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# HAWAII DEEP WATER CABLE PROGRAM

# PHASE II-D

## TASK 5

## REVISED BASIC DESIGN CRITERIA
## DATA BOOK



Department of Business and Economic Development

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## REVISED BASIC DESIGN CRITERIA
## DATA BOOK

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and the

State of Hawaii

Department of Business and Economic Development

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# PART 1

## INTRODUCTION

This Revised Basic Design Criteria Data Book supercedes the 1985, original version. Its purpose and structure have not changed, but technical data have been updated and a new section on the At-Sea Test added. The book remains a reference manual that identifies the major, basic design elements and criteria to which the cable, cable vessel and cable handling equipment subsystems must operate. It is NOT a final design criteria manual, and is NOT meant to replace detailed technical reports, drawings or specifications. It is intended to be used as a quick reference document for the subsystem listed above.

# PART 2

# ENVIRONMENTAL AND ROUTE FACTORS

## Environmental Factors

The design environmental criteria/conditions that apply to the Alenuihaha Channel are as listed below. All equipment and operations are to function under these conditions.

### Winds

The following information was generated by Haraguchi (Pacific Weather, 1986) from field measurements and literature comparisons.

Tradewinds are persistent during the summer months but are reduced to near 50% during the winter months. The average monthly wind speeds are strongest for the summer months and weakest for winter and fall months. However, the strongest daily tradewinds occur during winter and spring months when very strong high pressure cells pass from the west to east north of the islands. Figures 2-1 and 2-2 show the seasonal variations of the winds from the NWS Upolu Station based on two years of data.

The NWS Upolu Station is automatically queried every hour and the 1-minute sustained wind speed and peak gust data are available for operational use at the Honolulu office of the NWS. Unfortunately, the wind speed from this station has significant error in characterizing the channel winds because of the sensor location and land effects. Thus, another Upolu Point wind station (Upolu 38) was established for about one year in a more exposed location. Average monthly wind speeds from Upolu 38 are significantly higher than the NWS Upolu winds. Figure 2-3 compares the monthly % frequency of time in which the sustained winds are $\leq$20 knots for the NEW Upolu and Upolu 38 stations.

From Haraguchi's data, an operational design tradewind speed of 30 knots is established. A sustained tradewind speed of 30 knots is expected to be exceeded less than 5% of the time during a typical year. An operational design Kona wind speed of 25 knots is established. Southerly to westerly winds occurred only about 16% of the time during the 2-year data period. Of the times when Kona winds occurred, a sustained speed of $\geq$25 knots occurred less than 5% of the time.

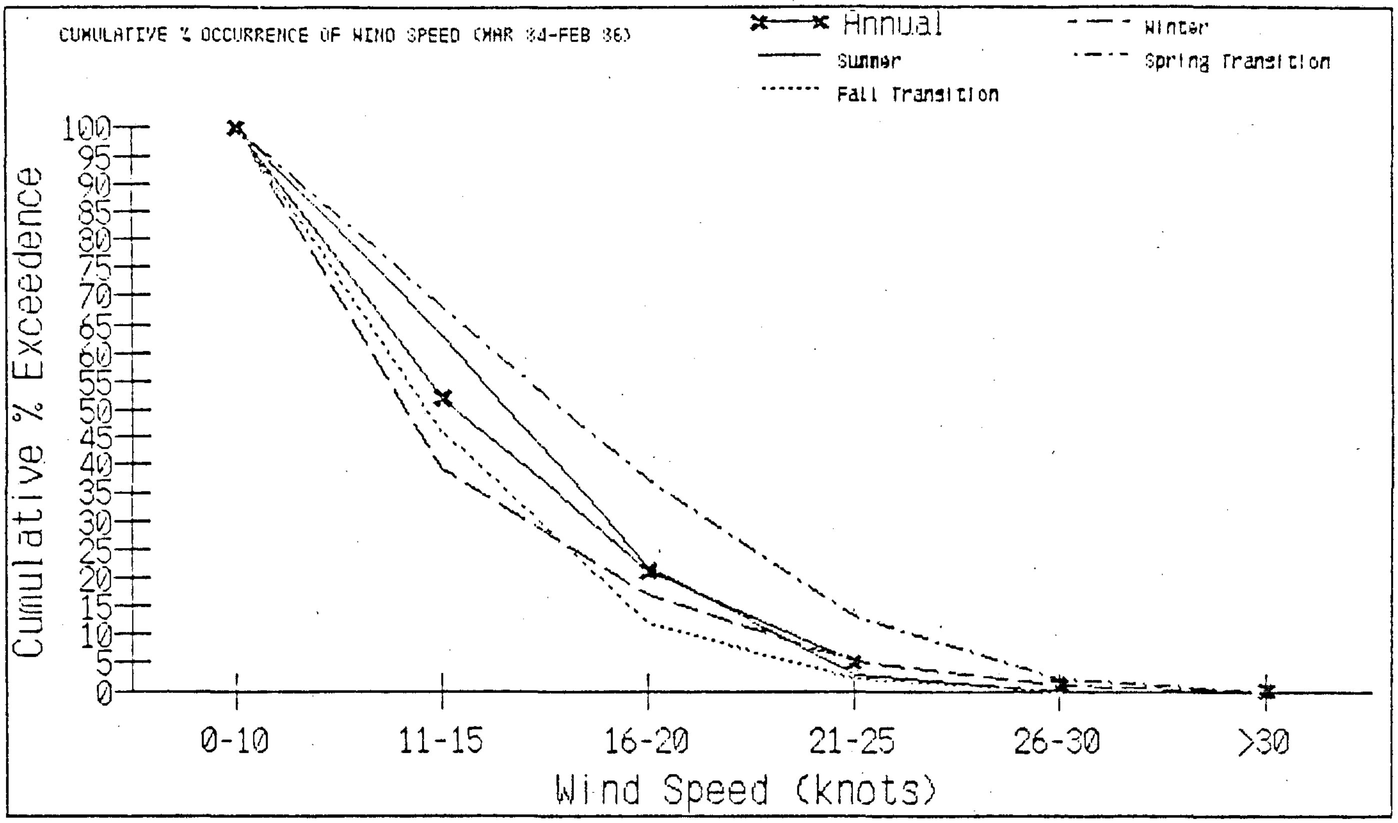



Figure 2-1 Cumulative percent frequency of exceedence of wind speed from NWS Upolu Station (March 1984-February 1986)

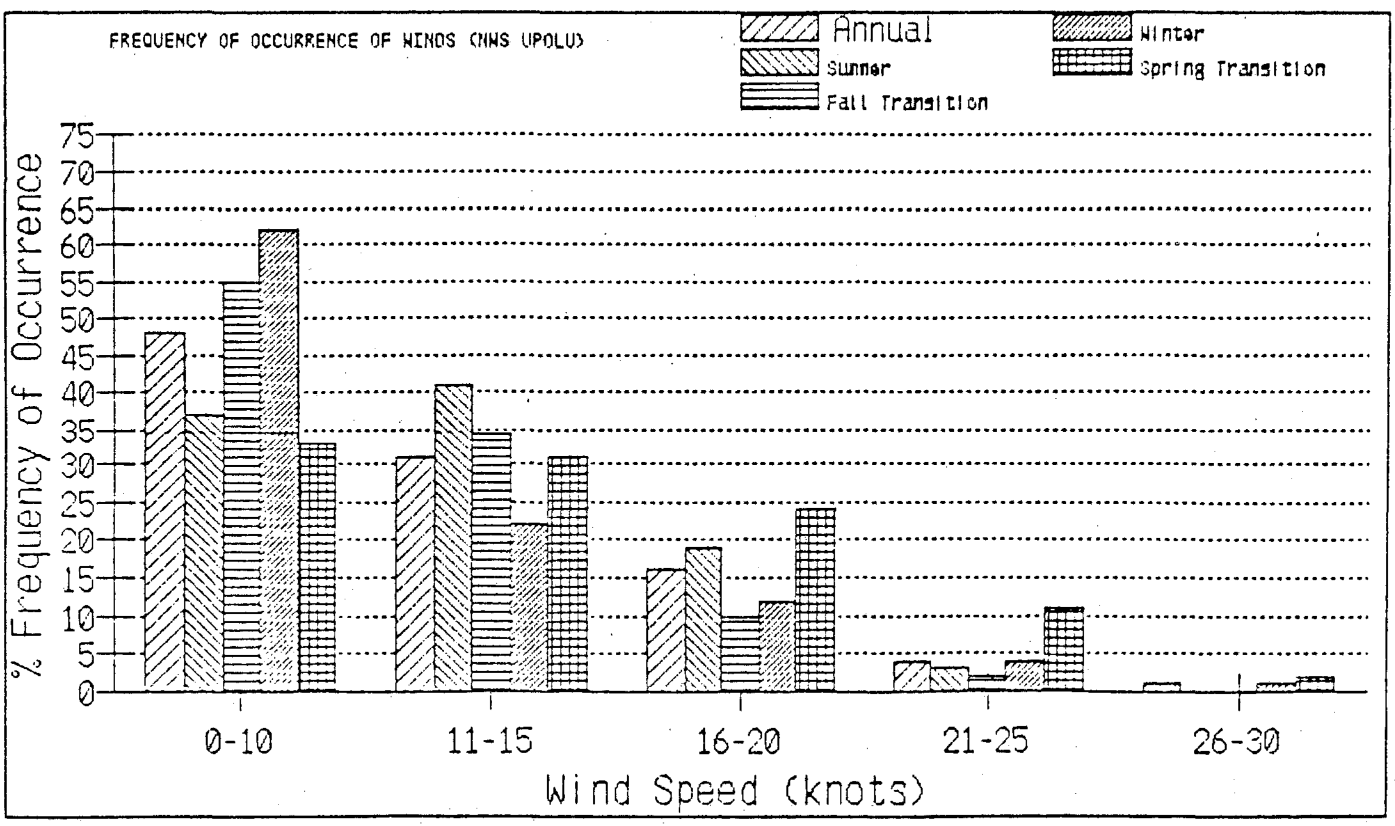



Figure 2-2 Annual and seasonal percent frequency of occurrence distributions of wind speed from the NWS Upolu Station

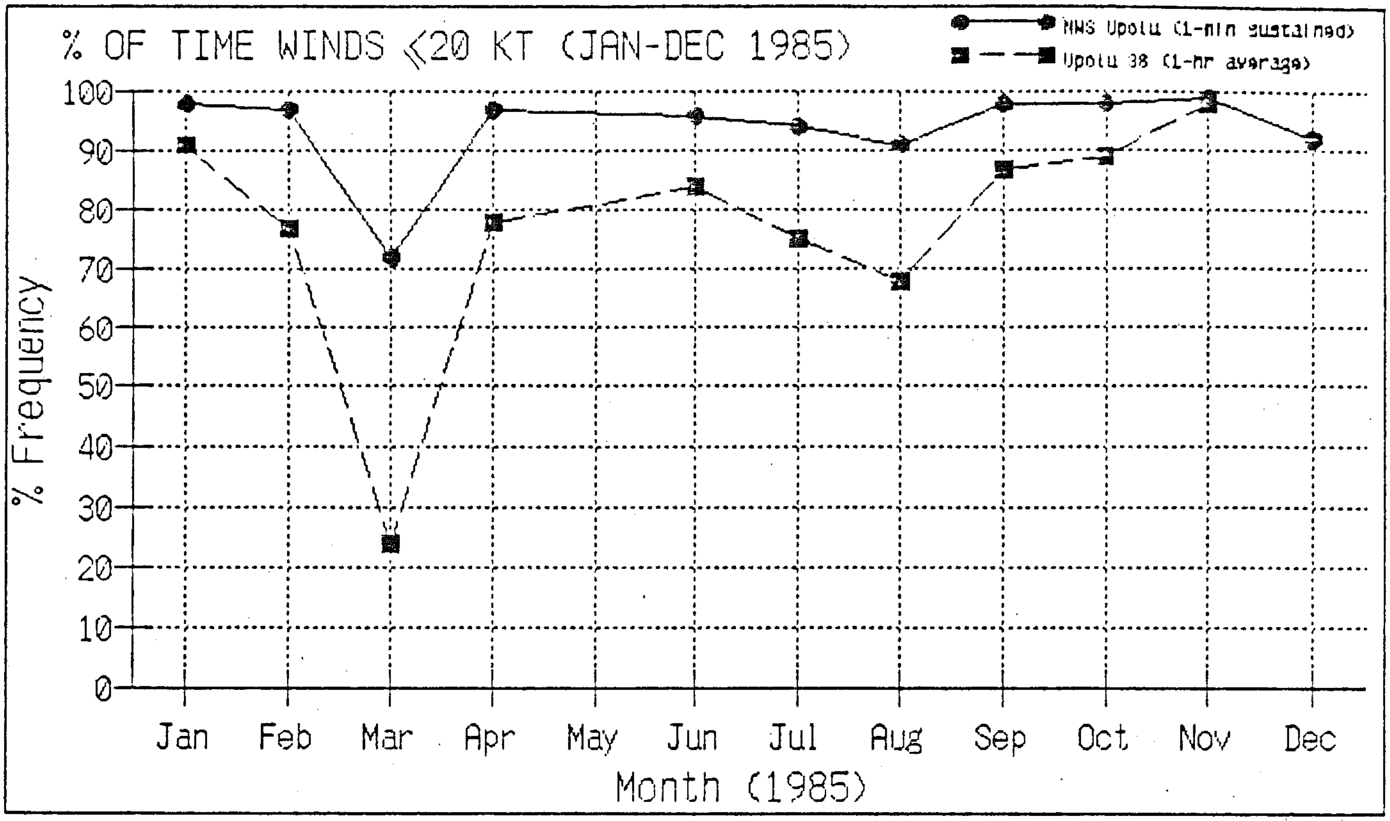



Figure 2-3 Comparison of monthly % frequency of time sustained winds ≤ 20 knots from NWS Upolu and Upolu 38 Stations

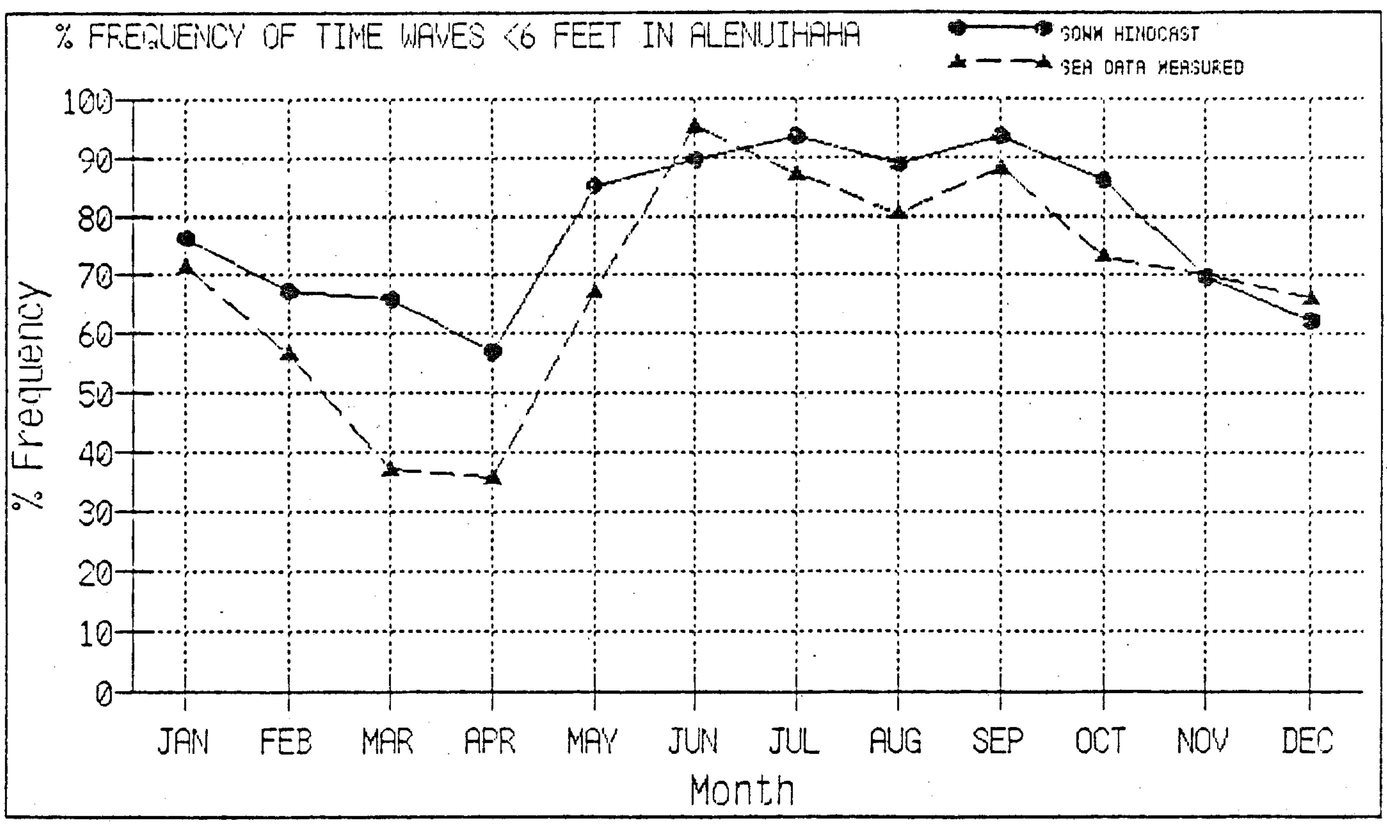



Figure 2-4 Monthly % frequency of time waves <6 feet in the Alenuihaha

## Waves

Operational wave criteria are summarized in Noda (1986) from field measurements and literature comparisons.

The wave climate in Hawaiian waters is characterized by two primary seasons: summer and winter. The summer wave climate is dominated by the strong northeasterly trade-wind-generated waves as well as southern swell generated by distant winter storms in the southern hemisphere. In the Alenuihaha Channel, the high-energy tradewind waves predominate over the low energy southern swell. However, these two wave types can occur simultaneously. The winter wave climate is characterized by a weakening of the tradewinds and the occurrence of infrequent southwesterly "Kona" storm waves as well as frequent northwesterly swell generated by winter storms in the North Pacific or by mid-latitude low pressure systems. The Alenuihaha Channel is somewhat sheltered from the northwesterly swell by the island of Maui, but is directly exposed to southwesterly waves.

In order to determine which month(s) are most favorable for deployment operations, Figure 2-4 shows the cumulative percentage of time that significant wave heights are ≤6 feet on a monthly basis. From this figure, it appears that the summer months of June through September are the most favorable in terms of significant wave heights being less than 6 feet about 80% or more of the time.

Since the wave climate varies seasonally, the operational design wave will be expected to vary depending on the time of year. The operational design wave is defined here as the significant wave height that is expected to be exceeded about 10% of the time during any given month. The design period is given as the range of average wave periods associated with the given design wave height. Table 2-1 lists the monthly operational design wave conditions.

**Table 2-1**

**ALENUIHAHA OPERATIONAL DESIGN WAVES**
**(EXCEEDED 10% OF THE TIME)**

| Month | $H_s$ (ft) | T (sec) |
|---|---|---|
| Jan | 8.6 | 4-10 |
| Feb | 9.4 | 6-10 |
| Mar | 11.1 | 6-10 |
| Apr | 10.0 | 4-8 |
| May | 7.8 | 4-8 |
| Jun | 6.1 | 4-6 |
| Jul | 6.6 | 4-6 |
| Aug | 6.8 | 4-6 |
| Sep | 6.2 | 4-8 |
| Oct | 7.6 | 4-10 |
| Nov | 8.8 | 4-8 |
| Dec | 9.8 | 4-8 |

The significant wave height ($H_s$) is defined as the average of the highest 1/3 of all wave heights. Thus, wave heights higher than the significant wave height occur simultaneously within the wave spectrum. Assuming a Rayleigh distribution of heights, the highest one percent of all waves is $H"_L"=1.67H_s$. This would mean, for example, that for a given sea state described by a significant wave height of 6 feet, the range of wave heights between $H_s$ and $H"_L"$ is 6-10 feet.

**Currents**

Coastal currents in the vicinity are typically comprised of the following components:

Tidal currents
Wind-driven currents
Eddy currents
Background oceanic currents

The relative magnitudes of these components vary depending on the particular location, distance from shore, and also vertically with depth.

Available current data in the Alenuihaha Channel indicate that the currents are primarily driven by the tides and winds, and are influenced by eddy currents. Eddy currents, while being a predominant component in waters west of Hawaii, are not as dominant a feature within the channel itself. It is postulated that strong winds blowing through the channel may be the mechanism for eddy formation. However, fully developed eddies do not "live" within the confines of the channel, although they may influence the near-surface currents within the channel.

Currents in the Alenuihaha Channel below about 300-400 meter depth are primary driven by the tides. These tidal currents rotate in direction, with peak currents occurring towards the ENE and WSW. The period between peak currents is between 6 and 12 hours corresponding to the high and low tide cycles of the semi-diurnal and diurnal tidal constituents. Currents in the upper 300-400 meter depth are influenced by wind-driven and eddy currents. These currents are superimposed on the tidal currents.

The tidal currents within the channel are influenced by bathymetry, and hence vary depending on location. For the proposed cable route, which crosses the channel nearly perpendicular to the bottom contours, the peak tidal currents are expected to flow nearly perpendicular to the cable axis. Based on correlations between the current meter data and the XCP vertical profiles, Table 2-2 gives the estimated peak tidal currents along the proposed cable route. These currents are provided as a function of nominal bottom depth along the cable route. Largest tidal currents occur in shallower water depths at the edges of the channel and on the steep Kohala slope in mid-channel. An interpolation of peak tidal currents along the proposed cable route is shown in Figure 2-5.

