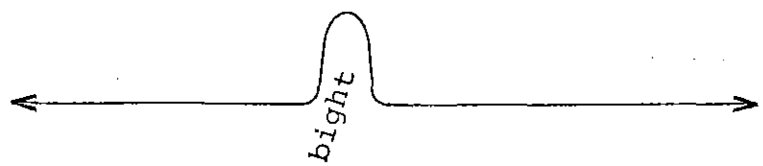


Figure 5

investigation involves the making of a repair in an underwater habitat. This would be limited to the operating depth of saturation diving which is 150-200 meters.

B. Repairs in Deep Water or on Steep Slopes

A Case II repair situation as defined by Pirelli would exist in areas of the route where water depth is greater than 600 meters or where there is a steep slope. The illustration in Appendix A shows that Case II situations would be found only in the deep portion and/or on the steep slopes of the Kaiwi and Alenuihaha Channels. The repair methodology for the Case I situation would not apply in these locations and the special procedures outlined by Pirelli for a Case II situation must be followed in order to avoid having to handle the cable on a steep slope or make a repair joint over deep water. A steep slope would complicate the process of grappling for the cable, present an unstable surface for the cut cable, and could even cause twisting of the bight due to irregular laying on the bottom. The deeper the water the wider the path required for laying the bight on the bottom (path width must be equal to water depth). Also, the deeper the water the heavier the load for the handling equipment to support when laying the bight (approximately 130 tons at 2100 meters).

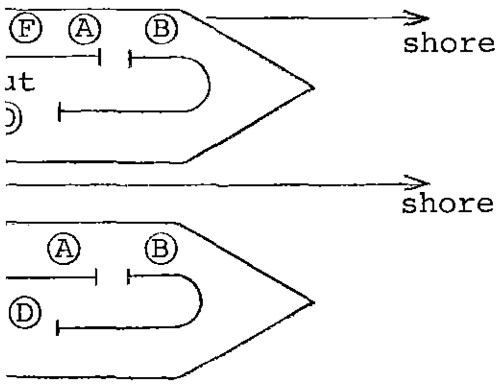
Pirelli states in Appendix A that it is not considered feasible to make a repair joint on a vessel positioned in water depths greater than 600 meters. The vessel has to be kept stationary when the jointing operation is in process and during this time the cable catenary from vessel to bottom is subjected to wave and current motions. The fatigue effect on the cable from this is most severe at the sheave where cable tension is greatest. Pirelli has calculated that Cable PCC #116 can withstand the resultant fatigue effect up to a water depth of 600 meters without adversely affecting the cable life after repair.

Figure 6 illustrates the recommended repair methodology which Pirelli describes in Appendix A for the Case II situation.

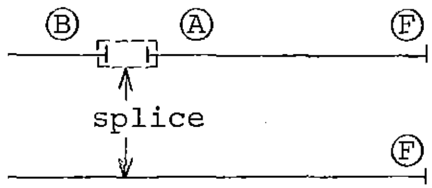
ƐPAIR CASE II

ʒreater than 600 meters
 of steep escarpment

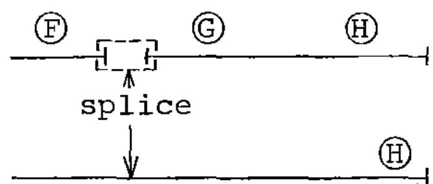
ɛ end A and retrieve
ɛ depth is 600m.
 E and lower to seabed.
 A-F on deck.



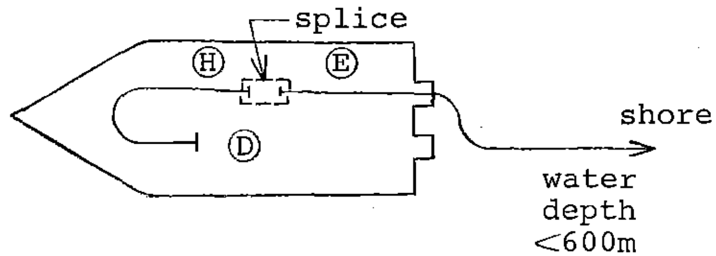
ʼbor, check out retrieved
ınd A-F, splice together
ɣy of paper is same.



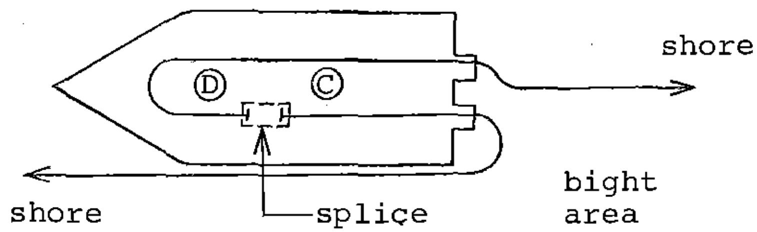
o spare length G-H
 equals length removed
 at bight area). Store
 turntable.



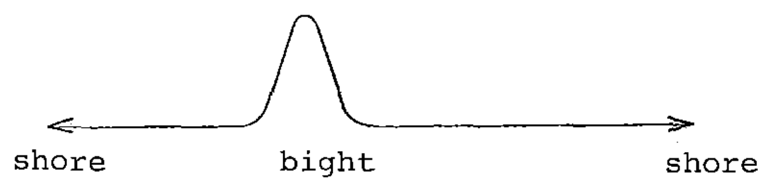
7. Return to location of cable end E. Recover E on deck and splice to H.



8. Lay cable up to position of C. Retrieve end C and splice to D.



9. Remove cable from laying machine, support the bight and carefully lay.



VI. REPAIR SCENARIO

A. Detection

When a cable fault has occurred and checkouts confirm that it is located in the underwater cable, the fault must be located before the total scope of the repair effort can be determined and the repair operation planned. As water depth gets beyond about 18 meters, the task of pinpointing this location can be extremely difficult, especially if the cable is buried.

Englemann, Searles, and Van Alt, in their paper entitled "A Different Approach to the Repair and Protection of Submarine Cable Systems," state that a fault location which has been determined by instruments to be approximately 6100 meters to the closest terminal can be off as much as 183 meters. Visual confirmation of the fault location is therefore required to ensure the repair effort is scoped correctly at the outset. This will require inspection by divers or ROV and could be a long and costly operation.

When a cable is buried and a considerable amount of cable has to be uncovered for the inspection (depending on embedment depth, water depth, and environmental conditions), it may be more economical to abandon the cable than attempt to pinpoint the fault. Appendix B discusses the technical-economic considerations relative to embedment. As discussed in Section IV above, it appears that it should be possible to limit the extent of embedment for the interisland cable to the shore take off and landing site zones.

Long Island Light Company's approach to fault locating is discussed by Engelmann, Searle, and Van Alt in the above referenced paper for water depths less than 61 meters. In the case of an oil leak without electrical fault the procedure calls for determining the general area by hydraulic measurement followed by an air search for an oil slick. If there is an electrical fault in addition to an oil leak a high voltage test is then performed for preliminary location. In both situations divers are used to confirm the location by physical inspection.

Appendix A discusses two systems that have been successfully employed by Pirelli to locate cables and cable faults. One of these is the Innovation Magnetic Tracking System for locating and continuously tracking buried cables by detection of the magnetic field produced by the steel cable armor. The other is an electric measuring system called the 16 HZ method with which Pirelli has located cables in water depths up to 300 meters with an accuracy of from a few meters to less than 20 meters.

B. Planning the Repair Operation

Once the fault location is accurately known and the probable cause of the fault is diagnosed, the type or repair and at-sea operation can be planned. Other primary factors influencing the planning include the availability of cable repair vessel, equipment, spare joints, spare cable, and trained personnel. Appendix A provides an estimate of 30 days to complete the planning for a repair operation once the fault has been located and analyzed.

C. Mobilization

The repair mobilization phase duration will depend on the availability of a cable vessel. If the cable vessel is laid up in Hawaii dedicated to the interisland cable system a mobilization period of about two weeks will be required for activating the vessel, rigging and loading out the vessel, checking out all cable handling and repair equipment, and conducting a short sea trial. In the case of a non-dedicated cable vessel additional time will be required to effect the transfer of the vessel to Hawaii. The amount of this additional time will be a function of the vessel's employment and location at the time.

D. Repair

The optimum submarine cable repair method at sea is the flexible repair joint or splice. The result is the connection of two pieces of identical cable with essentially the same dimensions and mechanical characteristics as the original cable. This makes handling the repaired cable and the relaying operation relatively easy. Being able to accomplish a flexible joint requires highly skilled technicians and specialized equipment. The jointing must be carried out in a dehumidified area. Each wire in the conductor is jointed separately and then the joint is insulated in a lapping machine. A crucial point in the operation is the jointing of the lead sheath which is followed usually by both x-ray and ultra-sonic inspection to insure adequacy of the joint. Finally, each of the armor wires are spliced. The repair scenario for Pirelli Case I requires two such splices while Case II requires four flexible splices.

The Long Island Lighting Company has developed a rigid splice that can be constructed by company personnel, thereby avoiding the costs associated with using the cable manufacturer's skilled technicians and equipment for repair. Special procedures are required for tilting the rigid splice over the cable sheave or chute during lowering. The development appears to work well for the cable characteristics and laying conditions of the Long Island Sound crossing which includes medium size cables, 3 inch (76mm) diameter and 8 lbs/ft (12 Kg/m) diameter and a maximum depth of 200 ft (61 meters). For the deeper waters and larger cable of the interisland cable system, however, the flexible repair joint remains the only proven, technically sound solution.

VII. EQUIPMENT REQUIREMENTS

In Appendix A Pirelli recommends that for cable repair at sea a properly equipped, dynamically positioned cable vessel be used for optimum performance. The major machinery required to transport, deploy, retrieve and repair the PCC 116 cable includes two cable sheaves, two linear tensioner laying machines (100 ton and 30 ton), cable turntable with pick-up arm, cable compensator, cable stoppers and dynammometer. Specific equipment items needed for the cable repair operation are listed in Appendix A and summarized below:

A. Cable Retrieval

A cable grapnel is used to retrieve the cable. The grapnel is towed along the bottom from the cable ship by rope until it hooks the cable. A cut-and-hold grapnel is usually used in deep water. This type of grapnel is designed to cut the cable and clamp on to one end.

Ancillary equipment and services required for the retrieval operation include workboats, scuba divers, ROV, marker buoys, grapnels, ropes and chain.

B. Cable Repair

The jointing operation requires a dedicated area on the ship for the air-conditioned tent, electric system, liquid nitrogen freezing system, oil feeding system, tools, trestles, press, etc. Additional deck space is needed in close proximity to the jointing area for installing nitrogen tanks, electric generator, air compressor, and gel storage.

C. Equipment Arrangement and Space Requirement Aboard Vessel

Appendix A provides two drawings of typical equipment layouts aboard a cable vessel for the repair jointing operation. One drawing gives a layout for splicing the first repair joint to the spare cable length and the other shows an arrangement for splicing the second joint. The major differences in the deck arrangements for the two situations are the locations of sectors, 30 ton laying machine, and working area for the jointing operation.

During the first jointing operation a sector is located on the after deck and used as a stationary bend restrictor and guide for the spare cable. The turntable and a cable distributor are employed to provide catenary compensation. For splicing the second joint a larger sector is located forward of the turntable and serves as the cable compensator. For this function the sector requires space to travel 20-30 meters to allow for movement of the catenary touchdown points on seabed and sheave.

The 30 ton laying machine is positioned and used only during the second jointing operation for handling the second catenary of the bight.

The location of the jointing work area for the second jointing operation must leave room on deck for bringing the second catenary of the bight aboard over the port sheave. Deck space is also required for sufficient reserve cable in a loop to provide for second catenary compensation. Deck space of approximately 34m x 8 m is required for the jointing work area.

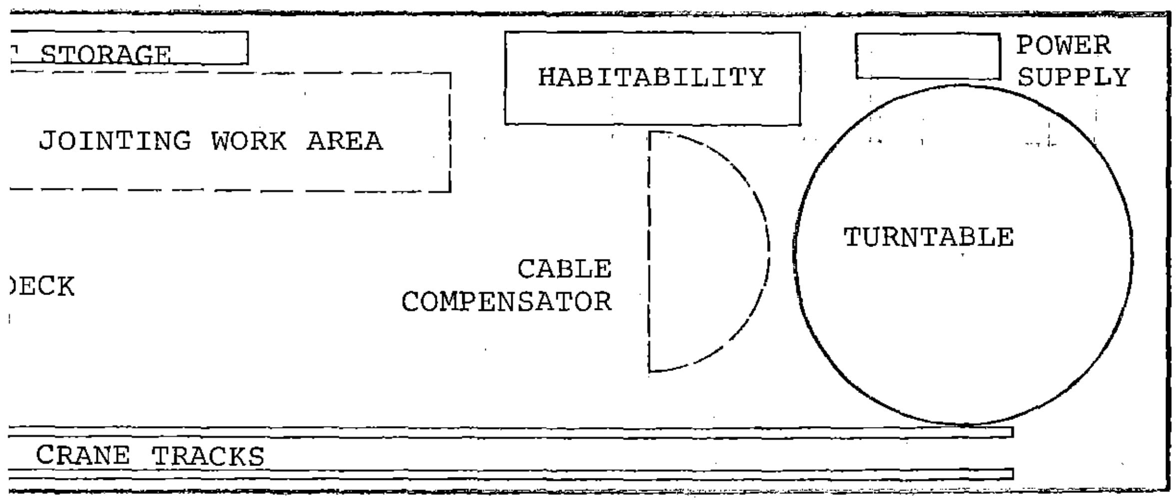
The conceptual vessel for the commercial cable program is a flat deck, ocean going cargo barge 122m (400 ft.) x 30.5m (100 ft.) x 7.63m (25 ft.). Figure 7 provides one possible deck layout of major cable handling equipment on the conceptual cable vessel to accommodate Pirelli's proposed cable arrangements for the jointing operation.

D. Remotely Operated Vehicles (ROV)

An ROV is a special requirement for the repair operation and space for one must be provided on the repair vessel along with the necessary support equipment and operating personnel. These vehicles can be configured with a wide variety of underwater instrumentation including cameras, video, and acoustic navigation equipment. Most ROVs are also outfitted with manipulators and can do limited work on the bottom.

In a cable repair operation, an ROV can be used to assist in any or all of the following applications: cable and fault location, selection of area for laying the bight, route survey, cable observation on or near the seabed, post-lay inspection.

Appendix C provides a separate discussion on the subject of ROVs and their potential for use in connection with the inter-island cable system.



SEL FOR INTERISLAND CABLE SYSTEM

HINERY/EQUIPMENT REQUIRED FOR REPAIR OPERATIONS

ACE FOR JOINTING-ON-BOARD OPERATIONS)

VIII. CONCLUSIONS

This report has presented a baseline approach for effecting repairs to a damaged section of the interisland submarine cable system which includes both the repair methodology and equipment requirements. The following conclusions drawn from the report pertain to several major areas which are critical to this approach.

A. Embedment

Cable protection from environmental and anchor damage should be provided by embedment at each of the shore take-off and landing sites out to a water depth of approximately ten fathoms (20 m).

It is expected that future bottom surveys will be successful in identifying cable paths that avoid the Lahaina anchorage area and three known, well-defined trawlable areas. Therefore the potential for cable damage from fishing gear or anchors will be non-existent or minimal along the route and embedment should not be required.

B. Repair Methodology

Approximately 73% of the proposed submarine cable route is located where a relatively straight forward and conventional repair procedure can be employed in the event of cable failure. For this portion of the route, the water depth is no greater than 600 meters and the slopes are moderate (less than 1 to 4).

Approximately 27% of the route is located in water deeper than 600 meters and/or where the slopes are greater than 1 to 4. The conventional repair procedure cannot be extended to these regions and a special procedure developed by Pirelli must be followed. With this procedure, the necessary repair joints are made in shallow water where the chances of cable damage due to fatigue effects at the sheave of the vessel during the jointing operation are eliminated. The procedure also provides for laying the bight in an optimum water location following repairs.

C. Repair Vessel

A dynamically positioned, fully-equipped cable vessel should be used for repair operations in order to provide adequate logistics support and the necessary degree of safety and steadiness during the jointing on-board operations.

The time schedule for a repair operation in Hawaii would be significantly reduced by having a cable repair vessel dedicated to the interisland system. Since this vessel would need to be capable of handling the PCC 116 cable along the deepest portions of the cable route, it should be the same vessel that was designed and equipped for the cable installation.

Machinery and equipment arrangement on the commercial system's conceptual cable laying vessel must provide sufficient deck space for handling the cable during jointing operations.

BIBLIOGRAPHY

Bazzi, G., "Advanced Technologies in HUAC and HDVC Submarine Power Cable Transmission," Fourth Conference on Electric Power Supply Industry (CEPSI), 1982.

Foxall, R.G., Bjorlow-Larsen, K., Bazzi, G., "Design, Manufacture and Installation of a 525 kV Alternating Current Submarine Cable Link from Mainland Canada to Vancouver Island," CIGRE International Conference on Large High Voltage Electric Systems, 1984.

Johnson, J.N., Holte, T.A., Larsen, P.B., "Submarine Power Cable Development in Norway," CIGRE International Conference on Large High Voltage Electric Systems, 1980.

"Rules for Building and Classing Steel Vessels," American Bureau of Shipping, 1976.

Searle, W.F., Englemann, W.C., and Van Alt, A.J., "A Different Approach to the Repair and Protection of Submarine Cable Systems," IEEE Translations on Power Apparatus and Systems, 1984.

"Ship Design and Construction," Society of Naval Architects and Marine Engineers, 1980.

Struhsaker, P. and Yoshida, H.O., "Exploratory Shrimp Trawling in the Hawaiian Islands," Marine Fisheries Review Paper 1169, National Oceanographic and Atmospheric Administration, 1975.

"Submarine Cable System Design and Installation Planning Manual," Naval Facilities Engineering Command Publication 906.

HAWAII DEEP WATER CABLE (HDWC) PROGRAM

CABLE REPAIR RATIONALE

Prepared by:

PIRELLI CABLE CORPORATION

and

SOCIETA CAVI PIRELLI

for

THE RALPH M. PARSONS COMPANY

APPENDIX A

June 26, 1986

HAWAII DEEP WATER CABLE (HDWC) PROGRAM

CABLE REPAIR RATIONALE

TABLE OF CONTENTS

1.0 INTRODUCTION

A report on at-sea surveys (1) covering the corridor from Oahu to Maui and the Alenuihaha Channel with bathymetry contour at 25 meter intervals was employed to postulate a route for the Cable Repair Rationale. Due consideration was given to the report on Preferred Route Analysis (2). This report investigated environmental conditions and constraints and discussed the preferred route selection. This route is shown in Figure 1. Employing the data from the at-sea surveys, the bottom profile along the route was plotted in Figure 2.

