I.O.S.

A GUIDE TO SEA WAVE RECORDING

J S Driver

Report No 103

1980

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

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2 INTRODUCTION

2.1 IOS has been involved in the routine measurement of sea waves since the mid-1950's, when the newly designed Shipborne Wave Recorder (SBWR) was first deployed on Light Vessels. Since then various other types of instrument have been used, the most notable being the Waverider buoy and Frequency Modulated Wave Recorder (FMWR).

Initially the incentive to measure wave heights and periods arose from a desire to learn more about waves for research purposes, and the data collected facilitated development of wave forecasting techniques as well as a better understanding of the processes involved in wave generation and propagation and the mathematical description of the waves themselves.

From the applied viewpoint the construction of harbours and sea defence works has always required some knowledge of wave conditions and before the techniques of relatively accurate measurement were developed the lack of precise knowledge was compensated for by increasing the safety factors and thus the dimensions of the structure under design.

More recently the expansion of offshore oil and gas exploitation has shown that it is vital to base designs on a good understanding of environmental conditions of which waves is one of the most important. The interest now being shown in the possible extraction of energy from waves has re-inforced the need for reliable wave data with recording periods of minimum length one year and preferably three or more at certain important sites.

Maintaining equipment in the hostile environment around Britain's exposed coasts has proved a difficult task. The instruments now used by IOS and the deployment techniques that have been developed are the result of experience gained over the 35 years or so since the first installations.

2.2 In an effort to assist those who need to measure waves, in particular engineers concerned with coastal protection, harbour works, etc, some of the experience gained, and techniques used, by IOS engineers and scientists are set down in this paper. Guidance is given in the various aspects of setting up a wave recorder project. The paper begins by discussing the considerations involved in selecting a suitable instrument bearing in mind the use to which the data will be put as well as the nature of the site and the surrounding sea areas. The principles of operation of some of the more commonly used instrument types are described and examples given of how some particular instrument/site combinations have been chosen for installations in the UK. Since many sites are in remote situations and sometimes mains power is not available (or is unreliable) it is important that both sea and shore based instruments are capable of working with minimum power consumption and maximum reliability.

Site survey methods and the planning and implementation of an installation together with calibration and servicing techniques are discussed and again reference made to actual problems that have been experienced in the field. Data recording can be of the simplest type, for example by use of a pen recorder, but most modern analysis techniques require digital data and the usual 10% data sample may prove to be inadequate, particularly if an energy assessment of a complete storm event lasting, say, 12 hours is required. Data storage and compatability is always a problem and usually it is necessary to strike a balance between a desk specification and the convenience of relatively simple site equipment and maintenance schedules. Certainly any system that involves the site operator in frequent and difficult exchanges of tape reels or cassettes and pen chart rolls is unlikely to produce long uninterrupted data sets. Quite often the loss of data coincides with periods of considerable wave activity.

There is a variety of ways of analysing and presenting wave data and these will depend on the use to which the data are to be put as well as the facilities available to process the data. Often it may not be economic to carry out full spectral analysis of all data collected, especially if the recording medium is an analogue trace on a pen chart. The paper lists some of the current analysis techniques and gives examples of the output graphics.

2.3 Not surprisingly, wave recorders are manufactured in many parts of the world and a substantial number of operating principles are involved. An appendix to this paper comprises an up to date list of currently manufactured wave recorders complete with brief description, price, delivery and manufacturers' names and addresses.

3 CONSIDERATIONS INVOLVED IN CHOOSING A SYSTEM

3.1 The waves which are the subject of this paper are known as gravity waves and are generated by the action of the wind on the sea surface. In principal they have wavelengths of 3 cm or longer, but the practical engineer working in the sea is rarely interested in waves with wavelengths shorter than about 6 m and having periods less than 2 s. Capillary waves are not considered and tsunamis (waves caused by seismic disturbances which are popularly, but incorrectly, described as tidal waves) are mentioned only briefly as are surges and tidal bores, the latter being particular forms of waves restricted in the British Isles to a few estuaries. Ref 1 is recommended for a more detailed description of tides and waves.