Table 2-2

**ESTIMATED PEAK TIDAL CURRENTS ALONG THE PROPOSED CABLE ROUTE, ALENUIHAHA CHANNEL**

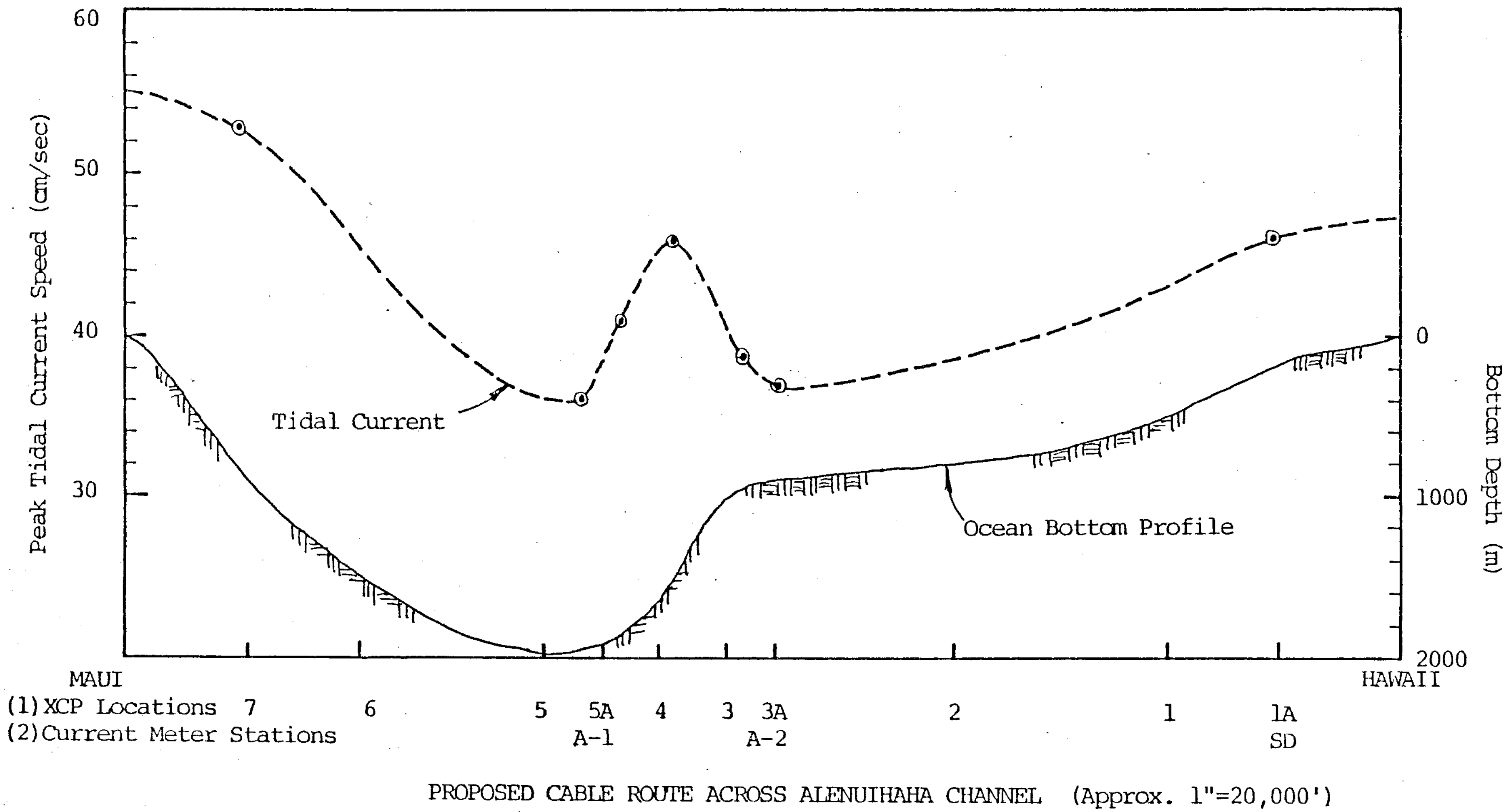
| Location | Bottom Depth (m) | Speed (cm/sec) |
|---|---|---|
| Offshore Upolu Pt | 170 | 46 |
| | 500 | 43 |
| | 800 | 39 |
| Top of Kohala Slope | 900 | 37 |
| | 1000 | 39 |
| | 1600 | 46 |
| Bottom of Kohala Slope | 1900 | 41 |
| | 2000 | 36 |
| | 1500 | 45 |
| Maui Slope | 900 | 53 |
| | 200 | 55 |

Note: Peak tidal currents can flow towards ENE or WSW, generally perpendicular to contours. Typical direction is $70^{o}$T/$250^{o}$T along cable path.

Mean background oceanic currents are also evident in the channel. These currents are superposed on the tidal currents and can occur in either an east-northeasterly or westerly direction, with an apparent period of oscillation of about 20-25 days. A background oceanic current of 10 cm/sec is assumed for the operational current criteria.

Currents in the Alenuihaha Channel in the upper 200-300 meters are influenced by wind-driven and eddy currents. Wind-driven currents are on the order of 2% of the wind speed near the surface, decreasing exponentially with depth. The direction of the surface current is $45^{o}$ cum sole from the direction of the wind, with the direction deflected clockwise with depth so that at a depth $z = D$, the direction is opposite to the surface current. At this depth D, which is about 200 meters for a wind speed of 30 knots, the current speed is only about 4% of the surface current speed. The wind-induced operational currents are given in Table 2-3 for strong tradewind and Kona wind conditions.

For the purpose of defining a design operational eddy profile, we assumed a mean eddy current uniform in speed and direction within the upper 50 meters, decreasing linearly to zero at 200 meter depth. The speed of the near-surface eddy current decreases from a maximum of 70 cm/sec on the Hawaii side of the channel to 20 cm/sec on the Maui side. Table 2-4 lists the estimated peak operational eddy currents along the proposed cable route.




(1) XCP locations are approximate and vary somewhat with each drop due to method of positioning.
(2) A-1, A-2 = Aanderaa near-bottom stations, SD = Sea Data near-surface station

Figure 2-5 Estimated peak tidal currents along the proposed cable route, Alenuihaha Channel

## Table 2-3

## OPERATIONAL WIND-INDUCED DESIGN CURRENTS FOR TRADEWIND AND KONA WIND CONDITIONS

TRADEWIND CONDITIONS
Sustained wind speed 30 knots
Wind direction from 70 $^{\circ}$T

| Depth (m) | Speed (cm/sec) | Direction ($^{\circ}$T) |
|---|---|---|
| 0 | 33.3 | 295 |
| 25 | 22.4 | 318 |
| 50 | 15.1 | 340 |
| 75 | 10.2 | 3 |
| 100 | 6.9 | 25 |
| 125 | 4.6 | 48 |
| 150 | 3.1 | 71 |
| 175 | 2.1 | 93 |
| 200 | 1.4 | 116 |

KONA WIND CONDITIONS
Sustained wind speed 25 knots
Wind direction from 225 $^{\circ}$T

| Depth (m) | Speed (cm/sec) | Direction ($^{\circ}$T) |
|---|---|---|
| 0 | 27.7 | 90 |
| 25 | 17.3 | 117 |
| 50 | 10.8 | 144 |
| 75 | 6.7 | 171 |
| 100 | 4.2 | 198 |
| 125 | 2.6 | 226 |
| 150 | 1.6 | 253 |
| 175 | 1.0 | 280 |
| 200 | 0.6 | 307 |

## Table 2-4

**ESTIMATED PEAK OPERATIONAL EDDY CURRENTS ALONG THE PROPOSED CABLE ROUTE, ALENUIHAHA CHANNEL**

| Location | Bottom Depth (m) | Speed (cm/sec) | Direction (°T) |
|---|---|---|---|
| Offshore Upolu Pt | 170 | 70 | 45 |
| | 500 | 65 | 50 |
| | 800 | 54 | 50 |
| Top of Kohala Slope | 900 | 45 | 50 |
| | 1000 | 44 | 50 |
| | 1600 | 40 | 50 |
| Bottom of Kohala Slope | 1900 | 38 | 60 |
| | 2000 | 34 | 80 |
| | 1500 | 25 | 115 |
| Maui Slope | 900 | 20 | 125 |
| | 200 | 16 | 130 |

Note: Eddy current given is the mean current within upper 50 meters. The eddy current is assumed to decrease linearly to zero at 200 meter depth.

**Summary of Environmental Factors**

Winds and waves vary seasonally while currents do not show a significant seasonal trend, as generally depicted in Figure 2-6. In this figure, significant wave heights <6 feet are expected to occur 81% of the time during the summer months, decreasing to 66% of the time during the winter months and 36% of the time during the spring months. Wind speeds <20 knots (measured at the NWS Upolu Station) are expected to occur about 97-99% of the time during the summer and fall months, decreasing to less than 90% of the time during the spring. Near-surface current speeds <50 cm/sec are expected to occur about 70% of the time throughout the year. From this data, the least favorable time of year for deployment operations is in the spring (March-April). Tradewinds are gusty and high wave conditions result from the combination of tradewind generated seas and late winter as well as early summer swell. The most favorable time of year is during the summer months when typical tradewind waves predominate.

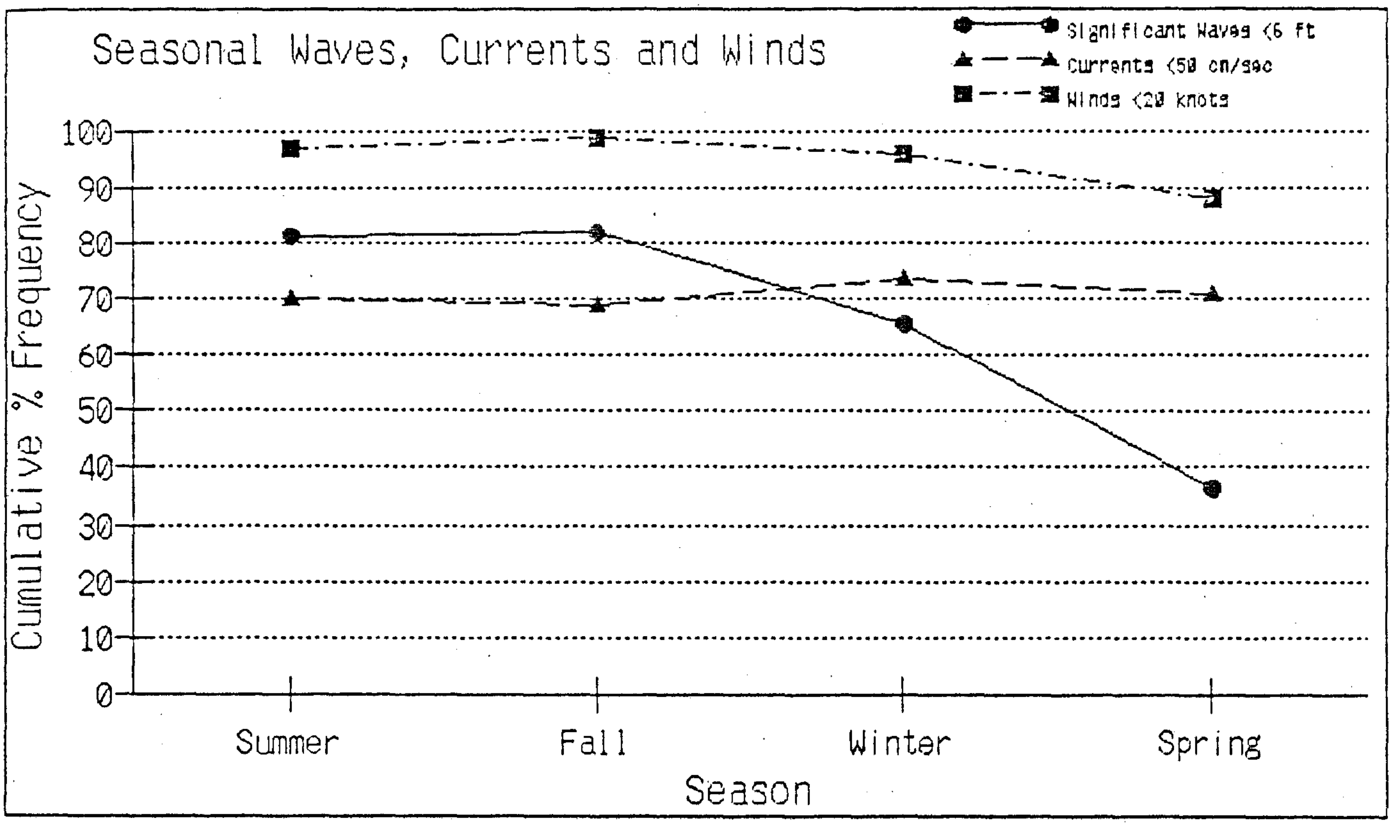



Figure 2-6 Seasonal variation of winds, waves and currents in the Alenuihaha Channel offshore Upolu Point

## Route Factors

Worst case thermal bottom conditions are as follows (H1G, 1983).

| MAXIMUM AMBIENT (degrees C) | COVER DEPTH (m) | THERMAL RESISTIVITY (c-cm/W) |
|---|---|---|
| 25 (77 degrees F) | 3 (9.8 ft) | 150 |
| 14 (57 degrees F) | 10 (32.8 ft) | 150 |
| 3 (37 degrees F) | 100 (320.8 ft) | 150 |

Sea bottom conditions around the Hawaiian Islands are unstable due to earthquakes, landslides, turbidity flows, volcanoes, etc.

Figure 2-7 is a composite drawing of a possible route from Hawaii to Oahu. Table 2-5 summarizes distances along segments of this route. The following subsections excerpt results of the most significant seafloor and terrestrial surveys which contributed to definition of this possible route.

**Table 2-5**

**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 | 1O | OH | 5 | 3 |
| | | TOTAL OVERHEAD | | 212 | 131 |
| | | TOTAL SUBMARINE | | 221 | 138 |

PERCENTAGE SUBMARINE = 51%

LONGEST SUBMARINE RUN = 154 km

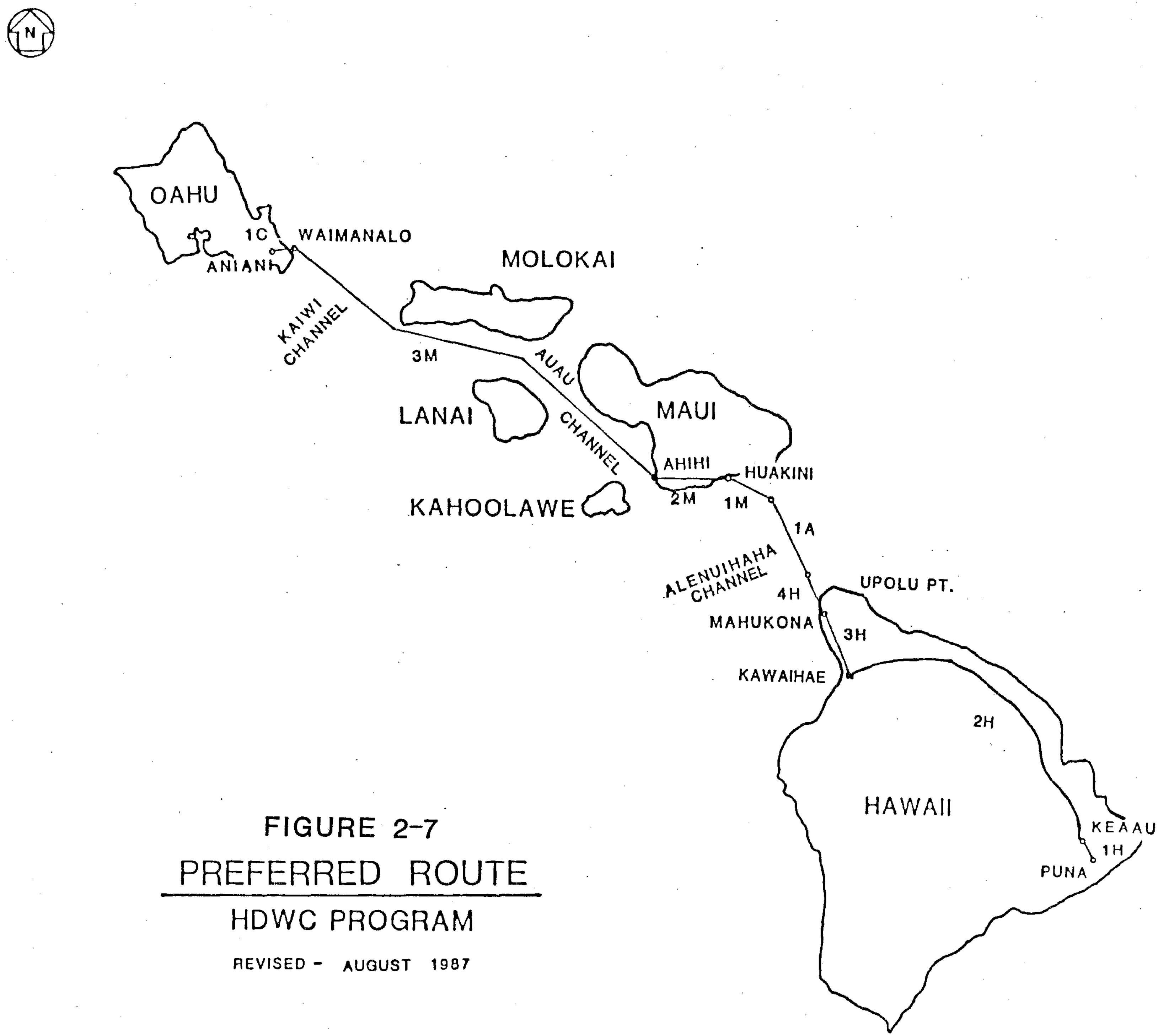



FIGURE 2-7

PREFERRED ROUTE

HDWC PROGRAM

REVISED - AUGUST 1987

**Submarine Route Segments**

The general nature of the bottom of the Alenuihaha Channel was characterized in several University of Hawaii surveys using side-scan sonar and bathymetric mapping. These studies served to identify the roughest areas of the cable route which were later studied in greater detail in the First Bottom Roughness Survey (MOE, EKNA and HIG, 1986). Figure 2-8 summarizes potential routes identified in that work. This survey found two very hazardous areas, one on the Kohala side of the channel and one on the Maui side of the channel, which necessitated an even more detailed survey, the Second bottom Roughness Survey (MOE and Scripps, 1987). Figure 2-9 is the final route across the channel recommended in that report. Figures 2-10 and 2-11 are more detailed drawings of the critical areas of the Maui and Kohala slopes, respectively. Key conclusions and recommendations of the Second Bottom Roughness Survey are as follows.

ROUTE LOCATION AND CABLE LAYING

- o A continuous path, but not an easy one, has been found that may be adequate for a commercial cable across the Alenuihaha Channel.
- o The path width, required bottom cable laying tensions and the bottom roughness have been defined for this selected cable route.
- o Precision cable laying will be required on both the Maui and the Kohala sides of the channel, but more so on the Maui side for accuracy, more so on the Kohala side for tension.
- o The bathymetry along a survey track has an accuracy of 10 m and the multiple surveys agree within 5 m.
- o Key obstacles are located to a 10 m accuracy, possibly better.
- o The positioning and bathymetry is adequate for laying the test cable except for possibly tying in the key obstacles into the cable laying navigation grid just prior to the cable lay.
- o The bottom of the recommended cable path is primarily smooth, spans are not a problem and low cable laying tension is not required except at the top of the Kohala slope where a low tension of 1000 kg is recommended. All other locations along the path have a recommended cable tension of 3000 kg or less.
- o As concluded in the first cruise, it is better to lay the cable at a low tension rather than a high one to avoid unacceptable spans.

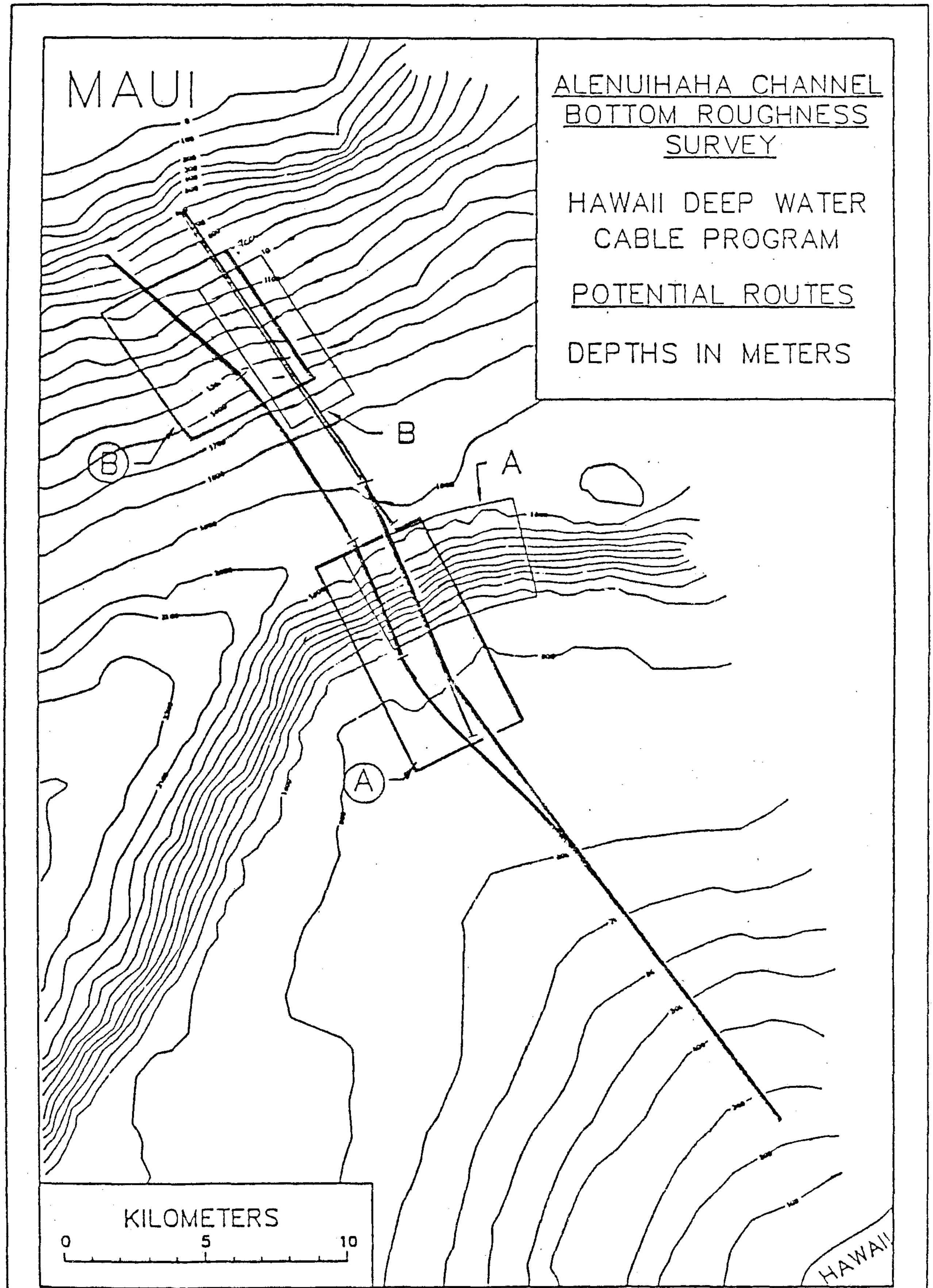

MAUI
ALENUIHAHA CHANNEL BOTTOM ROUGHNESS SURVEY
HAWAII DEEP WATER CABLE PROGRAM
POTENTIAL ROUTES
DEPTHS IN METERS
B
B
A
A
KILOMETERS
0
5
10
HAWAII