The methodology for the cable repair will be strongly influenced by the location of the fault with respect to the water depth and seabed profile. Since these conditions are significantly different between Oahu and Maui and from Maui to Hawaii, these two main sections are treated separately.

2.0 DETAILED ANALYSIS OF BOTTOM CONDITIONS

2.1 Oahu to Maui

The route between Oahu and Maui can be analyzed as follows:

- From the coast of Oahu at the Waimanalo Beach landing point the route follows a northeastern course for a distance of 3 kilometers where the depth is approximately 50 meters.
- The route then changes course (approximately 90^{o}) to the southeast. The bottom gently slopes to a depth of 175 meters over a distance of 10 kilometers.
- At this point the bottom falls steeply to 600 meters over a distance of 2.8 kilometers
- The bottom is then essentially flat at a depth of 600 meters, with a maximum depth of 700 meters, over a distance of 8.8 kilometers. This is the Kaiwi Channel.
- A second steep embankment rises from 600 to 200 meters over a distance of 4.6 kilometers.
- The bottom is then essentially flat with the water depth ranging from 100 to 200 meters over a distance of approximately 32.5 kilometers.
- At this point at the western end of Molokai there is the Molokai Canyon where the depth falls steeply to 700 meters.
- The route passes close to the coast of Molokai diverting around the Canyon at a depth averaging between 70 and 100 meters. Alternately, the route could proceed to shore for an additional landing point on Molokai.

- The bottom depth increases gently from Molokai to a depth of approximately 300 meters over a distance of 15 kilometers staying to the East of Molokai Canyon.

- From this point to the Maui landing point at Ahihi Bay, the bottom is again essentially flat ranging from 300 to 75 meters over a distance of 89 kilometers.

2.2 Maui to Hawaii

The route between Maui and Hawaii can be analyzed as follows:

- From the landing point at Maui at Huakini Bay the valley that forms the bottom of the Alenuihaha Channel is comprised of a steep slope down to 2000 meters and a rise against the edge of the Kohala Slope at 900 meters for a distance of approximately 24 kilometers.

- The bottom then rises gradually to a depth of 200 meters in the direction of Upolo Point over a distance of 21 kilometers.

- A flat sandy terrace then exists around the northern tip of Hawaii for a distance of 13 kilometers at an average depth of 150 meters to a point facing the landing point north of Mahukona.

- The final approach to shore for approximately 3 kilometers is along a regular slope perpendicular to the bottom contours.

FIGURE 1

PROPOSED ROUTE BETWEEN OAHU AND HAWAII

3.0 CABLE FAILURES

3.1 Mechanically Induced Failures

In submarine power cables, the main cause of mechanically induced damage and subsequent electrical failure is the impact of fishing gear, and to a lesser extent, the action of anchors dropped over the cables or dragged along the bottom which hook onto the cables. Based on available statistics, (3) these two causes are responsible for over 50% of all submarine cable failures.

The most likely locations along the postulated route for occurrence of these failures is in proximity to the landing points in water depths not exceeding 100 to 150 meters. Based on experience, some 500 to 1000 meters of cable will have to be excised in the case of such localized damage.

Another cause of mechanically induced faults is the laying of the cables over obstacles such as wrecks, bombs and shells or sharp rocks. During deployment of the cable, mechanically induced damage to the sheath and insulation can occur when the cable is excessively squeezed while passing through the cable handling equipment of the ship or when it is kinked because of formation of loops due to sudden variations in tensioning, ship speed or current waves.

On an overall basis, failures due to mechanically induced damage have been responsible for approximately 80% of all cable and joint failures.

3.2 Natural Phenomena Induced Failures

During deployment, a submarine cable may unintentionally be supported off the ground by an outcrop or may hang between two outcrops or barrier reefs. These conditions may subject the cable to low frequency alternate lateral displacements due to tidal current or to high frequency vibrations in the vertical plane due to vortex shedding phenomenon. The latter occurrence will damage the lead sheath due to mechanical fatigue during the life of the cable. Similar damage may be caused by tidal action depending on the strain imposed on the lead sheath.

Cable damage due to excessive tensions induced when a cable is caught up and drawn into a moving seabed mass can occur during submarine landslides and earthquakes. Submarine landslides, categorized as the mass movement of seabed sediment caused by uneven forces of gravity, are apt to occur where there is a rapid accumulation of loose, very low shear strength deposits. Submarine earthquakes induce seismic forces that may cause sliding of one face of a fault zone in relation to another for only a few meters or cause the slumping of blocks or sheets of seabed for a displacement of a few hundred meters. Earthquake vibrations can trigger a flow slide and turbidity currents.

Based on available information, the most likely areas for density flows are the south and east coasts of Maui. Active earthquake areas, such as the southern tip of Hawaii and north of Hawaii, were eliminated early in the program as potential routes. Most likely sites for tidal oscillations and vortex shedding are the Kohala Slope and the Haleakala Slope. Escarpments are more likely locations for turbidity currents and landslides induced by seismic phenomena.

The failure rate due to natural phenomenon is not well documented, however, it is considered to be quite low. This experience however may not necessarily apply to the Hawaiian Islands.

3.3 Electrical Faults

Intrinsic failure of the insulation is a very rare event.

Failure of joints has been experienced on some very early installations in which joints of the rigid design (extrapolation of joints for land cables) were made at sea to connect cable lengths together. The use of rigid joints has been abandoned in favor of flexible joints and the use of long lengths of continuous cable. The reliability of flexible joints has been proven by stringent qualification tests and by long service experience on many installations.

Statistically five percent of all submarine cable failures have originated in the dielectric with approximately 50% of these failures attributed to joints.

3.4 Unknown Cause

Approximately 12% of all submarine cable failures are classified as of unknown origin.

4.0 EXTERNAL CABLE PROTECTION

Since more than 50% of all submarine cable failures are attributed to impact by fishing gear and to the action of anchors, consideration should be given to external protection to the cable along the sections of the route where this damage is most likely to occur. The route areas that are most likely to be affected by external agents are generally located near the landing sites in relatively shallow water at depths up to 100 to 150 meters.

Burial of cables presents an effective, definitive protection against mechanical damage. Burial of cables in shallow water up to 20 meters in depth can be accomplished by trenching performed by dredging, blasting or jetting operated by divers. Trenches obtained by dredging, with or without blasting, have a minimum width of 1.5 to 2.0 meters.

In deeper waters down to approximately 180 meters, submersible equipment can be employed. Submersible equipment can be classified according to method of operation, e.g. pre-trenching, simultaneous laying and embedding and post embedding. Simultaneous laying and embedding has the advantage that the cable is protected immediately after laying. Embedding depths up to 2 to 3 meters are achievable. Disadvantages of this procedure are that it is applicable only in soft bottoms and the speed of laying is reduced thus increasing the time required for laying and hence increasing the danger of unfavorable weather conditions. Post embedding is an alternative to the previous method whereby in order to avoid the disadvantage of reduced speed of laying, the cables are laid and subsequently embedded.

Plowing or cutting of cable trenches before laying the cable requires precision laying of the cable and is usually limited to depths where divers can work for some time and where the water is comparatively calm. Trenches obtained by cutting can have a width of 0.5 to 1 meter.

Where the bottom conditions are such as to make burial of cables technically difficult and hence expensive, other means of mechanical protection can be employed. In a beach zone on dry land and in depths up to a few tens of meters, typical protection methods are cast iron pipe, cement blocks, concrete channels and stones. For greater depths but still near the shore, split cast iron protectors can be employed. A method of dropping gravel (60 to 100 mm in diameter) from a barge through the guidance of a tube has been applied at depths of about 70m. The use of steel ropes applied for many hundreds of meters off shore has been utilized at depths in the order of 100 meters.

In addition to the above prescribed methods, but with lesser reliability, prevention of mechanical damage can be achieved by (1) marking on navigation charts, (2) setting up of standard submarine cable signs, (3) light buoys in the water and (4) surveillance by radar stations located on the coast.

5.0 CLASSIFICATION OF CABLE REPAIR SITES

5.1 Case I - Damage at Depth $\leq$600 Meters and Moderate or No Slope (< 1 to 4)

Sections of the cable route between Oahu and Maui and between Maui and Hawaii marked by the symbol ① in Figure 2 satisfy the criteria for a Case I repair site.

Repairs that may be required in Case I sections of the route can be accomplished employing a relatively straight forward conventional repair procedure where the cable is repaired in the vicinity of the failure.

Note
The conventional repair technique has been successfully practiced to a water depth of 200 meters and it is considered that it can be readily adapted to a water depth of 600 meters by controlling the laying of the bight. It is not considered feasible to extend the conventional repair technique to a depth greater than 600 meters. This is because even though a flexible joint could be laid without problem at the maximum depth of 2000 meters, it is not considered feasible to make a joint on a ship positioned in more than 600 meters of water. The reason for this is that during the days when the ship has to be kept stationary in order to make the joint, the cable catenary from the ship to the bottom is subjected to movements impressed by waves and current motions. This fatigue effect is particularly severe on the cable at the sheave of the ship where the cable tension is greatest. It is not considered feasible to limit this effect by moving the cable at short intervals as would normally be practiced in lesser depths. Calculations have shown that by limiting the water depth to 600 meters, Cable No. 116 can withstand the resultant fatigue effect of the lead sheath without adversely affecting the cable life after repair.

5.2 Case II - Damage at Depth of >600 Meters or in Vicinity of Escarpments Where the Slope is Steep (> 1 to 4)

Sections of the cable route between Oahu and Maui and between Maui and Hawaii marked by the symbol ② in Figure 2 satisfy the criteria for a Case II repair site.

Along these routes there are at least 4 sections (2 between Oahu and Maui and 2 between Maui and Hawaii) where the slope is very steep over short lengths of a few kilometers for each escarpment. If failure occurs in these areas, it is not considered practical to repair the cable in the vicinity of the failure for the following reasons:

- Accurate fault locating at sea by frequency devices is difficult because of the sudden change in direction and angle of the cable to the surface.

- Cable locating by the sonar method along a steep slope is also difficult.

- Grappling of the cable on a slope is complicated by the presence of the slope.

- Ease of grappling is impaired by the likely irregularity of the slope.

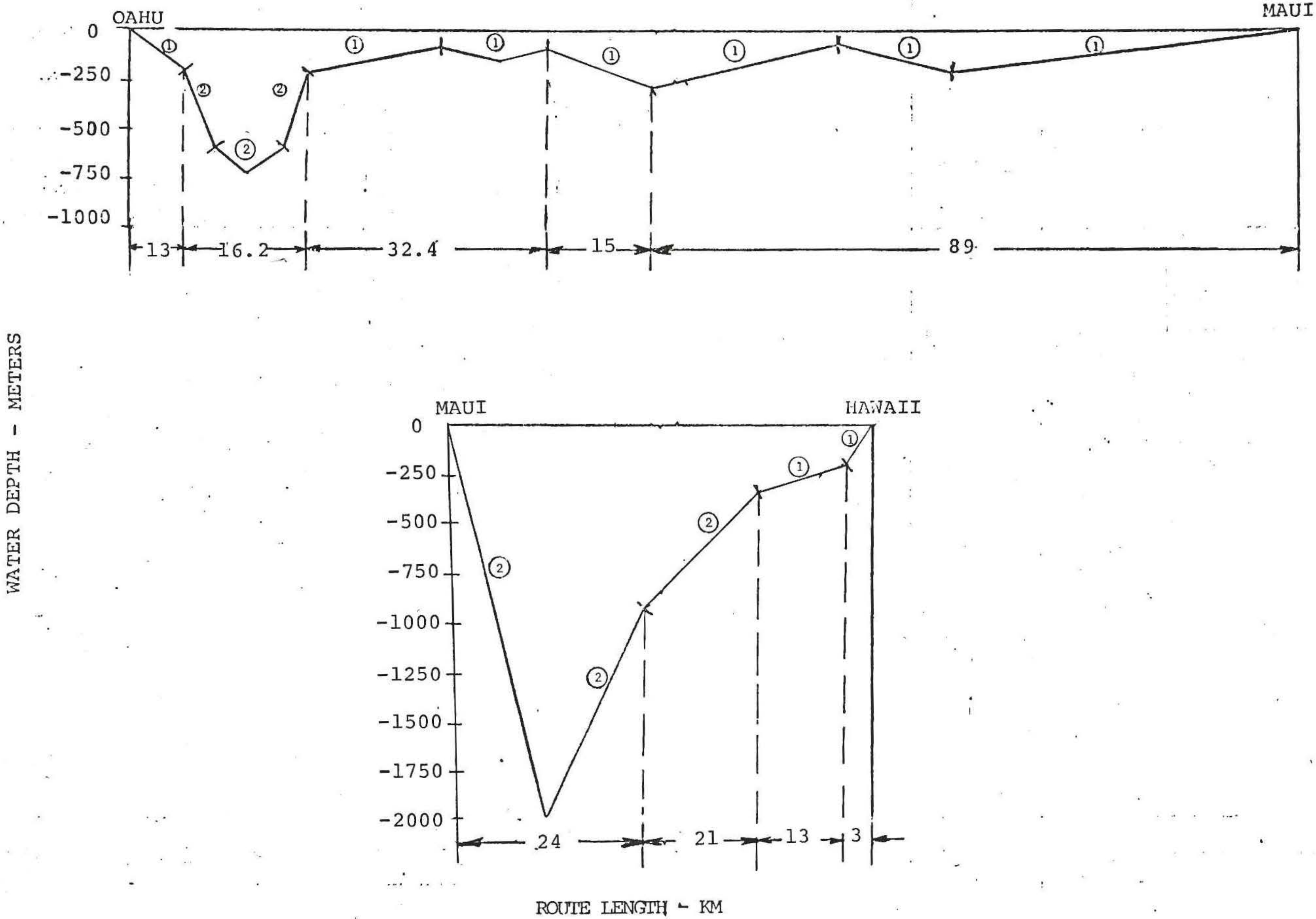
- Subsequent to grappling and cutting of the cable, the cable may be unstable on the surface of the slope.

- Since it is normally necessary to remove 250 to 500 meters of cable from the point of fault of locally damaged cable to reach dry cable, it is likely that this length will be less than the length of the slope itself. This would necessitate laying the entire repair bight on the slope creating a problem due to the unbalance of the catenaries under tension when the bight is lowered from the ship. It is likely that this would result in twisting of the bight and cause irregular laying on the bottom.

- It is not feasible to make a repair joint in water depths greater than 600 meters.

For the reasons cited, the conventional repair technique is not applicable at Case II failure sites and a somewhat more complicated and more time consuming procedure must be followed.

FIGURE 2 - BOTTOM PROFILE: OAHU TO MAUI & MAUI TO HAWAII



6.0 METHODOLOGY OF CABLE REPAIR

6.1 Case I - Damage at Depths of $\leq$ 600 Meters and Moderate or No Slope (<1 to 4)

1. Locate the fault. (See Section 10.0)

2. Position the repair vessel over the cable fault. Grapple and cut the cable on the bottom by means of an underwater cable cutter.

3. Recover each end of the cable in turn, and excise the damaged length. Normally in the case of localized damage, 250 to 500 meters must be cut from each end. Cap the ends of the sound cables in turn, attach to a surface buoy by means of a rope and re-lay on the bottom waiting for the jointing operations to be carried out either on the same vessel or on a different vessel at another time.

4. Select an unobstructed area where the bight can be laid.

5. Recover one end of cable aboard the repair vessel.

6. Test the section of cable prior to the jointing operation.

7. Connect one end of the recovered cable to a spare cable (spare cable length to be equal to twice the length of cable removed from each end plus twice the depth of the water) on board the vessel with a flexible joint.

8. Lay the joint and spare cable length through the laying machine up to the position of the other end on the bottom.

9. Recover this end of the cable on board the repair vessel.

10. Test this section of cable prior to jointing operation.

11. Connect this end of the recovered cable to the spare cable on board the vessel with a flexible joint.

12. Move the vessel towards the first joint while laying the second joint through the laying machine.

13. When at the designated unobstructed area (distance between adjacent cables must be at least equal to depth of water and both joints should be firmly on the sea bed to prevent twisting of the joints), remove the cable from the laying machines, support the bight by means of a suitable sector or bend restrictor, and carefully lay the bight.

14. Final test the repaired circuit.

6.2 Case II - Damage at Depth of >600 Meters or in Vicinity of Escarpments Where the Slope is Steep (>1 to 4)

1. Locate the fault. (See Section 10.0)

2. Position the repair vessel over the cable fault. Grapple and cut the cable on the bottom by means of an underwater cable cutter.

3. Recover each end of the cable in turn and excise the damaged length. Normally in the case of localized damage 250 to 500 meters must be cut from each end. Cap the ends of the sound cables in turn and attach to a surface buoy by means of a rope and re-lay on the bottom. The jointing and re-laying operations will be carried out by a jointing/cable laying vessel at a later time.

4. Select an unobstructed area away from the escarpment where the water depth is acceptable for laying the bight and the distance between cables is at least equal to the water depth.

5. Retrieve the cable from the point of fault to the selected bight area.

6. Cut the cable and cap the end. Lower the end of the cable on the seabed.

7. Retrieve the second cable from the fault to a point where the water depth is 600 meters. Cut the cable and cap the end. Lower the end of the cable on the seabed.

8. Take the retrieved cable lengths to the harbor.

9. Inspect and test the retrieved cable lengths to ascertain whether they can be reused.

10. Rewind the cables so that the ends first placed on the turntable of the vessel become the leading ends off the turntable.

    This operation is necessary so as to present the same direction of lay of the insulating papers to the end of the cable still at sea. This operation can be performed either in the storage area which must be properly equipped or by laying the cables at sea in shallow water and retrieving them on board from the leading end.

11. Connect the retrieved cable lengths together by means of a flexible joint assuring that the lapping lay of the insulating papers are the same.

10-12 in hours

12. Connect the retrieved cable length to a spare length of cable (spare length equal to the total length of damaged cable removed plus twice the depth of the water at the bight area) in the harbor at the storage area by means of a flexible assuring that the lapping lay of the insulating papers are the same.

13. Recover the end of the cable previously left on the bottom in 600 meters of water.

14. Test the section of cable prior to the jointing operation.

15. Make a flexible joint at sea to this end of the cable.

16. Re-lay the joint and the retrieved cable lengths plus the spare length through the laying machine up to the position of the other end of the cable.

