Technical Report No. 80
of PE/CK.8

Technical Report

INSTALLATION OF WAVERIDER BUOY
OFFSHORE RAROTONGA
21.274 S
159.726 W

Cook Islands

by

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Prepared For:

Committee for
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Technical Report No.80
of PE/CK.8
15 August 1987

INSTALLATION OF WAVERIDER BUOY
OFFSHORE RAROTONGA 21.274 S 159.726 W

Feasibility Studies for Harnessing
Wave Energy for Rarotonga

2 - 18 July 1987

INTRODUCTION AND BACKGROUND

This operation was undertaken as part of the CCOP/SOPAC Work Programme CCSP/CK.8 "Feasibility studies for Harnessing Wave Energy for Rarotonga".

The Government of Norway is funding a wave energy study program in the South Pacific and has supplied CCOP/SOPAC with Waverider Buoys for installation in several locations in the CCOP/SOPAC area. The following report contains some details regrading the mooring site, the anchoring system, the buoy installation, and receipt of data.

STUDY OBJECTIVES

The objective of this report is to document details of the buoys installation, and present an example of the data being received. The objectives of the wave energy programme were given in Technical Report No. 79 that describes the installation of a similar buoy system in Tonga.

PERSONNEL PARTICIPATING

The installation was a joint effort between the Cook Island Government and CCOP/SOPAC. Tony Utanga, Secretary of Internal Affairs represented Cook Islands and the Marine Scientist, Ralf Carter assisted by James Kamsoo, Electronics Technician represented CCOP/SOPAC in the operation. CCOP/SOPAC has the support and assistance of the Prime Minister's Department and the Ministry of Internal Affairs. Individuals assisting in the project included:

Mr. Stuart G. Kingan, Scientific Research Officer
Mr. Tony Utanga, Secretary, Internal Affairs
Mr. Bruce Carnahan, Captain "Manuvai"
Mr. Elgin Tetachuk, Owner of "Seafari"
Silk & Boyd Ltd, Inter-Island Shipping Service
Mr. George George, Director, Topographical Services Ltd.

The Harbour Master, members of "Manuvai's" crew, Department of Internal Affairs Staff and others provided services and assisted in the project.

EQUIPMENT, FACILITIES, AND METHODS

The following equipment was provided by CCOP/SOPAC:

Waverider Buoy (Supplied by Norway Aid)
Anchor Lines and Chain (Supplied by Norway Aid)
Other Buoys (Supplied by Norway Aid)
Blocks and Tackle
Hand Sounding System
Hand Tools
Charts
Trisponder System
Hand Held Radios
Hand Compass
Miscellaneous Supplies
Safety Equipment

The facilities and equipment supplied by the Government of Cook Islands included the following:

400 ton 142 ft "Manuvai" and Crew
7.6 ton 34 ft "Seafari" and Operator
Land Transportation
Storage Facilities for Equipment
Park Area for Calibration of Anchor Lines
Wharf Facilities
Survey Services for Trisponder Stations
Lumber for Launch
Lines for safety etc.
Scrap Iron for Clump Anchor
Communication Facilities

The operation was conducted in three steps. The first step was to survey the site (Figure 1 and 2), establish a depth profile in the general location for placing the buoy, and mark the location with a small buoy. The second step was to make up the mooring line and place the anchor system aboard the vessel, "Manuvai" for launching, reoccupy the site, and place the anchor. The third step was to transport the Waverider buoy to the site, remove the temporary buoys and safety line, attach the rubber snubber, and drop the Waverider buoy into the ocean. Norway was then contacted to determine if the wave data was being received in good order. The Harbour Master was advised of the buoys locations so it could be published in the Notice to Mariners.

SOUNDING

It is essential to sound the bottom using a lead line in addition to any depth determination using an echo sounder as the reef face may contain crevasses, overhangs, and steep slides that may not he detected by the echo sounder. The echo sounder indicated the distance to the reflecting surface within the sound cone which may not be the depth directly beneath the vessel. However, sounding by lead line in 300 meters of open ocean may require some care to insure accurate depth measurement.

The type of line and reel used is important. The line will have a significant drag against either currents or movement of the vessel. It will be necessary to raise the sounding weight almost to the water surface to move even a short distance to a new location. This will require some time to do while the vessel tends to drift with the wind or currents. So it is necessary to lower the weight rapidly and complete the measurement quickly before the vessel drift can be significant. Where there is some current and wave surge the drag on the line will produce a significant tension in the line causing it to stretch with the passing of the waves, and this will make it difficult to detect bottom contact with the weight. Use of heavier weight may require a larger diameter line that will develop a greater drag. Recovery of the heavier weight becomes more difficult and places greater stress upon the reel.

The FAO Design No WES-9 wooden fishing reel (Figure 3) which was used for the sounding reel was found to he satisfactory for holding up to 300 meters of the line, and it could be employed to reel out the 44.5 N (10 lb) weight. However, it can not be used to reel out a 222 N (50 lb) weight. This weight is excessive and cannot be controlled using the reel handle alone. Neither can it be used to pull in a 44.5 N (10 lb) weight. It can be used to reel in the line if the weight is pulled by hand.

The experience in the current operation indicated that a mono-filament or a braided line should give a better performance than the twisted cod line employed. The 1/8 inch 100 kg (224 lbs) test line had a significant stretch (1 in 8) when loaded 5 percent of its breaking strength. When the tension was relieved in the twisted line it developed a large number of kinks. When the weight was reeled in about 150 meters under tension it caused the wooden reel to fail. These problems could have been avoided by pulling the line by hand, but the kinking problem would then exist. Use of mono-filament line, while it also has a significant stretch would not. have the severe kinking problem when tension was relieved. If a kink is pulled out in the mono-filament line it will damage the line. A braided steel wire or solid wire may work, but kinks and pit corrosion are problems with stainless steel wire in sea water. A flexible low stretch, braided, high tensile strength fishing line may be the best. alternative.