Figure 2-8

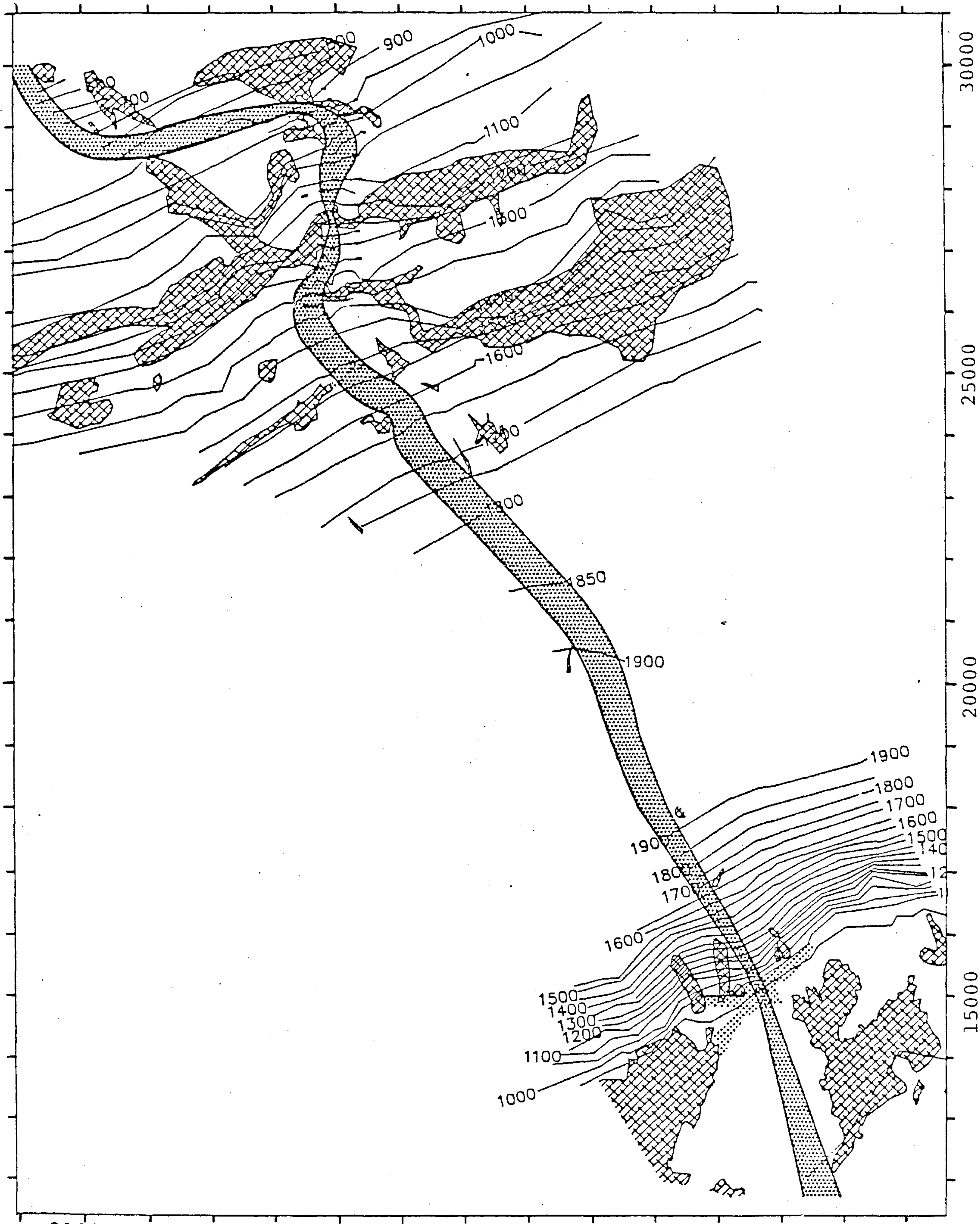



Figure 2-9 Cable Path across Alenuihaha Channel

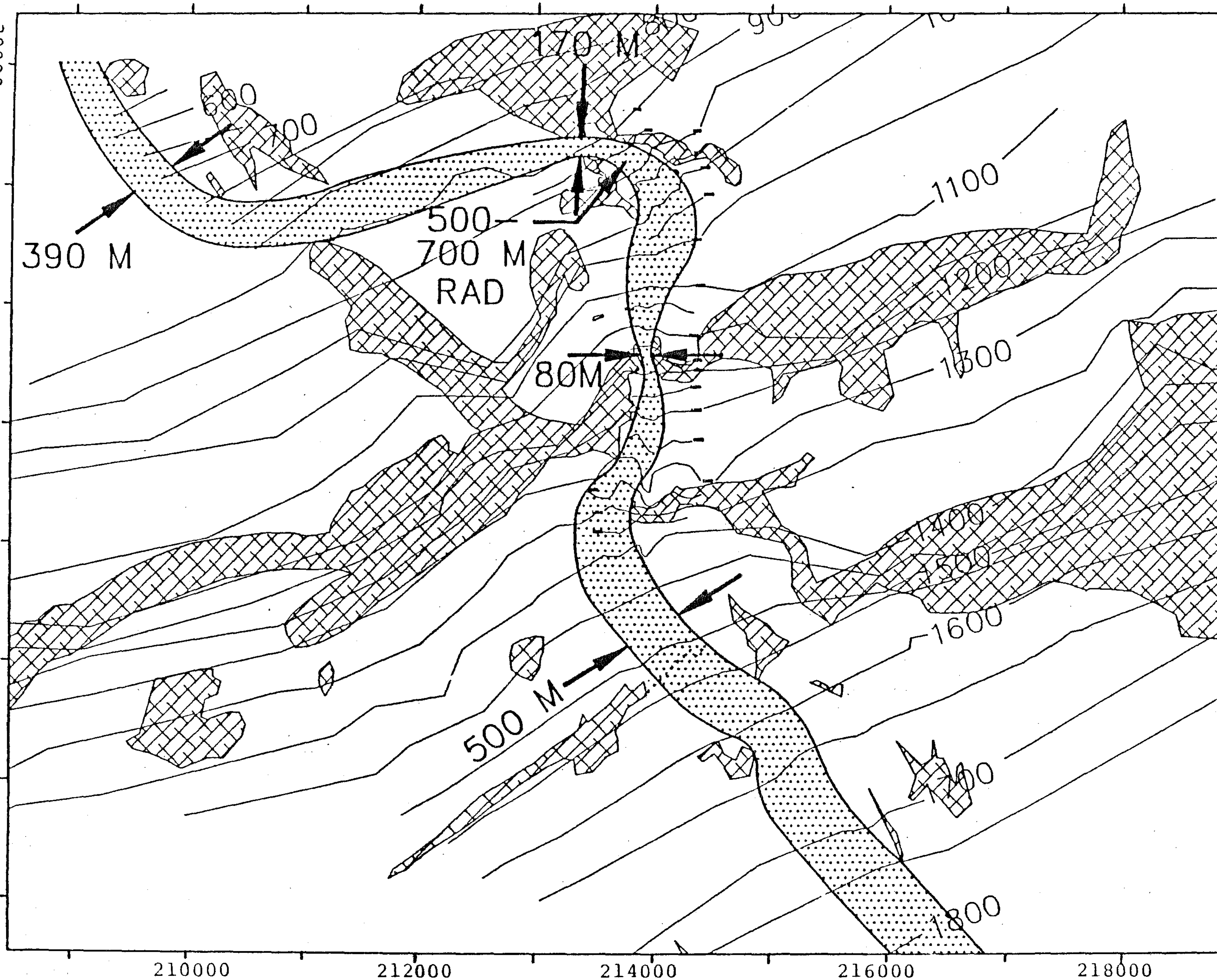



Figure 2-10 Final Recommended Cable Path for the Maui Slope
with Critical Widths Indicated

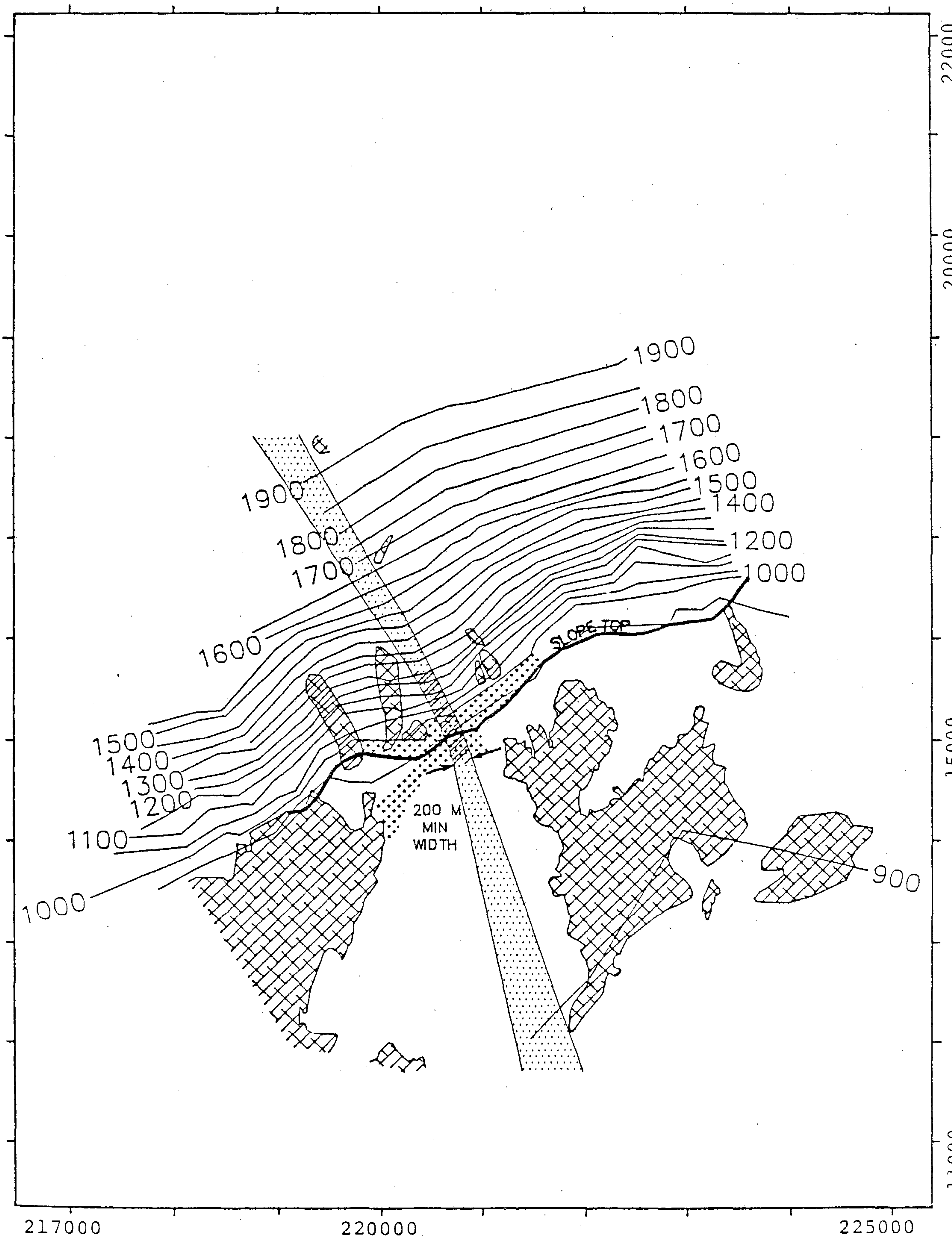



Figure 2-11 Final Recommended Cable Path for the Kohala Slope With Critical Widths & Cable Tensions Indicated. Hatched Path Area Requires Low Cable Tension at 1000 Kg.

MAUI SLOPE

- The Maui slope region above the saddle area in the Alenuihaha Channel is a complex series of terraced escarpments through which it was difficult to wind a continuous path.

- As a result of the excellent agreement between sidescan, precision bathymetry and Sea MARC, the surveyed portion of the Maui slope is now known well and an overall map of this region has been prepared.

- Major obstacles on the Maui slope occurred at the 1000 m level, 1200 m level and 1500 m level.

- The bottom of the recommended path is smooth in all regions and cables can be laid at a tension up to 5000 kg without unacceptable spans. 3000 kg or lower tensions are recommended, if possible.

- The path width is 400 m and wider in most locations with the exception of a narrow portion at 900 m depth which is 170 wide and the narrowest portion at 1200 m depth which is 80 m wide.

- The recommended Maui path is not straight with the sharpest bend occurring at 1000 m depth at a 500 m to 700 m turning radius.

- The shallowest portion of the recommended path is 550 m; the survey did not extend inshore of this point.

- Much of the survey time was spent searching for alternate cable paths and extending the search far to the east and the west of the originally planned area. Orienting the Sea MARC data relative to the Deep Tow tracks during the post-cruise analysis indicated that there are potential routes both further to the east and the west of the actual search area and one possible route short-cutting the sharp bend radius at 1000 m in the proposed cable path. Neither of these potential routes can be confirmed on the basis of the present data.

- For the search area covered, it is unlikely that there is an alternate acceptable path in the 1200 m to 1500 m region.

## KOHALA SLOPE

- The Kohala side of the channel is more easily defined with one single steep slope from 930 m to 1930 m and with several lava flows at the top of the slope.

- The lava flows at the top of the slope and the considerable roughness at the top edge of the slope are the major restrictions to a cable path.

- The lower portions of the Kohala slope were predominantly smooth.

- A path cannot be found across the top of slope that is free of unacceptable spans for a cable laid at 3000 kg or greater.

- The only means found of crossing the upper portion of the Kohala slope without an unacceptable cable span is to lay the cable at a low tension of 1000 kg or less.

- The acceptable width of the Kohala path at the top of the slope is difficult to determine by sidescan since it is only a qualitative tool and the area has some roughness. The final selected width of 200 m encompasses the region traversed by 5 seperate survey tracks.

- Alternate paths along the Kohala slope were considered but not found to be acceptable. An attempt was made at a path far to the east but that proved unacceptable. This survey did not prove, however, that an acceptable path does not exist in this region.

## CHANNEL BOTTOM

- The bottom of the channel is predominantly smooth, sediment covered on the Kohala side and with some small scale rubble on the Maui side.

- A wide, fairly straight path has been found across the channel bottom.

RECOMMENDATIONS

- o Although the majority of the cable path has a smooth bottom and no unacceptable spans are expected for cable tensions up to 5000 kg, lower tensions of 3000 kg or less are recommended, if operationally feasible, in order to further minimize the probability of unacceptable spans.

- o An additional survey with a submersible or ROV in the narrow regions on both sides of the channel would help in further understanding the cable path for the HDWC program. This would particularly be valuable at the top of the Kohala slope and at the 1200 m narrow region on the Maui slope.

- o For precise cable laying, it will be necessary to tie in the position of the major constraining obstacles into the cable laying navigation grid prior to laying the cable.

- o Because of the extreme topographic variations, particularly on the Kohala slope, great care will be necessary in the placement of the bottom transponders in any future acoustic navigation grid.

- o Before laying the commercial cable, further surveys of the route should be made concentrating along the selected path & insuring that all areas are 100% covered by sidescan and all questionable targets investigated with a BRS/Deep Tow fine resolution bathymetry system.

The remainder of the submarine route was surveyed by Seafloor Surveys International. The final route between Maui and Oahu indicated by their survey is shown in Figure 2-12. The data indicated that there were areas where critical cable spans occurred off Central Maui, west of Lahaina, north of Lanai, south of West Molokai, and across a submarine canyon off Makapuu, Oahu. Some of the critical spans, for example those off Lahaina, were only present at higher cable tensions and thus would not constitute a barrier to cable installation in these relatively shallow waters.

Special efforts were made to find routes around the steep areas. The potential cable spans off Central Maui, Panels 24 and 27 were due to very large blocks located at the base of the 100 meter reef. Several crossings of the base of this reef were made, and the blocks were found to be a common feature on all the crossings. With considerable searching, a route through the blocks could probably be found, but it seemed more logical to find an alternate route in shallower water where the bottom was expected to be smoother. This alternate route proved quite favorable, and became the preferred route. The calculated cable spans north of Lanai and off Makapuu are located in areas where the route crossed steep-sided submarine canyons. Acceptable routes around the heads of these canyons were found and surveyed.

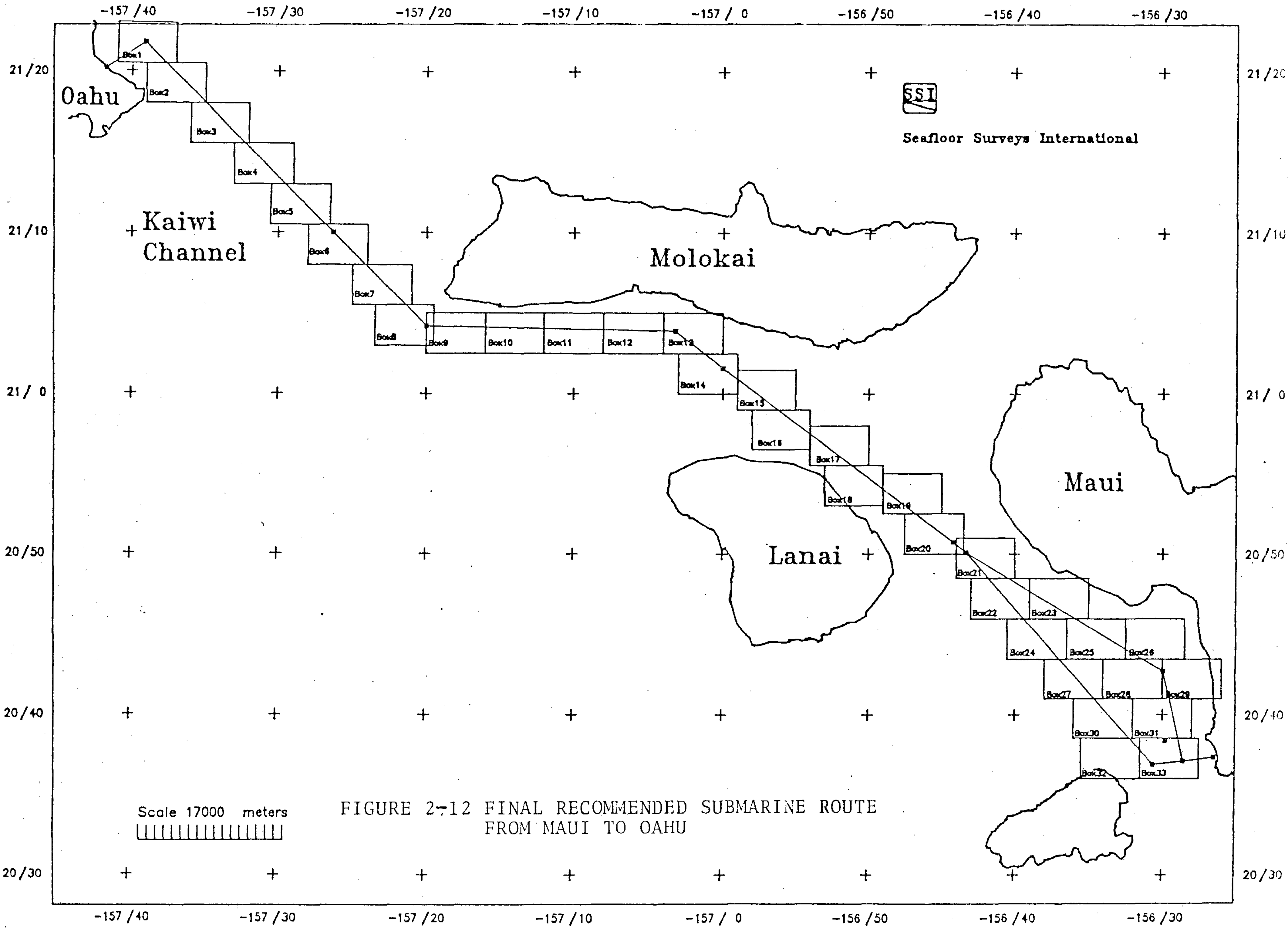



FIGURE 2-12 FINAL RECOMMENDED SUBMARINE ROUTE FROM MAUI TO OAHU

### Bathymetry

The submarine route has been divided into four depth ranges Table 2-6 below). The majority of the submarine route is in relatively shallow water. Approximately 80.5% of the route, or 178 miles, is less than 547 meters (1800 feet) deep. About 27 miles of the route are between 547 and 1094 meters (1800-3600 feet) deep. The deepest portions of the route include 8 miles in the 1094-1641 meters (3600-5400 feet) range and 8 miles in the 1641-2188 meters (5400-7200 feet) range.

**Table 2-6**

**APPROXIMATE DISTANCE WITHIN DEPTH RANGES FOR SUBMARINE ROUTE (KM)**

| | | DEPTH RANGES | | | |
|---|---|---|---|---|---|
| | Feet | 0-1800 | 1800-3600 | 3600-5400 | 5400-7200 |
| | Meters | 0-547 | 547-1094 | 1094-1641 | 1641-2188 |
| | Fathoms | 0-300 | 300-600 | 600-900 | 900-1200 |
| **From** | **To** | | | | |
| Mahukona | Kohala Slope | 27 | 5 | - | - |
| Kohala Slope | Maui Slope | - | 10 | 1 | 8 |
| Maui Slope | Huakini Bay | 7 | 2 | 7 | - |
| Ahihi Bay | Waimanalo | 144 | 10 | - | - |
| | TOTALS | 178 | 27 | 8 | 8 |
| | PERCENT | 80.5% | 12.2% | 3.62% | 3.62% |

### Overland Route Segments

The information on overland route segments should be considered preliminary since there has been no public review or input into the constraint identification process. Readers are requested to not interpret this information as representing any conclusions or commitments to the selection of potential corridors. However, potential overland corridors were identified in two studies by DHM Planners, Inc. (1985 and 1988). The methodology used two steps, as follows:

1) Identification of four specific land uses which should be excluded from further consideration for transmission line corridors. These are termed Exclusion Areas, and they include:

- Natural Area Reserves
- Protective Subzones
- National Parks
- Military Impact Areas

2) Evaluation of 15 specific factors for the degree of constraint they pose to construction of 300 kVdc powerlines. These are termed Constraint Factors, and they include:

- <u>Geophysical</u>

  Slope and Soils
  Geologic Hazards
  Hydrology

- <u>Biological</u>

  Vegetation
  Wildlife

- <u>Socio-Economic</u>

  Recreation
  Land Use
  Transportation & Utilities
  Land Ownership
  Visual Quality
  History and Archaeology
  Land Regulation

- <u>Costs</u>

  Land Value
  Maintenance
  Access

The criteria for designating areas for exclusion, and high, medium or low constraints are based on extensive reviews of data and information concerning each factor. The criteria and rationale are discussed in the report for each factor and the sources of information are provided. The constraint factors represent significant and discrete parameters of environmental sensitivity.

The exclusion areas and constraint factors are delineated using screens on mylar "overlays" placed over United States Geological Survey base maps. When placed on the base map and upon one another the overlays show areas ranging in shades of grey from black to white. "Exclusion areas" are shown as black, "high" constraint areas are dark grey, "medium" constraint areas are light grey and "low" constraint areas are white.

From the composite maps, the areas of "low" constraint are transferred to new maps and designated potential corridors. The potential corridors for Hawaii, Maui and Oahu are shown in Figures 2-13, 2-14 and 2-15, respectively.