17. Retrieve this end of the cable on board the vessel.

18. Test this section of cable prior to the jointing operation.

19. Connect this end of the cable to the re-laid cable with a flexible joint.

20. Move the vessel towards the first joint while laying the second joint through the laying machine to the previously selected unobstructed bight area. Both joints should be firmly on the seabed to prevent twisting of the joints.

21. Remove the cable from the laying machines. Support the bight means of a suitable sector or bend restrictor. Carefully lay the bight.

22. Final test the repaired circuit.

6.3 Repair of the Cable on the Bottom

In recent years, efforts have been made to develop reliable repair techniques for repairing submarine cables directly on the seabed. These techniques reduce substantially the period of intervention compared to repairs that are made out of the water. One of these techniques can be used only when the damage is limited to the armor or to the lead sheath (oil leakage) where there has been no effect on the insulation. It is therefore limited to minor damages and can be used only up to a maximum water depth of 50 meters, i.e. the operating depth of Scuba divers.

The technique of making repair joints in an underwater habitat is being investigated by several specialized companies involved in this field. The making of a joint in a habitat is being actively studied; but there are some areas which require investigation such as the water seal around an armored cable, size and type of joint and type of environmental conditions (relative humidity and temperature) in which a joint can be made.

The use of a habitat is also limited to a maximum depth to 150-200 meters, which is the operating depth of saturation divers and diving bells.

7.0 SEQUENCE OF EVENTS IN REPAIR OPERATION

The following is a chronological sequence of events to be followed when an interruption occurs:

- An interruption of service is experienced on the circuit.
- Checks are made to equipment and apparatus to confirm that fault is in the cable.
- Pumping stations are set to proper emergency conditions.
- A preliminary fault location is conducted to ascertain whether the fault location is at sea or on land.
- Organization responsible for maintenance is notified.
- Precise and accurate fault location is performed - frequency devices, sonar method, etc.
- Location of fault is plotted on as-laid charts.
- Type of repair and operation are planned after diagnosis of probable cause of fault.
- Availability of vessel, cable equipment, spare joints, cable and personnel are checked.
- Type of intervention is decided based upon:
    - Type of fault & location
    - Period of year
    - Availability of equipment
    - Availability of personnel
    - Urgency of reestablishing service
- Forces are mobilized.
- Work permits are obtained and notice to mariners and contractual and insurance matters are executed.
- At-sea repair operations are carried out.
- After repair, the circuits are hydraulically and electrically tested.
- Service is re-established.
- Work force and equipment are demobilized.
- Spares are replenished.

8.0 ESTIMATE OF TIME SCHEDULE FOR REPAIR OPERATION

8.1 Non-Dedicated Cable Laying Vessel

	Days		
. Fault location		10	
. Planning of operation		30	
. Mobilization, i.e. notice to ship, transfer to Hawaii, special rigging of vessel, preliminary at sea trial		60	
. Operation at sea			
- Repair with bight (Case I)	35		
- Repair in deep water (Case II)			50
Sub-total	135		150
. Demobilization		7	
Total	142		157

8.2 Dedicated Cable Laying Vessel

(Cable Laying Vessel in harbor in Hawaii with cable handling equipment on board and spare cable readily available)

	Days		
. Fault location		10	
. Planning of operation		30	
. Mobilization		10	
. Operation at sea			
- Repair with bight (Case I)	35		
- Repair in deep water (Case II)			50
Sub-Total	85		100
. Demobilization		7	
Total	92		107

9.0 CABLE VESSEL, EQUIPMENT AND PERSONNEL REQUIREMENTS

9.1 Cable Vessel

The use of a cable vessel for making repairs is recommended for optimum performance at sea and during the jointing-on-board operation. A properly equipped dynamically positioned vessel is preferred to facilitate mooring in very deep waters thereby providing the proper degree of safety and the steadiness required for providing the jointing operation. The vessel must have sufficient free deck space astern of the vessel to accommodate cable machinery, jointing equipment, stoppers and sufficient reserve-cable in a loop to allow for moving the catenary touch down points on the seabed and sheave during the jointing operation. See Drawings 985.2.059 and 985.2.061 for typical equipment layouts aboard a cable vessel for the repair jointing operation.

9.2 Cable Machinery

The following cable machinery is required to handle the cable during the repair operation:

- Two cable sheaves of proper diameter for handling of cable bight.

- Two laying machines: one machine must have the full tension capacity for retrieving and laying the cable at the maximum water depth (100 tons). The second must have sufficient tension capacity to handle the second catenary of the bight (30 tons)

- Rotating platform with pick up arm able to take the weight of maximum length of cable to do the repair. This length is the sum of the spare cable to be inserted plus the amount of cable that has to be retrieved from the seabed. In shallow waters (600 m), it could be in the region of 2000 meters. In deep water (greater than 600 m), it would be up to 20 kilometers for the worst cases.

- Cable compensator for the cable reserve loop with a travel of some 20-30 meters.

- Cable stoppers with dynamometric system able to travel with cable reserve loop.

9.3 Jointing Equipment

Jointing equipment for connecting in a spare length of cable comprises the following:

- Oil feeding system

- Liquid Nitrogen freezing system

- Electric power, compressed air, water cooling
- Double shell, air conditioned jointing tent
- Jointing tools, trestles, press etc.

9.4 Ancillary Services

The ancillary services required for the repair operation are as follows:

- Work boats
- Scuba divers
- ROV
- Cable floats
- Marker buoys
- Grappnels, ropes, chain, anchors etc.
- Electric test equipment and sealing ends
- Electric instruments
- On-board mobile radios

9.5 Accessory Equipment

The following additional equipment and services are required for the repair operation:

- Helideck and helicopeter service
- Patrol boats
- Crew boat
- Assistance and anchor handling tug
- Radio navigation land stations
- Oil feeding assistance on land (both ends)
- Radio mobile communication with services on land
- Accommodations and transportation facilities

9.6 Safety at Sea

Great care must be given to the establishment of safe and emergency systems at sea and on land. Depending on the type of selected ship, this aspect may represent a significant effort. It becomes complex for a ship of convenience because of the amount of extra equipment and number of people that have to be accommodated on board.

9.7 Personnel

On board

- Ship crew, navigation crew, specialist cable handling crew for work on 24 hour basis.
- Cable jointers
- Test engineer
- Divers
- ROV personnel
- Operation management
- Insurance representative
- Utility representative

On land

- Logistic management
- Radionavigation stations
- Oil feeding specialists
- Watchmen etc.

10.0 CABLE AND FAULT DETECTION SYSTEMS

Two systems are discussed which have been employed successfully for locating submarine cables and cable faults:

10.1 Innovation Magnetic Tracking System

10.1.1 Introduction

The Innovation Magnetic Tracking System is a device designed specifically for locating and continuously tracking buried pipe lines, cables and other magnetic systems. The only essential requirements for operation is that the tracked object has a magnetic field. The natural magnetism of standard line pipe and steel cable armor produces the required field. The field may also be provided by electric currents flowing in the tracked object.

10.1.2 System Components

The system consists of an array of magnetometer sensors, a data processing unit (DPU), a data distribution unit (DDU) and a tracking display unit (TDU) that gives continuous real time visual indication of the tracked object's position with respect to the sensor array.

10.1.3 Principles of Operation

The data processing unit, by interpreting the sensor array signals, calculates the most probable position of the tracked object. The processor is optimized for tracing long, cylindrical objects such as pipe or cable.

The second output (DEPTH) corresponds to the approximate vertical distance between the array reference point and the center line of the object. This output is considered valid only when the object lies within the "depth corridor" which is less than $\pm$ 22 degrees angular displacement from the reference point. For small vertical distances between object and sensors, the DEPTH output is directly proportional to the vertical distance. At greater distances, this relation is not linear. Charts and computer software are supplied to permit conversion of depth output to distance in any required unit.

10.1.4 Sonar Interface

A sonar altimeter input allows display of the submerged tracking vehicle height above the bottom on the TDU depth indicator. The input format must be an analog voltage increasing with height. This voltage is added to an offset voltage to account for height differences between the sonar transducer and the sensor to allow for cable diameter and causes the lighted bar display sensor height above the cable to be interrupted (flashed) down to the point indicating bottom position. The portion of the bar that remains lighted shows the depth of cover.

10.1.5 Cable Tracking

The magnetic field geometrics arising from intrinsically magnetic objects, i.e., line pipe or armored submarine cable, and from current carrying cables are quite different. On command, the system's processor can be configured to track either intrinsic or current produced magnetism. In the latter mode, the standard instrument only provides tracking information. The depth output is not provided.

10.2 16 HZ Method for Locating Cable Route and Point of Fault

10.2.1 Introduction

This method, developed by Pirelli in 1970, can locate cables 100 kilometers in length and in water depths up to 300 meters with an accuracy of from a few meters to 20 meters. Magnetic fields generated by proximity of other cables do not disturb the measurement due to its high selectivity. Laboratory tests are in progress to permit location of cables in deeper waters.

10.2.2 Measuring Equipment

The measuring equipment consists of the following:

- Three Phase Asyncronous Generator
  - 50 HZ
  - 7.5 kw Power Output
  - 0.8 Power Factor
  - 660 Volts at 9 Amperes; 380 volts at 15.5 Amperes
- Single Phase AC Generator
  - 5 kw Power Output
  - 0.8 Power Factor
  - 500 Volts at 10 Amperes; 250 Volts at 20 Amperes
- Single Phase Autotransformer
  - 10 hva Rating at 16 HZ
  - 250 Volts Input
  - 50, 100, 150, 200, 250 Output Voltage
  - 200, 100, 66, 50, 40 Output Current

- o Detection Set

  - Special Coil: 100,000 turns of enameled copper wire 0.1 mm in diameter wound on a wooden support.

  - Microvoltmeter at 16 HZ, measurement range of 120 microvolts to 3 volts Power Supply - two 4.5 volt batteries.

10.2.3 <u>Principles of Operation</u>

When ac current is applied in the loop formed by the cable conductor and the cable armor/sea bed, a magnetic field of the same frequency is generated. Consequently, voltages are induced in the coil of the detection set proportional to the field intensity and to the angle between the axis of the horizontally mounted coil and the direction of the field at that point. The generated voltage is a maximum when the angle is at 45 degrees. When the coil is exactly in the vertical of the cable, the angle is 90 degrees and the reading of the voltage is zero.

10.2.4 <u>Operating Procedures</u>

The vessel to house the detection set can be made by wood or steel.

In the latter case, it is necessary to put the coil overboard in order to avoid distortion in measured voltage value by the presence of metallic structure in close proximity of the coil. The search coil must be kept parallel to the sea floor as much as possible.

The cable is fed at one end by 16 Hz generator while the opposite end is short-circuited, i.e., conductor-lead-armoring in order to allow the current to flow along the lead-armoring-sea in parallel.

10.2.5 <u>Location of Cables</u>

By carrying out successive crossings perpendicularly to the cable route, it is possible to locate the cable.

The minimum value of voltage is obtained where coil axis is exactly on the cable vertical.

10.2.6 <u>Location of Faults</u>

Several type of faults can be located, such as:

a) Electric fault with low resistance to allow the return of the current through the fault itself.

b) Lack of armoring due to corrosion or mechanical abrasion.

In the presence of an electric fault having high resistance, it is necessary to burn down such fault with proper equipment.

After that, it is common practice to prelocate the fault area by means of electrical equipment in order to know how far is the fault from one cable end.

The in-site location is then started crossing the cable many times with the vessel, at first along the section between the feeding end and the fault area.

Because the current flow returns to the feeding end through the fault point running along the parallel sheet-armor-sea, the intensity of the magnetic field is high in this section and very low in the section next to the fault.

By means of several crossings in the fault area, the fault point is located where the maximum values or induced voltage decrease abruptly.

REFERENCES

1. Bathymetric Atlas and Draft Report Entitled "Hawaii Deep Water Cable Program, At-Sea Route Surveys, State Funded-Phase II-B by J. Frisbee Campbell dated August 1985.

2. Preferred Route Analysis Draft Report, Parsons Hawaii, dated April 1986.

3. Methods to Prevent Mechanical Damage to Submarine Cables, Prepared by CIGRE Study Committee 21 High Voltage Cables, Working Group 21.06.

APPENDIX B

SUBMARINE POWER CABLE EMBEDMENT

Embedment provides an effective means of protecting a submarine cable against external mechanical damage that can result from anchors, fishing gear, and environmental forces. In general, the areas along a cable route that would be most likely affected by these hazards are in the vicinity of the shore landing sites and in water less than 150 meters deep. This Appendix presents the various embedding and other protection methods, considerations related to cable disembedment and cable repair, and addresses the risk of anchor damage to the planned Hawaii deep water cable system along the preferred route.

A. Methods of Embedment

The method or technique used to bury a cable depends to a great extent on the depth of water and the nature of the ocean bottom. There are three basic categories of embedment methodology: Pre-excavated trenches, simultaneous laying and embedding, and post-embedding.

1. Pre-excavated Trenches

With this method, trenches are made in advance of cable laying and are normally backfilled after cable installation. This method is usually used for hard seabed conditions.

In waters less than approximately 20 meters deep, trenching can be accomplished by drilling, dredging or cutting. Special ploughing and dredging equipment is available which utilizes chain excavators and cutting wheels. In cases of a hard rock or coral bottom, blasting and dredging will probably be required. Trenching by cutting is most appropriate for a soft rock bottom.

The pre-excavation method was used by STK for the 500kv cable transmission system from mainland Canada to Vancouver Island which was completed in 1984. The six cables of this system were buried for protection seaward from the landing sites out to a water depth of 20 meters. Excavation and backfilling was performed by backhoes and derricks which were operated on dry land or from barges. Special blasting and excavating techniques were developed during this operation for underwater rock trenching.

For deeper water trenching, submersible equipment can be used. For example, remote submersible trenchers are available. These are operated by a control umbilical attached to a control console on the mother ship. These trenchers come equipped with both cutting jets and dredge units.

Trenches made by dredging, both with and without blasting, are limited in width to about 2 meters. Trenches obtained by cutting have narrower widths, in the range of .5 to 1 meter.

An obvious disadvantage of the pre-excavation method of embedment is that it requires precision laying of the cable.

2. Simultaneous Laying and Embedding

This method is limited to soft seabed conditions and has the advantage of providing protection to the cable immediately after it is laid. Equipment available for this method include ploughing and burial machines that operate independently or are towed directly by the cable laying vessel.

This method was used by COFLEXIP for the shore approach zones of the eight-cable France/United Kingdom power system which was partially completed in 1986. The specific method in this situation consisted of simultaneously trenching and laying 6" pipe over a distance of 700 meters through each landing zone. The cable was then pulled through the pipe. The purpose of this particular scheme was to facilitate the pulling of the cable through the shore approach area and to assure maximum cable protection from shipping.

The trenching machine used for the French and UK landing zones is self-propelled and crawler-mounted. It uses a cutting chain to excavate continuous trenches 0.5m wide and 2.5m deep. It was remote controlled by umbilical lines from the cable laying vessel. The machine crawls behind the vessel, with the cable being paid out through the stern of the vessel. The cable then crosses over the machine inside a guide spout which directs it to the trench. This particular machine is designed to operate to a depth of 150 meters.

Embedding depths up to 3 meters have been achieved with this method. A disadvantage of this method is that it increases the time required for laying.

3. Post-Embedding

Post-embedding is an alternative to simultaneous laying and embedding methods discussed above which makes for a comparatively slow cable laying operation. With this method, the cables are laid and then trenched and buried. Depending on the site conditions such as nature of sea bed, water depth, and sub-bottom materials, post-embedding can be accomplished by embedding machines which move along the laid cables or by divers operating jetting equipment.

The offshore portion of the cables of the France/United Kingdom system discussed above were laid and subsequently buried in pairs across 50 kilometers of the English Channel. The trenching machine used for this installation was controlled from a barge which operated with the cable laying vessel. The depth of water averaged approximately 40 meters.

Pirelli has recently developed a post-laying embedding machine which is track supported, controlled via umbilical cable, and uses a chain and water jets to excavate trenches up to 1.5 meters in depth. This machine has the ability to operate to depths up to 150 meters, however it is usually limited to soft seabed conditions.

B. Other Protection Methods and Considerations

There are various other ways to protect a cable when burial is impractical, too expensive or merely inappropriate for the situation, or when protection in addition to burial is desired. Measures in addition to embedment are usually necessary at cable beaching sites to provide adequate protection from environmental forces. The extent of the additional protection required will depend on the severity of the environmental conditions prevailing in the area. Under storm conditions on exposed coastlines, the normal environmental forces are greatly intensified and the breaker line advances farther offshore. The greatest environmental effect is experienced between the shoreline and the 10 fathom curve (18m). In this region the massive energy from breaking waves during a storm is directed toward the ocean bottom. The design of the cable protection system at the beaching site is based on the design parameters established for the particular installation. Typically, the 20-year storm basis is used for the structural integrity of the protection system. for a min. 30 yr cable life?

In shore approach zones out to 10-20 meters in depth, methods used include cast iron pipe and concrete channels. In the France/United Kingdom cable system installation discussed earlier, the cables were pulled through pipe in addition to burial for added protection at landing sites. In the Mainland Canada/Vancouver Island cable system installation also discussed earlier, cables above the low tide mark at landing sites were protected by rectangular reinforced concrete ducts backfilled with sand or sand/cement thermal material.

For protection a little farther out from shore, split cast iron protectors can be used. Pirelli reports dropping gravel from a barge through a guidance tube to cover a cable laid in water depths up to 70 meters.

Other ways to protect the cable include covering it with sandbags, concrete bags/blocks, rip-rap, and so forth. For the Sardinia-Corsica-Tuscany 200 kv power cable system where there is significant trawler activity, the cables are protected by two suitably suspended chains laid parallel to and on either side of the cables.

C. Cable Embedment Considerations

Determining the amount of protection necessary to guard against external hazards requires a risk assessment based on field site data and careful analysis. It requires that a careful balance be obtained between the technical-economical advantages and disadvantages of increasing protected route lengths on one hand, and being able to conduct repair operations on the other hand. The impact of embedment on cable installation costs and schedule must also be factored in to this analysis.

1. Cable Route Environment

The method and extent of cable protection required is almost completely dependent on the environmental conditions along the selected route, like the water depth, nature of the seabed, sub-bottom materials, thickness of various layers of the seabed, marine activities, existing underwater installations, wrecks, and so forth. Each individual cable laying project is different and constitutes a unique problem in itself when it comes to assessing the variables involved. Only with an accurate knowledge of the particular route environment obtained through route surveys and analyses, coupled with knowledge of the specifications of the cable to be laid and the laying equipment available for use, can a decision be reached which will ensure the best overall compromise between the many factors involved.