MARKER BUOY

A recommendation was made previous by wave experts from Norway to locate the buoy offshore near the Sailing Club. A straight reach of reef is located southwest of the Sailing Club that is thought to receive the higher concentration of wave energy about Rarotonga (figure 1) and it was selected for the site.

It was convenient. to locate Trisponder stations on the shore near each end of this reach of reef (Figure 2). Marker buoys were located and ranges were identified to the major mountain peeks so that the buoy site could be reoccupied using the ranges should the marker buoys be lost. The Trisponder would not be available for the launch of the Waverider anchor.

The initial marker buoy employed was a commercial 28.3 cm diameter net buoy that has approximately 94.5 N (21.25 lbs) net floatation. It was tethered on a 1/8 inch cod line that was tested to have a breaking strength of 980 N (220 lb). The buoy was anchored with a 222 N (50 lbs) anchor of reinforcing steel. Difficulty was experienced in lowering this amount of weight on the small line from the wooden reel. The line was 321 metres long (304 metres depth + 17 metres scope), and the length was determined with 44.48 N (10 lbs) of tension applied to the line. This buoy was missing when checked the following day. Local residents are of the opinion that it was taken by a passing boat as such buoys are collected for decorations.

A replacement buoy was located in 366 metres (1200 ft) depth water anchored with 200 N (45 lb) of iron on a 400 metre (1312 ft) length of 1/8 inch cod line. The buoy was a string of 4 large onion sacks each filled with about 20 empty plastic 1 liter bottles. The buoy and line was stretched out on the ocean surface behind the boat as the station was approached. Using the Trisponder ranging to two stations the anchor was dropped on station with the line through a snatch block secured to a davit. The anchor descended at about 2 metres per second until it sounded. The water depth was estimated by the amount of line remaining at the surface. This method of placing the buoy was quite satisfactory. The location had been selected for a depth of 304 metres estimated from a previous sounding 60 metres to the southwest or parallel with the reef. The greater depth appears to be irregularities in the bottom depth. Rather than move the buoy it was decided to leave it at that location. Pulling the anchor with the small line would be quite difficult. The plan was to move 100 metres closer to the reef for the Waverider location.

ANCHOR DEPLOYMENT

The 1595 kg clump anchor (a refrigeration compressor) was placed onto a timber pad set on the ships port shear strake amid-ship and the main hatch cover to form a launch platform. It was shackled to a 7 metre length of chain attached to 234 metre 3/4 inch braided line, 30 metre of 3/4 braided polyolefins line with 8 of the 11 inch floats at its upper end followed by 59 metres of 3/4 inch float rope, and the 55 metres of safety line with two 0.7 metre diam. inflatable buoys. The lines were flaked out on the main hatch cover, and the line with the buoys were lead over the side and the buoy string was lashed in festoon fashion with a break-away line. Snubbing line were attached to the clump anchor and secured to two deck stanchions. These lines were removed when the anchor was made ready to cast off.

The second marker buoy survived the harsh seas and were used to locate the Waverider anchor station. The weather had turned bad and visibility was limited to about 200 metres during the time that the large anchor was placed. The wind was from the north west from Rarotonga when the ship arrived at the marker buoy. As the ship was brought into position to heave the anchor the wind came abruptly to the south west and rainfall increased appreciably. The new set persisted and the seas began to build rapidly. It was evident that if the anchor was to be placed this day that it should be done quickly before the ship became difficult to manage. Visibility was now falling rapidly. The ranges selected on Rarotonga could not be seen due to the heavy rainfall and low cloud ceiling. Even the reef became obscured from vision. The wave clutter on the radar screen could not be reduced so to allow identification of the reef due to the heavy seas. The set of the marker buoy, wave orientation, and wind direction was used to place the ship relative to the marker buoy anchor location and occupy the drop site.

The ship was brought to location from a bearing taken to the marker buoy. The crew was ordered to clear the area, and the anchor was heaved over from its pad by means of timber on the roll of the ship. The line ran free at what appeared to be about 7 meters per second until the slack was taken up by the buoys. The lashing parted and the eight submergible buoys fell free. The line continued to run until the anchor sounded bottom. The line came slack near the safety line attachment, and the remaining line and two large buoys were heaved over. The ship came astern slowly to clear the line. The ship circled the buoys several times to see if the anchor was fast and not sliding down the steep bottom slope. There was no apparent movement of the anchor and the ship returned to port.

LAUNCHING THE WAVERIDER BUOY

The Waverider buoy inside of its cradle was passed down to a skid placed on the stern of the small 34 ft vessel the "Seafari" by hand from the quay some 2 meters above. It was removed from the cradle and secured with lines to the deck cleats as can be seen in the attached picture. The 15 metre rubber snubber was attached to the short chain attached to bottom of the buoy (see drawing of the buoy system in an Appendices to this report) with a stainless steel shackle and the connection was tapped to protect the connection.

The temporary floats and the marker buoy were located at the anchor site. The floats were hauled aboard and the safety line was heaved aboard along with a length of the float line. The main anchor line was belayed to a ship cleat while the rubber snubber was connected with a stainless steel shackle to the anchor line. The connectors, thimble, and short chain on the buoy were of stainless steel. The connection was tapped to protect the line from chaffing and pulling free of the thimble if stretched under load. The anchor line was veered and the vessel was allowed to drift down current to put a strain on the anchor line. As the strain came onto the buoy it was walked off the skid platform and allowed to fall free into the sea. The launch occurred on 17 July 1987 at 1100 hours local time or 2100 hrs Zulu.