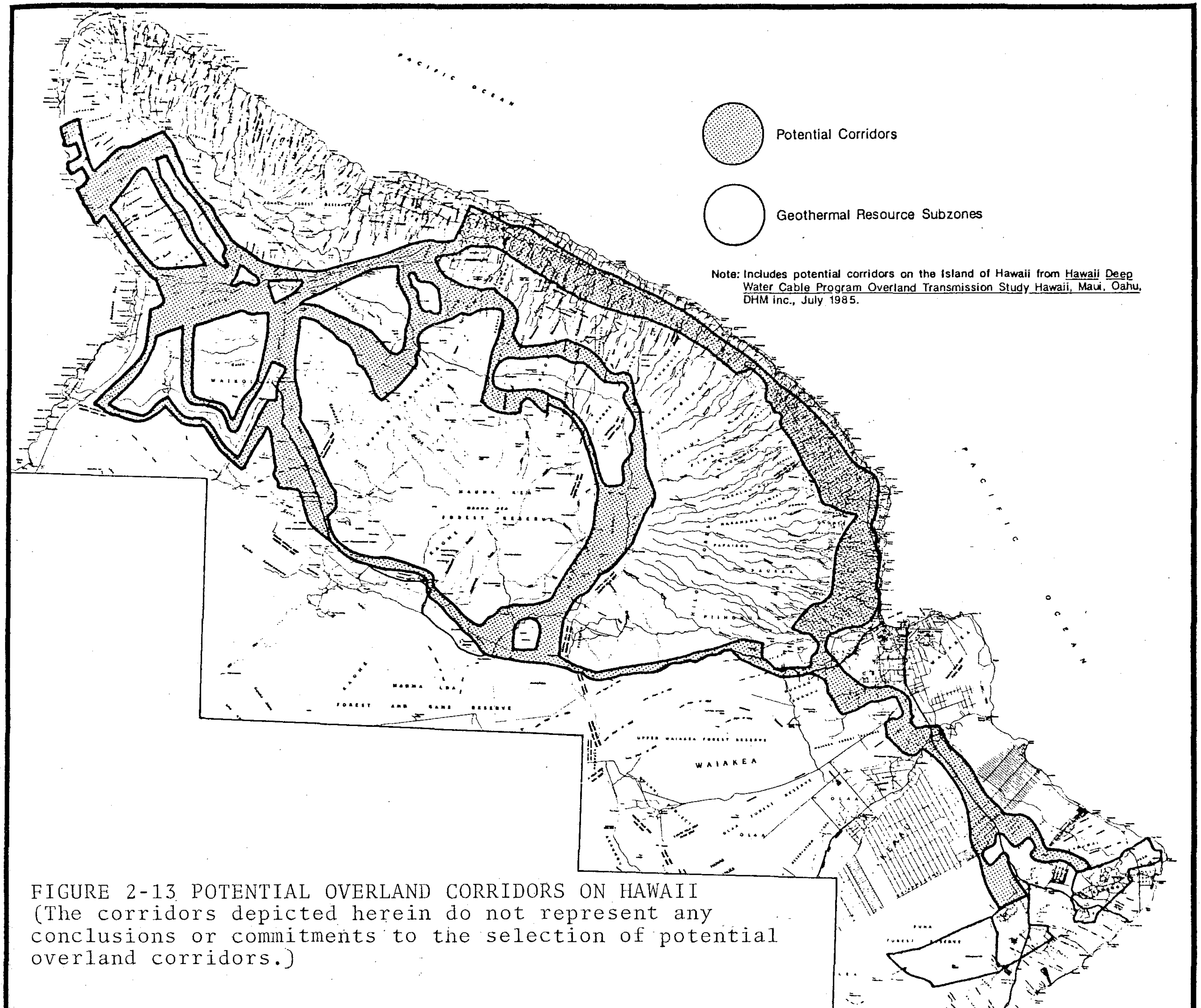



FIGURE 2-13 POTENTIAL OVERLAND CORRIDORS ON HAWAII
(The corridors depicted herein do not represent any conclusions or commitments to the selection of potential overland corridors.)

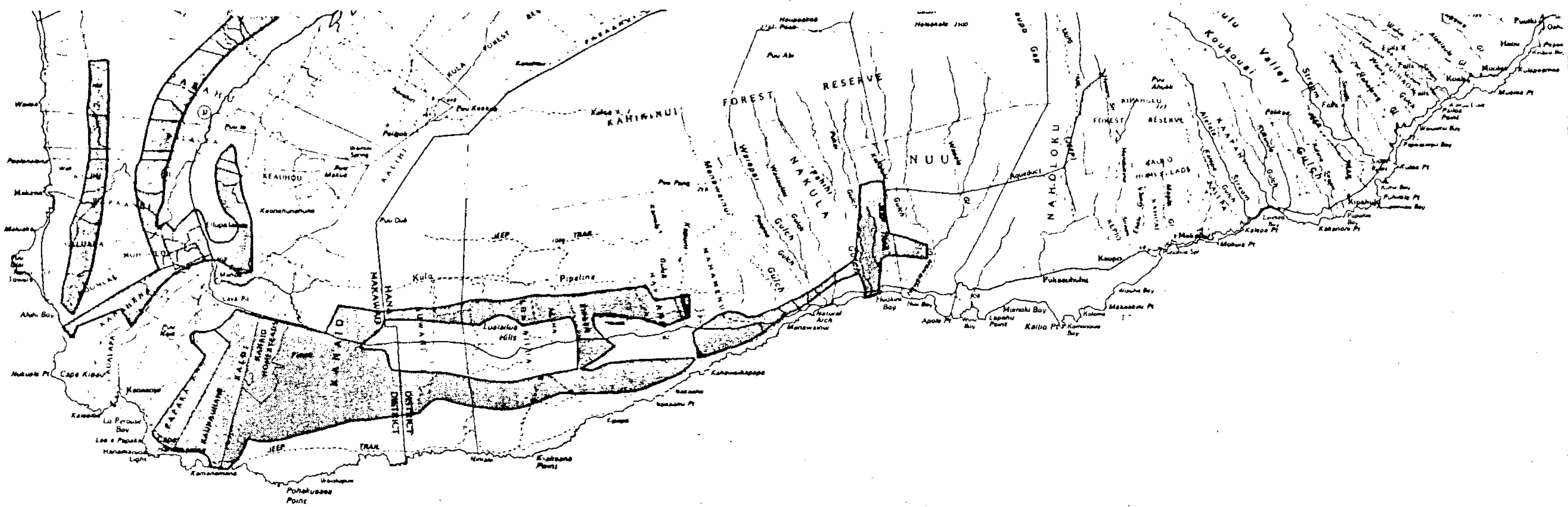
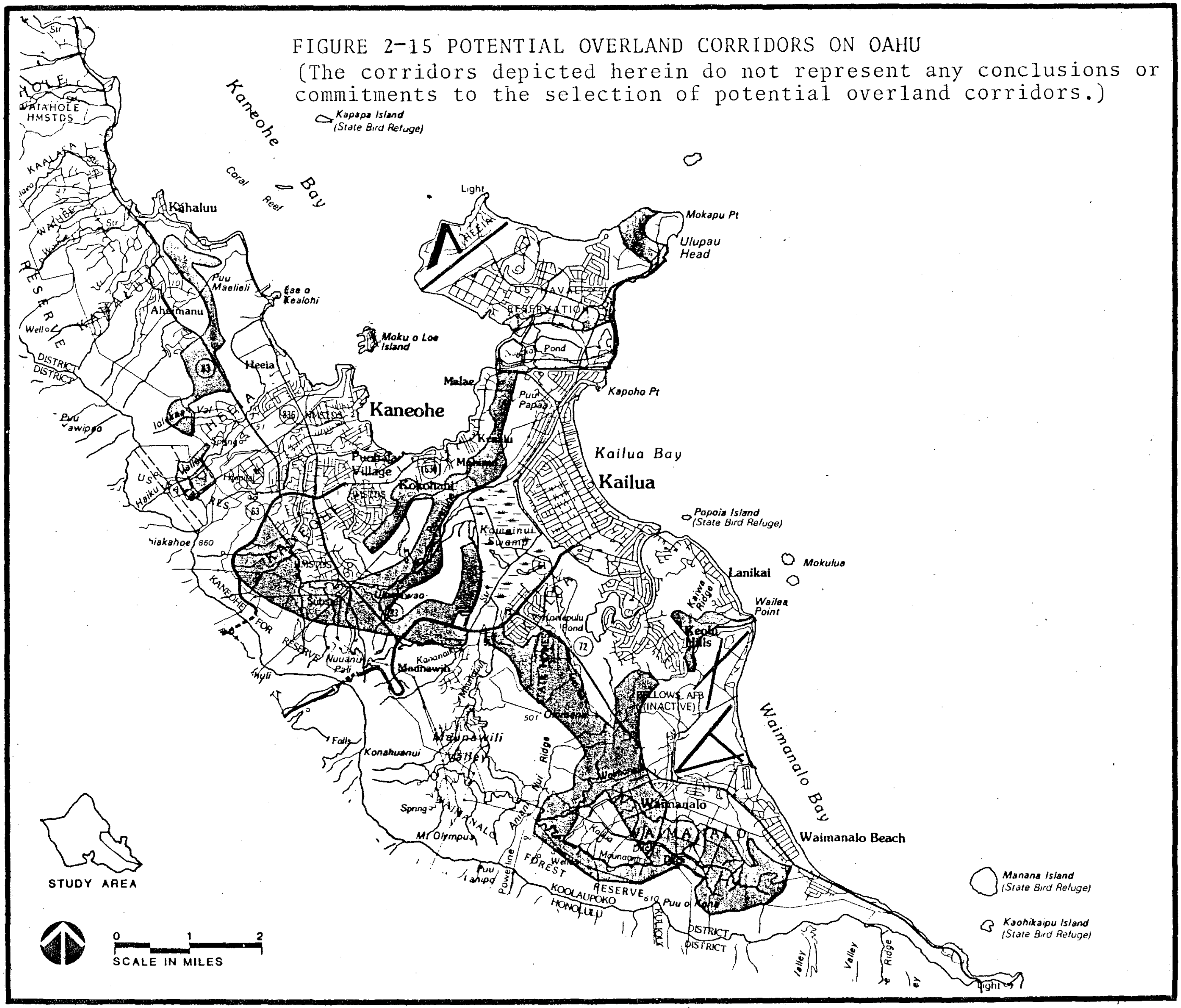




FIGURE 2-14 POTENTIAL OVERLAND CORRIDORS ON MAUI
(The corridors depicted herein do not represent any conclusions or commitments to the selection of potential overland corridors.)

FIGURE 2-15 POTENTIAL OVERLAND CORRIDORS ON OAHU
(The corridors depicted herein do not represent any conclusions or commitments to the selection of potential overland corridors.)



# PART 3

# ELECTRICAL GRID SYSTEM

## Electrical Grid System Design Conditions/Criteria

The basic electrical grid system design conditions and criteria, as they affect the submarine cable system were identified and described by PTI (1984 and 1986) and specified in the System Feasibility Criteria (Parsons, 1985). They are as follows:

- o Maximum loss of power transfer requirement is 500 MW.
- o Maximum loss of power transfer on first single contingency is 125 MW.
- o Daily load swing on the cable system is expected to be from 500 to 200 MW.
- o Present projected annual peak on Oahu is 926 MW in 1992.
- o Annual load growth rate is 0.30 percent per year.
- o Annual minimum projected load on Oahu is 413 MW in 1987.
- o Range of feasible transmission voltages for grid system is 150 to 600 kV.
- o Surge arrestors to have capability to control impulse over-voltages to levels of 2.2 pu of normal system voltage.
- o System BIL requirement (775 kV) based on 20 percent margin between BIL level and highest impulse voltage to be experienced by the cable system. Based on CIGRE standards.
- o Internally and externally generated levels of switching surges on HVDC systems are relatively low. Highest switching surge type phenomenon is typically caused by single line to ground faults on the overhead line which can generate overvoltage levels up to 1.7 pu of system voltage.
- o Polarity reversal is assumed to occur. In the impulse range the reversal will be to a level of 2.15 pu in the reverse direction. In the switching surge and fundamental frequency range the reversal will be to a level of 1.0 pu.
- o A metallic return is considered a requirement for any cable system configuration due to sensitive and critical Department of Defense (DOD) and telecommunication cables.

- All terminal equipment and interconnection facilities will meet the same normal load and single contingency requirement as the cable.

- Commercial cable system to consist of two operating cables and one spare cable.

- Expected low cable outage rate = once every ten years = unavailability of 5 percent.

- Expected high cable outage rate = once every two and one-half years = unavailability of 20 percent.

- Allowable cable outage duration is six months.

- Cable system short circuit current and corresponding duration = 50 kV and one second.

- Assumed cable spacing of 61 to 91.5 m (200 to 300 ft).

Subsequent work by PTI in Phase II-C allowed the following overall Program conclusions and recommendations to be made.

## EVALUATION OF THE GEOTHERMAL DEVELOPMENT

PTI subcontracted with the Ben Holt Company to evaluate aspects of the potential geothermal development. The major conclusions of that study were that:

1) Evaluation of the production cycling potential of the geothermal system, based upon well test data from HGP-A and PGV wells, indicates the possibility that production can be cycled down by 90% in a single phase vapor system and by 60 to 70% in a two-phase system. However, further research and testing is necessary in order to confirm the feasibility of large scale geothermal development in the ERZ and to establish the ability of the reservoir to be cycled.

2) Of the four energy conversion systems evaluated in detail a single-pressure saturated steam cycle proved to be most economic in terms of capital expenditure; the installed costs ranging from $1,794/kW to $2,285/kW.

3) Energy costs were calculated based upon an assumption of a single, private ownership and operation of all plant facilities. The cost of energy was based upon revenue requirements for support of an unleveraged hurdle rate of 15% and for three different load factors. The 1995 bus bar costs of energy for the initial year of operation, 1995, are predicted to be $0.124/kWHr, $0.169/kWHr and

$0.2155/kWHr for the three load factors, 100%, 85% and 75%, respectively. Based upon an 8% annual increase in the forecast price of fuel oil, the HECO production cost for 1995 will be $0.0897/kWHr. For a 4% increase in oil cost the same energy cost is calculated to be $0.062/kWHr.

## ECONOMICS

A re-evaluation of the production and capital costs was performed in order to factor in new oil price forecasts, (4 and 8% escalation rates), new cable and installation costs and to include an evaluation of a smaller, 250 MW scheme. Further, a review of two-cable versus three-cable schemes was made. The results show that:

1) The installation of only two cables instead of three does not increase savings on an annual basis at commencement of the project. The two- and three-cable schemes are identical in cost savings until the year 1999 when the three-cable scheme begins to show lower savings because the cost of financing the third cable is then added. However, as time progresses the difference between the schemes diminishes. For all cases except a low fuel escalation rate coupled with a high FCR, the three-cable scheme has equal or higher savings than the two-cable scheme in the later years because of its higher availability.

2) Reducing the size of the scheme, to 250 MW, as would be expected, results in a reduced capital outlay initially and payback is apparently faster. There are initially negative net savings, however, if the Fixed Charge Rate (FCR) is high enough and/or the fuel price is low enough. The 500 MW scheme makes available more dollars per MWHr imported, on a flat present worth basis, than does the 250 MW scheme for all combinations of parameters.

3) The ratio of dollars saved to energy purchased from the geothermal resource is higher, by about 10% (on a total 20 year present worth basis) with the 500 MW scheme than it is for the 250 MW scheme.

4) While economy of scale makes a 250 MW scheme more expensive, in terms of dollars per installed kilowatt, the 250 MW scheme is more attractive from the financial point of view because of its higher load factor.

OPERATION

The system can be operated with down to only three units on line at minimum load without losing frequency control. They also demonstrate the need for up to 400 MVAr of installed voltage controlled devices. A large percentage of that required total would be installed at the inverter station to supply the inverter (250 MVAr). The rest is a system requirement which can be met in several ways.

- o Installation of switched capacitor banks at strategic locations
- o Additional capacitive support at the inverter controlled by the HVDC control
- o Use of synchronous condensers (rotating machines for reactive power generation)
- o Thyristor switched capacitors
- o Convert redundant generation to synchronous condenser operation

HVDC Configuration

In terms of economics, the specifics of the dc configuration are not of paramount importance. Whether or not a bipole or monopolar arrangement is used, the total amount of equipment and cable will be essentially the same. The bipole is the most efficient configuration as it minimizes ground return and electrode requirements. What is important with a bipole is that the two poles should be independent, that is, no single contingency outage should result in loss of both poles.

The bipole arrangement should, therefore, depend upon duplication of services, such as cooling and auxiliary power supplies, in order to separate operation of the two poles. The complete isolation of the poles, however, is not possible since some communication between them will be necessary. Loss of a pole, for example, will call for an increase in power transmitted on the remaining pole such that effectively only 125 MW of transmission capability is lost. That is no worse than loss of the largest unit in the HECO system, a contingency which will normally be accounted for by spinning reserve.

It is important therefore to recognise that a bipolar arrangement is convenient for minimization of ground return but must be engineered in such a way that the poles are quasi-independent. With a bipole, both electrode requirements and potential interference problems are minimized.

For the HVDC equipment itself, the choice lies between having only one valve-group per pole or two. The former has the advantage of being initially less costly but other factors demand use of two 125 MW valve-groups per pole as opposed to one 250 MW valve-group. Firstly, the project is presently programmed to be developed over about a 10 year period. This allows for building the system in parts. It is convenient to divide the system into four parts, each of 125 MW, in order to match the generation development. This immediately removes the possibility of losing 250 MW whenever a valve-group outage (the most common) occurs. Secondly, during maintenance, which comprises the highest cause of system unavailability, no power is lost with a valve-group out of service since the remaining three valve-groups are sized for a 150% capability. In terms of costs the two valve-group scheme is not necessarily more expensive because half the investment is delayed on each pole.

In terms of cable configuration, previous studies demonstrated the superiority of the three-cable scheme over the four-cable and two-cable schemes in terms of reliability and cost.

Evaluation and preliminary design work was done on the overhead transmission part of the HVDC project. In summary, it was shown that for bipolar structures, guyed towers are the least expensive of the three alternatives studied; those being guyed, self-supporting lattice and steel pole. What was further shown, however, is that it would be less expensive to build two monopolar, wooden structures, (each independently carrying one, 250 MW, pole conductor). These could be constructed on separate Rights-of-Way (ROW) in order to obviate the possibility of losing the entire system as a result of a major line contingency.

The reliability studies, performed during Phase II-B, evaluated the relative performances of schemes with and without a metallic return cable for various operating criteria and quite clearly showed that a scheme with sea return which allows ground current to flow freely would be the most reliable.

MECO TAP

For a tap configuration there are three main parameters associated with its design. They are:

- Series or Parallel tap
- Tap rating
- Tap polarity

In general a series tap is expected to be less expensive than a parallel tap if its rating is about 10% or less of the main bipole rating. Cost information received from manufacturers support this idea but show that the differences are not significant. What will determine the tap type is related to the main bipole structure. If the $\pm 300$ kV bipole is constructed in four stages such that for some time the poles will operate at 150 kV, such operation will obviate the use of a parallel tap or will call for a doubling of its converter transformer turns ratio when the pole voltage increases to 300 kV.

The rating of the tap is a wide open question which can be answered in part by MECO's generation expansion plans. Those plans should specifically define the balance of power, needed on the island, which could be imported.

AC SYSTEMS

The three island systems will need to be connected to the HVDC three-terminal system by modification to their existing networks.

For Oahu, system studies showed that the two probable sites at Aniani and Meadowlands were essentially equivalent in terms of performance and cost of modifying the 138 kV network to accommodate the incoming power. On balance it is seen that the Aniani site is less environmentally sensitive, is closer to the cable landing point and is central to two large load substations at Koolau and Pukele.

Three converter sites on Hawaii were investigated in the system studies. They were at Mahukona on the north-west point of the island, at Kaumana near Hilo and at a site near Puna. The Mahukona site involved crossing the island with ac lines from the geothermal sites to a distant rectifier station. That configuration is very expensive and difficult to operate since it moves the rectifier away from the strength of the system to one of low short-circuit level. A site at Kaumana works well since it is relatively close to the resource. However, it would be best to locate the rectifier station as electrically close as possible to the geothermal units, which suggests a site somewhere in the Puna region.

The MECO network comprises a 69 kV loop which is presently fed from two MECO stations at Maalaea and Kahului; the latter via the low voltage network. The siting for a tap location will in all probability be determined by available space and environmental considerations. Studies have shown that from an electrical viewpoint the tap functions at any point in the southern part of the 69 kV loop. The cable route parallels the southern shore of Maui and so it makes sense that the tap location will be at that side of the island. The criterion should be to select a site as close to Maalaea as possible since this is the central point of the 69 kV network while minimizing the cross-island dc requirements.

## PROJECT SCHEDULE

Figure 3-1 shows a conceptual schedule for a 10 year development plan while Figure 3-2 indicates the relevant configuration stages. The major aspects of the schedule are that;

- Geothermal unit installations progress linearly in time with the first unit being ready for operation as the first part of the transmission system is completed.
- Unit size is 25 MW or 50 MW. The Ben Holt report indicates that a 50 MW unit size is the optimum rating. This is supported to some extent by existing installations.
- The transmission capacity grows with installed capacity.
- The cable availability and timetable is based upon information received from Pirelli.

What is indicated by Figure 3-1 is that the geothermal development drives the overall timetable although that development is arbitrary. From a transmission viewpoint, 500 MW could be transmitted by the time the second cable is commissioned. This highlights the need for an analysis of the possible timetable for source and generation development. That analysis needs to account for financing and investment possibilities since to accelerate the generation program implies significantly greater levels of financing earlier.