The characteristics of sea waves depend on the situation in which they occur, particularly in confined waters. A well designed harbour will contain only waves of relatively small height: these waves may well be steep, but the short fetch (the distance over which the wind can act without appreciable change of direction in the course of generating waves) will always limit the wave height and period. At the other extreme waves present in the open part of, say, the North Atlantic may have been generated in storms several thousand miles away. Not only are there many variations or combinations between these extremes, but the situation may well be complicated by the presence of seiches (standing waves induced by the action of storm waves or surges normally in a confined area such as lakes, harbours, channels and estuaries) or other long period resonance effects. In (shallow) coastal waters the height, wave length and periodicity of the wave activity will be influenced by the depth of water present and thus tidal and surge conditions will have significance.

A typical distribution of energy for waves and currents is shown in figure 1. It is waves of period between 2 seconds and 5 minutes that are usually of most concern to an engineer designing marine structures, although, as already mentioned, tide and surge effects will need to be taken into account.

3.2 It becomes clear that any wave recording scheme must start with a desk investigation into the type of waves most likely to be present at the site in question. It is by no means unknown for the wrong type of instrument to be chosen due to insufficient thought about this aspect - for example an instrument with a restricted high frequency response would be of little use in a protected situation where only short period waves were possible. Indeed, an examination of site exposure and wind