BUOY LOCATION

The primary bench mark in Rarotonga is BM-1 located at the Court House in Avarua. The original grid system is measured in Chains with the origin 0,0 at BM-1 (L&S Map No 149). As the buoy location is in the fourth quadrant with respect to BM-1, the distance to the buoy was determined in metres south and metres east of BM-1. The conversion from chain to metres is 20.1168 metrea/chain.

Two Trisponder stations were located on the beach in the area where the buoy was to be placed, and the coordinates for those stations are given in Figure 2. A marker buoy was placed at a distance of 1645 m and 1611 m from Station A and B respectively. The location of the marker buoy would then be 7599.05 S and 4672.98 E. The anchor for the Waverider buoy was dropped approximately 100 meters shoreward of the marker buoy. The bearing to the marker buoy was 152 true. The calculated location of the buoy would then be 7510.76 S 4626.03 E. This value was plotted on a chart and the location of 21 16.16'S 159'43.81'W was estimated for the buoy (Utanga and Lewis, 1981). On 21 July 1987 the Argos Satellite reported the buoy location as 21'16.56'S 159'43.80'W or very close agreement. with the estimated location.

DEPTH OF WATER AT BUOY

The echo sounders available for the site evaluation operated with a frequency of 200 kHz and would not indicate the water depth. The near shore bathymetry for that area (Utanga and Lewis, 1981) were found to show the bottom slope to sufficient accuracy; however, the depth error was significant. A depth of 366 meters was sounded with a line at the marker buoy where the charted depth is 230 metres. The anchor line used was 334 metres (1100 ft) in length. When the Waverider was attached about 5 metres of the line was pulled aboard and the angle on the anchor line was about 45', so the actual water depth would be close to the estimated 304 metres depth. The tide was about mid-flood at Avatiu Harbour when the Waverider was attached, 1100 hrs local time on 17 July 1987. There was minimal drag on the anchor line as it was pulled by one man. The pull was estimated to be about 222 N (50 lbs) as the boat was backed down onto the line.

ANCHOR STABILITY

The charted depth indicates that the bottom should have a slope on the order of 1.47 to 1 dipping out from the reef. The sounding made during the site survey (Figure 5) confirm the steep slope, and they indicated that the slope at the site parallel with the reef was about 1 to 1 dipping to the northeast. It should be difficult for a clump anchor to hold on such steep slopes; however, the bottom is expected to be quite irregular with some chance for the anchor to lodge and hold. As the 1595 kgf (3.5 kip) cast iron anchor did not slide following its free fall, it appears to have lodged. A safety line with a Danfort anchor was prepared and made ready to deploy. The Master of the vessel was reluctant to place the safety anchor near the reef and have the anchor line in the water near the vessel while the clump anchor was placed when visibility was so limited. The change in the wind, loss of visual contact with the reef, and the unavailability of a suitable vessel to place the anchor for at least 10 days lead to the decision to drop the clump anchor without the safety anchor.

An estimate was made of the falling velocity of the Clump anchor based on hydraulic drag on the anchor and on the anchor line calculated using constants from Buoy Engineering (Berteaux, 1976). Assuming a cross section area of 3.75 square feet and a drag coefficient of 1.18 for the anchor and a tangential drag coefficient of 0.005 for the 19 mm diam (3/4 inch) line the velocity of the anchor at 1000 ft depth would be 23.8 fps. This would be the same speed as would occur after the anchor fell 9 feet in air. This velocity would be expected to produce some sort of depression in anything except solid rock. It would be quite reasonable to expect a sliding friction coefficient near 1.0. In the following analysis a value of 0.9 was used.

An analysis of the worst case for the anchor was considered. It is the case when the tension, T in the mooring cable is being pulled in the direction of maximum slope downward. The maximum slope was assumed to be 45' and the friction factor was assumed to be 0.9. The 30 metre scope on the 334 metre anchor line in 304 metre depth water may result in as much as 26 angle with the vertical. The specific gravity of the anchor would be 7.86, so the buoyancy of the 1595 kgf anchor would be 203 kgf. Referring to the free body diagram (Figure 4), and expression 1) where W is the weight of the anchor, B is its buoyancy, T is the tension in the mooring line, is the angle of the mooring line with the vertical, u is the friction factor, N is the force normal to the bottom, and is the angle of slope with the horizontal:

$$W = B+T \sin 0+T \cos 0[(uN \sin + \cos 0)/(uN \cos 0 - \sin 0)] \qquad 1)$$

it can be seen that as long as the tension in the mooring line did not exceed 159 kgf (350 lbs) the anchor would be stable. A horizontal force of 70 kgf (152 lbs) would result in the critical tension in the line. This is not a very large force to be developed by current drag on the 304 metre line. As the anchor has not moved to date it is assumed that it was indeed lodged on the bottom, the friction factor is greater than one, the falling anchor produced a crater, or landed on a slope of less then 45', as the drag on the line caused by the tidal currents should exceed this critical force.

WAVE OBSERVATIONS

The data format for the transmission of wave data from Norway back to the South Pacific is given in Technical report No. 79 entitled "Installation of Waverider Buoy Offshore Tongatapu" (Carter, 1987). In general three sets of wave data are transmitted at one time. The observations are averaged over three hours and the average values for the most recent three hours are first listed. This set of data is followed by the next set of three hour averages, and that set of average data is followed by the three hours of data averaged previous to that period. The number of the Waverider transmitter, the location of the buoy, the day of the year and the time are also listed in the transmission. Eight energyflux density values, the significant wave height and the energyflux period are the values averaged. A typical plot of the energy flux densities transmitted by Telex is shown in Figure 6. The significant wave height for that data set was 3.5 metres and the related period was 10.4 seconds. The period corresponds to a frequency of 0.096 cps.