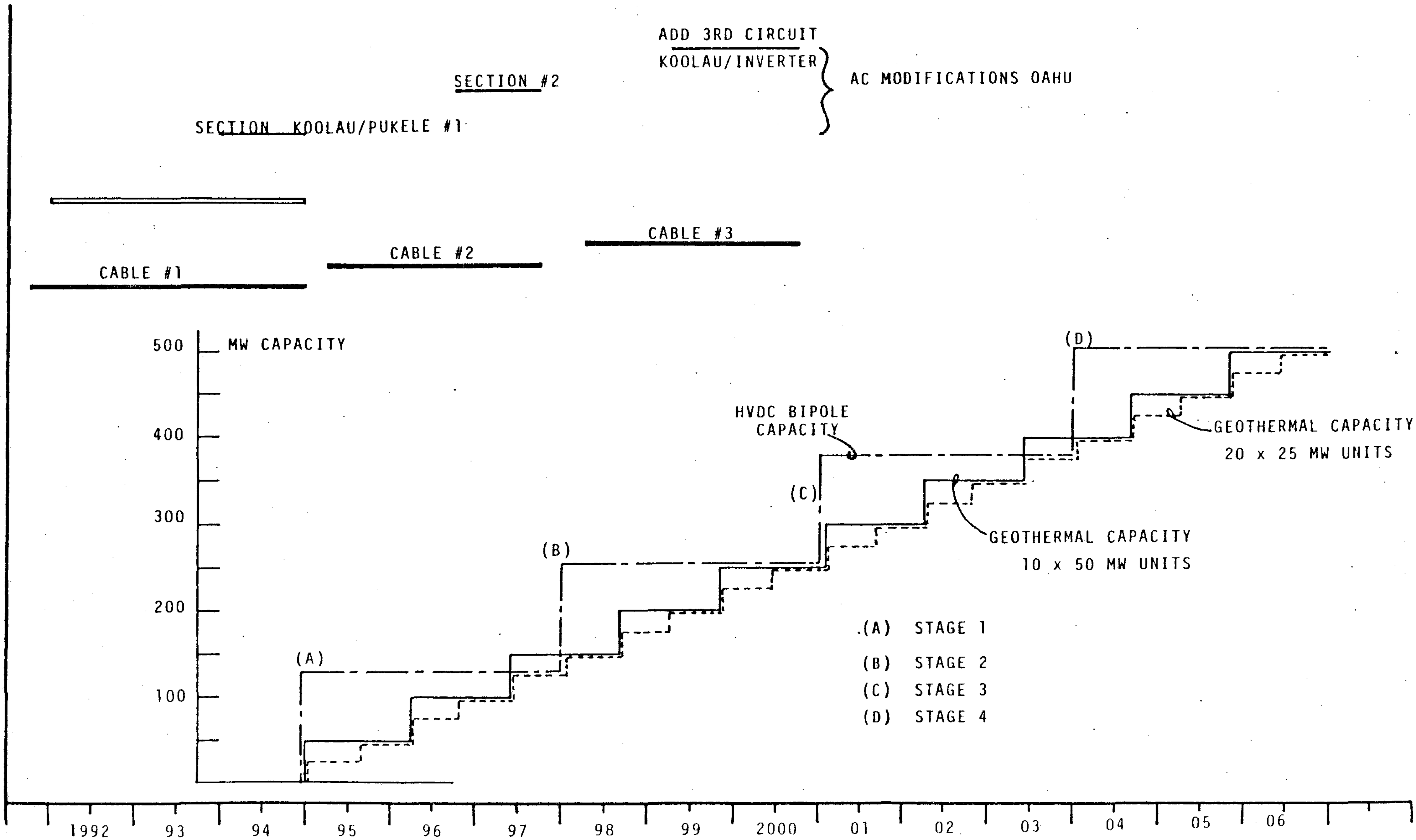
## OPERATION

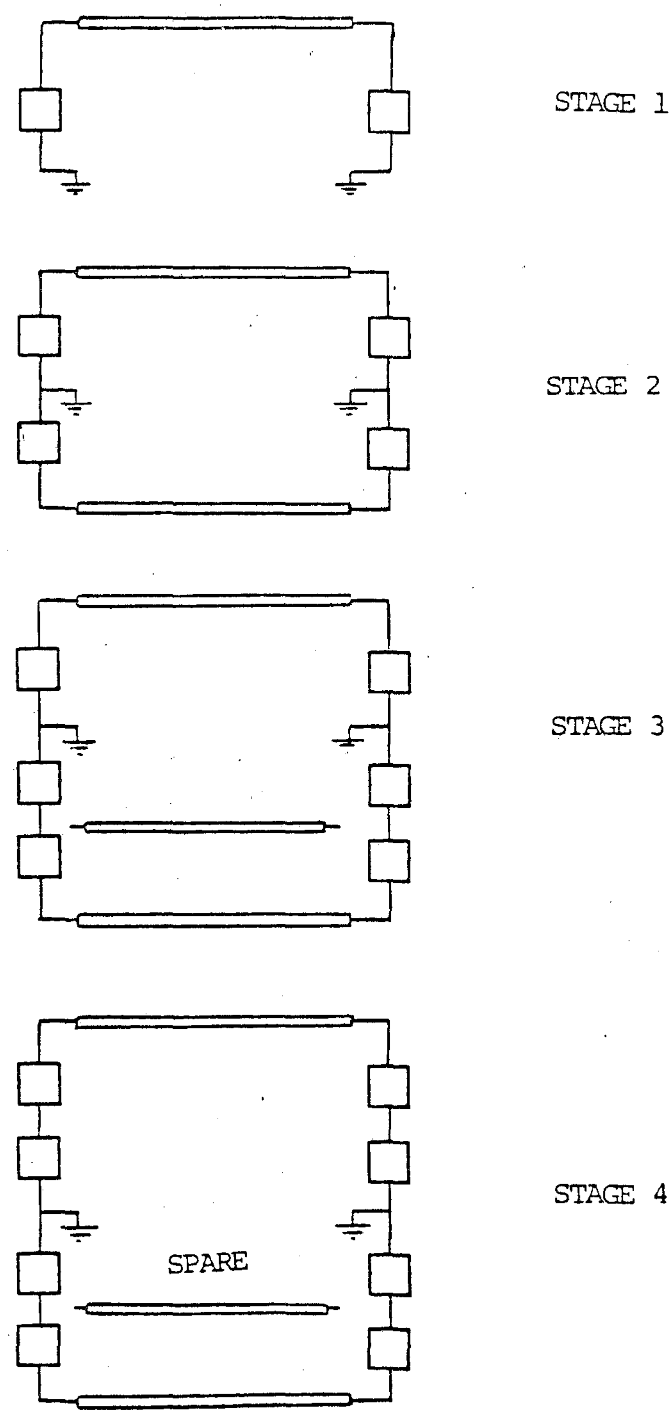
The fundamental question of cycling the 500 MW geothermal installation has been partially answered by the Ben Holt report on the basis of available information on the resource. There it is stated that the output from a 500 MW installation can be cycled down on a daily basis to 150 MW without incurring any cost additions over that which would be required for an installation which does not cycle but is base loaded. Consequently we have as a basis ten 50 MW units connected to the HECO grid which have a minimum load of 15 MW each.

Secondly, there is a need to unload the existing HECO units in order to maximize import from Hawaii. This implies not only taking units off line but selecting units which are ostensibly base load plants and modifying their operation such that they can go to two-shift operation or operate at minimum loading less than currently allowed. This is to specifically maximize imports during minimum demand periods. System operation was studied by

FIGURE 3-1

CONCEPTUAL SCHEDULE FOR HDWC/HVDC PROJECT






CABLE CONVERTER STAGING

FIGURE 3-2

using a Unit Commitment program to identify the manner in which the geothermal units and the existing HECO units would operate over typical daily load cycles on the basis of different numbers of 'must-run' or base loaded HECO units. The constraints imposed on the units were the known ramping rates, maximum and minimum loading and system spinning reserve requirements.

What was seen in the results of that study was that there is no significant problem in plant operation or in ability to load follow for the combination of HECO and geothermal units, given that some of the present 'must-run' units could be modified to operate in a two-shift mode. It was further seen that based on cost, reducing the existing number of must run units below three or four was not cost effective since start-up costs negate savings in fuel cost.

# PART 4

## CABLE SUBSYSTEM

The cable design selected for final design, fabrication, testing and interfacing with other subsystems is Pirelli Cable Corporation (PCC) Design Case No. 116 (see Table 4-1). Figure 4-1 shows a cross-section of this cable, and Table 4-2 lists the dimensions of the layers shown in the figure. The following additional parameters apply to this cable:

1. A three-cable system will be employed--two operating cables plus one spare.

2. Seven factory splices, one at-sea splice and two ship loadings per cable length (Big Island to Oahu) will be required.

3. The maximum allowable conductor temperature is 85 degrees C. Expected conductor temperature at rated load is 48.6 degrees C.

4. E-type lead alloy will be used as the sheath material.

**Table 4-1**

**SELECTED BASIC DESIGN CHARACTERISTICS OF CABLE DESIGN NO. 116**

| PARAMETER | DESCRIPTION |
|---|---|
| Cable Type | SCOF |
| Voltage | $\pm$300 kVdc |
| Conductor Cross Section | 1,600 sq mm (2.48 sq in) |
| Total Transmission Load, Bipolar | 500 MW |
| Transmission Load Per Cable | 250 MW |
| Rated Current Per Cable | 833 amps |
| Conductor Material | Aluminum |
| Conductor Type | Hollow Core Segmental Strip (Keystone) |
| Design Electrical Stress | 35 kV/mm (cold and hot) |
| Oil Duct Diameter | 25 mm (0.98 in) |
| Oil Type | High density synthetic low viscosity |
| Number of Cables for System | 2 plus one spare |
| BIL | 775 kV |
| SIL | 580 kV* |
| Polarity Reversal | Allowed |
| Conductor Diameter | 51.9 mm (2.043 in) |

| | |
|---|---|
| Insulation Thickness | 10.9 mm (0.429 in) |
| Cable Finished Diameter | 118.4 mm (4.66 in) |
| Cable Weight in Air | 37 kg/m (24.9 lb/ft) |
| Cable Weight in Water | 27 kg/m (18.2 lb/ft) |
| Maximum Oil Feeding Length | 190 km (118.1 mi) |
| Design Oil Feeding Pressure | 30 atm (440 psi) |
| Conductor Resistance | 0.0179 ohm/km |
| Losses at Rated Current Per Cable | 12.4 kW/km |
| Actual Maximum Cold Screen Stress | 32.1 kV/mm |
| Actual Maximum Hot Screen Stress | 30.6 kV/mm |
| Ratio Between Actual and Design Stress | 0.92 |
| Electrical Design Safety Factor | 3.27 |
| Pulling Tension for 7,000 ft Water Depth (Based on PCC Formula) | 65.1 mt (71.8 t) |
| Maximum Allowable Cable Pulling Tension | 78.7 mt (86.8t) |
| Corresponding Maximum Water Depth (Based on PCC Formula) | 2,626 m (8,615.5 ft) |
| Minimum Allowable Bending Diameter During Installation: | |
| a-Without Tension | 7.0 m (22.97 ft) |
| b-With 7,000 Ft Pulling Tension | 11.6 m (38.06 ft) |
| c-With Maximum Allowable Pulling Tension | 12.0 m (39.37 ft) |
| Mechanical Design Safety Factor | 3.02 |
| Initial Maximum Allowable Squeeze Per Unit Length | 3.00 mT/m |
| Total Cable Unit Cost of Which: | 306 $/m |
| a-Material Cost | 49 $/m |
| b-Incremental Manufacturing Costs | 247 $/m |
| Unit Capital Transmission Cost Per Cable | 1,224 $/MW km |

* Assumed value.

The basic construction of the SCOF cable type is as follows:

- o Conductor: Aluminum hollow core segmental strip (keystone) conductor. The strips are applied with suitable stranding pitch in two, three or four layers according to conductor size. Oil duct inside the conductor 25 mm (1 in) or alternatively of 50 mm (2 in).

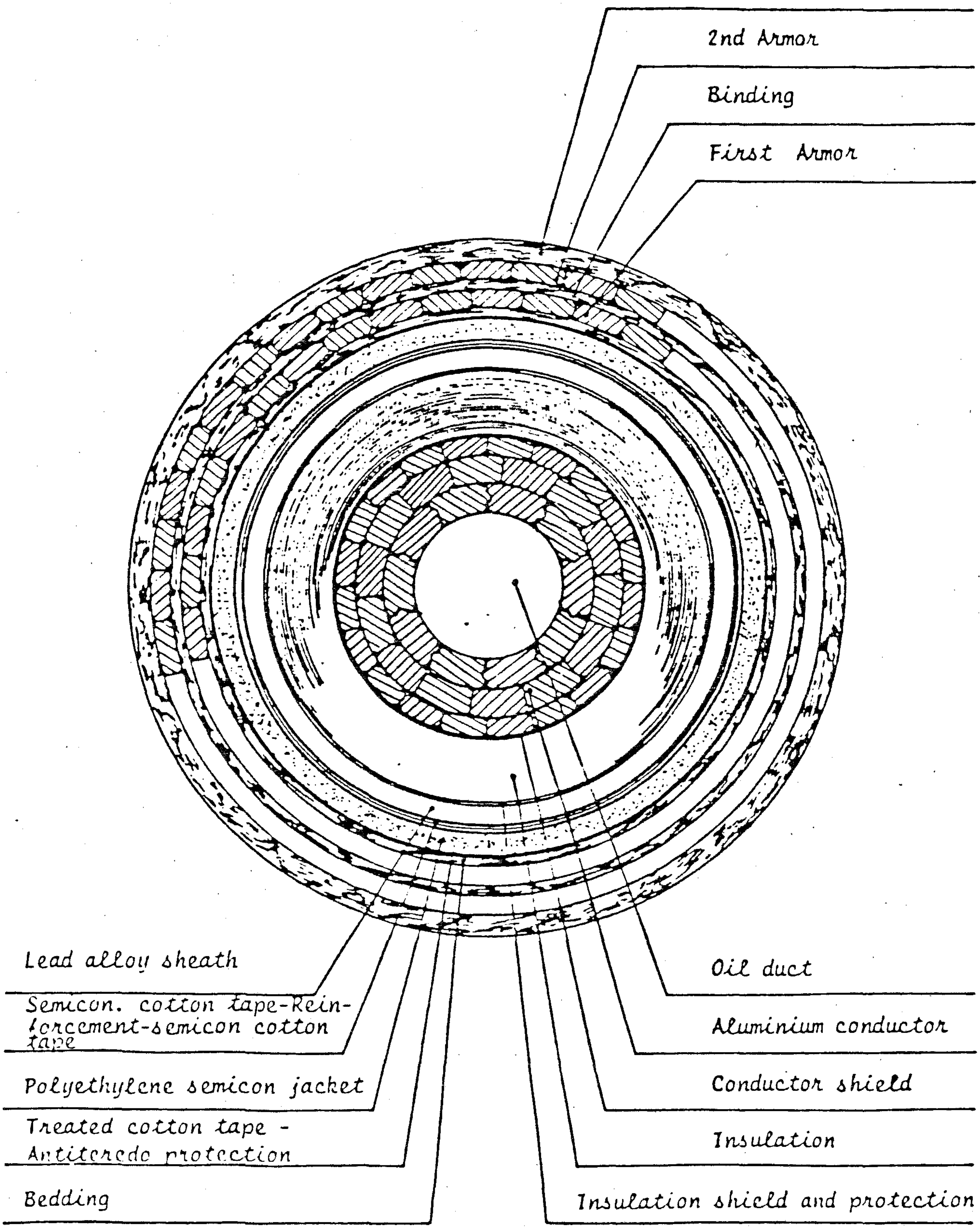
- o Shield Over Conductor: Carbon black paper tapes.

FIGURE 4-1

WEIGHT OF CABLE IN AIR: 37kg/m (24.9 lb/ft)
WEIGHT OF CABLE IN WATER: 27kg/m (18.2 lb/ft)

PIRELLI
CABLE CORPORATION

CABLE CROSS-SECTION




| | | | |
|---|---|---|---|
| SCALE<br>NTS | DRAWN BY<br>SC/pb | Self Contained Oil Filled Cable<br>$1 \times 1600$ mm$^2$ - 300 kV d.c. | B/M |
| DATE<br>3/85 | APPRD BY<br>LB | HAWAII DEEP WATER CABLE PROGRAM | DRAWING NO.<br>2 |

Source: Pirelli Cable Corporation, 1985b

- Insulation: Deionized water washed wood pulp paper suitably graded in thickness and impregnated with high density synthetic low viscosity (highly aromatic hydrocarbon) synthetic oil. Application of tapes with predetermined lapping tensions in conditioned room.

- Shield Over Insulation: Carbon black duplex type paper plus carbon black paper intercalated with metallized paper.

- Protection of the Insulated Core: Copper woven fabric tape binder overlapped.

- Lead Alloy Sheath: Type E.

- Semiconductive Textile Tape Bedding

- Reinforcement of Multilayer Bronze Tapes

- Special Anticorrosion Bituminous Compound

- Textile Tape

- Polyethylene (PE) Jacket

- Textile Tape

- Antiteredo Copper Tape

- Bedding of special polypropylene yarn of suitable thickness and suitably applied.

- First Armor: One layer of 3 mm (0.12 in) thick flat wire of high strength galvanized steel (breaking strength of 120 $kg/mm^2$). The flat wires are applied with a suitable laying pitch.

- Special Anticorrosion Bituminous Compound

- Binding of special polypropylene yarn of suitable thickness and suitably applied.

- Second Counterhelical Armor: One layer of 3 mm (0.12 in) thick flat wire of special high strength galvanized steel (breaking strength of 120 $kg/mm^2$). Flat wires are applied with a suitable laying pitch in direction opposite to that of the first armor.

- Special Anticorrosion Bituminous Compound

- Serving of special polypropylene yarn suitable applied.

Additional Considerations for Cable:

- A low resistance connection between lead sheath and armors is required in order to reduce induced overvoltages on the jacket. This can be accomplished by use of a semiconducting jacket or by metallic connections at predetermined intervals.

- Both cable types (Solid and SCOF) should be wound during manufacture, storage, transportation and laying on turntables due to their double counterhelical armor design and in order to avoid any twisting to the cables. Coiling on fixed platforms is not possible.

- The parametric study (PCC, December 1984) is valid for both the F-3 and E Type lead alloys. The use of Alloy E is considered preferable for submarine cables because of its comparable mechanical properties and its superior extrudability.

**Table 4-2**
**CABLE DIMENSIONS (NOMINAL)**

| Components | Layer Thickness | Diameter |
|---|---|---|
| Al conductor (1600 mm2) | oil duct 25 mm (0.98 in) | 51.9 mm (2.043 in) |
| Conductor shield | 0.6 mm (0.024 in) | 53.2 mm (2.094 in) |
| Insulation | 10.9 mm (0.429 in) | 75.0 mm (2.953 in) |
| Insulation shield | 0.2 mm (0.008 in) | 75.5 mm (2.972 in) |
| Core protection | 0.3 mm (0.012 in) | 76.2 mm (3.000 in) |
| Lead sheath | 3.3 mm (0.130 in) | 82.8 mm (3.260 in) |
| Bitumen | -- | -- |
| Semiconducting cotton binder tape | 0.3 mm (0.012 in) | 83.4 mm (3.283 in) |
| Bitumen | -- | -- |

| | | |
|---|---|---|
| Bronze tapes | 0.6 mm (0.024 in) | 84.6 mm (3.33 in) |
| Bitumen | -- | -- |
| Semiconducting cotton binder tape | 0.45 mm (0.018 in) | 85.8 mm (3.378 in) |
| Polyethylene jacket | 4.0 mm (0.157 in) | 93.8 mm (3.693 in) |
| Treated cotton bedding tape | 0.34 mm (0.013 in) | 94.5 mm (3.720 in) |
| Antiteredo tinned copper tapes | 0.1 mm (0.004 in) | 94.7 mm (3.721 in) |
| Polypropylene yarn bedding | 1.1 mm (0.043 in) | 96.9 mm (3.815 in) |
| First flat steel armor | 3.0 mm (0.118 in) | 102.9 mm (4.051 in) |
| Bitumen | -- | -- |
| Polypropylene yarn bedding | 1.6 mm (0.063 in) | 106.1 mm (4.177 in) |
| Second counterhelical armor | 3.0 mm (0.118 in) | 112.1 mm (4.414 in) |
| Bitumen | -- | -- |
| Polypropylene yarn serving | 3.3 mm (0.130 in) | 118.7 mm (4.673 in) |

# PART 5

## CABLE VESSEL SUBSYSTEM

Design of the vessel for a potential commercial cable laying operation was the subject of the report System Analysis and Parametric Studies (HD&C, et al., 1984). Since the adoption of a "reduced-scale At-Sea Test," vessel analyses focused on selection of an appropriate platform for the At-Sea Test, rather than on further design of a commercial vessel. A description of the vessel selected for the At-Sea Test is included in Part 7. The remainder of this section provides details about a generic vessel appropriate to a commercial cable deployment in the Alenuihaha Channel.

Cable Vessel: (Preliminary)

Flat Deck, Ocean-Going Cargo Barge
122 m (400 ft) x 30.5 m (100 ft) x 7.63 (25 ft)

Propulsion System:

For the HDWC Program Two Thrusters Attached to Vessel.
Attachment Location To Be Determined.

Total Cable Tension From Vessel:

(See Figure 5-1)

Cable Laying Environmental Loading:

(See Figure 5-2)

Design Barge Forces:

(See Figure 5-3)

Principle Cable Vessel Subsystem Feasibility Criteria:

- o Vessel must have adequate deck space and be structurally designed for the cable and cable handling equipment and deployment/retrieval/repair operations.

- o Vessel must be able to maintain predetermined bottom path for deployment/retrieval operations and maintain position during repair operations.

- o Vessel must be able to maintain stability requirements for deployment/retrieval/repair operations.