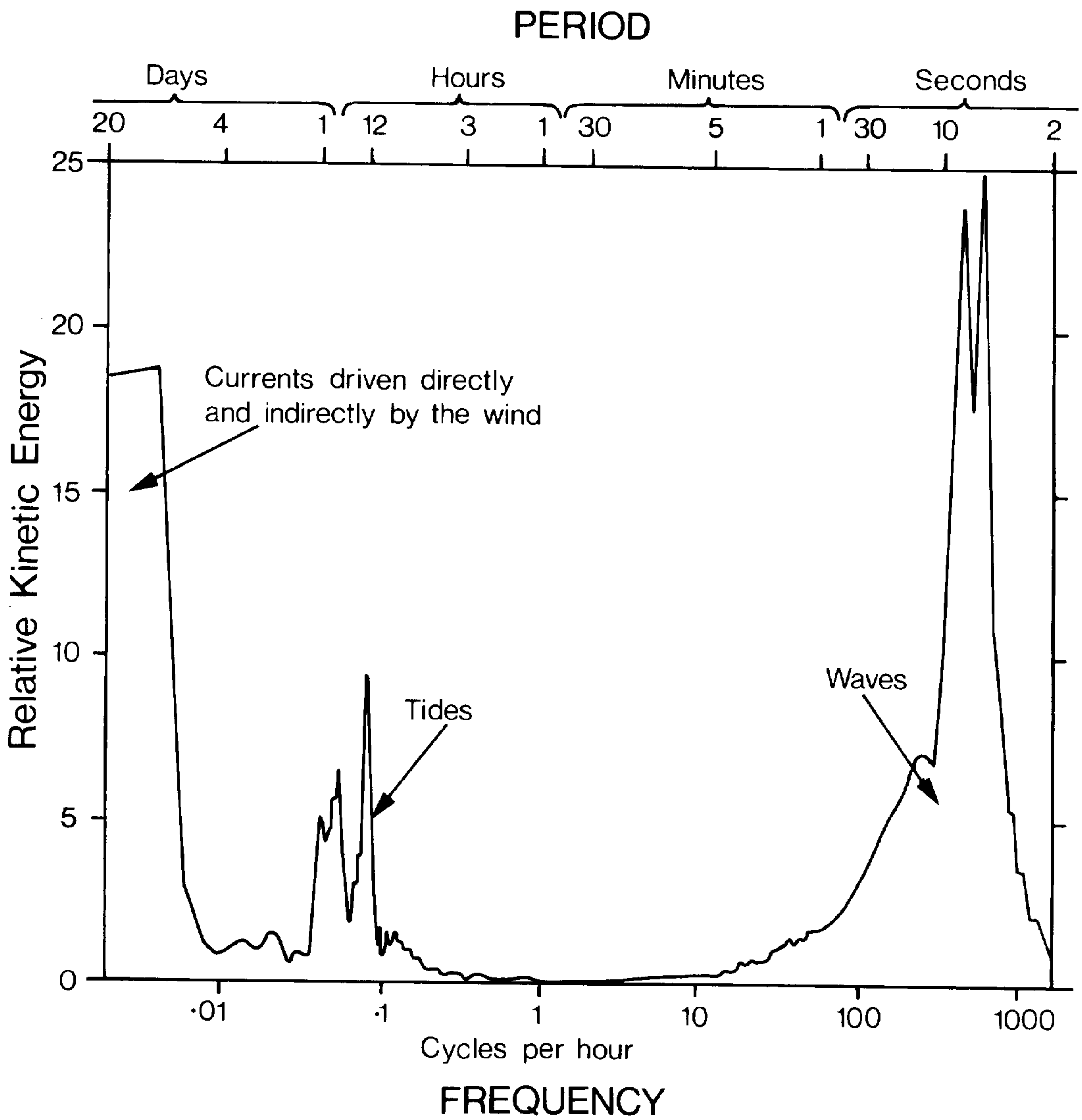
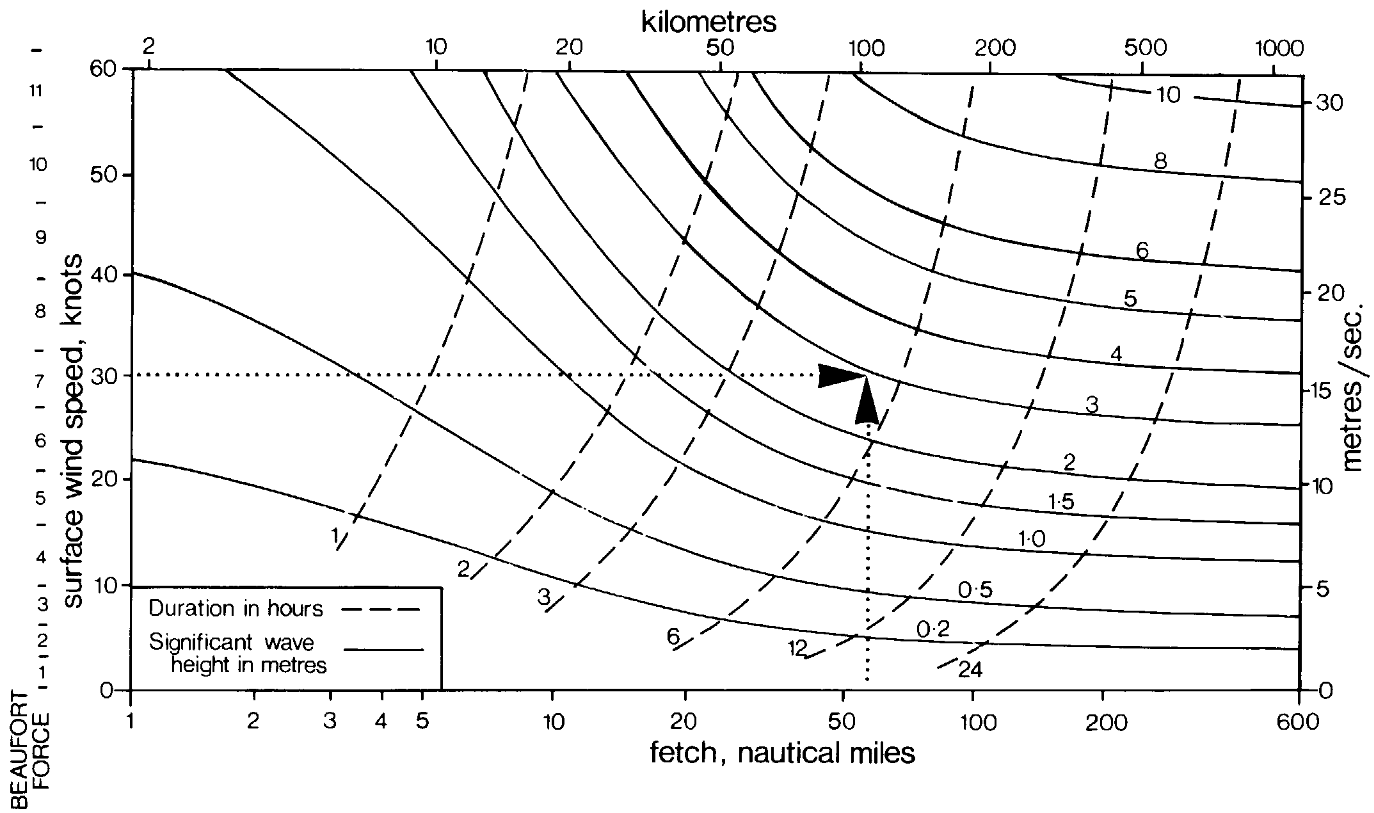