The data reviewed on 4 August 1987 indicated that the Waverider was located at 21.274S 159.726W or 21 16.43'S and 159'43.57'W. On 21 July the Argos Satellite reported the position as 21'16.56'S 159'43.80'W. These data would indicate a difference in location of 464 metres (1523 ft). The difference in location is assumed to be within the normal variation of the reporting system. Values of 300 meters are common and an occasional deviation of 1 to 2 km may occur.

CONCLUSIONS

The conclusions given are based upon observations made during the deployment of this buoy system, and experience elsewhere.

1. The placement of a clump anchor in 304 metre (1000 ft) depth water by free fall with the anchor line flaked on the deck worked well with the submergible buoys festooned outboard on break-away lines.

2. The sounding of the depth by means of 100 kg test line and a 4.5 kg weight in 304 meter depth water was a practical method to determine the water depth on the steep slope seaward of the reef.

3. The 1.6 ton (3513 lb) clump anchor was easily tipped overboard from a deck level launch pad using a timber as lever.

4. The anchor in a free fall impacted the ocean bottom at a velocity of about 7.6 mps (25 fps or the same as being dropped 2.7 metres (9 ft) in the air.

5. It would he desirable to make a bathymetry chart of the general area where the buoy is deployed in order to better select the place to drop the anchor.

6. It would he desirable to make a current survey over a tidal cycle in the general area prior to placing the anchor.

7. The location of marker buoy using a small vessel and the Trisponder system proved to he useful in the placement. of the anchor from a larger vessel in a good location during very poor weather conditions.

8. A backup system for locating the selected anchoring location is essential for completing the deployment of the system under adverse sea and weather conditions.

9. The Argos reporting of buoy location appears to be reliable to about 400 metres.

10. Dropping the Waverider buoy off a skid from the stern of a small vessel where the drop is on the order of a metre was a simple operation with light wind conditions.

11. A high strength braided line that has low stretch properties should perform better than the 100 kg test, twisted, polypropylene line used.

12. A marker buoy made of discarded materials that are unattractive to collectors appears to be more reliable than a commercial buoy.

13. The Waverider buoy placed in Rarotonga is operating in a satisfactory manner and reporting wave data via the Argos satellite. The anchor system appears to he stable on the very steep reef slope.

14. The crew of a ship-of-opportunity used to employ a heavy anchor in deep water should receive some instructions regarding the staying clear and out of the bright of mooring lines etc when the anchor is dropped. It should not he assumed that they will know the risks from the handling of cargo and routine ship activity.

15. The buoy system used during placement of the clump anchor should be sufficient in buoyancy to stop the downward slide of the anchor on a steep slope during the drop of the anchor. The anchor could always be hoisted up free of the bottom and floated to a more shallow depth for a second try at finding a stable footing.

16. The Waverider should not be attached to the mooring placed on a steep slope before at least a complete tidal cycle has passed to test the security of the mooring.

17. When a safety wire cannot he attached to the clump anchor on a steep slope, at least three small Danfort anchors should he secured to a short length of chain and attached to the clump anchor to be dropped. The length of chain should he shorter than the length of chain attached to the clump anchor that is attached to the main mooring line so that the small anchors will not damage the main mooring line during the free fall.

REFERENCES

Berteaux, H.O. 1976 "Buoy Engineering" John Wiley & Sons, New York, London, Sydney, Toronto.

Carter, R.C. 1987 "Installation of Waverider Buoy Offshore Tongatapu" United Nations Technical Report No 79 for CCOP/SOPAC, Suva, Fiji 22 June 1987.

Myers, J.J., C.H. Holm, and R.F. McAllister 1969 "Handbook of Ocean and Underwater Engineering" McGraw-Hill Book Company New York, San Francisco, Toronto, London, Sydney.

Utanga, A.T. and Lewis K.B. 1981 "Rarotonga Nearshore Bathymetry, 1:20,000 N.Z. Oceanographic Inst. Chart Misc, Series No 56 (being also CCOP/SOPAC Misc. Series Chart 1:20,000)

L&S Map No. 149 1983 "Map of Rarotonga, Cook Islands" Published by the Lands & Survey Department, Government of the Cook Islands, by arrangement with the Surveyor General, New Zealand.