Total Tension From Vessel:

(See Figure 5-1 and Tables 5-1 and 5-2)

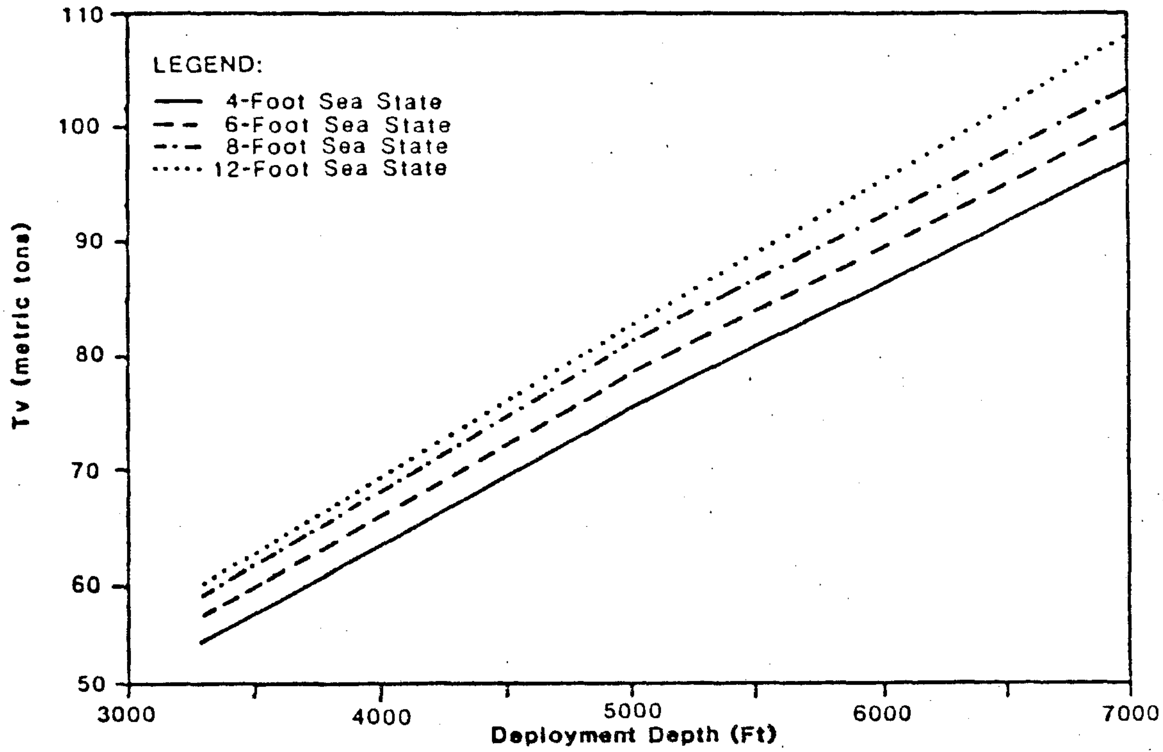



FIGURE 5-1

**TOTAL TENSION FROM VESSEL**

**400-Foot Barge, Stern Depth 32.14 kg/m**

TABLE 5-1

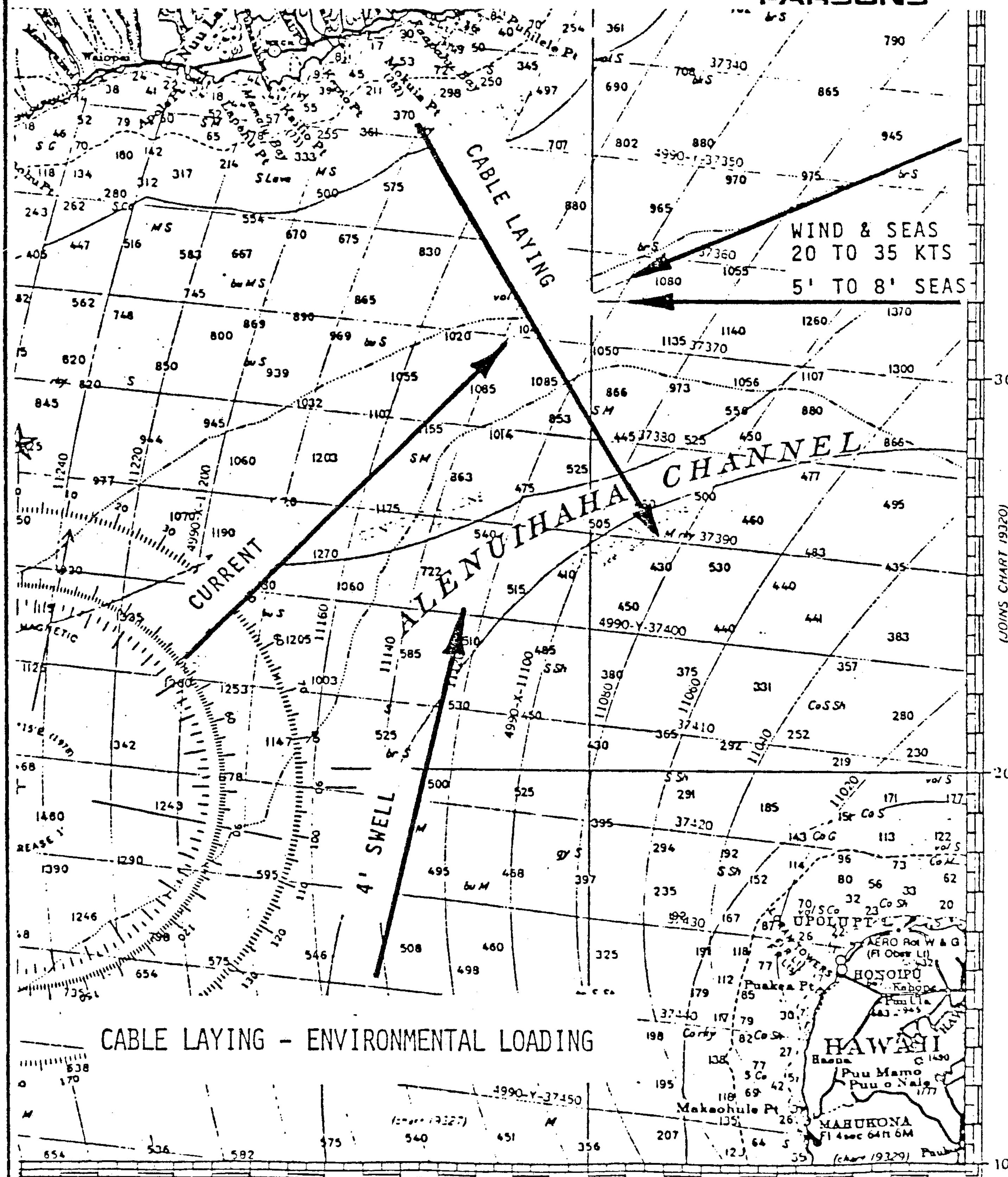
INPUT DATA FOR VESSEL Tv GRAPH

| DEPTH | DEPTH (FT) | SEA STATE | η | Wxh | Tv |
|---|---|---|---|---|---|
| 2,133.60 | 7,000 | 4 | 0.70x0.30 | 68.6 | 96.5 |
| 1,524.00 | 5,000 | 4 | 0.37x0.70 | 49.0 | 75.2 |
| 1,005.84 | 3,300 | 4 | 0.70x0.40 | 32.3 | 54.9 |
| 2,133.60 | 7,000 | 6 | 0.87x0.30 | 68.6 | 100.0 |
| 1,524.00 | 5,000 | 6 | 0.37x0.87 | 49.0 | 78.2 |
| 1,005.84 | 3,300 | 6 | 0.87x0.40 | 32.3 | 57.1 |
| 2,133.60 | 7,000 | 8 | 0.30 | 68.6 | 102.6 |
| 1,524.00 | 5,000 | 8 | 0.37 | 49.0 | 80.6 |
| 1,005.84 | 3,300 | 8 | 0.40 | 32.3 | 58.8 |
| 2,133.60 | 7,000 | 12 | 0.37 | 68.6 | 107.4 |
| 1,524.00 | 5,000 | 12 | 0.00 | 49.0 | 82.2 |
| 1,005.84 | 3,300 | 12 | 0.44 | 32.3 | 60.1 |

Assumes: 400 ft barge, stern cable deployment baseline cable = weight 32. 14 kg/m wet. Uses algorithm: Tv = Wxh + Tbot + ηWh.

Note: Figure 5-1 and Table 5-1 to be recalculated following selection of specific vessel and determination of equipment weight distribution.

PARSONS




CABLE LAYING — ENVIRONMENTAL LOADING
FIGURE 5-2

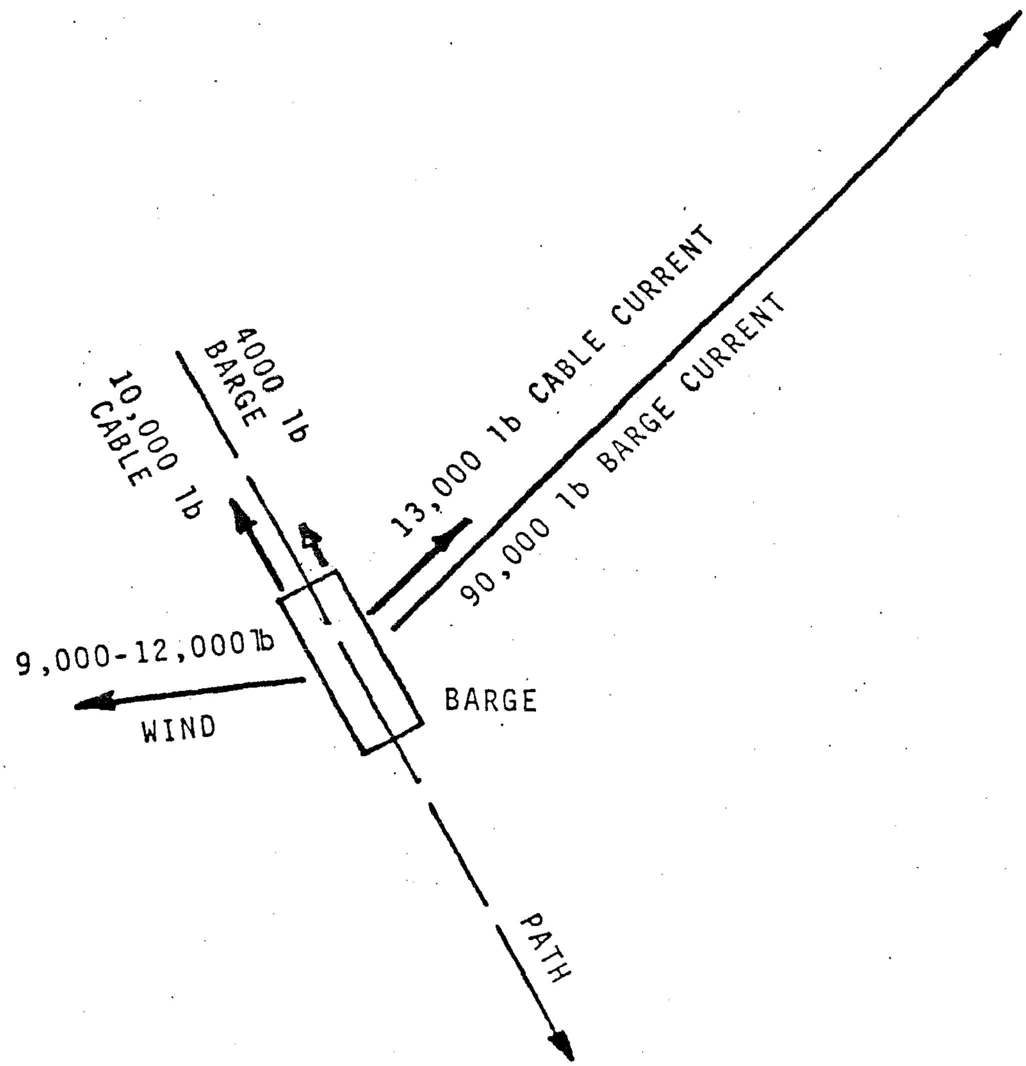



FIGURE 5-3
DESIGN BARGE FORCES

Table 5-2

SUMMARY OF TENSION DYNAMIC AMPLIFICATION FACTORS FOR THE BASELINE CABLE AND THE GENERIC BARGES CONSIDERED UNDER SEA CONDITIONS OF SIGNIFICANT HEIGHT 2.4 M (8 FT) AND 5.5-SECOND PEAK PERIOD (CABLE ATTACHMENT AT STERN OF BARGE IS ONLY GIVEN HERE)

| BARGE | DRAUGHT | WATER DEPTH | DYNAMIC AMPLIFICATION (N) [2.] |
| --- | --- | --- | --- |
| 122 m x 23 m [1.] (400 ft x 75.4 ft | 3.1 m (10.2 ft) | 2,134 m (7,000 ft) | 0.30[3.] |
| 122 m x 23 m [1.] (400 ft x 75.4 ft) | 3.1 m (10.2 ft) | 1,000 m (3,280 ft) | 0.40[3.] |

1. 122 m (400 ft) x 30.5 m (100 ft) barge to be modeled following determination of vessel layout and weight distribution on deck.

2. n for 122 m (400 ft) x 30.5 m (100 ft) barge in 1.8 m (6 ft) and 3.7 m (12 ft) seas to be modeled following determination of vessel layout and weight distribution.

3. Derived using a baseline cable of:

   133.0 mm (5.25 in) Diameter
   46.4 kg/m (31.2 lb/ft) Dry Weight
   32.1 kg/m (21.6 lb/ft) Dry Weight

NOTE: The selected cable is significantly lighter than this baseline cable (see Part 4, Cable Subsystem).

# PART 6

## CABLE HANDLING EQUIPMENT SUBSYSTEM

Preliminary design work for the Cable Handling Equipment Subsystem was completed in 1985 by Western Gear Machinery Co. As was the case for the Cable Vessel Subsystem, once the reduced-scale At-Sea Test concept was adopted, design efforts focused on equipment suitable for the test rather than for the commercial cable deployment. Cable Handling equipment for the test will be provided aboard the vessel, and no major additional design, fabrication or procurement efforts were necessary.

The most significant systems development effort has been that of the Control and Operating Equipment. This system is applicable to both the test and a commercial deployment, and is described in Part 7.

Cable Handling Equipment Preliminary Design Criteria and Estimated Deminsions: All cable handling equipment and controls to be designed and sized to handle Cable Design No. 116.

Preliminary Equipment Outline Dimensions Layout: (See Figure 6-1)

Overboard Sheave:

Sheave radius over guards = 6.6 m (21.6 ft)
Sheave width over guards = 2.0 m (6.6 ft)
Sheave width over hub = 3.0 m (9.8 ft)

Dynamometer:

1.0 m (3.28 ft) high x 0.75 m (2.5 ft) wide x 2.25 m (7.4 ft) long

Length of device to be parallel to cable travel

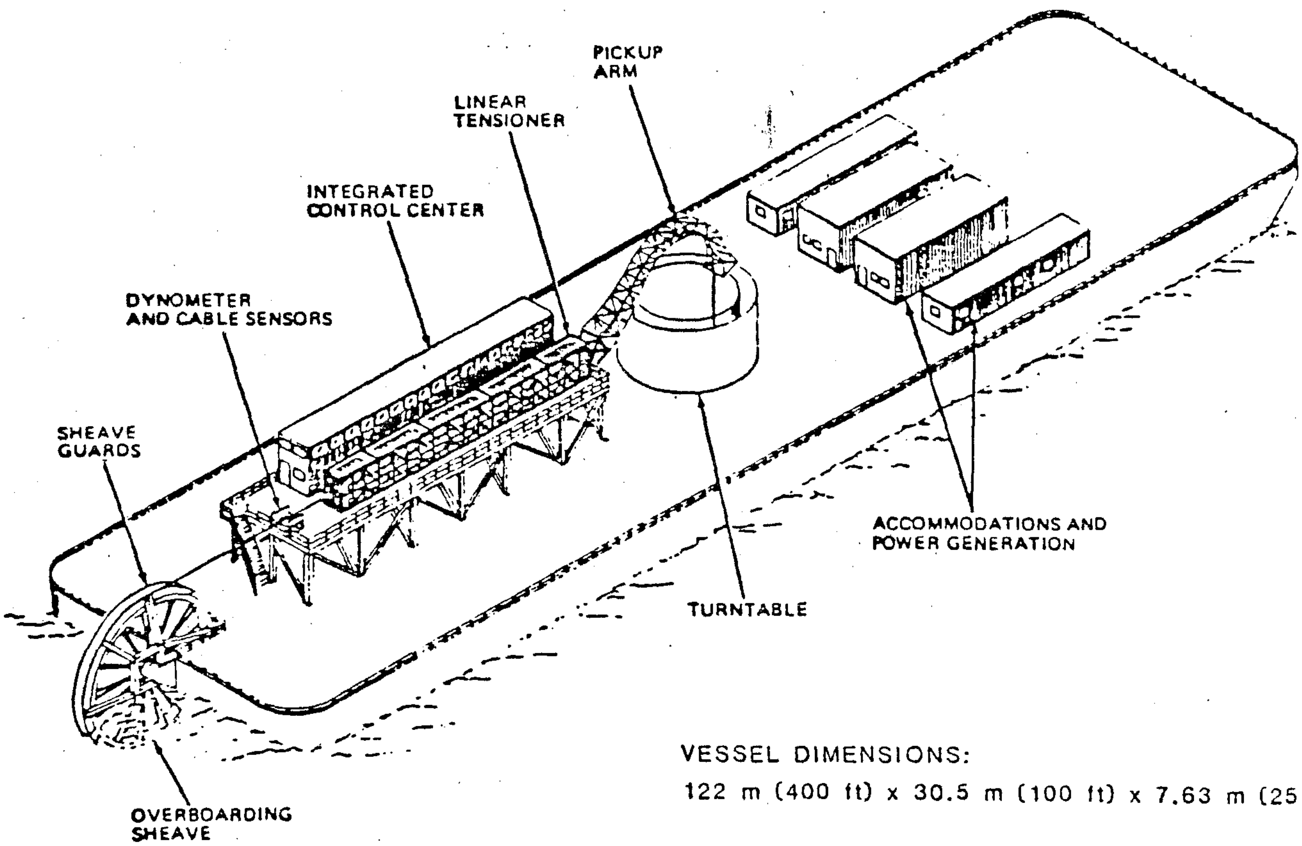
Sensor Platform:

0.75 m (2.5 ft) high x 0.5 m (1.64 ft) wide x 1.25 m (4.1 ft) long

Length of device to be parallel to cable travel

Linear Tensioner:

3.75 m (12.3 ft) high x 5.0 m (16.4 ft) wide x 32.0 m (105 ft) long




VESSEL DIMENSIONS:
122 m (400 ft) x 30.5 m (100 ft) x 7.63 m (25 ft)

FIGURE 6-1

CONCEPTUAL DRAWING OF THE MAJOR
CABLE HANDLING MACHINERY
FOR THE HDWC PROGRAM

SOURCE: Western Gear Machinery Co., Jan. 1985.

Pickup Arm:

Pickup arm is cantilever as shown on Figure 6-1. Vertical (wall) mounting surface is located approximately 5.0 m (16.4 ft) from the outside diameter of the turn-table.

Cable Storage/Turntable:

Turntable dimensions for the HDWC Program to be defined following discussions with owners of existing equipment and additional preliminary design studies. The minimum inside (hub) diameter of the turntable is 7.0 m (23 ft) and the outside diameter of the turntable is 10.0 m (32.8 ft) for the HDWC Program.

Troughing:

Metal troughing will be used where it is needed such that the cable is continuously supported throughout its passage through the cable handling equipment. This is necessary to prevent cable bend diameter violation and/or hangups during low tension operations.

Assume metal trough is a "U" shaped sheet metal device approximately 30 cm (22.8 in) wide with length and support as required.

Controls:

Assume all controls to be within the integrated control center.

Principle Cable Handling Equipment Subsystem Feasibility Criteria:

- Cable handling equipment must be able to maintain appropriate cable tension during deployment/retrieval/repair operations. Acceleration in one min. to one min./sec., payout one min./sec., takeup rate 0.5 min. per/sec.

- Cable handling equipment must be able to load cable from dockside storage to onboard storage at the rate of 2 min./sec.

- Cable handling equipment controls must be fully integrated and designed to handle all foreseen emergency conditions.

# PART 7

## THE AT-SEA TEST

### CABLE

The cable selected for the At-Sea Test (AST) is a wire rope smaller, lighter, and much less expensive to fabricate than Cable No. 116. This is to allow use of an existing vessel and handling equipment. The weight to diameter ratio, however, has been matched to that of Cable No. 116 so that controlling the bottom position and tension will be equally as difficult for this "surrogate" cable as for No. 116.

A cross-section of the surrogate cable is shown in Figure 7-1 and technical data are listed in Table 7-1.

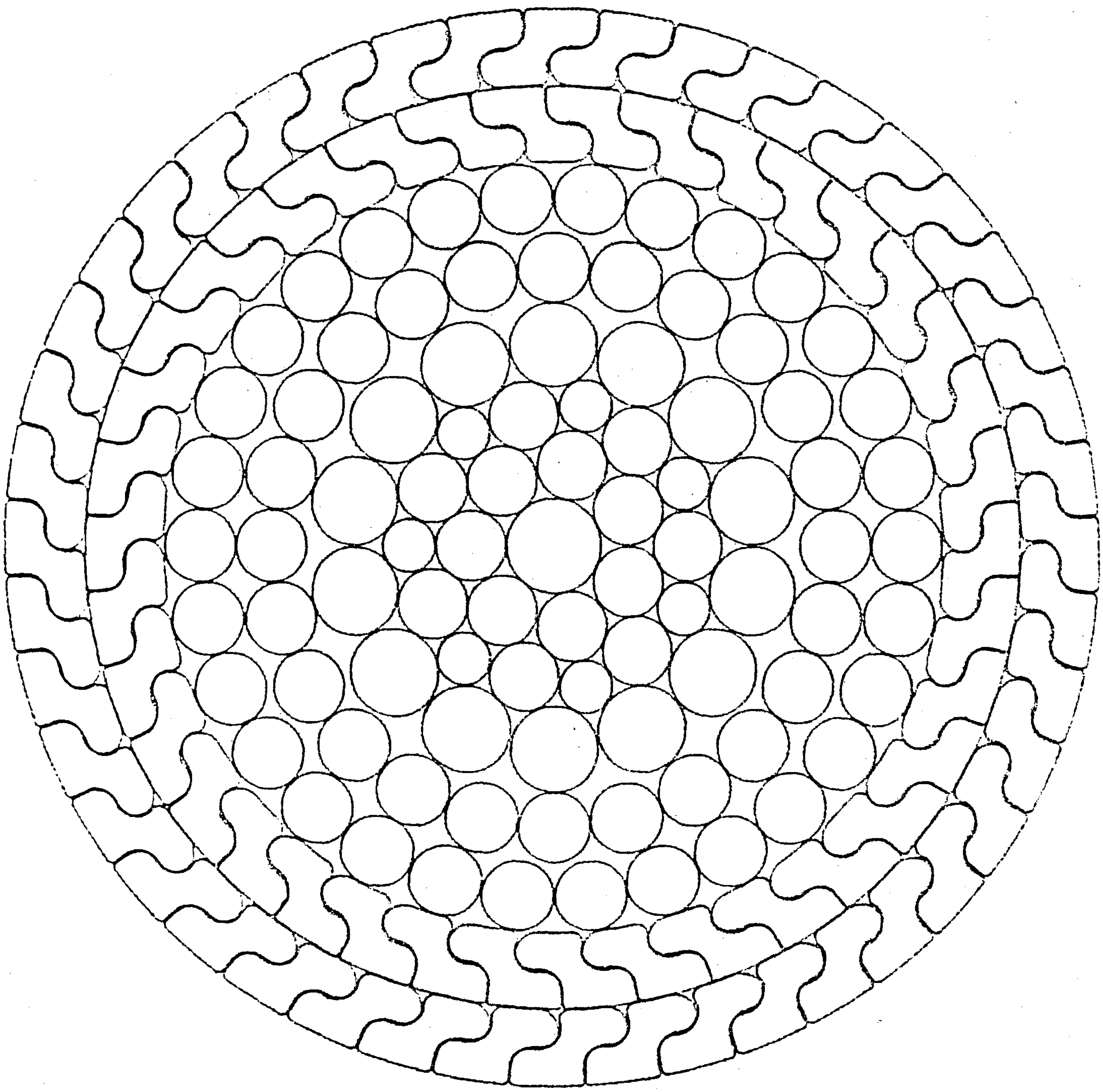
**Table 7-1**

**TECHNICAL DATA ON SURROGATE CABLE**

| PARAMETER | VALUE |
|---|---|
| Length | 8,000 meter, unspliced |
| Type | Full-locked coil, torque-balanced |
| Young modulus | 15,000 daN/mm$^2$ $\pm$ 500 |
| Moment of inertia (Stiffness) | 20.90 x 10$^6$ kg-mm$^2$ |
| Minimum bending ratio | 80/1 @ 20 mt tension (dynamic)<br>35/1 @ 3 mt tension (static) |
| Minimum sheave diameter | 3.6 M |
| Recommended sheave diameter | 4.5 M |
| Sheave shape | V |
| Thermal coefficient of expansion | 11.5 x 10$^{-7}$ /$^o$C/m $\pm$ 2% |
| Coeffiecient of friction (expected) | 0.15 (steel/steel)<br>0.25 (steel/pur) |
| Torque | Maximum 161.7 N-m (under 60 MT) |
| Rotation | Maximum 30$^o$/100m (under 60MT) |
| Squeeze | Maximum 2% at max. tension = (40 MT)<br>Maximum radial pressure of 15 kg/mm$^2$ on the outer wire rope surface with $\pm$ 0.2% maximum change in diameter.<br>Maximum squeeze at zero tension 1% |
| Standing angle | 15$^o$ for round wires<br>23$^o$ for "Z" wires |
| Composition | bright steel round wires, drawn galvanized steel for "Z" wires |
| Outer layer pitch | 303.8 mm (11.96 in) |

FIGURE 7-1

Diametre: 45.0 mm
Rupture: 1885.00 KN



| | |
|---|---|
| Nominal diameter | 45 mm (1.775 in) |
| Cross-section | 1334.54 $mm^2$ (2.068 $in^2$) |
| Nominal breaking strength | 1885 KN (423.69 kips) |
| Weight (in air) | 11.45 kg/m (7.626 lbs/ft) |
| (in sea water) | 9.86 kg/m (6.590 lbs/ft) |
| Cable filling | amorphous polypropylene |

**Cable Vessel**

The vessel M/V Flexservice 3, operated by Coflexip, has been selected for the AST. It is described in Table 7-2 and shown in Figure 7-2.