2. Cable Repair Problems

Another major technical-economic consideration is that a cable system should not be overly protected by embedment to the detriment of fault finding and cable repair or replacement. Repair time and cost depends on such factors as weather conditions, standby equipment, and the availability of a repair vessel, and can be significantly affected by the difficulty in pinpointing fault location.

In order to locate a fault in a buried section of cable, the cable has to be uncovered so that an effective inspection can be made. Once the fault is located, additional uncovering will probably be required to replace the damaged cable section. Therefore, from the standpoint of repair operations alone, submarine cables should not be embedded. When embedment is necessary, the depth of burial should be only enough to give protection against the most likely source of external damage as both the equipment and effort required to uncover, raise, and replace a damaged section of cable have a marked impact on the time and cost of the repair operation.

D. Anchor Protection for the Hawaii Interisland Cable

It can be concluded from the above discussions that the Hawaii submarine cables should be protected from anchor damage only along those portions of the route where the damage risk is high. This section discusses marine traffic in Hawaii, the types of anchors in use, and considerations relative to the risk of cable damage from anchors along the cable route.

1. Types of Vessels

Marine vessel traffic in Hawaiian waters consists primarily of Navy ships, cargo vessels, commercial fishing vessels and pleasure craft of various types. Commercial passenger ships, Coast Guard, ~~Army~~ Navy, research, and charter fishing vessels are also present but in lesser numbers.

Figure B-1 provides the types of vessels which are most likely to be found operating in the vicinity of the cable route.

2. Anchor Characteristics

Most Navy ships and larger commercial vessels carry one or two stockless type anchors, made of cast or forged steel. The smaller coastal vessels normally carry kedge anchors which are stock type anchors. Both stock and stockless anchors are characterized by flukes which dig into the sea-bottom. The characteristics of the anchors may differ in fluke shape, angle between flukes and shank, and fluke tripping arrangement. Stock anchors have a transverse bar, or

TYPES OF MARINE VESSELS
MOST LIKELY OPERATING IN
VICINITY OF CABLE ROUTE

Category	Types
US Navy	Guided Missile Destroyers, Frigates, Submarines
US Coast Guard	High Endurance Cutters, Patrol craft
NOAA	Fisheries Research Vessel, Open Ocean Research Vessel
Commercial Cargo	Container vessels, Container barges and tugs
Commercial Passenger	Cruise ships
Commercial Fishing	Trawlers, Longline vessels, Pole and Line vessels
Pleasure	Sailboats, power boats, yachts

Figure B-1

stock, which orients the flukes so that one of them digs in when the anchor is dragged along the bottom. The holding power of a stock anchor far exceeds that of a stockless anchor. Both anchor types, however, obviously present a significant hazard to submarine cables.

Most submarines carry what is called a mushroom anchor, so named for its shape. This anchor has less holding power than other standard anchor types and is probably less likely to damage a power cable than one which has flukes, however it still presents a serious hazard.

3. Anchorage Depths

The maximum depth of water in which a ship is capable of anchoring depends primarily on anchor size and type, length and strength of anchor chain, seabottom condition, and wind and current loads expected. When a ship is at anchor the anchor chain hangs in a catenary between the hawsepipe and the bottom, and the scope of chain should be selected so that the lower end of the catenary will be horizontal when the tension at the anchor shackle is equal to the maximum holding power of the anchor. In a heavy blow normally more anchor chain is required than under calm weather conditions. In practice, anchor chain scope for a particular ship is selected to fit the anchoring situation; this selection is based on one or all of the following: specially calculated anchor chain scope tables, practiced rules of thumb, experience of the captain or pilot.

Considering the types of Navy and commercial ships operating in Hawaiian waters together with the length of anchor chain these ships carry, 20 fathoms (37m) is about the maximum depth water any of them would anchor under normal conditions.

4. Risk of Anchor Damage to Hawaii Interisland Cable

The following are considerations relative to protecting the cable from anchor damage:

There are varying degrees of marine activity in the vicinity of the shore take-off and landing areas. The United States Coastal Pilot publication by the National Oceanic and Atmospheric Administration states that suitable anchorages can be found within .5 km of Makaohule Point in Mahukona Harbor, Hawaii and also in Ahihi Bay, Maui, the two shore take-off sites for the interisland cable. The shore landing site for the cable on Oahu is in the vicinity of Waimanalo Beach Park and the Coastal Pilot presents Waimanalo Bay as an all-weather shelter for small craft due to the barrier reefs that parallel most of the bay's shore. Although the cable landing site on Maui, Huakini Bay, is not a good anchorage area, there is fishing and other marine activity in the area. To assure cable protection from both erosion and small craft shipping, the cable should be embedded at each of these locations out to a water depth of approximately 12 fathoms (22m) at low tide.

Navy ships routinely anchor off Lahaina, Maui for

why less than the 20 fathoms mentioned above?

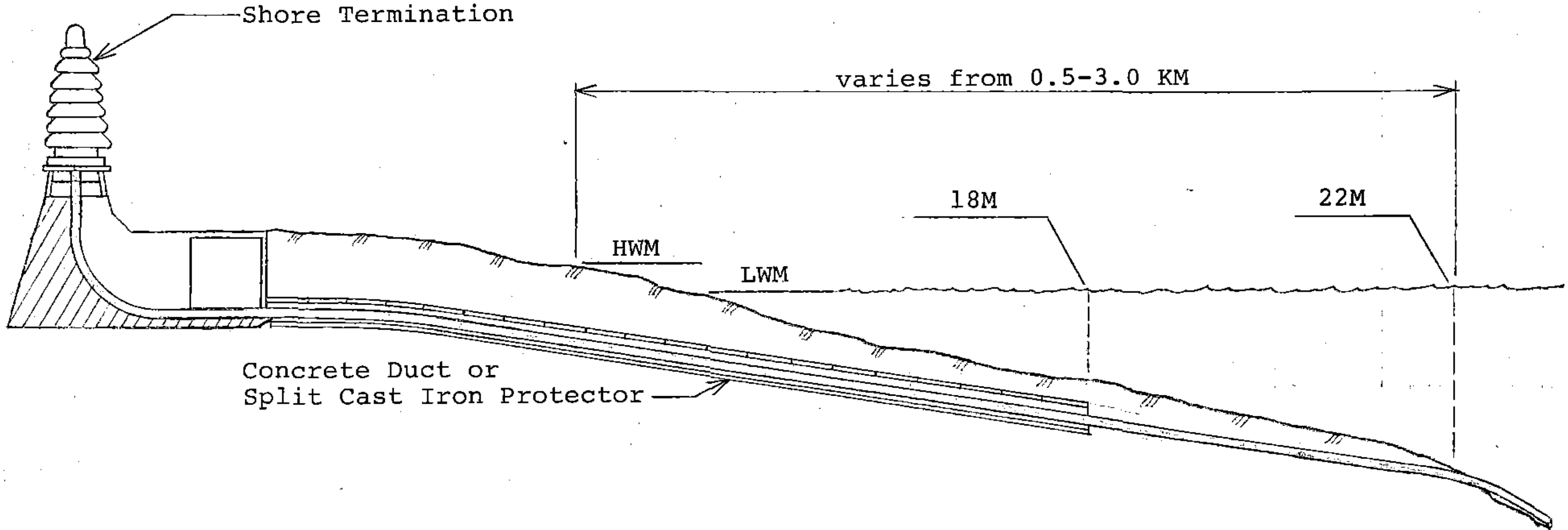
weekend port visits. Cable protection should therefore be provided there if the cable were to be laid inside the 20 fathom curve (37m) which lies within approximately 3km of the Lahaina coastline. However, to avoid the need for protection a cable path should be selected which lies outside this danger area. — Is this feasible?

Fishing vessels occasionally anchor when bottom fishing. This activity is primarily limited to shallow water areas less than 15 fathoms (27m) along the Penguin Banks and in the Auau Channel. Cable protection should be provided if the cable were to be laid at depths less than 15 fathoms (27m) in these areas of the route. However, these areas should also be avoidable through cable path selection.

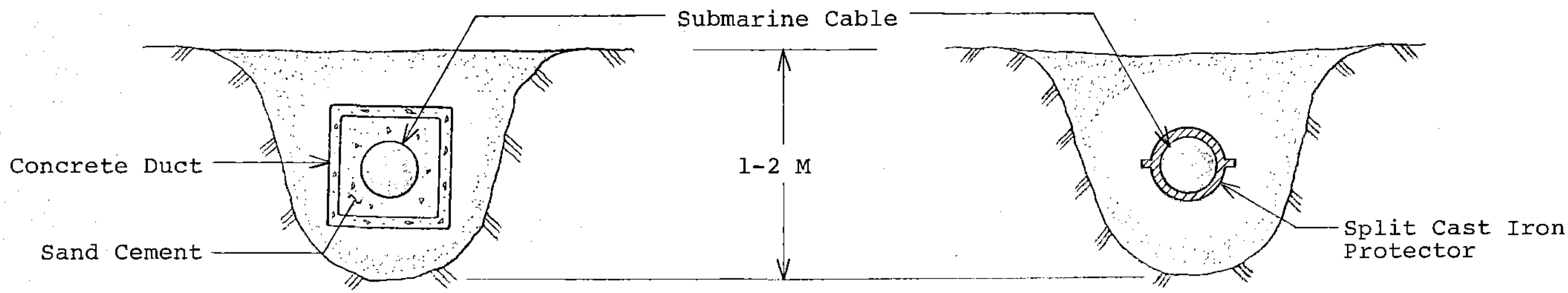
E. Additional Cable Protection at Shore Take-Off and Landing Sites

It will be necessary to provide measures in addition to embedment at the four shore take-off and landing sites to provide adequate protection from environmental forces due to wave motions. This added protection should be provided from the shoreline out to approximately the 10 fathom curve (18m) at each site. This distance may vary somewhat between sites when their actual locations are determined and environmental effects for the specific areas are analyzed.

Due to the prevalent rocky areas along the coastlines at the planned shore sites, effective methods of protection would include surrounding the cable with split cast iron protectors or a concrete duct. Figure B-2 depicts these two protection methods and an installation for the takeoff and landing sites of the interisland cable system.



HAWAII CABLE SHORE LANDING PROFILE



PROTECTION METHODS FOR EMBEDDED CABLES

Figure B-2

HAWAII DEEP WATER CABLE PROGRAM

USE OF SUBMERSIBLES AND REMOTE OPERATED VEHICLES TO ASSIST IN REPAIR OF THE HDWC CABLE

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Appendix C

December 12, 1986

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APPENDICES

HDWC PROGRAM-POTENTIAL USE OF REMOTELY OPERATED VEHICLES AND MANNED SUBMERSIBLES FOR CABLE REPAIRS

1.0 Introduction

An investigation has been made of the aspects of using Remotely Operated Vehicles (ROV) and/or manned submersibles (hereinafter called "Subs") to assist in the repair of HDWC submarine electrical transmission cables contemplated for installation primarily between the islands of Hawaii, Maui and Oahu.

This investigation has consisted primarily of the following tasks:

- Perform a literature survey identifying the role that ROVs and subs have played in the past relative to cable repair.
- Perform a literature survey and operator survey to define the availability, applicability and costs of ROVs and subs.
- Define the potential role of an ROV or sub, and the repair scenario for the inter-island cable system.
- Identify the required support and dedicated equipment.

A literature survey was performed using a computer search of four major databases, including NTIS, Oceanic Abstracts, Compendex and Aquatic Resources, as well as several other smaller databases. Several search passes, combining various relevant key-words and variations, produced a total of approximately two hundred document titles of recent publication. From amongst these, approximately sixty were noted to be of relevance and the associated abstracts were brought online for review. Approximately twelve of these were of sufficient interest to acquire the full-text articles. In addition, correspondences and telephone conversations with companies and persons engaged in submarine cable, repair operation and the development of equipment for such operations were used. A bibliography is included with this report.

2.0 Submarine Cable Repair Applications

Documented information on the use of ROVs and subs in submarine cable repair operations is difficult to find based on the computer search of database files performed for this study. The reason probably is that publicity of such operations has been limited and repairs are few.

The great majority of submarine cable repairs that have been made have been on telecommunication cables. Despite the differences in design of a telecommunication cable and a power transmission cable, the applicable cable repair tasks of ROVs and subs are practically the same. In very general terms, the submarine cable repair operation consists of the following operations:

a)* Locate the cable.

b)* Locate the fault of the cable. This task may be postponed until part of the cable has been brought onboard the cable repair ship.

c)* For buried cable: uncover it.

d)* Cut the cable. and cap it's ends (SCOF)

e)* Attach lifting lines to cable ends.

f) Lift cable ends to surface and secure onboard repair vessel.

g) Locate and assess fault.

h) Cut out portions of the cable on either side of the fault. Under certain conditions and/or circumstances the cable ends may be capped, buoys attached and then lowered back to the bottom for later splicing.

i) Splice in a new section of cable.

j) Tests of the repaired cable.

k) Attach lowering lines to the cable.

l) Lower cable to the bottom.

m)* Inspect as-laid cable. Make corrections as necessary.

n) Tests of the cable.

o)* Retrieve lowering lines.

p)* Bury cable when/where required.

ROVs and subs are suited for or can be equipped for performing many of the above tasks. The applicable tasks for ROV's and Subs are marked with an * in the above list. This investigation has been restricted to studying performance records of ROVs and subs in accomplishing these tasks, and to the potential deployment of such vehicles for performing similar tasks in Hawaiian waters. Each applicable task is discussed in the following:

2.1 Locate the Cable

Locating a buried cable has in most cases been accomplished by grapnels which, dragged on the bottom on a course perpendicular to the cable run, catches the cable. However it is emphasized by several operators contacted by MOE that the grapnel technique is not always successful particularly where the cable is buried and frequently requires several runs before the cable is hooked (4). In addition there is a potential risk of the grapnel damaging the cable.

The use of an ROV or a submersible to locate the cable would reduce or eliminate these problems and these vehicles have been used in the past to accomplish the location and inspection of cables. A number of submarine cable detectors have been developed, some of which are suitable for an underwater vehicle. An example is the Model 101 developed by Margus Offshore Co., Bridgewater, NJ which is configured for hand held operation by a diver or for installation in an ROV, a sub or a surface vessel (2). The Scarab ROV and the CIRRUS, among others, are outfitted with cable detectors. On the SCARAB, four magnetometers respond to the magnetic field generated by a 25-Hz current sent through the cable from a shore terminal. It should also be noted that the subs PISCES III and AQUARIUS equipped with an electromagnetic probe and magnetometer respectively have been used for locating buried cables. However the operator comments that "both submersible types suffer from limited battery power and have limited bottom time" (21).

2.2 Locate the Fault

Localizing the fault while the cable is still submerged has been done by the use of magnetometers mounted on ROVS or subs. The SCARAB with its permanently installed four magnetometers is used to locate faults in telecommunications cable which are electrically cycled at 25 Hz. Pirelli uses an electromagnetic gradient method with a sensor on the surface and 16 Hz applied to the cable to locate cables and cable faults (1). An ROV equipped with similar sensors can perform the same work but in deeper water.

2.3 Uncover or Bury the Cable

Vehicles and equipment for burying and uncovering submarine cables have been developed for over 50 years. Two prime methods have been used: moving bottom sediments by either towed, bottom-reliant ROVs or by high capacity water jets mounted on tethered free swimming ROVs or subs. The plow type vehicles are large and heavy (25 tons or more dry weight) and most of these vehicles require special support vessels. In addition to plowing, they may move bottom sediment by water jets or suction pumps (16, 18). The speed of operation varies from about 5 m/min to 60 m/min depending on type of vehicle, depth and soil conditions (16). PISCES type subs have been deployed for cable burying using water jets. According to one source of information (4), burial of one mile of the transatlantic cable TAT 6 in 30 fathoms of water using a sub required 14 days and cost about $250,000. The same source of information states that if the SCARAB had been available at the time of this operation, the job would have been completed in a few days at a cost of about $50,000. The SCARAB evidently buried one mile of cable in 12 hours shortly after the vehicle was commissioned in 1980 which equals the operating speed of about 2.2 m/min.

2.4 Cut the Cable — additional details on the capping operation

In recent years special grapnels have been developed which not only catch the cable but also cut it. One of these grapnel types for communication cable uses hydraulic power to operate guillotine blades. This type of cutting grapnel was used successfully at the depth of 223 meters when repairing the 37 mm diameter armored cable between Spain and the United Kingdom.

A cutting tool mounted on an ROV or sub would not subject the cable to towing tensions and hence this cutting method should be advantageous in some cases. Several ROV's currently have circular blade cable cutters, the SCARAB being the most notable, but these have been developed for the smaller communications cables. Since ROV's have been used in the past to cut pipelines in the oil industry, techniques can be developed for an ROV cut of the HDWC cable.

2.5 Attach Lift Lines

After cutting the cable, the two ends must be brought onboard the repair ship for performing the repair. Hence, lift lines have to be attached to the cable ends. An ROV or sub with two manipulators would be well suited for the task and the SCARAB ROV with its two manipulators would be a prime candidate.

2.6 Inspection of the cable

After splicing the cable and lowering it to the seafloor, observation/inspection of the cable is made and its position is adjusted/corrected as may be necessary. Any type of ROV or sub with good video equipment would be well suited for this task. The ROV operator or the submarine pilot would give directions to topside personnel on how to correct the position of the cable.

Do we need to address lifting and lowering from the standpoint of lead sheath limitations for point loading? i.e. how will we lift and lower in a way that does not damage the lead sheath?

2.7 Release Lowering Lines

The next step to be performed underwater is releasing or cutting the lowering lines so they can be retrieved to the repair ship. The simplest way to do this is to have an ROV or a sub cut the lines as close to the cable as possible. Special release hooks have been designed for operation at depths of 5000 fathoms with a working load of 100 kN. A prototype was tested successfully in a real operation in the Atlantic at 2800 fathoms (12).

3.0 Remotely Operated Vehicles and Manned Submersibles

3.1 General overview.

The Offshore Oil Industry's need for underwater services in deeper and deeper water depths created an explosive expansion of the world's fleet of ROVs in the nine years of 1975-1983. The number of tethered, free swimming vehicles, the most versatile ROV type in offshore oil field work, increased from about 25 in 1975 to about 430 in 1983 (18).