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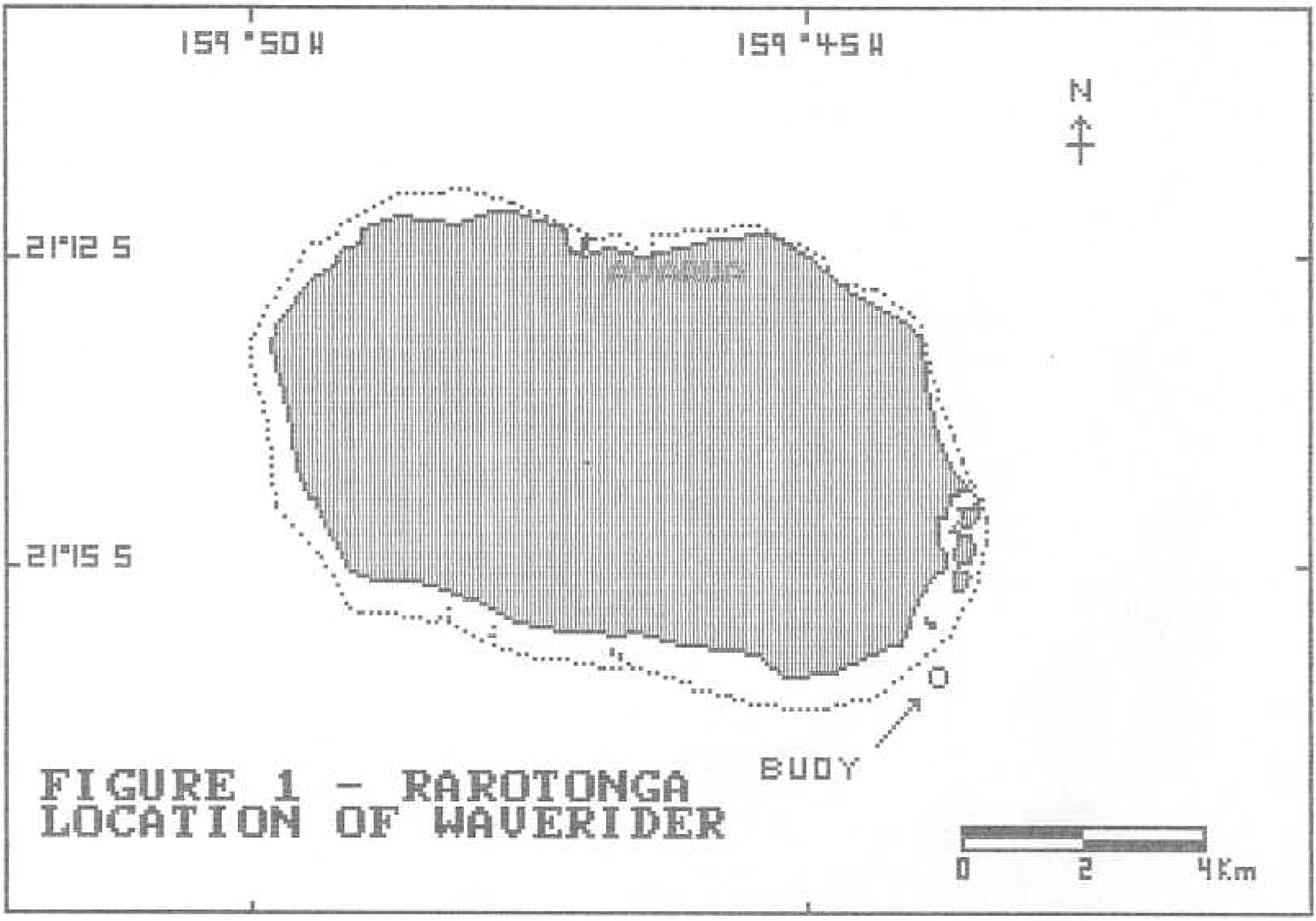
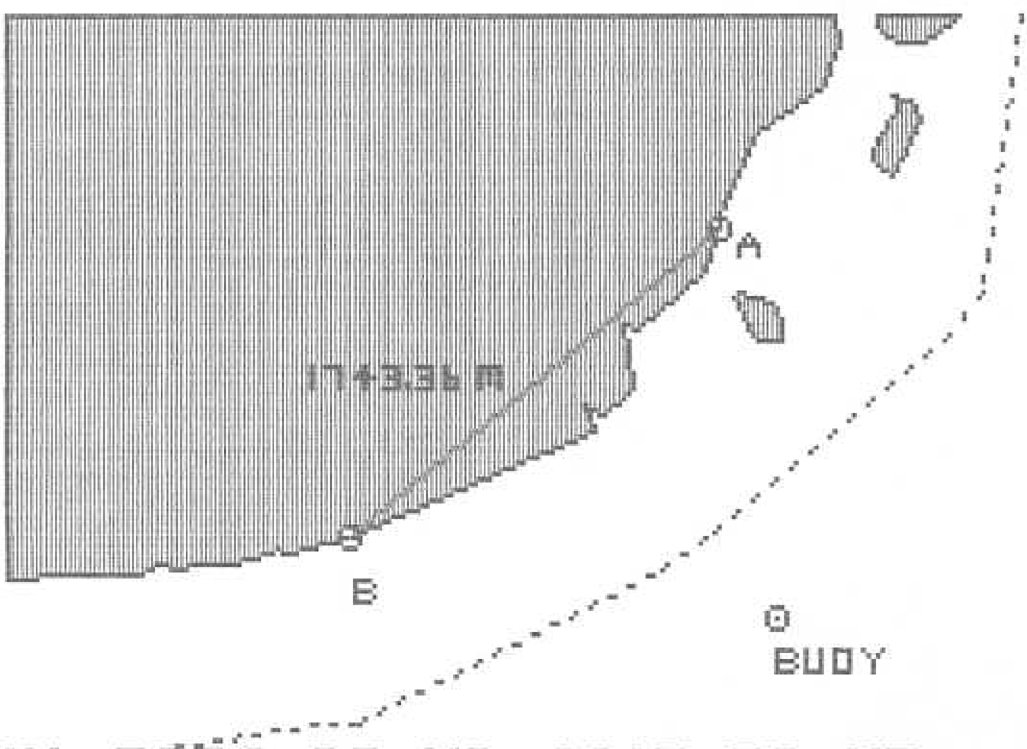
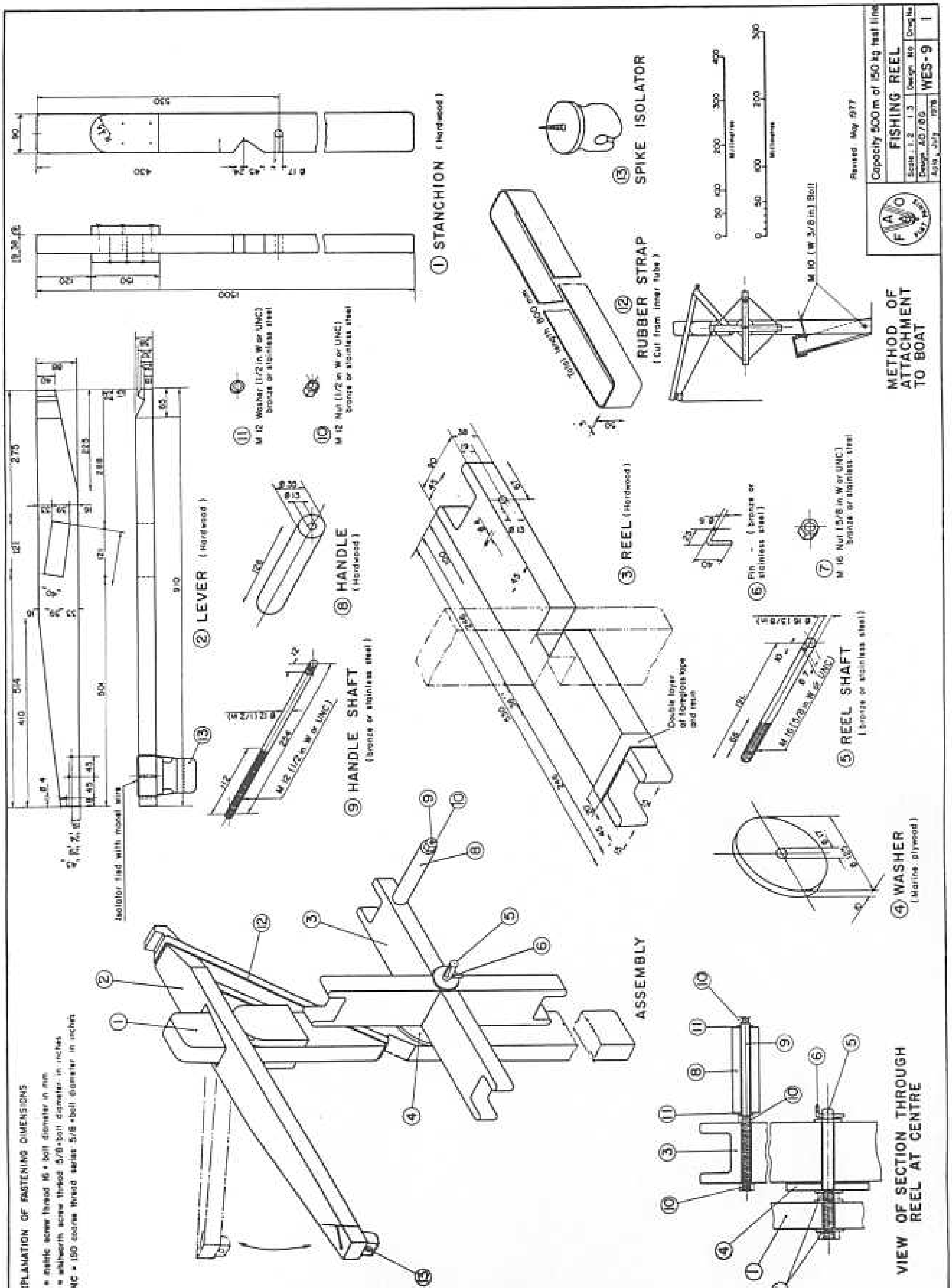