**Table 7-2**

**TECHNICAL DATA ON FLEXSERVICE 3**

| PARAMETER | VALUE | |
|---|---|---|
| Classification | DNV + 1 A1 - SUPPLY VESSEL - SF - EO DYN POS AUTR (ERN: 99, 99, 93) | |
| Length overall | 83.20 m | 273' |
| Length between p.p. | 75.20 | 246'9" |
| Breadth overall | 19.80 m | 65' |
| Breadth moulded | 19.40 m | 63'8" |
| Depth (main deck) | 4.67 m | 16'4" |
| full scantling | 5.89 m | 19'3" |
| Draught (summer freeboard) | 5.12 m | 16'10" |
| full scantling | 7.00 m | 23' |
| Deadweight | 3050 metric tons at 5.12 m | |
| full scantling | 5400 metric tons at 7 m | |
| Gross tonnage | 1600 GRT at 5.12 m draught | |
| Deck cargo | about 3600 tons with center of gravity placed 1.65 m above deck | |

| | |
|---|---|
| Deck loading | 10 tons/sqm |
| Clear deck area | 52.0 m x 17.0 m = 884 sqm |
| Water ballast/drill water | 2420 tons + 140 tons for pipes pressure test |
| Drill water discharging | 2 x 100 tons/hr against 9 bars |
| Fresh water generator capacity | 1 x 12 tons per day |
| Fuel | |
| - heavy fuel oil | 790 CBM |
| - gas oil | 985 CBM |
| Fuel oil discharging | 1 x 250 CBM/hr against 9 bars |
| Bulk cement/mud | 6 vertical tanks, each 2000 cuft total 12000 cuft (340 CBM) |
| Bulk discharge rate | 2 x 20 CBM/hr at 5 bars |

---

Other relevant vessel equipment is as follows:

Navigation Equipment

2 Decca radars, type RM 916 C (1 X 10 cm, 1 X 3 cm)

1 Furuno SFP radio direction finder

2 Robertson Gyro SKR 80 with auto pilot AP.8

1 Simrad echosounder ED 38

1 Simrad navigation log

1 Satellite navigator, type MAGNAVOX

Radio Communication Equipment

1 main radio transceiver, type SAILOR 80 SSB, 800 W frequencies: SW/MW

1 Siemens sell call C X 2

1 mobile VHF emergency transmitter radio beacon

1 mobile VHF emergency communication set

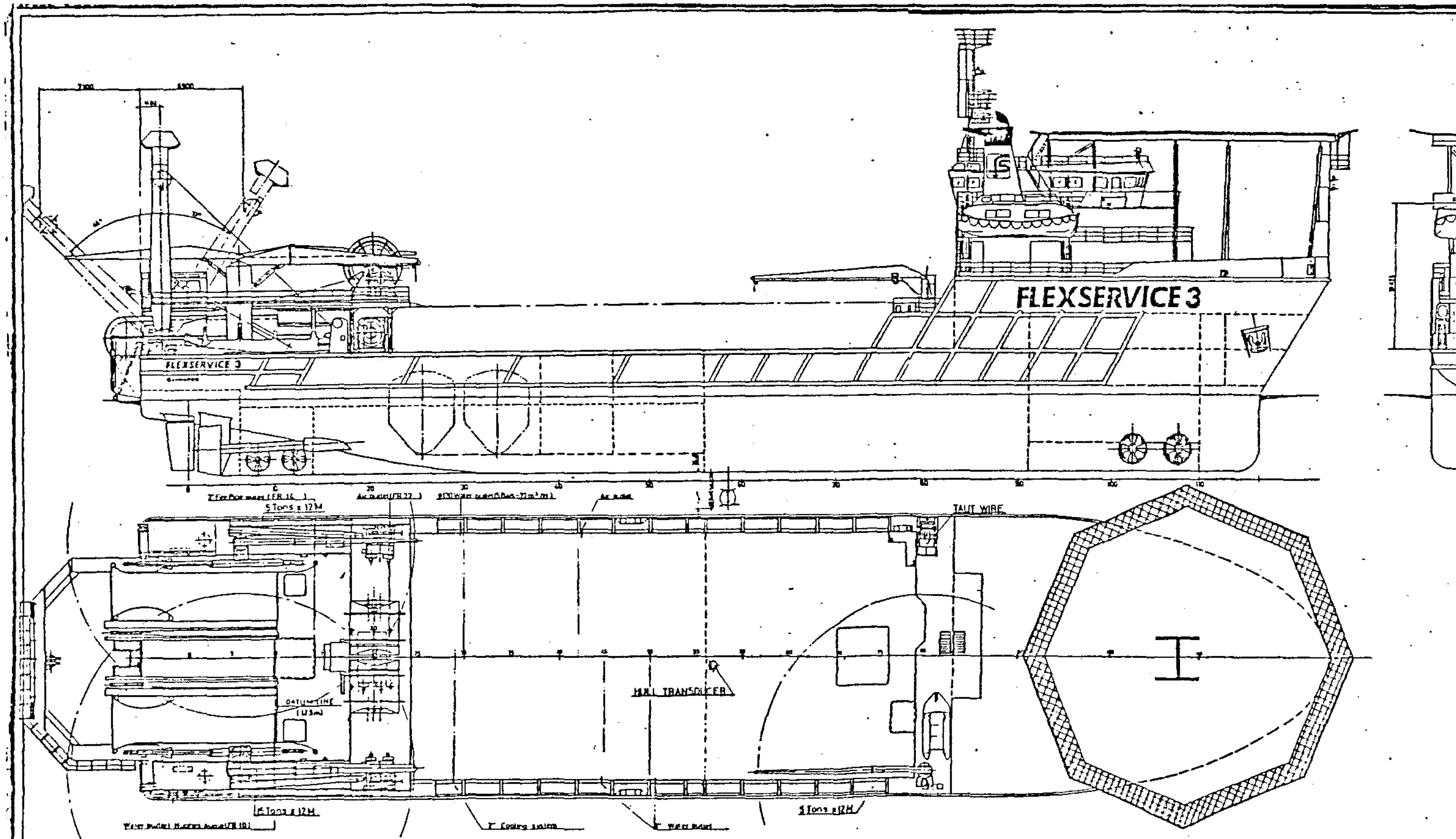



FIGURE 7-2

| | |
|---|---|
| coflexip | |
| FLEXSERVICE 3<br>BASIC EQUIPMENT | |
| 1/300 | N° 5060 FS 25 C |

1 internal ship calling system including speaker on aft deck

1 lifeboat emergency transmitter

1 UHF

1 international telex

**Cable Handling Equipment**

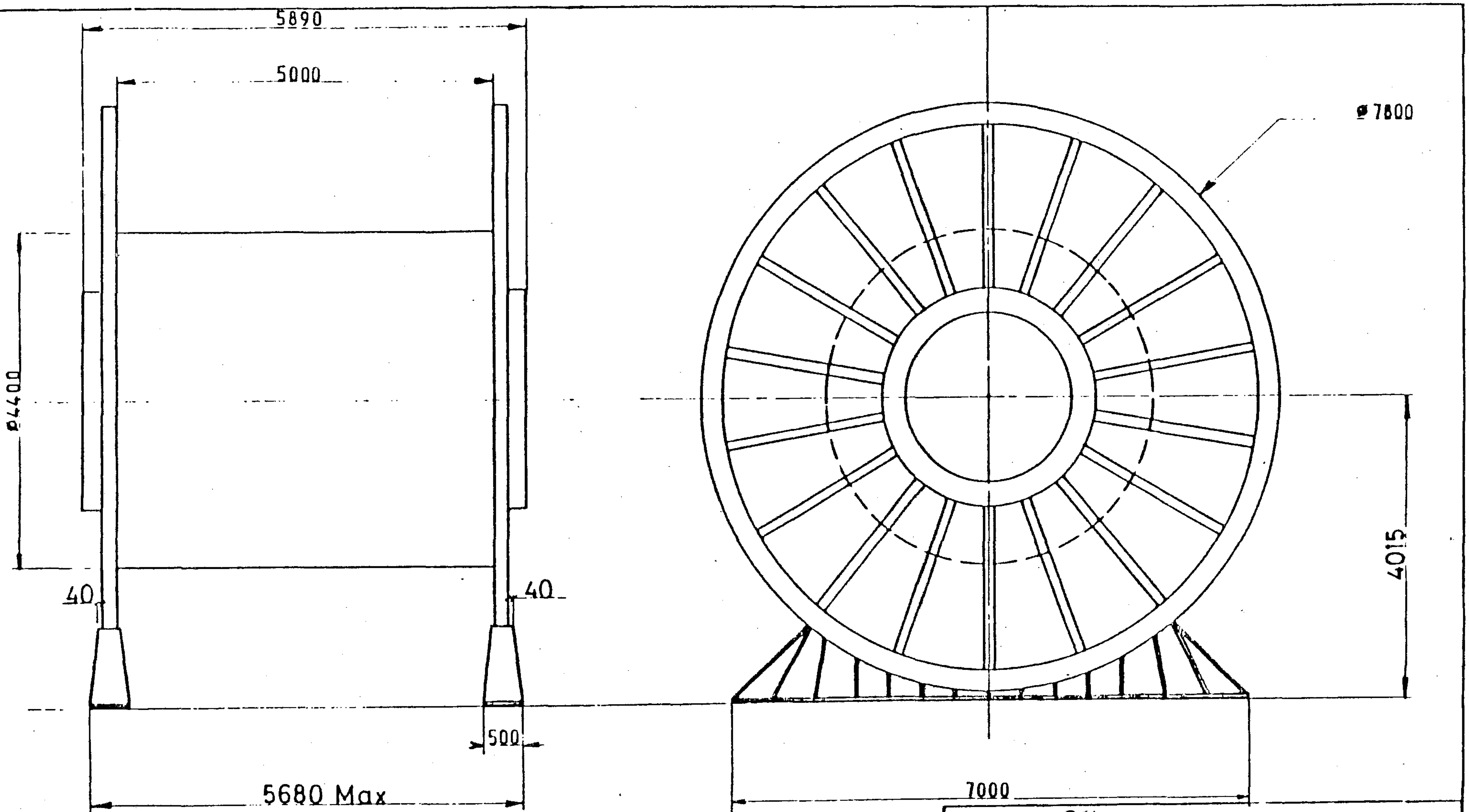
The major items of equipment required to lay the selected surrogate cable in the water depths involved and to the specification given are:

- o a reel to store the surrogate cable (Figure 7-3) and a winch to lift and allow rotation of the reel (Figures 7-4 and 7-5).
- o a reel to store the abandonment and retrieval rigging and a winch to lift and rotate the reel (Figure 7-6).
- o a reel and winch to deploy and retrieve the abandonment and retrieval rigging. A resourceful rigging design indicates that the deployment reel be separate from the storage function.
- o a tensioner (Figure 7-7) capable of deploying and retrieving the surrogate cable.
- o an overboarding sheave (Figure 7-8).

**Cable Handling Control and Data Acquisition Systems**

Descriptions of the final designs of the cable laying control and data acquisition systems are contained in Makai and Noda (1988) Because of the very high accuracy required for positioning and tensioning, a computerized control system is being developed to precisely lay the cable.

The overall control for the cable laying process is illustrated in Figure 7-9. The goal of the cable laying control system is to accurately place and properly tension the cable on the bottom, and the system output is instructions for the vessel to proceed along a particular course and instructions for the cable tensioner to pay out the cable at a specific speed. Corrections are constantly being made to these instructions provided to the tensioner and the vessel dynamic positioning system based on differences computed between the desired cable touchdown conditions and the actual touchdown conditions. In order to determine the actual touchdown conditions, the cable shape must be constantly computed based on input information such as ship




COFLEXIP

REEL 78 x 44 x 50 AND SUPPORTING CRADLE 7m

| | |
|---|---|
| Dessiné par / Drawn by | |
| Le / On | 14.04.81 |
| Vérifié par / Checked by | E.B. |
| Le / On | 14.04.81 |
| Approuvé par / Approved by | |
| Poids / Weight | 30 T |
| Ech. / Scale | 1/50 |
| Format / Size | A 3 |
| Fl. / Sheet | 1 |
| N° | 108-3-0002 |
| Rev | 0 |

| Rev | Modification | Date | Dessiné / Drawn | Vérifié / Checked |
|---|---|---|---|---|
| 0 | FIRST ISSUE | 14.4.81 | | |

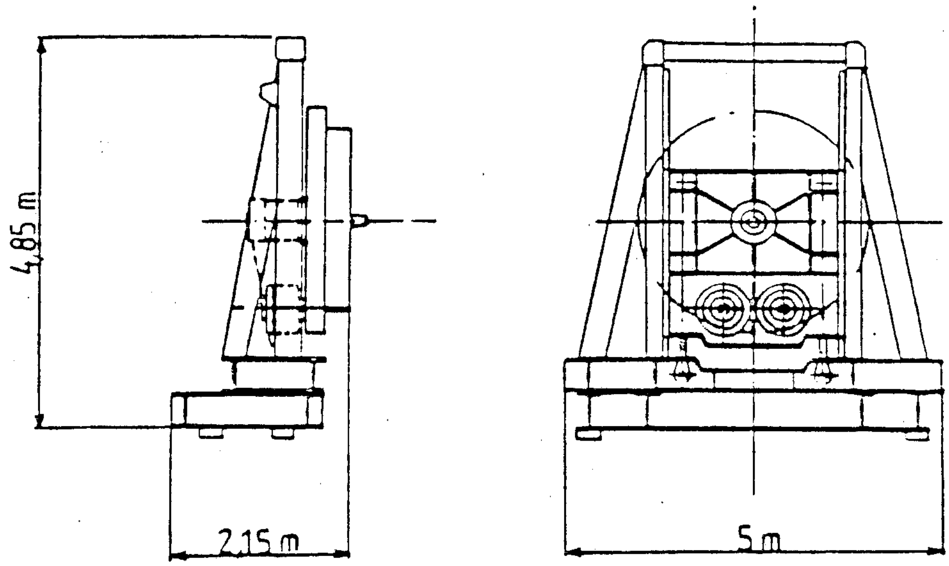
TOTAL WEIGHT: 28+(1×2) = 30T.

FIGURE 7-3 DEPLOYMENT REEL FOR SURROGATE CABLE

FIGURE 7-4

# TR 23 WINCH

Used with TR25A, TR34 (cargo rail)
or TR25A+L, TR34+L, TR33




## MAIN FEATURES

(All features include the use of TR25)

| | | |
|---|---|---|
| Output power | | : 105kw (hydraulic motor driven) |
| Loading capacity | | : 2000kN (440900lbs) |
| Spool type | | : 78.44.50 |
| | | 55.26.50 |
| Maximum torque | | : 700mkN (505900 ftlbs) |
| Maximum pull | | : 318 kN (70100 lbs) , with 78.44.50 spool |
| Revolution per min. | | : 0 to 2.2 |
| Spooling device | | : Not fitted |
| Dimensions | Length | : 5.00m (16 ft 5in) |
| | Width | : 2.15m (7ft) |
| | Height | : 4.85m (15ft 11in) |
| | Weight | : 225kN (49600lbs) |
| Power pack | Length | : 3.40m (11ft 2in) |
| | Width | : 1.50m (4ft 11in) |
| | Height | : 1.70m (5ft 7in) |
| | Weight | : 18kN (3900lbs) |

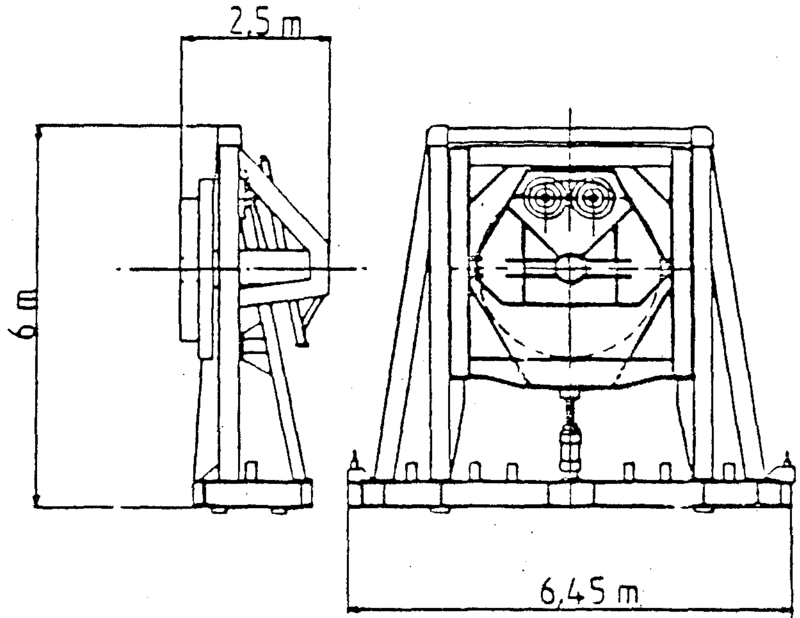
## POWER INPUT

| | |
|---|---|
| Power pack (elect) | : 117kw, 3x440v/60hz |
| Elect. cable | : 750MTH-4x70mm2, PD02047001 |
| Seawater cooling | : 3m3/h at 0.3MPa |
| Seawater hose | : 2in, PD05000055 |
| Hose coupling | : 2in, PH........ |

FIGURE 7-5

# TR 25 WINCH

Used with TR23A, TR33,
TR25A+L, TR34+L




MAIN FEATURES

(All features taken with use of TR23A, TR33, TR34+L)

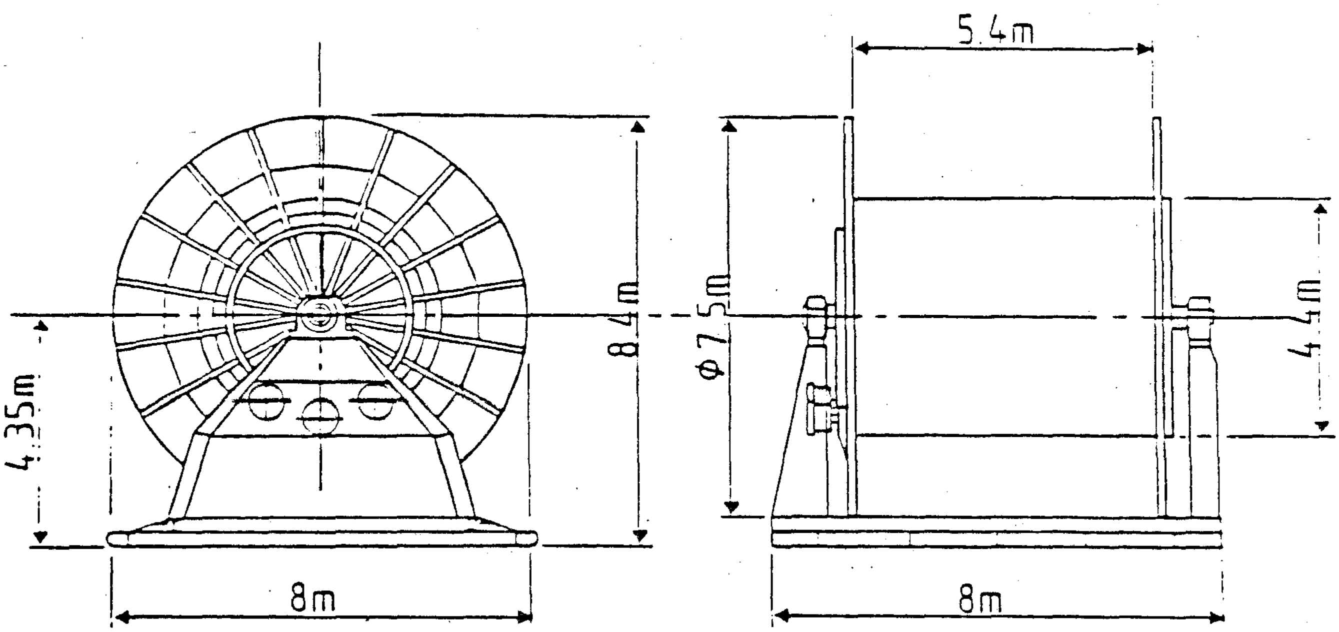
| | | |
|---|---|---|
| Output power | | : 105kW (hydraulic motor driven) |
| Loading capacity | | : 2000kN (440900lbs) |
| Spool type | | : 78.44.50 |
| | | 55.26.50 |
| Maximum torque | | : 700mkN (505900 ftlbs) |
| Maximum pull | | : 318 kN (70100 lbs) , with 78.44.50 spool |
| Revolution per min. | | : 0 to 2.2 |
| Spooling device | | : Not fitted |
| Dimensions | Length | : 6.45m (21ft 2in) |
| | Width | : 2.50m (8ft 3in) |
| | Height | : 6.00m (19ft 8in) |
| | Weight | : 225kN (49600lbs) |
| Power pack | Length | : 3.40m (11ft 2in) |
| | Width | : 1.50m (5ft 11in) |
| | Height | : 1.70m (5ft 7in) |
| | Weight | : 35kN (7720lbs) |

POWER INPUT

| | |
|---|---|
| Power pack (elect) | : 117kw, 3x440v/60hz |
| Elect. cable | : 750MTH-4x70mm2, PD02047001 |
| Seawater cooling | : 3m3/h at 0.3MPa |
| Seawater hose | : 2in, PD05000055 |
| Hose coupling | : 2in, PH........ |

FIGURE 7-6

# TR 7 WINCH




## MAIN FEATURES

| | | |
|---|---|---|
| Output power | : | 88kw (hydraulic motor driven) |
| Loading capacity | : | 2000kN (440900lbs) |
| Drum type | : | 80.44.54 |
| Maximum torque | : | 1100mkN (795000 ftlbs) at 0.5rpm |
| | | 600mkN (433600 ftlbs) at 0.8rpm |
| Maximum pull | : | 500kN (110230lbs) at 0.5rpm |
| | | 273kN (60120lbs) at 0.8rpm |
| Revolution per min. | : | 0 to 0.8 (see above) |
| Spooling device | : | 2m/min (6ft 7in/min) |