FIGURE 1 TYPICAL ENERGY DISTRIBUTION OF WAVES AND CURRENTS

statistics may allow some estimation of wave height and persistence by use of prediction graphs, an example of which is shown in figure 2. There are also physical limits to wave height. Theoretically (ref 2), in deep water a wave exceeding the limiting steepness of $H_o/L_o = 0.142 \approx 1/7$, where H_o and L_o are respectively the deepwater wave height and length, will begin to break. This theory applies to an idealised wave train, but is some guide to practical limits. The height is also limited by the water depth and beach slope and as a guide it is useful to say that waves with a height of greater than 0.78 of the mean water depth into which they are being propagated are likely to break. In this situation the installation of a wave measuring instrument would only be justified if knowledge of parameters such as persistence and scatter of wave height and period were required. It should also be borne in mind that adequate data might already exist, the Marine Information Advisory Service (ref 3) should be contacted at an early stage.

3.3 The next questions the engineer must ask are: what is the data presentation requirement, and how will the results be used or applied? If the design of a marine structure is involved then the ability of the structure to withstand the largest likely wave in its lifetime will be of importance. Protection against fatigue effects will require a knowledge of wave height and period statistics with particular reference to persistence information. It may decided that a spectral representation is essential, many scientific and some engineering investigations demand this approach. The answers to the sort of questions posed above will form the basis for decisions concerning instrument type and accuracy, recording format, data sampling rates, and processing and presentation methods. Regrettably there are many well documented cases of wave recording projects having been carried through at considerable expense and effort only for the design engineer to discover at the end that the data are quite unsuitable for use in his particular application. Such cases illustrate the importance of constructing a comprehensive information base and applying it to the design problem in hand.

3.4 If the data requirement has not been met by data bank sources or prediction calculations then hopefully several apparently suitable instrument and recording systems will have emerged from the desk study thus far carried out, and the next stage in the planning process will be to relate these devices to the possible sites of operation. Survey of sites will be discussed in greater detail in a later section, but suffice it to say that site facilities and environmental hostility both for sensor and signal receiving/recording



How to use the Wave Height Prediction Graph

Example; 30 knot wind blowing for 12 hours over a 60 mile fetch.

Enter from left at 30 kt moving horizontally to right. The 60 mile fetch limit line is reached before the 12 hours limit line. Read off Significant Height = 3.0 metres.

(Adapted from Darbyshire & Draper, 1963, Engineering, 195,482-484. q.v.)

FIGURE 2 WAVE HEIGHT PREDICTION GRAPH FOR COASTAL WATERS (DEPTH TYPICALLY 20-200 METRES) system will be paramount considerations. The existence and quality of power supplies will also be major factors. It could be that for reasons of high probability of data return a more 'sympathetic' site will be preferred to the one that is the ideal position for wave exposure; put another way, a continuous data set modified to take account of the sensor's less than ideal location may be more use than an intermittent or patchy set obtained from a sensor deployed in apparently the best location for the monitoring of waves of interest. Clearly the desired lifetime of the recording station will have a bearing on these decisions, it may be worth situating the sensor in a vulnerable position if only a month or so of data are required whereas a 3-year programme of routine data collection will dictate a safer site.

3.5 Finally the cost of equipment procurement, installation, maintenance and data processing must be considered and here the engineer (and the accountant) must relate the financial outlay of the wave recording project to the cost of the scheme as a whole. In a multi-million pound sea defence construction it makes little sense to economise on wave recording to save a few thousand pounds and thus put at risk the acquisition of a reliable wave data set.

4 PRINCIPLES OF OPERATION OF SOME WIDELY USED INSTRUMENTS

4.1 It should be made clear from the outset that there is no ideal wave recording device. Making measurements of environmental extremes is difficult anyway and to ask that electronic instruments should do this reliably over long periods in the sea is to place quite exceptional demands on instrument performance. Although a variety of wave measurement techniques will be discussed in this section, it is likely that in a given situation there will be only one contender since generally speaking only one type of instrument (and often only one specific instrument) will come close to meeting the range of criteria imposed by the engineer or scientist's requirement for data and the conditions prevailing on site.

It is convenient to divide wave recording instruments into four classifications: (a) instruments that measure waves from above the surface; (b) instruments that measure waves at the surface; (c) instruments that measure wav es from below the surface; and (d) wave direction recording.