FIGURE 1 - RAROTONGA
LOCATION OF WAVERIDER

FIGURE 2 - Rarotonga Buoy Location



A 5974.30 MS 4415.59 ME
B 7147.83 MS 3126.43 ME



EXPLANATION OF FASTENING DIMENSIONS
M = metric screw thread 16 = bolt diameter in mm
W = whitworth screw thread 5/8 = bolt diameter in inches
UNC = ISO coarse thread series 5/8 = bolt diameter in inches
ASSEMBLY
VIEW OF SECTION THROUGH REEL AT CENTRE
① STANCHION (Hardwood)
② LEVER (Hardwood)
③ REEL (Hardwood)
④ WASHER (Marine plywood)
⑤ REEL SHAFT (bronze or stainless steel)
⑥ Pin - (bronze or stainless steel)
⑦ M 16 Nut (5/8 in W or UNC) bronze or stainless steel
⑧ HANDLE (Hardwood)
⑨ HANDLE SHAFT (bronze or stainless steel)
⑩ M 12 Nut (1/2 in W or UNC) bronze or stainless steel
⑪ M 12 Washer (1/2 in W or UNC) bronze or stainless steel
⑫ RUBBER STRAP (Cut from inner tube)
⑬ SPIKE ISOLATOR
Isolator tied with monel wire
Double layer of fibreglass tape and resin
METHOD OF ATTACHMENT TO BOAT
M 10 (W 3/8 in) Bolt
Millimetres
Revised May 1977
Capacity 500 m of 150 kg test line
FISHING REEL
WES-9