The quality, capability and the versatility of ROVs have shown a significant improvement from 1975 to present. From being merely a mobile underwater TV camera in 1975 designed for observation tasks, present vehicles are sophisticated underwater work machines capable of performing a large variety of underwater tasks, varying from observation/inspection to rather complicated manipulation tasks using elaborate manipulation arms. The development trend has been to specialize the design to enhance the performance of certain tasks. As a result, the present range of tethered and free swimming ROVs encompasses various types of vehicle designs from small machines of about 50 kg dry weight which use video and camera systems for observations and documentation tasks, to large vehicles of about 500-3000 kg dry weight, capable of performing such tasks as: observation, surveys, NDT inspection, dive support, search/identification/location, object retrieval, debris clearance assistance, underwater construction assistance, drilling assistance, etc. Depth capabilities of current ROVs range from 300 meters to about 3000 meters.

The current development trend aims at a basic vehicle design and a variety of interchangeable work modules (tools, instruments) which can be accommodated by the basic vehicle. The type of job at hand then determines the type and the number of work modules to use. Improvements to expect in the future include: the power supply, the communication/control systems and the manipulators. The industry's ultimate goal is an untethered vehicle (18, 19).

ROVs have in the past ten years replaced subs and divers in performing a number of underwater tasks. The major reasons are (19):

- Practically unlimited operational endurance.

- No need to expose man to the underwater environment.
- Wide range of operating environments.
- Relatively low operating costs.
- Simple, small operating platform. In most cases a vessel of opportunity is sufficient.
- Technical expertise topside can analyze real time video and other data.
- Flexibility and air transportability

As a result the use of subs has declined to encompass only jobs where the man's presence at the underwater work site could be advantageous. Most subs that are operational now belong either to Navy organizations or to universities or other marine research oriented organizations. The subs are used primarily for military oriented tasks, search and recovery tasks (examples: the Air India accident, the Shuttle CHALLENGER accident) oceanic biological/geological research projects and for the survey of certain shipwrecks (e.g., the "Titanic").

Four ROVs have been developed for the particular purpose to assist in the repair and maintenance of submarine cables, SCARAB I, SCARAB II, GEMINI and CIRRUS. The first two vehicles named the SCARAB I and II, were conceived by an international consortium of telecommunications companies; Transpacific Communications, Inc. (a subsidiary of AT&T Long Lines), Teleglobe Canada, Cable & Wireless, Ltd., (a British company), British Telecom International (formerly the British Post Office) and the French Postes et Telecommunications. These two identical vehicles were built by Ametek Straza, El Cajon, Ca. Final fitting and operational readying was completed by Bell Laboratories and others in 1980 (4). The reasons for the development of the two SCARAB vehicles are best defined by this excerpt from the paper listed as number (4) in the bibliography.

> "In the past, buried cable was retrieved with grapnels (specially designed hooks), or by divers or submarines. These methods are not always satisfactory. The grapnel technique is tricky because it requires multiple passes and there's no guarantee that the grapnel hooks will find the cable buried in the sand. Divers are limited by time and depth restraints. A submarine with crew cannot stay down for more than 8 hours and usually requires a two-ship support operation (cable ship and mother ship), and is not always available when needed."

3.2 <u>The SCARAB Vehicle</u>.

The SCARAB vehicle is briefly described as a representative of the state-of-the-art ROV technology as it is applied to submarine cable repair. It should be noted however that some other ROVs are suited to perform submarine repair tasks if special tools, instruments, etc. can be accommodated by the vehicle.

Technical data of the SCARAB vehicle is provided in appendix A. (16). Its maximum operating depth is 1829 meters (6,000 feet), it is 3.35 meters long, 1.83 meters wide, 1.52 meters high and weighs 2268 kg. The SCARAB system is completely self supporting, requiring only enough deck space on a support vessel for the vehicle, the launcher subsystem, the power generator/distribution subsystem, the control/display subsystem, a work shop with spare parts, the bridge display equipment and the vehicle locator pad. All these subsystems and equipment are stored and shipped in nine air transportable containers. The total shipping weight is 42,638 kg. A schematic of the SCARAB system is shown in fig. 1 (3). The power generation/distribution and the control/display subsystem containers are structural igloos to be installed on the support vessel. The other subsystems and equipment are removed from the containers before installation in the support vessel.

The electrical cable of the system is about 3000 meters long. Location of the vehicle relative to the support ship is determined by the vehicle locator pad, receiving signals from either an acoustic pulse transmitter onboard the SCARAB or a pinger dropped by the SCARAB on command. The vehicle locator pad is suspended underneath the ship and the signals are processed by a mini computer in the control console and the data displayed on consoles in the control hut and on the ship's bridge.

A submarine cable, buried or uncovered, and a damage of the cable can be located by the use of four magnetometers onboard the SCARAB. The magnetometers respond to a 25 Hz current in the cable by sending signals to the mini computer in the control console. The computer then processes the information which is then presented as a continuous graphic display of the cable location relative to the vehicle. A sudden change in the magnetic field will be reflected on the display consoles and hence indicate the location of the damage.

The propulsion system of the vehicle enables operation of the vehicle up to three knots surface currents and half a knot current at 6000 feet depth. For operation in the Alenuihaha channel, this would pose a restriction and limit operations to certain times where the currents were sufficiently low. Bottom currents in the channel can be up to 1 kt.

A Continuous Transmission Frequency Modulated (CTFM) sonar onboard the SCARAB detects underwater objects like rocks, debris, etc, and acoustic beacons. Pan and tilt mounted TV cameras and lights provide for visual observation of the area in front of the vehicle and a fixed 35 mm camera can take up to 150 still pictures.

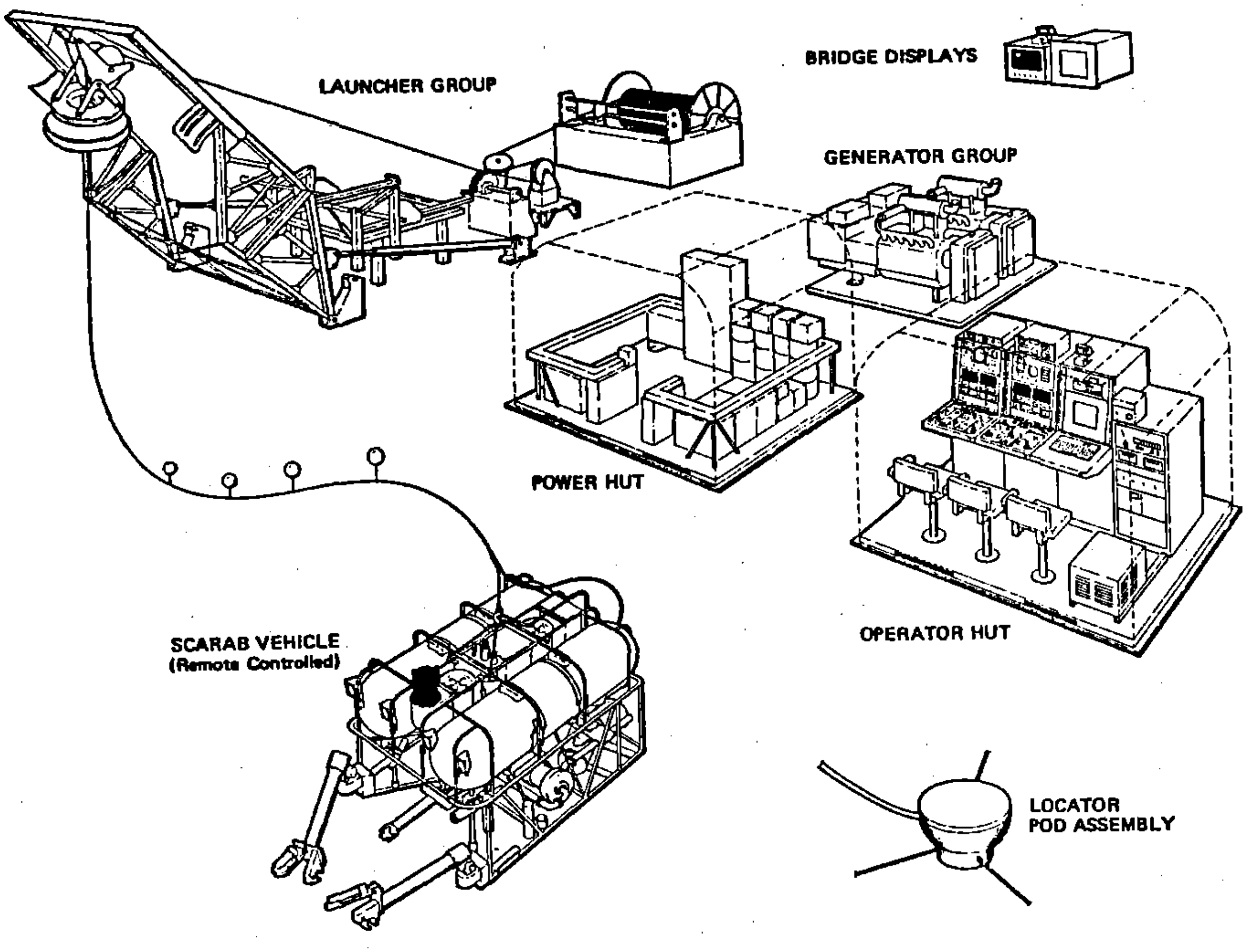


FIGURE 1.

The SCARAB Vehicle Schematic
(Ref 3)

The tools of the SCARAB include:

- o A jetter which is a four nozzle tool to eject powerful streams of water in the sea bed. It is used to uncover and/or bury cables. It has a capacity of digging a three feet deep by two feet wide by six feet long trench in 5-10 minutes.
- o A circular blade or wheel for cutting cables.
- o The manipulators which attach gripper hooks for lifting lines to cable ends and then release their hold on the gripper hooks.
- o Line cutters to cut lowering lines.

The two manipulators are of the rate-type, i.e., the manipulator or a segment of it moves at a constant speed as long as the switch or the manipulator or the segment is "on". Each manipulator has five degrees of freedom and can lift more than 90 kg while extended five feet. More elaborate manipulators have seven degrees of freedom and are spatially correspondent manipulators, i.e., movements of the "slave" arm on the vehicle follows the movements of a "master" arm in the control room. Some of these manipulators have force feedback capability so the operator gets an indication of the force required to perform the task at hand.

Three people are required to operate the SCARAB system; one person operates the propulsion controls, another the video systems and the manipulators and the third person handles the mini computers.

3.3 ROVs and Manned Submersibles for Cable Repair in Hawaii

If the service of the HDWC cable is interrupted due to a faulty cable, then actions will be taken to restore service as soon as possible no matter the water depth. The actions could be either laying a new cable or repairing the damaged one. The decision on which action to take will depend on trade-off analysis of several factors including: cost, time to restore service, availability of facilities and equipment and urgency of restoring service.

This section presents a number of ROV and sub systems capable to assist cable repair operations in Hawaii. The information provided is derived from "Undersea Vehicles Directory, 1975" by Busby Associates, Inc., Arlington, VA (16). Technical details of the ROVs and subs are provided in appendices A and B. It should be recognized that each ROV, with the exception of the four specially designed cable repair vehicles, and each sub must be fitted with tools and instruments to perform the tasks they will be required to perform.

a) <u>ROVs and subs for 1829 meters (6000 ft) or more</u>

SCARAB I & II

The vehicle is especially designed and built to assist in submarine cable repairs. One vehicle is operated by Ocean Search, Inc., Lanham, MD for Eastport International, Inc., East Marlboro, NJ and the other vehicle by Cable & Wireless Systems Ltd., London, England. These vehicles are discussed in detail in section 3.2. Both are now committed for cable repair stand-by to their consortium owners and would be unlikely candidates for a repare "today". This consortium approach to assure the presence of a cable repair capability may be the most desirable approach for the final Hawaiian commercial cable.

CURV II C & CURV III

Both vehicles are U.S. Navy owned. They are operated by Naval Ocean Systems Center, San Diego, CA., (CURV II C) and Naval Sea Systems Command (SEA-OOC) Washington D.C. (CURV III). CURV III is a 10,000 ft vehicle (3048 meters).

HYDRA

Several HYDRA vehicles have been built by International Submarine Engineering Ltd., Port Moody, B.C. Canada for Oceaneering International, Houston Texas. The DUAL HYDRA 2500 is a 2500 meter depth vehicle designed for a broad range of underwater tasks.

Other ROVs

There is also a British vehicle, the DRAGONFLY and a Japanese vehicle, the DOLPHIN 3K that are capable of operating at depths of 1829 meters or more. However, it is questionable that these vehicles could be made available for repairs in Hawaii.

PISCES V

The PISCES V, a manned submersible, is owned by the Research Corporation of the University of Hawaii (RCUH) and operated by the Hawaii Undersea Research Laboratory (HURL). She is a 6000 ft sub. Home based in Hawaii, the Pisces V is conveniently located to assist in cable repairs in Hawaiian waters.

TURTLE & SEA CLIFF

Both subs are owned by the U.S. Navy and operated by Submarine Development Group One, San Diego, CA. The TURTLE is a 3048 meter sub and the SEA CLIFF a 6000 meter sub.

b) <u>ROVS and Subs for water depths less than 1829 meters (6000 ft)</u>

The ROVs listed below have been selected because they have the payload and power essential for operation of tools and instruments required for performing all underwater tasks of submarine cable repairs.

TONGS 1 & 2

Naval System: Warfare Center, Ft. Lauderdale, FL., is the builder and operator of these vehicles. They are used to recover cables on the seafloor. For that reason a variety of mechanical devices are available for attachment to retrieval cables. Maximum operating depth: 600 meters.

SCORPIO

Several SCORPIO vehicles have been designed and built by Ametek Straza, El Cajon, CA. SCORPIO vehicles have performed well in a variety of offshore oil field tasks. They are operated by various ROV operators for example: Taylor Diving & Salvage Co., Inc., Bell Chasse, La.; Subsea International, New Orleans, La.; Oceaneering, Houston Tx. Maximum operating depth: 914 meters.

CIRRUS

This is a British vehicle recently built. Cable & Wireless Systems Ltd., London England is the operator of the vehicle which was under construction as of March 1985. The vehicle, the first of several, is designed for submarine cable work. It's permanent tools and instrumentations include a cable cutter, a burial tool, a jetting head, a water pump and a cable detection system. In addition it has two manipulators, one a sophisticated 7-function master/slave type with position feedback. Maximum operating depth: 1000 meters.

GEMINI

The GEMINI represents the new generation of vehicles comprised of a basic vehicle and work module. It is used primarily for submarine cable repair work and is operated by Eastport International, Inc., East Marlboro, N.J. Maximum operating depth: 1524 meters (3048 meters optional).

TRITON

This is another basic vehicle/work module design. It has recently been commissioned, was built by Perry Offshore, Inc., Riviera Beach, Fl. and is operated by Sonat Subsea Services, Houston, Tx. The TRITON has a remarkably good standard payload capacity: 227 kg and its umbilical has a built in "space" capacity of 50 HP for work modules that may be used for certain jobs. Maximum operating depth: 1524 meters.

CHALLENGER

The vehicle was launched in 1985 and is operated by Sonat SubseaServices, Houston, Tx. Its maximum operating depth is 1525 meters. Standard instrumentation onboard the vehicle includes locating equipment.

DEEP DRONE

The vehicle is owned by Naval Sea Systems Command, Supervisor of Salvage, Washington D.C. and operated by Eastport International, Inc., Ocean Search Division, Lanham, Md. It is kept on standby for emergency calls. Maximum operating depth: 1645 meters.

JOHNSON-SEA-LINK I & II

This is a manned submersible with a maximum operating depth of 805 meters. It has a payload of 544 kg with a pilot and one observer. The sub is owned and operated by Harbor Branch Foundation, Inc., Ft. Pierce, Fl.

c) ROVs and Subs for water depths less than 600 meters (2000 ft)

There are a very large number of active ROVs in the depth range of 600 meters and less. Most of the vehicles are small and designed primarily for performing observation type tasks. Some of the larger vehicles are listed below which could be fitted with tools and instruments needed for cable repair jobs.

HYDRA

This HYDRA vehicle is of similar design as the HYDRA mentioned in paragraph b) above. The maximum operating depth for this vehicle is 500 meters. Oceaneering International, Houston Tx. is the operator of several HYDRA vehicles.

RCV-150

Several RCV-150 vehicles have been built by Hydro Products, San Diego, Ca. They have performed well in various tasks in offshore oil fields. There are several operators of this type vehicle for example: Sonat Subsea Services, Houston, Tx; Taylor Diving & Salvage Co., Inc., Belle Chasse, La.

RECON N S

The RECON N S is designed and built by Perry Offshore, Inc., Riviera Beach, Fl. It is a 457 meter vehicle with a payload of 114 kg. Onboard equipment includes a cable cutter. Operator: Sonat Subsea Systems, Houston, Tx.

CONSTRUCTOR

The CONSTRUCTOR is a manned submersible with a power/life support umbilical. Operating depth is 488 meters and the payload capacity 1042 kg. Owner/operator is Can-Dive Services, Ltd., North Vancouver, B.C., Canada.

MAKALII

The MAKALII is probably the oldest sub in operation today. She was designed and built by Electric Boat Division, General Dynamics Corp., Groton, Ct. in 1965. Maximum operating depth is 366 meters and the payload capacity 113 kg. The sub is owned by the Research Corporation of the University of Hawaii (RCUH) and operated by the Hawaii Undersea Research Laboratory (HURL). Hence she is conveniently located for participation in cable repair jobs in Hawaiian waters.

DEEP ROVER

The DEEP ROVER sub has a payload of 181 kg. Maximum operating depth is 366 meters. Onboard equipment includes two 5-function sensory feedback manipulators. The pressure hull consists of two acrylic plastic hemispheres, providing an almost 360° viewing of the ambient environment. Can-Dive Services, Ltd., North Vancouver, B.C. Canada is the owner/operator.

MERMAID II

The MERMAID II sub is capable of operating at maximum 305 meter depth. The payload capacity is 680 kg. Viewing of the ambient environment is provided through a 91 cm diameter plastic bow dome. International Contractors, Inc., City Island, N.Y. is the owner/operator.

3.4 Future Developments

The SCARAB ROVs, the British CIRRUS ROVs and GEMINI appear to be the major efforts in the past five years to develop equipment capable of performing all underwater tasks of a submarine cable repair operation. These developments have been primarily for telecommunications cables. Repairs of the two types of cables are, however, related and trends in the communications industry for deep cable will probably be followed by power cables as greater depths are reached.

Other development efforts in the past have been directed towards the creation of special type vehicles and equipment capable of performing a limited number of tasks. Examples are: towed, bottom-reliant ROVs for burying and uncovering cables; and grapnels for cutting and holding cables.