4.2 Group (a) comprises instruments carried by aircraft and satellite as well as those fixed to structures above the sea surface. Radar, laser and radio altimetry are the techniques involved and in all cases the energy, be it continuous wave or pulsed, is beamed down to the sea surface. The reflection or echo signal is received and processed to yield an electrical output which is normally a voltage directly proportional to the distance between transmitter and the reflecting surface.

Both radar and laser systems are commercially available in a portable solid state form and have been deployed for routine data collection purposes. They are usually fixed to tower or pier structures and as with aircraft, measure the sea surface elevation with a downward looking beam. The disadvantage with this principle of operation, and this applies to aircraft and satellite based measurements also, lies in the difficulty of making accurate measurements of the sea/air interface when the surface is aerated or spray is present. This will happen when waves break and/or have their tops blown off and so the very time when strong wind conditions and large waves exist will be the time at which the data become unreliable. There are also difficult practical problems connected with the inherent variability of echo strength combined with possible reflections from the supporting structure. To some extent digital averaging of the data and employment of error detection and rejection techniques will compensate for these shortcomings, but it may be possible to adequately correct the data during severe storms.

The presence of the support structure will very likely cause distortion of the wavefield and this effect must be taken into account. Having said this, measurements from fixed structures made when 'good echoes' are being received are potentially of high resolution and accuracy (of the order of 1% or better) and can encompass a wide bandwidth of sea state, certainly from 1 sec. period waves through to tidal and surge components. Where the transmit/receive equipment is aircraft-borne (either fixed wing or helicopter) compensation must be made for the movement of the aircraft relative to the ground. Such systems are complex and expensive to operate and are not considered suitable for routine data collection. Use of synthetic aperture radar from satellites is a recently introduced concept. The term 'synthetic aperture' refers to the technique whereby a narrow beam is achieved by electronic means as compared to using a large antenna. Wave length and direction can be derived, but as yet the relationship between the return signal and these parameters is not fully understood. The leading edges of short rise time pulses transmitted by satellite-borne radio altimeters are modified as a result of reflection from ocean waves. It is possible to infer r. m. s. wave height by careful signal processing of the return pulse, but here again further work needs to be done before such systems can be considered proven.

It is true to say that satellite systems show promise and are likely to be more widely used in future schemes, but clearly the cost of collecting data in this way could be high and may be geographically limited.

Recently a considerable amount of investigation has been carried out into the use of h. f. radar signal transmissions to make wave measurements. Here backscattering from the sea surface is measured and long ranges may be possible by making use of propagation via the ionosphere. However, for the moment this approach must be regarded as experimental.

4.3 Instruments that measure waves at the surface, category (b), include staffs, heave measurement systems installed on buoys and ships, and photographic techniques. Wave staff sensors can broadly be described as those which have a vertical or near vertical wire or pair of wires stretched through the water surface. Resistance, capacitance, inductance and even tuning of a high frequency oscillator by the change in electrical wavelength of the unwetted wires are used as indicators of water level changes. High resolution, accuracy and frequency response are characteristics of these devices except, again, in extreme conditions when aeration and wire wetting by spray are likely to give rise to substantial errors. Figure 3 demonstrates spikes due to water splash. In common with some of the sensors in (a), a structure is needed to support wave staffs and it may be considered that the accuracy of measurement would suffer significantly if the sensor was fixed nearer to the structure leg than ten times the leg diameter. One wave recorder listed in the Appendix comprises a float moving in a vertical tube. Where regular inspection is possible a very simple mechanical system such as this has advantages.

Because wave staffs are wide bandwidth devices they are particularly well suited to measuring tides, surges, and long period waves as well as storm waves. Their long term stability is good and calibration of output signal against depth of immersion is easy to achieve. Apart from the spray problem mentioned above the staffs are prone to give erroneous results if oil, seaweed or refuse material becomes attached to the wire.