FIGURE 3

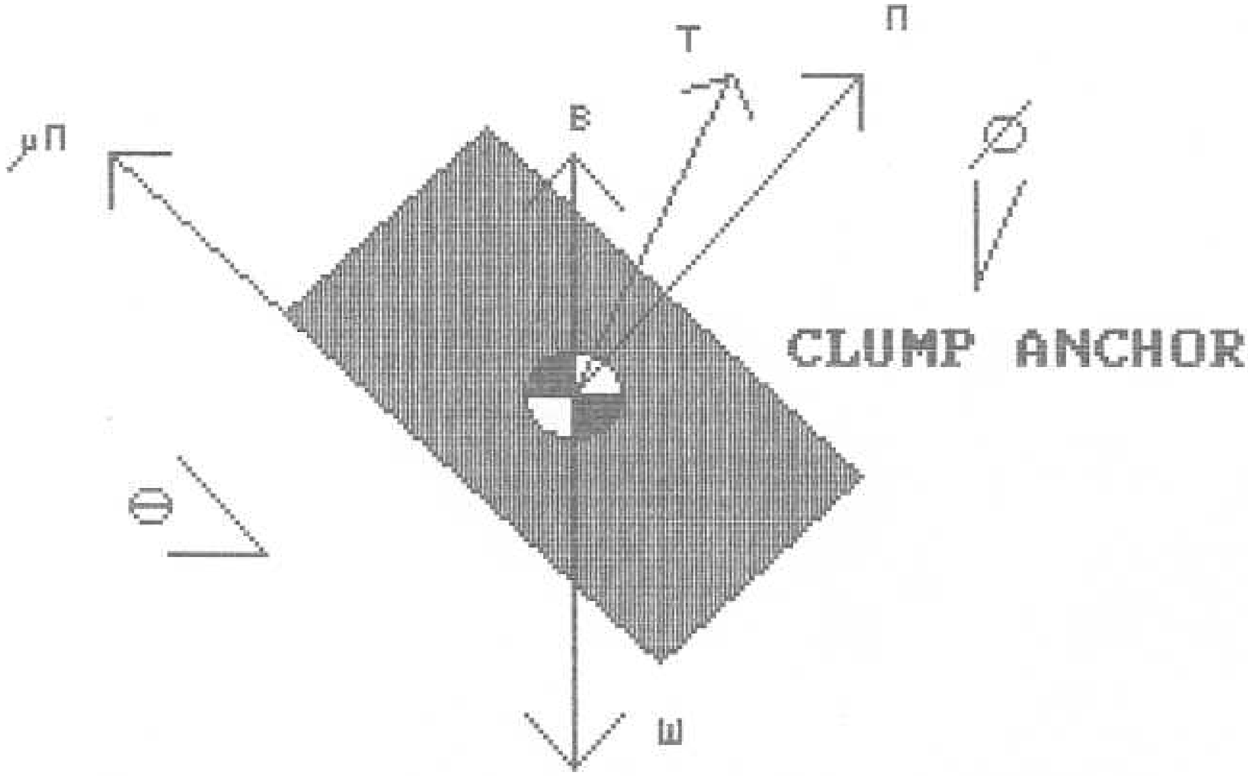


FIGURE 4 - FREE BODY DIAGRAM

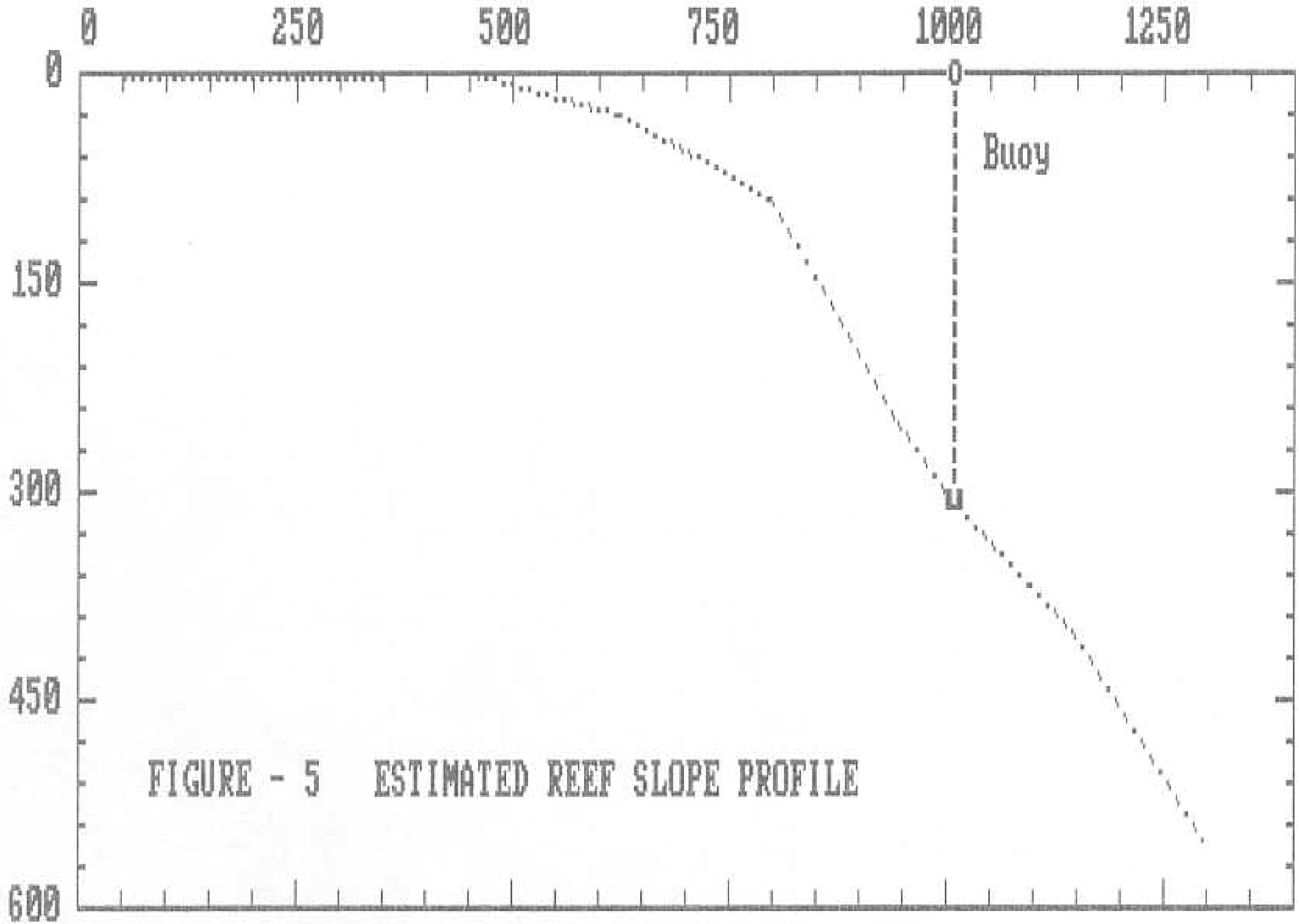


FIGURE - 5   ESTIMATED REEF SLOPE PROFILE

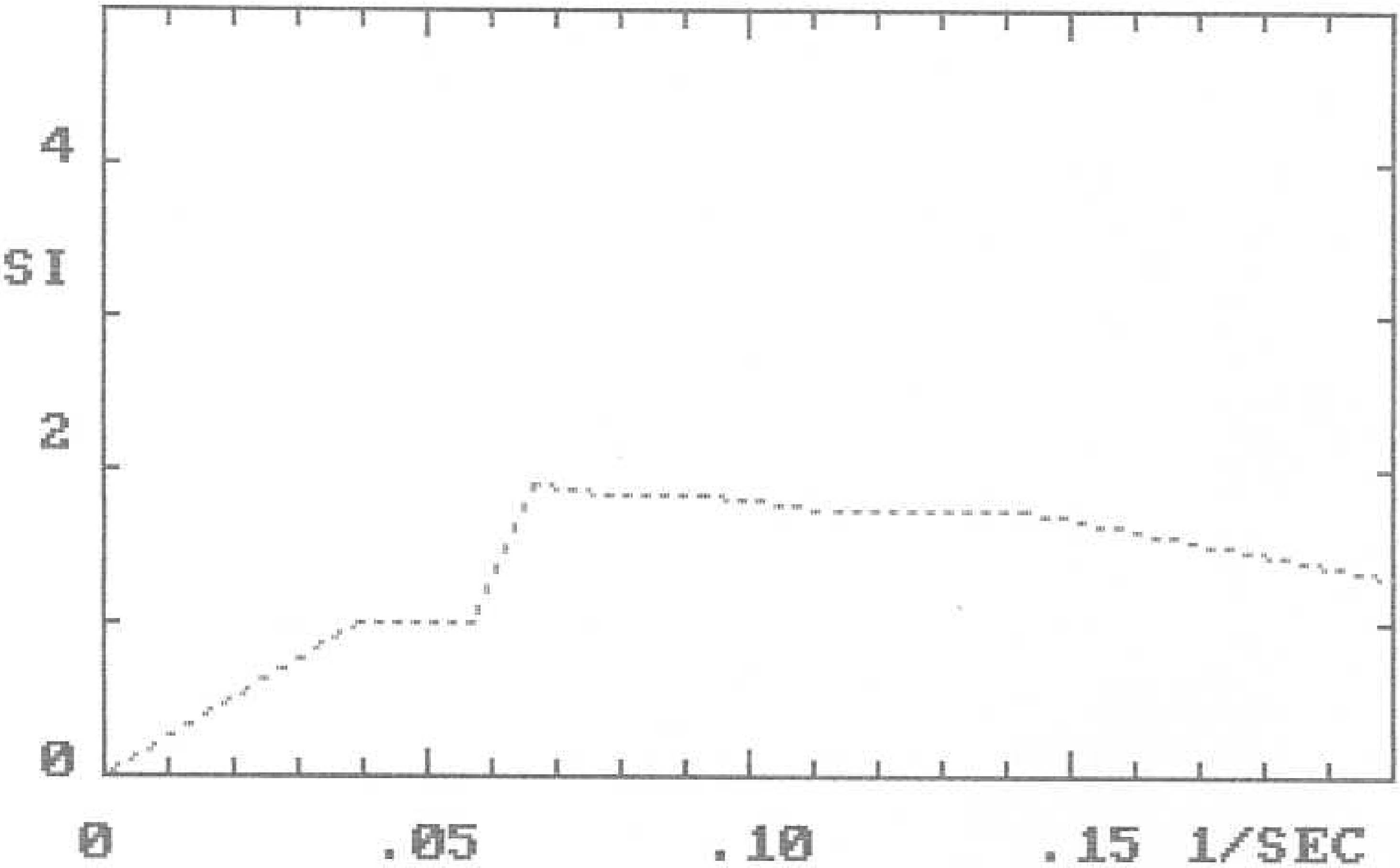


Figure 6 - Wave Energy Spectrum, kW/m

Sounding line
tensioned for
calibration

Anchor
string
prepared

4.5 Kg lead ball
to tension
sounding line
with reel

Waverider buoy made ready

950 Kg clump anchor

400 metres sounding line installed on wooden reel

Served Boline
on thimble
in braided
3/4" line

Trisponder
station at
shore area
Taakoka Motu

Deck of
Manuvai following
anchor deployment

Stern view of
400 tonne
Manuvai in
Avatiu Harbour

Tapped line
connection

Master
Trisponder chain
aboard Seafari,
aerial on mast

Waverider being transported around Rarotonga for launch aboard 7.6 ton 34 ft Seafari

Sacks of 1 litre plastic container used in marker buoy on Station

Waverider at

21° 16'.16S
159° 43'.81W in 305 metre deep water 0.3 Nautical Miles offshore Rarotonga