Future developments will probably follow the same path, i.e., both all-task and special-task type of equipment will be developed,as cost-effective analysis favor one type of equipment or the other. Transfer of technology from other fields may enhance the developments. It appears that technologies developed for and applied to underwater work in offshore oil fields would be of particular interest. A few ideas are presented for consideration.

ROVs will be available in the future without umbilicals, relying on "artificial intelligence" to perform tasks and be free of large surface support and not be hindered by the huge drag of the umbilical. It is conceivable that an all-task ROV equipped with an onboard minicomputer could be pre-programmed to complete many of the cable repair tasks.

Underwater repair of cable may be possible in the future. Systems for hyperbaric welding of submarine pipelines have been used in the offshore oil industry for over 15 years. A successful test of welding a 36" diameter pipe (1" wall thickness) in 305 meter water depth was completed early in 1978. Welding is done by diver/welders in welding habitats kept dry by maintaining the habitat atmosphere at ambient sea water pressure. Taylor Diving & Salvage Co. Inc., Belle Chasse, La. started the development of an one atmosphere welding system for 2000 ft in 1977. The system would include a dry welding chamber kept at regular atmosphere pressure. The intent was that welders would do the welding at first and automatic welding machines would later replace the welders. Southwest Research Institute, San Antonio, Tx. was contracted for the design and construction of the system. The design was practically completed by early 1980, when the decision was made to discontinue the development. The system was to be capable of accommodating pipelines of various diameter up to 36". One of the most critical parts of the development was the longitudinal and circumferential seals between the chamber and the pipe. Scaled down prototype seals were successfully tested in 1979, indicating that a solution had been found to the sealing problems. It may be possible and feasible to transfer that technology to the development of a dry, one atmosphere submarine cable splicing chamber. Such a development would be costly particularly because the cable is a far more complex structure than a pipeline.

4.0 Support Requirements

Most ROV systems can operate from practically any surface support platform or vessel as long as it provides enough deck space for system components. A few systems require electrical power to be provided, normally 440 VAC, 3 phase, 60 HZ. Naturally it is advantageous to the performance of the ROV if the support vessel is well equipped. Some features of specific value are: stability, station keeping and sonars. It appears that almost any vessel contemplated for a submarine cable repair operation would be well suited to accommodate also the ROV system.

Towed, bottom-reliant vehicles which are used for burying and uncovering submarine cables are dependent on special types of support ships. They are heavy and massive vehicles, requiring heavy launch and recovery equipment which greatly reduces the availability of suitable support vessels for this type of ROV.

Manned submersibles require special types of support vessels to launch and retrieve the sub, and to recharge batteries and resupply oxygen and CO_2 absorbent. They are generally more difficult to support than ROVs hence their decline in popularity in the offshore industry. Partial exceptions from this general statement are the two submersibles home based in Hawaii; the MAKALII and the PISCES V. Each of these two subs uses a special, submersible platform, the LRT, for transport of the subs to and from dive sites and for launching and recovering the subs. This platform only requires a small support vessel and operations can be performed in rough seas of Sea State 5. Because these two subs are available in Hawaii and regularly operate in Hawaiian waters, they are prime candidates for some of the tasks in a cable repair scenario.

5.0 Operational Costs

The operation costs for ROVs vary with the type of vehicle. Obviously day rates for small, observation type ROVs are lower, than those for large, multi-purpose vehicles. For example, the typical day rate for the small RCV-225 is about $2000. The larger SCORPIO goes for $2500. per day. These rates include the complete vehicle system and two technicians to operate it. Costs for shipping, specialized equipment and support vessel are extra. If a project is of such nature that the vehicle system may be kept on stand-by for periods of time, stand-by rates could probably be negotiated with the ROV operator. It should be recognized that charter rates for ROVs are low now because of strong competition for ROV jobs and because the offshore oil business is slow.

The day rate for the GEMINI system consisting of vehicle, controlroom, A frame, umbilical winch, hydraulic power unit and a generator with four technician operators for 12 hr/day operation of the system is $5000. To operate the system 24 hr/day requires eight operators and the day rate then is $6300. Costs for optional equipment, shipping, load and unload the support vessel and personnel travel are extra. In addition, mobilization and demobilization of the system will cost an estimated $7500.

It should be recognized that most ROV systems are self sufficient, i.e., they include launch and recovery equipment, power generation units, etc. Consequently, a special ROV support vessel may not be required if the cable repair vessel has enough deck space for the ROV system.

Charter rates for subs are usually higher, mainly because they require special surface support ships. The day rate for the MAKALII is about $8000. The price includes everything needed to operate the sub; the personnel, the LRT and a towing vessel. Costs for specialized equipment required for the job are extra. Charter rates for the PISCES V, the other Hawaii-based sub, has not yet been established, however, it is realistic to believe they will be higher than the MAKALII's charter rates. The PISCES V will be operational at the beginning of 1987.

6.0 Conclusions

1. The state-of-the-art of submarine cable repairs require the cable to be lifted onboard a repair vessel where the damaged section is cut out and a new section spliced on. After testing, the repaired cable is re-laid on the seafloor. This cable repair scenario involves several underwater tasks well suited to underwater vehicles. These are as follows:

    - o Locate the cable.
    - o Locate the fault of the cable. This task may be postponed until part of the cable has been brought onboard the cable repair ship.
    - o For buried cable, uncover it.
    - o Cut the cable.
    - o Attach lifting lines to cable ends.
    - o Inspect as-laid cable. Make corrections as necessary.
    - o Disconnect or cut lowering lines.
    - o Bury cable when/where required.

2. ROVs and submersibles have been used for all of the above tasks in repairing communications cable. ROVs have been the most cost effective.

3. The offshore industry has moved away from submersibles and very much toward remote operated vehicles, ROVs. The latter are less expensive to operate and can perform 24 hours per day. ROVs are preferred over subs for cable repairs.

4. The general conclusion of this review of some published reports on underwater cable repair tasks are:

    a) Some specialized new equipment have been developed in recent years to perform some specific underwater tasks. Examples are: towed, bottom-reliant plowing ROVs for burying and uncovering cables and grapnels for finding, cutting and lifting cables and release hooks for releasing lowering lines.

b) Four ROVs, have been developed for carrying out all underwater tasks. The SCARAB I and II were the first such vehicles to be developed.

c) Some other ROVs and subs could be outfitted to perform all underwater tasks.

5. The HDWC cable is larger and heavier than communications cables and would therefore require different equipment than that used for the smaller cables. Inspection, location, fault finding, and burial are not expected to be much different than for the communication cable. Cutting would be more difficult, but not much more so than for pipelines which ROVs currently do. Lifting lines would be heavier and this would require some additional capability of the ROV for attachment and cutting.

6. The primary operational limitation to ROV use along the HDWC cable path is strong currents approaching 1 kt at the bottom of the Alenuihaha channel. These are beyond the operational capability of present cable repair ROVs at 2000 m depth, but ROVs that can work in those currents are conceivable.

7. Burying of cables has been done by manned submersibles and by bottom-reliant, towed ROVs and lately by tethered, free swimming ROVs. Major disadvantages of subs are: short underwater endurance, requires a support ship capable of launching and recovering the sub and weather dependency. Bottom-reliant towed ROVs are big and heavy machines requiring special support ships. Tethered, free swimming ROVs equipped with large capacity water jets have performed well. Most of these ROVs operate from a ship of opportunity, for example the repair vessel, hence eliminating the need for an ROV support ship.

8. Indications are that tethered, free swimming ROVs will be used more and more in submarine cable repair operations. Special vehicles like the SCARAB I and II and quite recently the GEMINI and the CIRRUS (England) were developed for the particular purpose of performing all underwater tasks of submarine cable repair operations, from locating the cable to re-burying if after completed repair. The disadvantages with these vehicles are: high development cost because of the specialized design and relatively high operating costs because of low utilization. There are not many cable repair jobs requiring the deployment of these sophisticated vehicles. Higher utilization, by using the vehicles for other jobs, conflicts with a commitment for standing-by readiness for high priority cable repair jobs. Due to the high costs, companies from the U.S., Canada, England and France formed a consortium for the development of the SCARAB vehicles. The companies are responsible for the telecommunication cables across the

Atlantic ocean. The SCARAB I is now kept on stand-by for cable repair jobs on the European side and the SCARAB II for repair jobs on the North American side of the Atlantic. There are no such vehicles in the Pacific.

9. The Hawaii commercial program may wish to follow the lead of the communication cable industry and have a a modern, multipurpose ROV comprised of a base vehicle and attachable work modules. If so, it may be feasible for interested parties to create a consortium and to jointly develop or purchase a modern ROV system, and operate it exclusively in the Pacific. The vehicle would be kept "on alert" for cable repair jobs.

10. Because of Hawaii's relative geographical "isolation " from the rest of the country, equipment and methods for submarine cable repairs in Hawaii should be selected with concern for costs and availability. The two subs MAKALII and PISCES V located in Hawaii could be quite cost effective for some cable repair tasks.

11. It is likely that new equipment and new methods of performing submarine cable repairs will be developed in the future. As power cables are laid deeper, the deep water techniques used successfully by the communication cable industry will be used more and more. In addition, rapid advances in ROV design and capability have been made in recent years and far more capability can be expected in the near future.

12. The following suggestions are offered as to methods and equipment to use if a submarine cable were to be repaired in Hawaii now.

a) If the vehicle systems could be made available, and if costs are justifiable, the SCARAB II or the GEMINI system should be used for all underwater tasks.

b) One of the Navy's CURV system be used for all underwater tasks providing it could be made available at reasonable cost. Specialized equipment to be installed before shipping to Hawaii.

c) One of the ROV systems mentioned in section 3.3 be equipped with proper tools and instruments and shipped to Hawaii for performing all underwater tasks.

d) The subs MAKALII and/or PISCES V be used for some underwater tasks. Special equipment required for the job be shipped to Hawaii and installed in the subs.

13. ROVs and submersibles can be quite cost effective, if they are in general use and have a wide capability. Specialized ROVs that are on stand-by for cable repair are costly to develop and, because of thier low usage, costly for each repair.

BIBLIOGRAPHY

1. Pirelli Cable Corporation et al: Hawaii Deep Water Cable (HDWC) program. Cable repair rationale. 6.26.86

2. A.H. Dodeman, Margus Co., Inc., N.J.: Correspondence and telephone conversations, June-Aug '86.

3. Deam W. Given, Ametek, Straza Division, El Cajon, Ca.: The SCARAB Undersea Vehicle System: MTS-IEEE OCEANS '77 Conference.

4. Harold R. Lunde, et al: Bell Laboratories Holmdel, N.J.: SCARAB: Sea Sleuth Stalks cable, Bell Job record Sept. 1981.

5. George C. Schorley & Craig T. Mullen, Alcoa Marine Corp. and Dan Johnson, Ametek/Straza: A new family of Tethered Underwater Remote Controlled Work Vehicles, OTC #2403, 1975.

6. Gerald M. Rich, et al: AT&T Communications, International Engineering, Morristown, N.J.: SCOOP-An improved submarine cable recovery system. IEEE Conference 1984.

7. W.C. Engleman & A.J. Von Alt, Long Island Lighting Co., Hicksville, N.Y. & W.F. Searle Jr.. Searle Consortium Ltd., Alexandria, Va.: A different approach to the repair and protection of submarine cable systems. IEEE Conference 1983.

8. William A. Scholes, Sidney, N.S.W. Australia: New Zealanders lay subsea power lines, Ocean Industry, Aug. 1969.

9. Terry Croon: "Pacific Guardian", an ultra modern cable maintenance ship. Unidentified magazine, Jan 1985.

10. Kikuo Shirai, Kokusai Cable Ship Co., Ltd, Sakaguchi, Kokusai Denwa Co., Ltd: Buried submarine cable grapnel, OTC #3987, May 1981.

11. D.N. Dick, C. Eng., British Post Office: Design and development of new cable-repair ships for the British Post Office. Post Office Electrical Engineers' Journal, July 1975.

12. J.G. Cosier, et al: British Post Office, Development of equipment for the recovery and repair of submarine cables (grapnels and release hooks). International Conference on Submarine Telecomm. Systems, London, England, Feb. 1980.

13. R.L. Brachett et al: Civil Engineering Laboratory, Port Huemene, Ca.: Improved hardware and techniques for maintenance and repair of split-pipe-protected cables. Technical note #N-1498, Nov. 1977.

14. U.S. Department of Energy: Bottom segment design underwater cable power transmission system. DOE/ET/20324-1, Nov. 1978.

15. Makai Ocean Engineering, Inc.: File on the HDWC Program 1984-1986.

16. Busby Associates, Inc., Arlington, Va.: Undersea Vehicles Directory, 1985 edition.

17. Craig Mullen & Roy Truman, Eastport International Inc., Upper Marlboro, N.J.: Correspondence and telephone conversations, July-Aug 1986.

18. The Marine Technology Society: Operational Guidelines for ROVs, 1984.

19. Makai Ocean Engineering, Inc.: A feasibility analysis: Underwater tetherless remotely operated vehicles powered by a HEME Oxygen Extraction Engine, April 1984.

20. International Submarine Engineering, Ltd., Port Moody, B.C. Canada: Telephone conversation and correspondence with Jim McFarlane.

21. Walter Foster, Teleglobe Canada: Undersea Cable Maintenance and Repair, a review: OTC#3031, 1977.

22. Marine Technology Society: "ROV '83" and "ROV '84" proceedings.

23. University of New Hampshire, Marine Systems Engineering Laboratory: Fourth International Symposium proceedings on Unmanned Untethered Submersible Technology, June 1985.

24. Dave A. Edgerton, Western Instrument Corp., Ventura, Ca., F.R. Frisbie Oceaneering International, Houston, Tx., Mike MacDonald, International Submarine Engineering Ltd., Port Moody, B.C., Canada; Design of a full function work vehicle system for 2500 meter operation. Oceaneering Dual Hydra 2500.

25. H.L. Shatto, Shell Offshore Inc.: ROV drilling support for deep water. OTC #4751, 1984.

26. F.R. Frisbie et al: Oceaneering International, Houston, Tx.: Unique problems associated with deepwater drilling support operations.

APPENDIX A

Technical Data of Various ROVs

SCARAB I and II
(Submersible Craft Assisting Repair and Burial)

OPERATING DEPTH: 1,829m
DIMENSIONS (LXWXH): 335cm x 183cm x 152cm
LAUNCHER (LXWXH): None
WEIGHT IN AIR: Vehicle - 2,268kg
Launcher - 0
SPEED: Max Surface - 3 kts
Max Operating Current - 0.5kt at 1,829m
STRUCTURE: Open tubular framework cage enclosing and supporting vehicle components.
BUOYANCY CONTROL: Cylindrical flotation tanks provide 23kg of positive buoyancy when submerged.
POWER REQUIREMENTS: 480 vac, 3-phase, 150 kW. Portable diesel (2 ea fully redundant). Electric generator supplies all power requirements. A 3,048m long umbilical cable (3.2cm diameter) powers and controls the vehicle.
PROPULSION: Six, 5 hp each, electrical motors; one, 5 hp, hydraulic motor and one 2hp hydraulic motor provide propulsive power.
INSTRUMENTATION: Two low light level TV cameras (with zoom) on pan and tilt units, one wide angle on tilt only. One 35mm still camera, lights, bottom contour following sensors, altimeters, depth sensors, magnetometer (for cable location). Two hydraulically-powered manipulators, 5 degrees-of-freedom, equipped with various devices for cable cutting and gripping. Jet pump to uncover and bury cables.
NAVIGATION: 360 degree scanning CTFM sonar capable of interrogating bottom-mounted transponders or locating pingers for relative bottom positioning. Computer driven graphics display tracking unit on support craft for obtaining vehicle's relative range and bearing.
SHIPBOARD COMPONENTS: Power distribution unit, control/display console, navigation plotter, operator's chairs (three each), spare parts, diesel generators, cable, cable floats, vehicle locator unit and motion compensated launcher with cable floats, cable storage reel, traction winch, hydraulic power unit, auxiliary power unit.
SUPPORT SHIP REQUIREMENTS: Deck space for shipboard components and vehicle.
OPERATING/MAINTENANCE CREW: Two teams of four: operator assistant operator observer and supervisor for 24 hour operation.
TOTAL SHIPPING WEIGHT: 42,638kg.
TOTAL SHIPPING VOLUME: Nine standard air freight containers hold all components. Volume of each container (LD-3) is 4.5cu m.
STATUS: Operational
BUILDER: Ametek Straza, with extensive modifications by Bell Telephone Laboratories.
OWNER: AT&T Longlines, Morristown, NJ
OPERATOR: SCARAB I: C&W Ltd., London, England
SCARAB II: Ocean Search Inc., Lanham, MD

CURV IIC
(Cable-controlled Underwater Recovery Vehicle)

OPERATING DEPTH: 1,829m
DIMENSIONS (LXWXH): 533.4cm x 182.9cm x 182.9cm
LAUNCHER (LXWXH): None
WEIGHT IN AIR: Vehicle - 3,130kg
Launcher - 0
SPEED: Max Surface - 4 kts
Max Operating Current - NA
STRUCTURE: Structural I-beam aluminum framework enclosed with syntactic foam on both sides of I-beam. Foam offsets frame weight in water. Frame supports all components.
BUOYANCY CONTROL: Syntactic foam blocks provide slight buoyancy when submerged (4.5-6.8kg).
POWER REQUIREMENTS: 400 vac, 120 vac, 3-phase, 50 kW. A portable 60 kW diesel generator supplies all power to the system.
PROPULSION: Three, 1 hp, pressure-compensated, electric motors provide power to three propellers. Two provide forward-reverse motion and one provides vertical motion. All are capable of independent operation.
INSTRUMENTATION: Television (2 ea), 35mm still camera, 16mm movie camera, strobe light, mercury vapor lamps, altimeter, depthometer, emergency light, active and passive sonar (Applied Research Lab) with digital readout. Compass (Digicourse-312).
NAVIGATION: By compass and sonar system in conjunction with boat-mounted acoustic locating device.
SHIPBOARD COMPONENTS: Control/display console (in a portable van), power supply (generator) and conversion equipment, and surface handling equipment.
SUPPORT SHIP REQUIREMENTS: Station-keeping capability and cable handling area away from screws. Deck space for seven items approximately 7 to 11.2sq m each.

OPERATING/MAINTENANCE CREW: Seven normally, ten in an emergency mission.