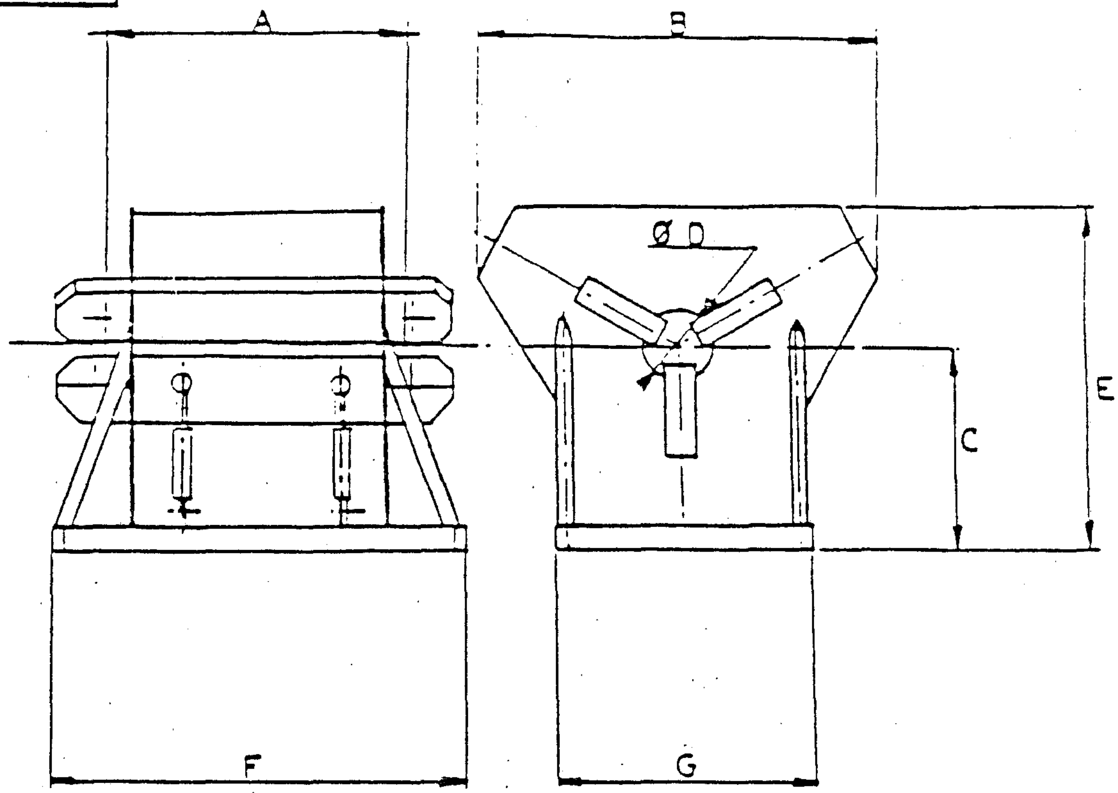
| | | | |
|---|---|---|---|
| Dimensions | Length | : | 8.80m (28ft 11in) with spooling |
| | | | 8.00m (26ft 3in) without spooling |
| | Width | : | 8.00m (26ft 3in) |
| | Height | : | 8.40m (27ft 5in) |
| | Weight | : | 790kN (174100 lbs) winch only |
| | | | 50kN (11025lbs) spooling |

## POWER INPUT

| | | |
|---|---|---|
| Power pack (elect.) | : | 88kw, 3x440v/60hz |
| Elect. power cable | : | 750MTH-4x70mm2, PD02047001 |
| Seawater cooling | : | 3m3/h at 0.3MPa |
| Seawater hose | : | ..in, PD........ |
| Hose coupling | : | ..in, PH........ |

FIGURE 7-7

# 50 TON TENSIONER




## CARACTERISTIQUES / CHARACTERISTICS

| | | | |
|---|---|---|---|
| Puissance | Power | | 125 kW |
| Tension | Voltage | | 440 V |
| Frequence | Frequency | | 60 hz |
| Dimensions | Sizes | E | 4450 mm |
| | | F | 5600 mm |
| | | G | 3310 mm |
| | | C | 2670 mm |
| | | A - length in contact with pipe | 3800 mm |
| | | D | 900 mm |
| Vitesse | Speed | | 0 to 10 m/min |
| Couple | Torque | | |
| Tension | Pulling strength | | 500 kN |
| Charge | Load | | |
| Poids a vide | Weight empty | | 450 kN |

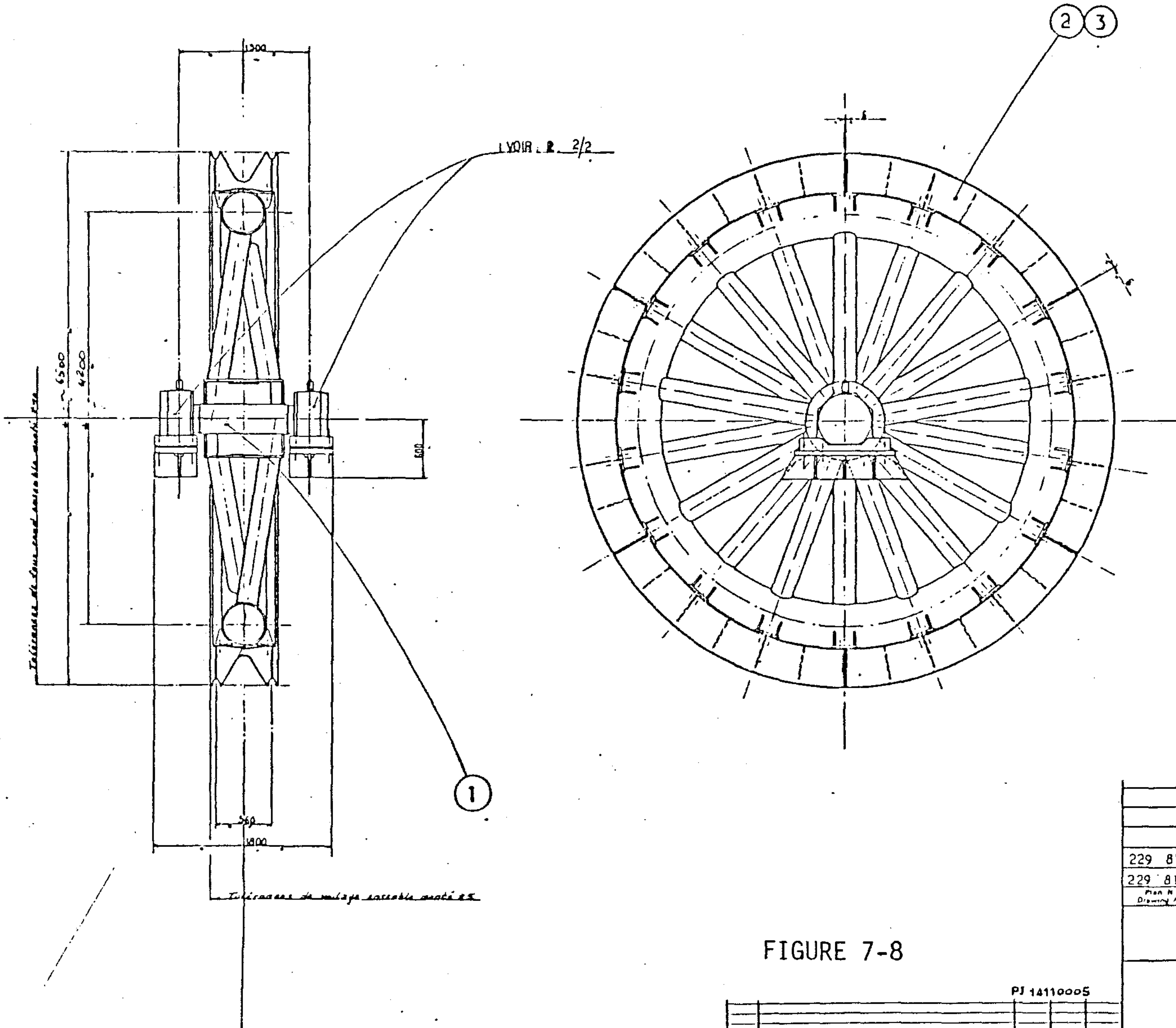



FIGURE 7-8

| Plan N / Drawing N° | Rep / Item | Nbre / No | Désignation / Designation | Matière / Material | Observations / Remarks |
|---|---|---|---|---|---|
| | 3 | 72 | Boulon H M 30 x 70 | Classe 10.9 | Cuivré |
| 229 818 | 2 | 6 | JANTE (SECTEUR) | | |
| 229 819 | 1 | 1 | MOYEU | | |

COFLEXIP

OVERBOARDING SHEAVE

Dessiné par / Drawn by: CM — Le: 11.84
Vérifié par / Checked by — Le: 3.01.85

Traitement / Treatment: DT 019

Ech / Scale: 1/20 — Dimension / Size: A1 — PL / Sheet: 1/2

N° 141.1.005

| Rev | Modification | Date | Dessiné / Drawn | Vérifié / Checked |
|---|---|---|---|---|
| 1 | ISSUED FOR CONSTRUCTION | | | |

PJ 14110005

position, currents, cable transponders, etc. Much of the control loop concentrates on these computations.

In order to properly compute cable touchdown conditions and the cable bottom tensions, the controller requires accurate measurements of the information shown on the left of Figure 7-9. Under most circumstances, accurate knowledge of the current profile, vessel navigation, cable payout, the planned path including bathymetry, and the history of the cable lay is adequate to determine a sufficiently accurate touchdown point and tension. For cases of very high tension or position accuracies, transponders will be added to the cable to reduce the computation error.

The Data Acquisition system is provided on the cable vessel to achieve the two secondary goals of the At-Sea Test: recording the performance of the control system and recording the dynamics of the waves, ship and top cable tensions. These data will be used after the test to evaluate the performance of the control system and to perform an independent study of the dynamics of the suspended cable and ship.

The basic control loop for the integrated system is illustrated in Figure 7-10 and each of the blocks are described below:

1. Ship and cable sensors provide the basic input information to the control computer (see Figure 7-9).

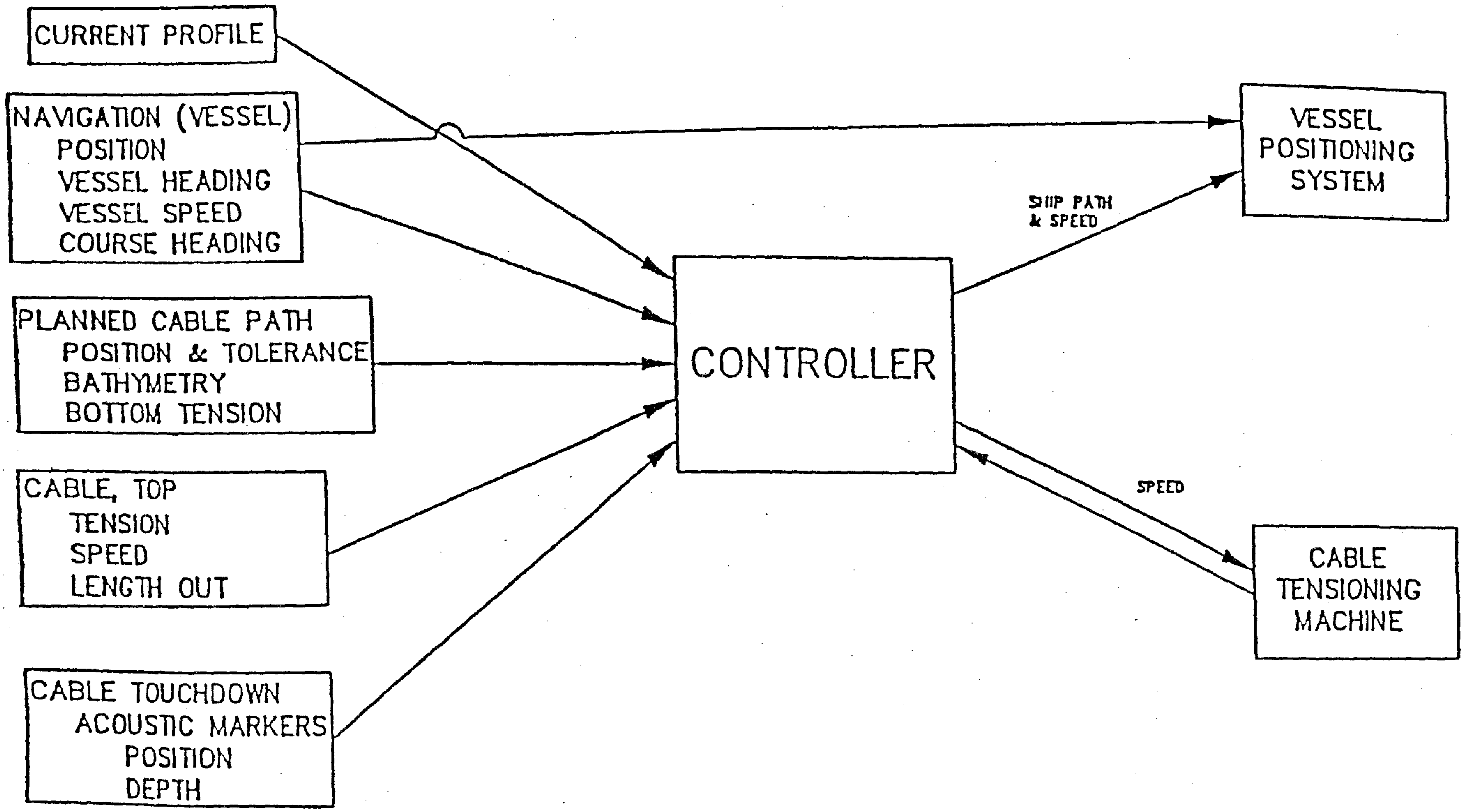
2. The Actual Path Calculator (APC) is a subroutine which, by iterative process, computes the actual cable touchdown point and bottom tension. It solves a mathematical model of the cable computing the position and the forces along the suspended cable length.

3. The comparator determines the difference between the actual touchdown values and the desired values.

4. The planned cable track on the bottom is corrected, if necessary, to bring the cable back to the desired path in the immediate future.

5. The Vessel Response Specifier (VRS) is a subroutine which computes the ship's course and speed and the cable payout speed in order to achieve the desired cable path and tension specified in Step 4, above. This subroutine provides instructions directly to the vessel and cable handling equipment crew.

6. The ship's captain and cable handling equipment operator receive the instructions from the Vessel Response Specifier. The ship and the cable handling equipment respond to their directions and the ship and cable sensors monitor the performance. Hence, the control loop returns to Step 1.




INPUTS/OUTPUTS TO INTEGRATED CONTROL SYSTEM

FIGURE 7-9

BASIC CONTROL SYSTEM LOOP

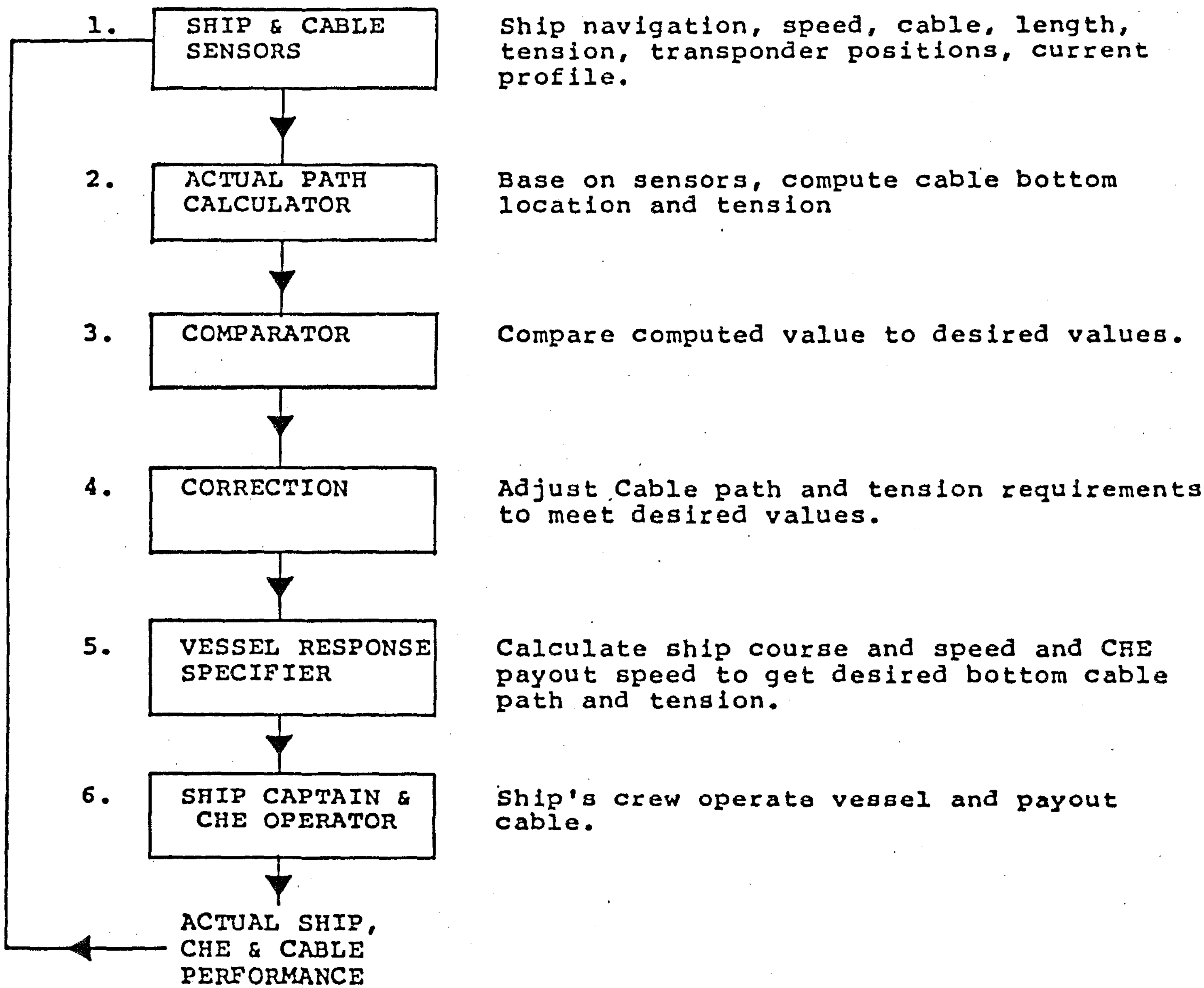



FIGURE 7-10

## At-Sea Test

The At-Sea Test for the HDWC Program will involve repeatedly laying a surrogate cable across the more difficult regions of the Alenuihaha Channel. The major components of this At-Sea Test are illustrated in Figure 7-11. Two primary vessels will be used: the cable ship and a support vessel. The primary function of the cable ship is to lay the cable and on that vessel will be the Integrated Control System, the Data Acquisition System and the acoustic navigation. The support vessel will be used primary to operate an acoustic doppler current profiler. These current data are transmitted via radio between the two ships.

As the cable is being layed, two different navigational systems will be used. A surface electronic range range navigation system will guide both the cable ship and the support vessel on the surface. Underwater, a long-based acoustic navigation system will be used to primarily follow transponders attached to the cable suspension, but to also occasionally follow a manned submersible checking the layed cable.

The PISCES V submersible will check the location of the finally layed cable (through the long-based navigation system), visually look for suspensions or other improper bottom cable configurations and measure tensions in the bottom layed cable. The PISCES V is not an active part of the cable laying process but rather a final check on the success/failure of the cable laying operation. Data from the PISCES V will not be fed back into the control system during the cable lay.

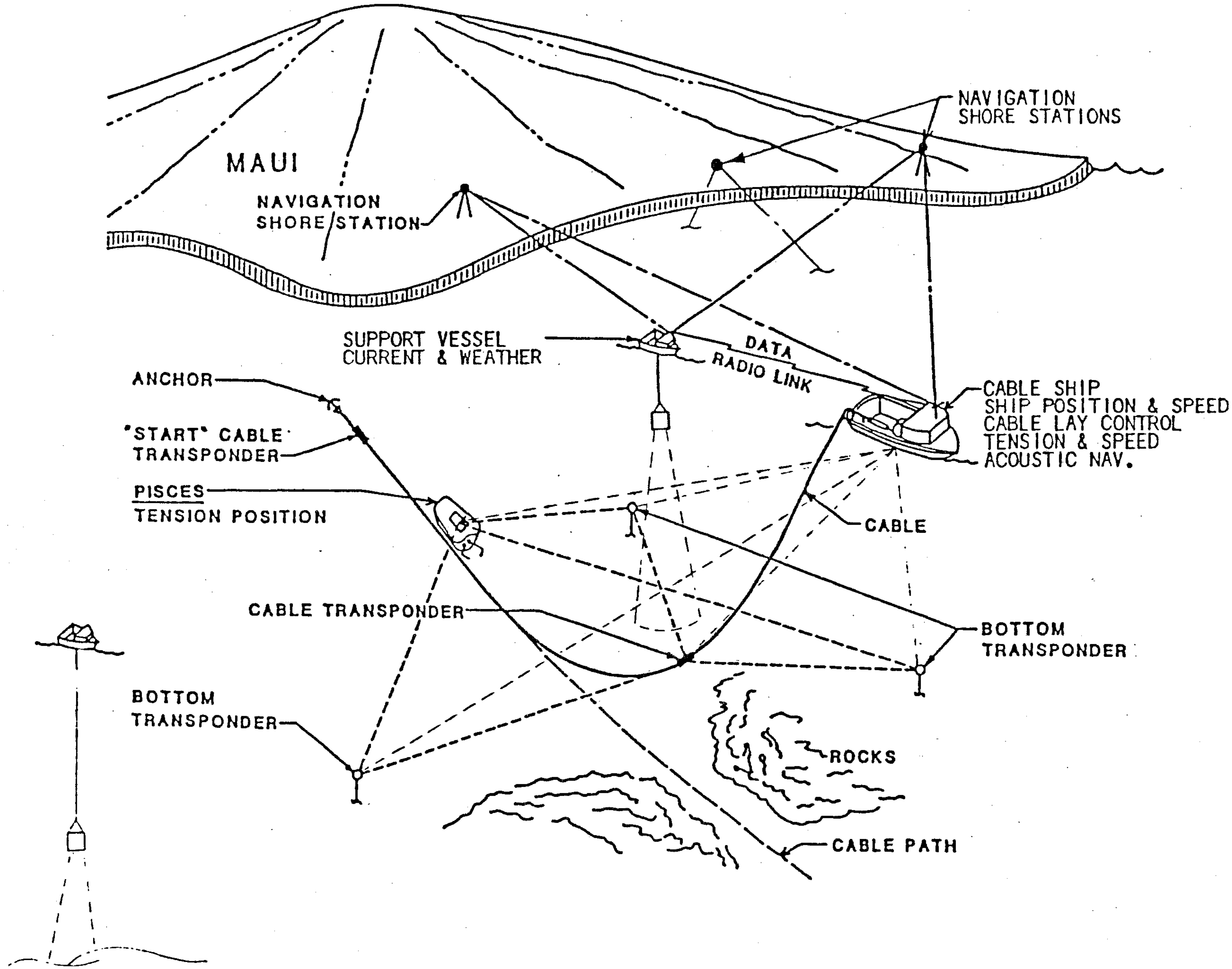



FIGURE 7-11

Shins and Components of the HDWC At-Sea Test

## PART 8

## BASIC DESIGN CRITERIA REFERENCES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