TOTAL SHIPPING WEIGHT: 23.6t (not including handling crane)

TOTAL SHIPPING VOLUME: 127.4cu m. For operations to 475m the total system (not including handling crane) can be loaded aboard a C-141 aircraft. For emergency operations on unknown ship of opportunity two C-141s are required.

STATUS: Operational

BUILDER: Naval Ocean Systems Center, San Diego, CA

OPERATOR: Same as above.

REMARKS: CURV IIB now at San Diego is to be replaced with the updated CURV IIC as described above.

CURV III
(Cable-controlled Underwater Recovery Vehicle)

OPERATING DEPTH: 3,048m
DIMENSIONS (LXWXH): 414cm x 198cm x 213.3cm
LAUNCHER (LXWXH): None
WEIGHT IN AIR: Vehicle - 2,517.5kg
Launcher - 0
SPEED: Max Surface - 4 kts
Max Operating Current - NA
STRUCTURE: Channel and angle aluminum. Rectangular shape.

BUOYANCY CONTROL: Syntactic foam provides positive buoyancy, vertical thrusters provide depth control.

POWER REQUIREMENTS: 400 vac, 120 vac, 3-phase, 50 kW. A portable, 60 kW diesel generator supplies all power to the system.

PROPULSION: Three 10 hp, pressure-compensated, electric motors provide power to three propellers. Two provide forward-reverse motion and one provides vertical motion. All are capable of independent operation.

INSTRUMENTATION: TV cameras (2 ea), 35mm still camera, lights, altimeter, depthometer, magnetic compass, active and passive CTFM sonar (Ametek Straza). Manipulator, hydraulically-powered, three degrees-of-freedom, circular-type (torpedo grasping) claw.

NAVIGATION: By compass heading and visual sighting. The support craft, YFNX-30, is equipped with a boat-mounted acoustic locating device (BALD) which monitors CURV III's relative bearing during a dive.

SHIPBOARD COMPONENTS: Control/display console (in a portable van), power supply (generator) and conversion equipment, and surface handling equipment.

SUPPORT SHIP REQUIREMENTS: Station-keeping capability and cable handling area away from screws. Deck space for seven items approximately 7 to 11.2sq m each.

OPERATING/MAINTENANCE CREW: Seven normally, ten in an emergency mission.
TOTAL SHIPPING WEIGHT: 24,789kg
TOTAL SHIPPING VOLUME: 1,132.8cu m
STATUS: Storage
BUILDER: Naval Ocean Systems Center, San Diego, CA
OPERATOR: Naval Sea Systems Command (SEA-OOC), Washington, DC
REMARKS: None

HYDRA

OPERATING DEPTH: 500m, 1000m and 2500m
DIMENSIONS (LxWxH): 2.03m x 1.32m x 1.24m (2500m model)
LAUNCHER (LxWxH): 2.7m x 1.52m x 2.44m (2500 model)
WEIGHT IN AIR: Vehicle - 1200kg
Launcher - 1300kg
SPEED: Max. Surface - 2.5 kts
Max. Operating Current - 2.5 kts

STRUCTURE: Syntactic foam atop an open frame of T6061 aluminum members. A single one atmosphere telemetry and electronics housing.

BUOYANCY CONTROL: Syntactic foam with 91kg of removable lead for payload and buoyancy adjustments.

POWER REQUIREMENTS: 75kw of 460vac, 3-phase, 60Hz power transmitted in a 3 x RG11, 4 power conductors and 3 each fiber optics umbilical.

PROPULSION: Two 10hp and 3 @ 10hp independent electro-hydraulic power packs driving 4 @ 10hp hydraulic thrusters. Automatic depth and heading control, gyrocompass.

INSTRUMENTATION: High resolution pulse sonar, SIT and color TV cameras on pan/tilt, 4 @ 500w infinitely variable lights, onboard diagnostics with acoustic coupling to shore.
NAVIGATION: Sonar, visual, compass.

SHIPBOARD COMPONENTS: Control console, power distribution box, power boost box, main lift winch with armored umbilical, subsea deployment system with winch.
SUPPORT SHIP REQUIREMENTS: Station keeping, primary power, washdown water.
OPERATING/MAINTENANCE CREW: Three
TOTAL SHIPPING WEIGHT: 8000kg with spare vehicle, spares, tools.
TOTAL SHIPPING VOLUME: One 6m (20 ft) container plus one 2.4m (8 ft) x 3.6m (12 ft) x 2.4m handling/subsea deployment unit.

STATUS: Operational
BUILDER: International Submarine Engineering Ltd., Port Moody, BC, Canada
OPERATOR: Oceaneering International
DATE VEHICLES LAUNCHED: DUAL HYDRA 501 - 1 July 1982
DUAL HYDRA 1001 - 12 March 1983
DUAL HYDRA 1002-1005 - March/June 1983
DUAL HYDRA 2501 - 10 May 1983

REMARKS: The DUAL HYDRA is designed as a compact, cage-deployed remote work system Unmanned Tethered Submersible (UTS) designed for a broad range of offshore tasks with a variety of configurations

SCORPIO

OPERATING DEPTH: 914m
DIMENSIONS (LXWXH): 223cm x 122cm x 163cm
LAUNCHER (LXWXH): None
WEIGHT IN AIR: Vehicle - 680kg
Launcher - 0
SPEED: Max Surface - NA
Max Operating Surface - 1 kt against 1 kt current at maximum depth (approximate).
STRUCTURE: Two pressure resistant flotation tanks atop of - and enclosed within - an open tubular aluminum framework. Electronics are housed in removable chassis drawers in buoyancy tanks.
BUOYANCY CONTROL: Vehicle is positively buoyant. Negative buoyancy is dynamically controlled by a vertical thruster.
POWER REQUIREMENTS: 440 vac, 60Hz, 3-phase, 50 kW.
PROPULSION: Four proportionally controlled high velocity, hydraulic thrusters each delivering 113kg thrust; 2 axial, 1 vertical, 1 lateral.
INSTRUMENTATION: Underwater TV camera mounted on pan and tilt mechanism CTFM (Ametek Straza 250) sonar mounted on upper front frame for 360 degree search and obstacle avoidance. Sonar also tilts 90 degrees downwards for bottom search and survey. Hydraulic five-motion manipulator extends from bottom front frame. Automatic heading and depth control. Cable turns counter. Acoustic pinger and strobe flasher to assist in emergency subsurface and surface recovery. One 250 w thallium iodide light and one 250 w tungsten quartz iodide light.
NAVIGATION: CTFM sonar, short baseline acoustic positioning system.
SHIPBOARD COMPONENTS: Control console with portable control box for visual launch and recovery of vehicle, sonar, TV and locator displays, operator, bridge, winch station communications sets, power distribution unit, winch and cable reel and spare parts. Power generator and launching frame are optional.
SUPPORT SHIP REQUIREMENTS: Enclosed area for control console and operators (can be supplied as optional item). A suitable power source with a rating of 440 to 480 VAC, 60Hz, 3-phase and 75 kW is recommended for operation of the vehicle and cable winch motors. A smaller (e.g., 50 kW) power rating is possible. A crane, boom or A/U frame is required to launch and recover vehicle (can be supplied as optional item); should have capacity to handle vehicle maximum weight of 907kg which includes optional sensors/tools. Good station-keeping ability for live-boat operations. Deck space 6.1m long by 3.3m wide required for vehicle, winch and flotation hose.
OPERATING/MAINTENANCE CREW: Three to four, 6 for extended periods
TOTAL SHIPPING WEIGHT: 4,536kg maximum
TOTAL SHIPPING VOLUME: 17cu m depending on spares and options.
STATUS: Operational
BUILDER: Ametek Straza
OPERATOR: Various
REMARKS: None

TONGS
(Television Observed Nautical Grappling System)

OPERATING DEPTH: 600m
DIMENSIONS (LxWxH): N/A
LAUNCHER (LxWxH): N/A
WEIGHT IN AIR: Vehicle - N/A
Launcher - N/A
SPEED: Max. Surface - 2.9kts
Max. Operating Current - 2kts
STRUCTURE: Open metallic frame work with steadying fin.

BUOYANCY CONTROL: Vehicle is negatively buoyant. Vertical motion is optained by reeling-in/reeling-out umbilical cable.

POWER REQUIREMENTS: Supplied by onboard batteries which provide four hours continuous thruster power and power to the instrumentation.

PROPULSION: Two thrusters provide maneuverability in the horizontal plane. Vehicle maneuverability is also provided by maneuvering the support ship.

INSTRUMENTATION: TV camera, directional hydrophone and scanning sonar mounted on pan/tilt device. Various mechanical devices are available for attachment of retrieval cables.

NAVIGATION: Magnetic compass

SHIPBOARD COMPONENTS: Crane, cable (lift and umbilical) and control pod.

SUPPORT SHIP REQUIREMENTS: N/A
OPERATING/MAINTENANCE CREW: N/A
TOTAL SHIPPING WEIGHT: N/A
TOTAL SHIPPING VOLUME: N/A

STATUS: Operational

BUILDER: Naval System: Warfare Center, Ft. Lauderdale, FL
OPERATOR: Same as builder.
DATE VEHICLE LAUNCHED: First vehicle in 1955. There has been progressive modification of the vehicle from 1955 to the present. A second vehicle (TONGS II) is under construction.

REMARKS: TONGS is used to recover cables on the sea floor. Lift is provided by a separate, detachable cable from vehicle-to-surface. Weight of 2 kN can be retrieved.

CIRRUS

OPERATING DEPTH: 1000M
DIMENSIONS (LXWXH): 330cm x 200cm x 180cm
LAUNCHER (LXWXH): NA
WEIGHT IN AIR: Vehicle - 3000KG
Laucher - NA
SPEED: Max Surface - 3kts
Max Operating Current - NA
STRUCTURE: Syntactic foam atop an open rectangular framework, which supports and encloses all components.

BUOYANCY CONTROL: Vehicle is positively buoyant underwater,vertical thruster is used for depth control.

POWER REQUIREMENTS: 415v, 3-phase, 50Hz, 200KW continuous.

PROPULSION: Seven hydraulic thrusters total, two longitudinal (38cm), two lateral (34.5cm), three vertical (34.5cm). SEL Model HA203 (38cm), SEL Model HA201 (34.5cm).

INSTRUMENTATION: Five TV cameras total: pilot's (Osprey OE1334) on pan/tilt unit; one on each manipulator (Osprey OE1311 with zoom lens) on pan/tilt unit, one on the stern (Osprey OE1311 with wide angle lens) on pan/tilt unit, and one on the burial tool (Osprey OE1311 with wide angle lens) on tilt unit. Two manipulators (SEL Model TA9) 7-function master/slave with position feedback. Cable cutter (SEL Model TA19). Cable gripper (SEL Model TA17). Burial tool (SEL design). Jetting head (to SEL design). Water pump ('STORK' CEN. 65-200-2). Eight lights (Duddon Electronics) 4kVA total. Depth sensor, altimeter, pitch/roll sensor, temperature sensor and internal water detectors. Xenon flashing light. Radio beacon. Cable detection system (SEL design based on 4 Triaxial magnetometers mounted on the ROV).

NAVIGATION: Magnetic compass, transponder (Honeywell Hydrostar), sonar (UDI AS360), and pinger detector (HELLE Model 6555).

SHIPBOARD COMPONENTS: Control/display console in cabin, deployment crane, umbilical winch, diesel generator, and hydraulic power pack.

SUPPORT SHIP REQUIREMENTS: Open deck space. Reasonable station keeping qualities in sea conditions up to Sea State 5.
OPERATING/MAINTENANCE CREW: NA

TOTAL SHIPPING WEIGHT: 31.5 tonnes (estimated, does not include control cabin, and control/display console).
TOTAL SHIPPING VOLUME: 132 cu m (estimated)
STATUS: Under construction in March 1985.
BUILDER: Slingsby Engineering Limited
OPERATOR: Cable and Wireless Systems Limited UK
DATE VEHICLE LAUNCHED: 1985
REMARKS: The name of this vehicle has been chosen by the operator. Future vehicles will be marketed under the name COBRA.

GEMINI

OPERATING DEPTH: 1524m (3048m optional)
DIMENSIONS (LxWxH): 272cm x 183cm x 127cm
LAUNCHER (LxWxH): 185cm (diam.) x 183cm
WEIGHT IN AIR: Vehicle - 2041 kg
Launcher: 1588 kg
SPEED: Max. Surface - 2 kts
Max Operating Current - 3 kts (below cavitation depth)

STRUCTURE: Rectangular shape, open frame modular consruction (aluminum extrusion). Manipulators and special sensors fitted to work module.

BUOYANCY CONTROL: Syntactic foam with 136 kg payload, plus 544 kg vertical thrust.

POWER REQUIREMENTS: 440vac, 60Hz, 3-phase

PROPULSION: Two 40 hp hydraulic power units (80 hp total). Seven proportional controlled hydraulic thrusters capable of 227 kg thrust each. Automatic heading and depth control.

INSTRUMENTATION: Inspection pan/tilt capable of 4 TV cameras and lights. Pilot pan/tilt capable of SIT wide angle and lighting. Depth sensor (accurate within 0.3m). Pitch/roll sensors and stabilizers. Fluxgate gyrocompass. Pinger (27 kHz). Strobe light. Altimeter.

NAVIGATION: Gyrocompass (plus or minus 1% of magnetic standard; 0.1% optional). CTFM sonar.

SHIPBOARD COMPONENTS: Winch, pilot/operator control console, power distribution unit, deck cables.

SUPPORT SHIP REQUIREMENTS: 440 VAC, 60 Hz, main power.

OPERATING/MAINTENANCE CREW: 3-4 for 12 hour shifts.

TOTAL SHIPPING WEIGHT: NA

TOTAL SHIPPING VOLUME: NA

STATUS: Operational

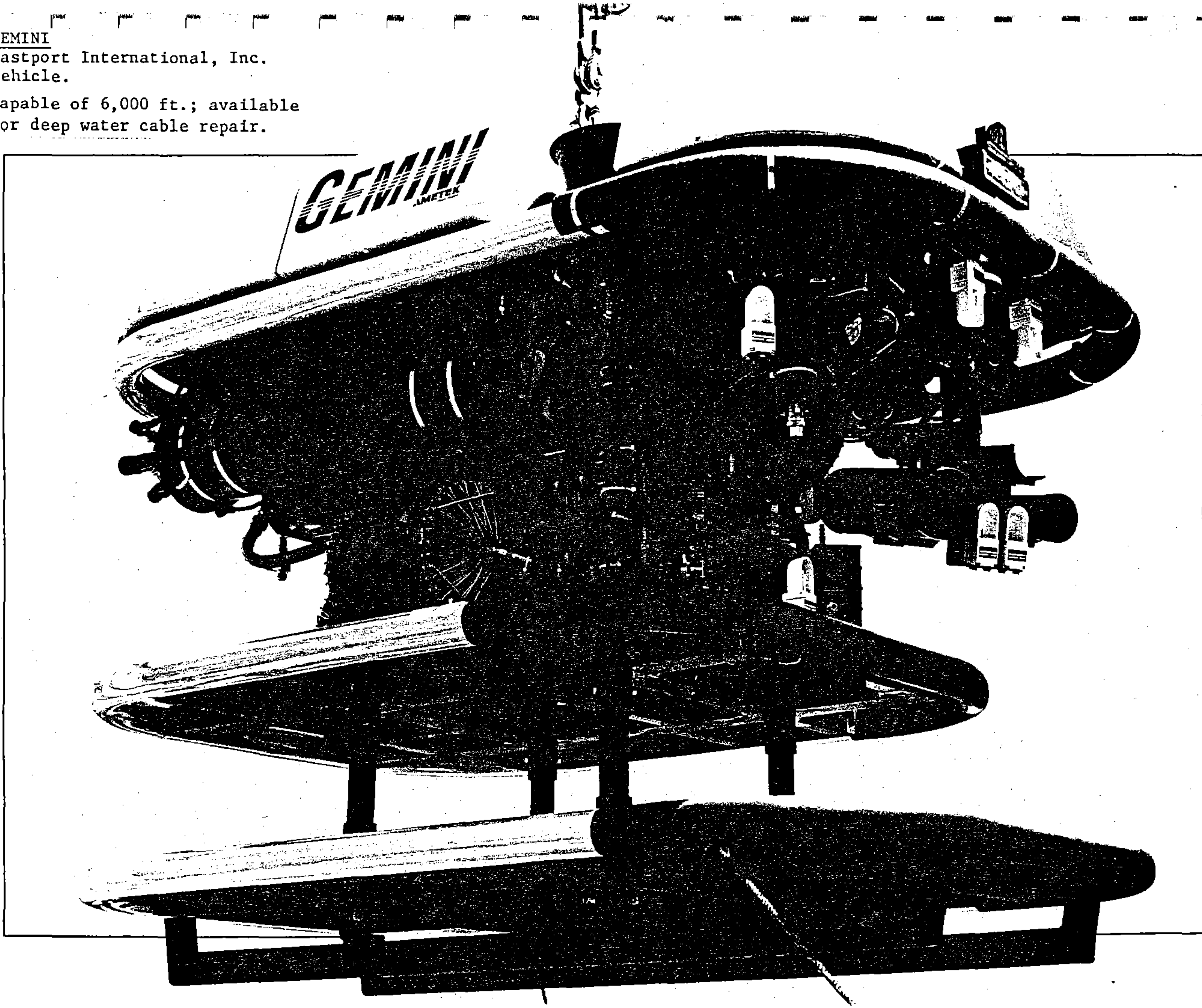
BUILDER: AMETEK, Straza Division
El Cajon, CA

OPERATOR: AMETEK, Straza Division

REMARKS: Over-the-side launcher or knuckle boom crane can be supplied on request

GEMINI
Eastport International, Inc. vehicle.

Capable of 6,000 ft.; available for deep water cable repair.



GEMINI

MODULAR ROV WORK SYSTEM

GEMINI is an open frame, highly adaptable subsea work system based on four generations of ROV design manufacture and testing. Dual 40 hp hydraulic power units increase reliability. Seven high performance thrusters provide in excess of 1,000 pounds of lateral thrust and 1,500 pounds of lifting force. Full pitch and roll stabilization is standard.

GEMINI utilizes modular construction to maximize adaptability. The upper module contains propulsion, flotation, and electronics. The lower work module may be equipped with a variety of sensors or tools including high pressure jetters, manipulators or specialized equipment. Work modules can be quickly removed and replaced.

GEMINI is designed to operate at depths to 5,000 feet with optional capability to 10,000 feet. Tether management system enhances launch and recovery operations. Dual FM multiplexer permits simultaneous operation of up to six television cameras.

GENERAL SPECIFICATIONS

PERFORMANCE

Depth	5,000 ft (1524m) standard 10,000 ft (3048m) optional
Lift Capacity	1,500 lbs min (w/o additional bouyancy)
Payload	400 lbs (w/o additional bouyancy)
Propulsion	7 hydraulic thrusters 2 axial, 3 vertical, 2 lateral
Forward Speed	3.0 kts (1,000 lbs thrust) minimum
Hydraulic Power	80 hp, twin power units 20 gpm @ 3,500 psi each
Available Payload Power	
Hydraulic	45 hp for optional tools
Electrical	5 kVA for optional sensors (additional available from 3 kVA source)

INSTRUMENTATION

Sonar	AMETEK 250A CTFM Range 4–2,000 ft Optional scan converter
Television	3 camera interfaces standard; expandable to 9
Pan and Tilt Camera Mounts	
Inspection	±270° pan, ±60° tilt (80 ft/lbs minimum)
Pilot	±150° rotation, from −10° to 30° vertical
Lights	6 ea 250W variable control (additional lights optional)
Depth Sensor	Accuracy ±1% of full scale standard ±0.1% optional
Depth Control	Auto/Manual proportional type ±1 ft in auto mode
Heading Sensor	Gyro accuracy of ±1° magnetic reference (slave, free, and magnetic)
Heading Control	Auto/Manual proportional type ±1° in auto mode
Pitch & Roll Stabilization	Dynamic servo control with pilot trim adjust
Emergency Locators	
Acoustic Beacon	27 kHz ± 1 kHz, 30-day life
Strobe Flasher	High intensity xenon, 100-hour life
Multiplexer	
Command/Control	TDM, 128 channels up, 128 channels down
Video (optional)	3 channel (baseband plus 2 FM)

PHYSICAL

Length	107 in. (272 cm)
Width	72 in. (183 cm)
Height	70 in. (189 cm) less work module
Weight	Approx 4,300 lbs (1,950 kg) less work module
Work Module	Basic configuration or to customer specification

Standard Features and Equipment

- Operator Control Unit
- Remote Control Unit
- TV Monitor
- CTFM Sonar
- Flux Gate Gyro
- Sonar Display
- Intercom System
- Umbilical Cable
- Electrohydraulic Cable Winch
- Power Distribution Unit
- Technical Manuals
- Acoustic Altimeter
- Video Character Generator
- 128 Channel Multiplex
- Tether Management System (TMS 100)
- Variable Intensity Lights

Options

- 7-Function Master-Slave Manipulator (with force feedback option)
- Auto Parking System
- Interfaces for Navigation/Tracking Systems
- Special Stills and TV Camera Units & Interfaces
- Video Tape Recorder
- Interfaces for Side Looking Sonar, Pipetracker, Profiler, & CP Probe
- Launching Equipment
- Cable Cutter
- Deep Operating Modification (10,000 ft)
- Multiple TV Cameras
- Short Baseline Navigation System
- High Accuracy Depth System
- Water Jetters

Specifications subject to change without notice.

AMETEK
STRAZA DIVISION, ROV SYSTEMS • 790 GREENFIELD DRIVE, EL CAJON, CA 92022
TELEPHONE: (619) 442-3451

TRITON

OPERATING DEPTH: 1000m
DIMENSIONS (LxWxH): 2.44m x 1.42m x 1.32m
LAUNCHER (LxWxH): 1.83m (L) x 1.83m (Diameter)
WEIGHT IN AIR: Vehicle - 1905 kg
Launcher - 1364 kg
SPEED: Max. Surface - 3 knots
Max. Operating Current - NA

STRUCTURE: Rectangular configuration, open metallic framework with syntactic foam block atop framework.

BUOYANCY CONTROL: Vehicle is positively buoyant underwater. Depth is controlled by vertical thrusters. Payload: 227 kg standard.

POWER REQUIREMENTS: 2400 VAC, 3-Phase, 50/60 Hz supply to vehicle from surface power transformer unit. Two kVA electrical power available at vehicle for work modules (additional 50 hp capability for work modules is built into umbilical).

PROPULSION: Two electro-hydraulic power units, each is 25 hp. 2400 VAC, 3-Phase, 60 Hz for a total of 108 LPM @ 211 kg/sq cm. Three verticle thrusters at 82 kg thrust each. Three horizontal thrusters at 204 kg thrust each. All motors are servo-controlled. Thruster nozzles are Innerspace Model 1002 assemblies.

INSTRUMENTATION: TV camera (One Merpro pan and tilt; one SubSea Systems CM-8 B&W). One 5-function manipulator with 7-function valve package. Scanning sonar (UDI Mod. A5360M SI). Emergency Pinger (O.R.E. Mod. 269). Flasher (OAR Type SF500-1-100-PHOS). Sensors: Heading (magnetically slaved gyrocompass); depth sensor (Teledyne Taber); pitch and roll sensor (Humphrey). Altimeter (Mesotech).

NAVIGATION: Gyrocompass

SHIPBOARD COMPONENTS: Power Distribution Unit and Power Transformer Unit. Control Console. Launch and Recovery system.

SUPPORT SHIP REQUIREMENTS: NA

OPERATING/MAINTENANCE CREW: 3-4

TOTAL SHIPPING WEIGHT: 20962 kg with launch and recovery System. 5086 kg without.
TOTAL SHIPPING VOLUME: 57.85 cu m

STATUS: Construction
BUILDER: Perry Offshore, Inc.
OPERATOR: SONAT Subsea Services
DATE VEHICLE LAUNCHED: 1985
REMARKS: None

DEEP DRONE

OPERATING DEPTH: 1645m
DIMENSIONS (LXWXH): 259cm x 148cm x 132cm
LAUNCHER (LXWXH): None
WEIGHT IN AIR: Vehicle - 726kg
Launcher - 0
SPEED: Max Surface - 3.5 kts
STRUCTURE: Two, pressure-resistant flotation tanks atop of - and enclosed within - an open, tubular aluminum framework.
BUOYANCY CONTROL: Positive bouyancy of 29kg is provided by the flotation tanks when submerged. Negative buoyancy is dynamically-provided by the thrusters.
POWER REQUIREMENTS: 115 vac, 1-phase, 10 kva; 480 vac, 3-phase, 25 kva. Umbilical consists of a 2,133m long, 3.3cm diameter cable with strength member. A diesel motor generator provides all power required to operate the vehicle system.
PROPULSION: Five thrusters, two are for forward-aft propulsion (thrust and yaw), one is for vertical propulsion (heave) and two lateral thrusters. Each motor is fixed, reversible, shrouded by a Kort nozzle and rated at five shaft horsepower at 1,725 rpm. Lateral thrusters are rated a 3 hp each.
INSTRUMENTATION: Two TV cameras (one is fixed and one is mounted on a pan and tilt mechanism), 35mm still camera with strobe light, CTFM sonar with transponder interrogation and pinger location capabilities, altimeter, depth meter.
NAVIGATION: The CTFM sonar is designed to interrogate a bottom-mounted transponder and, using it as a benchmark, can position the vehicle. A locator system aboard the surface craft can obtain the vehicle's relative range and bearing. An acoustic navigation system is utilized for navigation in deep operations providing ship and vehicle position.
SHIPBOARD COMPONENTS: Control console, control cable, handling system, vehicle locator, diesel motor generator, support spare parts.
SUPPORT SHIP REQUIREMENTS: Station-keeping ability if conducting underway operations, and deck space to accommodate the system.
OPERATING/MAINTENANCE CREW: Five-man (minimal) - more depending on nature and length of task.
TOTAL SHIPPING WEIGHT: 20t
TOTAL SHIPPING VOLUME: 68cu m. Packaged for shipment on USAF pallets.

STATUS: Operational, on standby for emergency calls.
BUILDER: Ametek Straza, El Cajon, Ca
OWNER: Naval Sea System Command
Supervisor of Salvage, Washington, DC
OPERATOR: Eastport International, Ocean Search Division
Lanham, MD

REMARKS: None

APPENDIX B

Technical Data of Various Subs

PISCES V (P5)

LENGTH...........	6.1m	LIFE SUPPORT DURATION....	336 man hrs
BEAM.............	3.2m	TOTAL POWER..............	39 kWh
HEIGHT...........	3.3m	SPEED: CRUISE...........	1 kt
DRAFT............	2.7m	MAX..............	2 kts
WEIGHT IN AIR....	10.8t	CREW: PILOTS...........	1
OPERATING DEPTH..	1,500m	OBSERVERS........	1
COLLAPSE DEPTH...	2,743m	COLOR: HULL.............	White
HATCH DIAMETER...	49.3cm	SAIL.............	White
PAYLOAD..........	278kg	LAUNCH DATE..............	1973

PRESSURE HULL: Spherical shape, composed of HY-100 steel 2.03m diam, 2.54cm thick.

POWER SOURCE: Lead acid batteries, 120 v, 300 amp-hrs, pressure compensated.

MANEUVERING CONTROL: Two, five hp each, reversible thrusters are mounted p/s amidships. Thrusters are rotatable 90 degrees upward to 30 degrees downward from the horizontal.

LIFE SUPPORT: Two flasks of O_2 are carried externally and provide 7.9cu m at 330kg/sq cm. CO_2 is removed by scrubbing cabin air through soda sorb. Monitors for O_2, CO_2, temperature, humidity and pressure.

VIEWING: Three viewports on bow (15cm diam) all look forward. Two televisions mounted externally on pan/tilt mechanism. One TV is mounted forward and one aft.

MANIPULATORS: Two, both hydraulically-powered and both have jettisonable claw. One has two degrees-of-freedom and is designed for 906kg grasping capacity and is used for torpedo recovery. The second has six degrees-of-freedom and is designed for 91kg grasping capacity. The heavy lift manipulator has an opposing 'C' shaped claw; the lighter lift manipulator has a parallel jaws-type claw.

SURFACE COMMUNICATIONS: UHF (Motorola) range approximately 5.6km. Emergency power supply provided.

SUBSURFACE COMMUNICATIONS: One (Mesotech) underwater telephone is carried and operates off the main batteries. It transmits and receives on either 9 or 27 kHz.

SONARS:

Scanning - Wesmar (SS140S) scanning sonar is mounted on the bow and scans an 180 degree forward sector. Display is PPI and audio.

Pingers - The underwater telephone can act as a pinger with a one second rep. rate on 27 kHz and operates off the main batteries.

Echo Sounders - None

Transponders - None

Directional Hydrophones - A pinger/receiver (Hydro Products) is mounted on the bow to receive a 27 kHz pulse.

Doppler - None

STATUS: Operational

CLASSIFICATION/CERTIFICATION: American Bureau of Shipping

OPERATOR: Research Submersibles Ltd., Cayman Is., BWI

BUILDER: HYCO, Ltd., Vancouver, B.C., Canada

TURTLE

LENGTH	7.9m	LIFE SUPPORT DURATION	210 man-hrs
BEAM	3.7m	TOTAL POWER	30 kWh
HEIGHT	3.7m	SPEED: CRUISE	0.5 kt
DRAFT	2.3m	MAX	2.5 kts
WEIGHT IN AIR	23t	CREW: PILOTS	2
OPERATING DEPTH	3,048m	OBSERVERS	1
COLLAPSE DEPTH	4,572m	COLOR: HULL	White
HATCH DIAMETER	50.2cm	SAIL	Orange
PAYLOAD	NA	LAUNCH DATE	1968

PRESSURE HULL: Spherical shape, HY-100 steel, 2.1m OD, 3.8cm thick.

POWER SOURCE: Lead acid batteries, pressure compensated, 30 and 60 vdc, each rated at 540 amp-hrs. Emergency power consists of two silver zinc batteries (30 amp-hrs each) inside the hull which provide power for communications, CO_2 scrubber, jettisoning and internal lights.

MANEUVERING CONTROL: One propeller which is stern-mounted, reversible and trainable 45 degrees p/s provides main propulsion. Two thrusters mounted p/s amidship are trainable 360 degrees in the vertical and are reversible (about 270kg lift), four hp each.

LIFE SUPPORT: O_2 is carried inside the pressure hull in three flasks. Each flask carries 2.4cu m at 210kg/sq cm. The system allows any flask to provide O_2 to either the main system or EBS (closed loop). CO_2 is routinely removed by scrubbing through LiOH. O_2, CO_2, temperature, humidity and pressure are monitored. Backup O_2 and CO_2 monitors are carried.

VIEWING: Five viewports total, four large and one small. The large viewports are oriented to look forward, vertically downward and p/s of the forward looking port. The small viewport is located in the hatch cover.

MANIPULATORS: Two, hydraulically-powered, six degrees-of-freedom with wrist rotate and linear extension, various claw types (scissors, parallel jaws, cable cutters), jettisonable.

SURFACE COMMUNICATIONS: One radio transceiver, handitalkie convertacomm, 20 watt, 37km range.

SUBSURFACE COMMUNICATIONS: One (Ametek Straza with TIPE option), 8.0875 kHz, CW (8.887 kHz). Two transducers, both topside, one transmits in a conical beam and one is omnidirectional.

SONARS:

- Scanning - CTFM (Ametek Straza 500), 87 to 72 kHz.
- Pingers - None
- Echo Sounders - With upward and downward-looking transducers, operates on 50 kHz with 366m range.
- Transponders - None
- Directional Hydrophones - None
- Doppler - None

STATUS: Undergoing refit (July 1985)

CLASSIFICATION/CERTIFICATION: U.S. Navy

OWNER: U.S. Navy

OPERATOR: Submarine Development Group One, San Diego, CA

BUILDER: Mare Island Shipyard, San Francisco, CA

SEA CLIFF

LENGTH........... 9.3m	LIFE SUPPORT DURATION. 216 man-hrs
BEAM............. 3.2m	TOTAL POWER........... 48.6 kWh
HEIGHT........... 3.8m	SPEED: CRUISE........ 0.5 kt/4hrs
DRAFT............ 2.35m	MAX.............. 2.5 kts
WEIGHT IN AIR.... 25.4t	CREW: PILOTS........... 2
OPERATING DEPTH.. 6,096m	OBSERVERS........ 1
COLLAPSE DEPTH...7,620m	COLOR: HULL............. NA
HATCH DIAMETER... NA	SAIL............. NA
PAYLOAD.......... NA	LAUNCH DATE.............. 1968

PRESSURE HULL: Spherical shape, titanium.

POWER SOURCE: Batteries, 60 volts (32.4kWh), 30 volts (16.2kWh).

MANEUVERING CONTROL: Stern propulsion (1.5hp) with steering shroud. Side thruster pod (port/starboard), trainable propulsion 4hp each.

LIFE SUPPORT: Normal: 144 man-hrs., emergency: 72 man-hrs.

VIEWING: Three 11.4cm diam. viewports forward. One 3.7cm diam. viewport in the hatch cover.

MANIPULATORS: Two, 7-functions.

NAVIGATION AND SEARCH INSTRUMENTS: Five underwater lights, TV camera, still camera and 2 strobes, gyrocompass, backup compass, depth gage, echo sounder, CTFM sonar, underwater telephone with transponder interrogator option, tracking transponder.

STATUS: Operational

CLASSIFICATION/CERTIFICATION: U.S. Navy

OWNER: U.S. Navy

OPERATOR: Submarine Development Group One, San Diego, CA
BUILDER: Mare Island Shipyard, San Francisco, CA
REMARKS: None

JOHNSON-SEA-LINK I & II

LENGTH	7.2m	LIFE SUPPORT DURATION	480 man hrs
BEAM	2.5m	TOTAL POWER	32 kWh
HEIGHT	3.1m	SPEED: CRUISE	0.75 kt
DRAFT	2.3m	MAX	1.25 kts
WEIGHT IN AIR	I: 9,707kg II:10,391kg	CREW: PILOTS	1
OPERATING DEPTH	805m	OBSERVERS	1
COLLAPSE DEPTH	2,438m	DIVERS	2
HATCH DIAMETER:	PILOT.49cm LOC...60cm	COLOR: HULL	Aluminum
		SAIL	None
PAYLOAD	544kg	LAUNCH DATE	I: 1971 II: 1975

PRESSURE HULL: Two hulls: one sphere (fwd) and one cylinder (aft). Sphere: acrylic plastic 168cm OD, 10cm thick. Cylinder: Aluminum, 151cm OD, 2.4m long, 8.5cm thick.
POWER SOURCE: Fourteen, two vdc, Exide DTSC-29, pressure compensated, lead acid batteries rated at 1,105 amp-hrs.
MANEUVERING CONTROL: Eight thrusters with kort nozzles, 1.25 hp reversible. Four forward mounted amidships, two vertical mounted fwd/aft, two horizontal mounted fwd/aft.
LIFE SUPPORT: Oxygen - two external cylinders 7.1cu m at 210kg/sq cm. Eight external air cylinders of 6.6cu m capacity each at 210kg/sq cm. Nine mixed gas cylinders of 6.2cu m at 210kg/sq cm (cylinder) and 50.1cu m at 133kg/sq cm (sphere) capacity each. CO2 scrubber compound: LiOH, 18kg spare carried in pilot sphere, 2.7kg soda sorb to perform routine mission. Two CO2 monitors each in pilot's sphere and LOC. One PO2 monitor in pilot's sphere, one in LOC. Diver life support, locked out, is from a KMB-10 open circuit mask with a bailout cylinder.
VIEWING: Pilot's sphere: panoramic viewing. LOC: one viewport each side, one forward, one in both hatch covers.
MANIPULATORS: One, six function, rotatable grips (scissors, parallel jaws), 183cm maximum extension. Not jettisonable.
SURFACE COMMUNICATIONS: FM transceiver.
SUBSURFACE COMMUNICATIONS: Sub-to-ship: Underwater telephone, frequency 8.087 kHz, CW, 18,288m max range. Sub-to-diver: underwater telephone, 200Hz with speaker/microphone in pilot's sphere, LOC and diver's helmet. Inter compartment: A sound-powered phone.
SONARS:

- Scanning - CTFM, transmits from 122 to 107 kHz.
- Pingers - Two, one , dual frequency (9 and 45 kHz), rep rate of 1.5 sec, the other powered by the submersible's battery.
- Echo Sounders - Two each.
- Transponders - One (Vickers) receiving at 39 kHz replying at 178 kHz, powered by submersible's batteries.
- Directional Hydrophones - None
- Doppler - Two: Sperry DNS; Sperry SRD 101

STATUS: Operational
CLASSIFICATION/CERTIFICATION: American Bureau of Shipping
OWNER: Harbor Branch Foundation, Inc., Ft. Pierce, FL
OPERATOR: Same as above
BUILDER: Same as above