Probably the most widely used system for collecting routine wave data is the Waverider buoy. It is one example of a class of instruments that measure waves by floating in the surface of the sea and measuring their own vertical motion. The Waverider contains an accelerometer which is stabilised in the vertical plane for storm and swell wave frequencies (Fig 4). The accelerometer output signal is integrated twice to derive an analogue voltage representing heave and this is frequency modulated onto a 259 Hz sub-carrier. A radio transmitting frequency in the 27-30 MHz range is amplitude modulated by the sub-carrier and the buoy continuously transmits the signal at a radiated power of 0.17 watts. The buoy is a stainless steel sphere 700 mm in diameter and is moored by a compliant mooring which is designed to allow the buoy to follow waves up to 30 metres in height (Fig 5). The buoy signal may be monitored by a sensitive receiver over a maximum range of 50 km although this depends very much on the level of r.f. interference in the vicinity of the receiving installation. The advantages of this type of system are as follows:

1 The buoy may be moored at ranges up to 50 km from the shore, platform, rig or ship.

2 Under most conditions the buoys will contour the sea surface and generate heave signals to accuracies of better than 5%.

3 Reliability of the electronics systems is high.

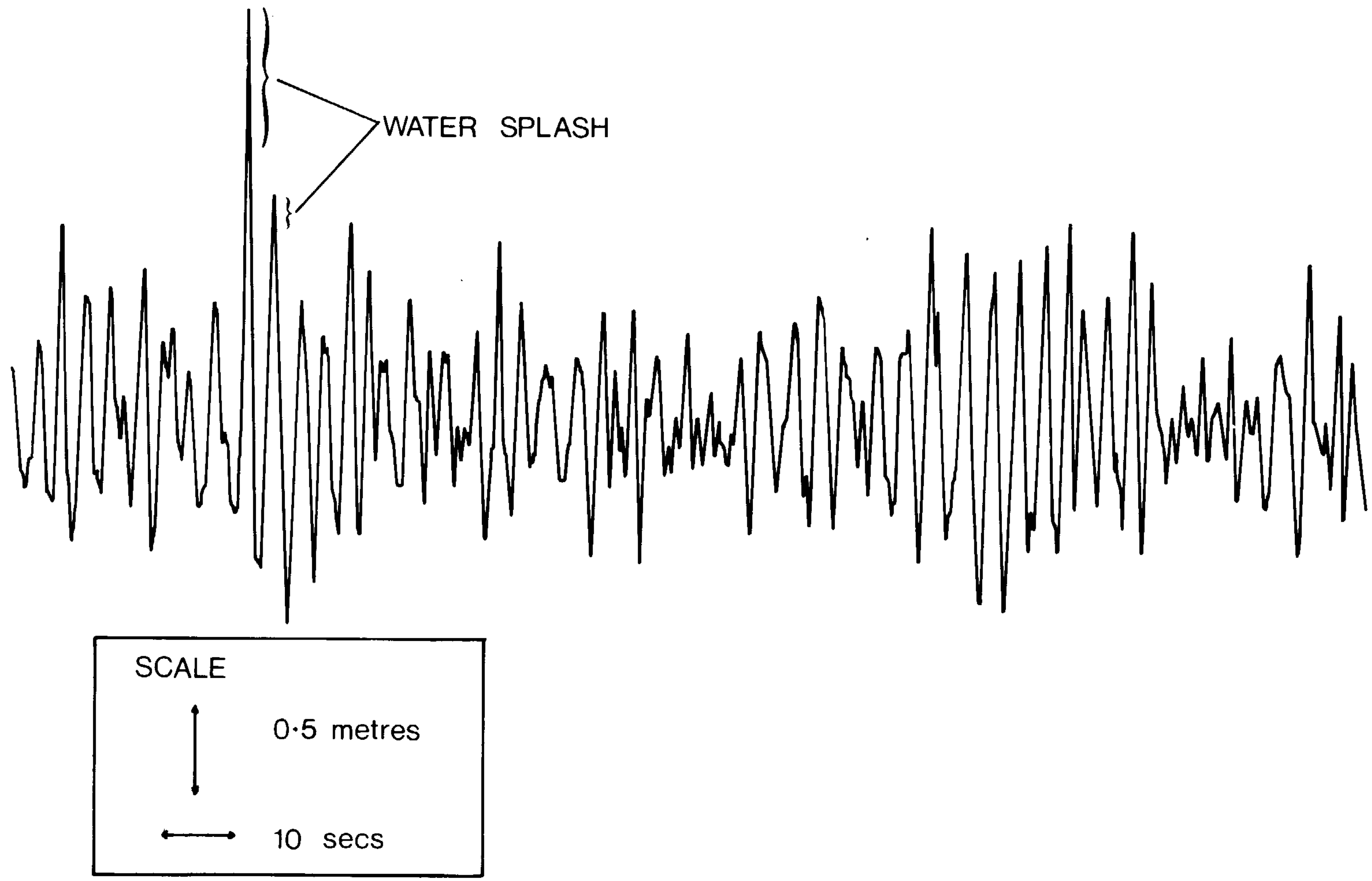


FIGURE 3 CAPACITANCE WIRE WAVE RECORDER

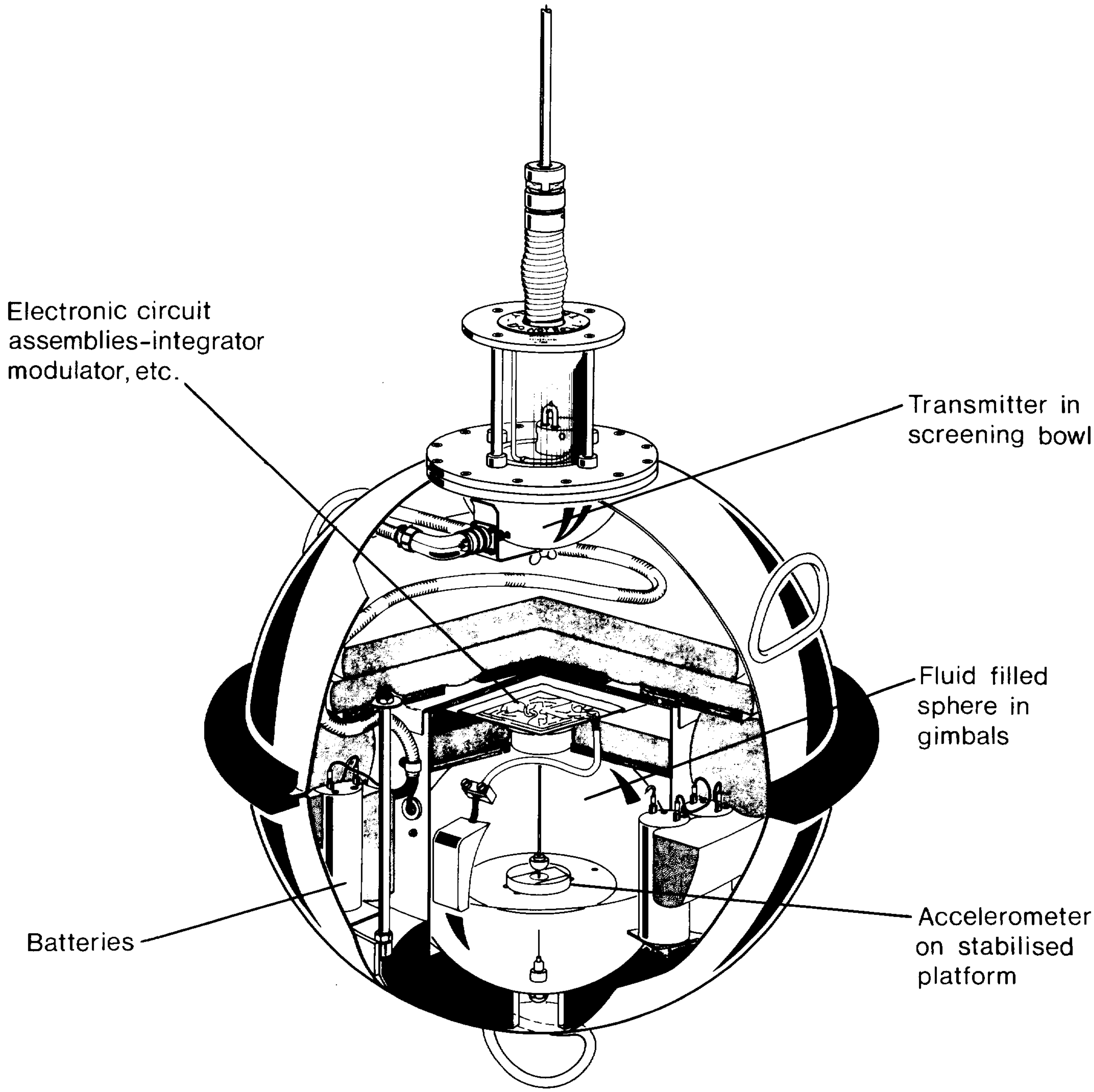


FIGURE 4 CUTAWAY VIEW OF WAVERIDER BUOY

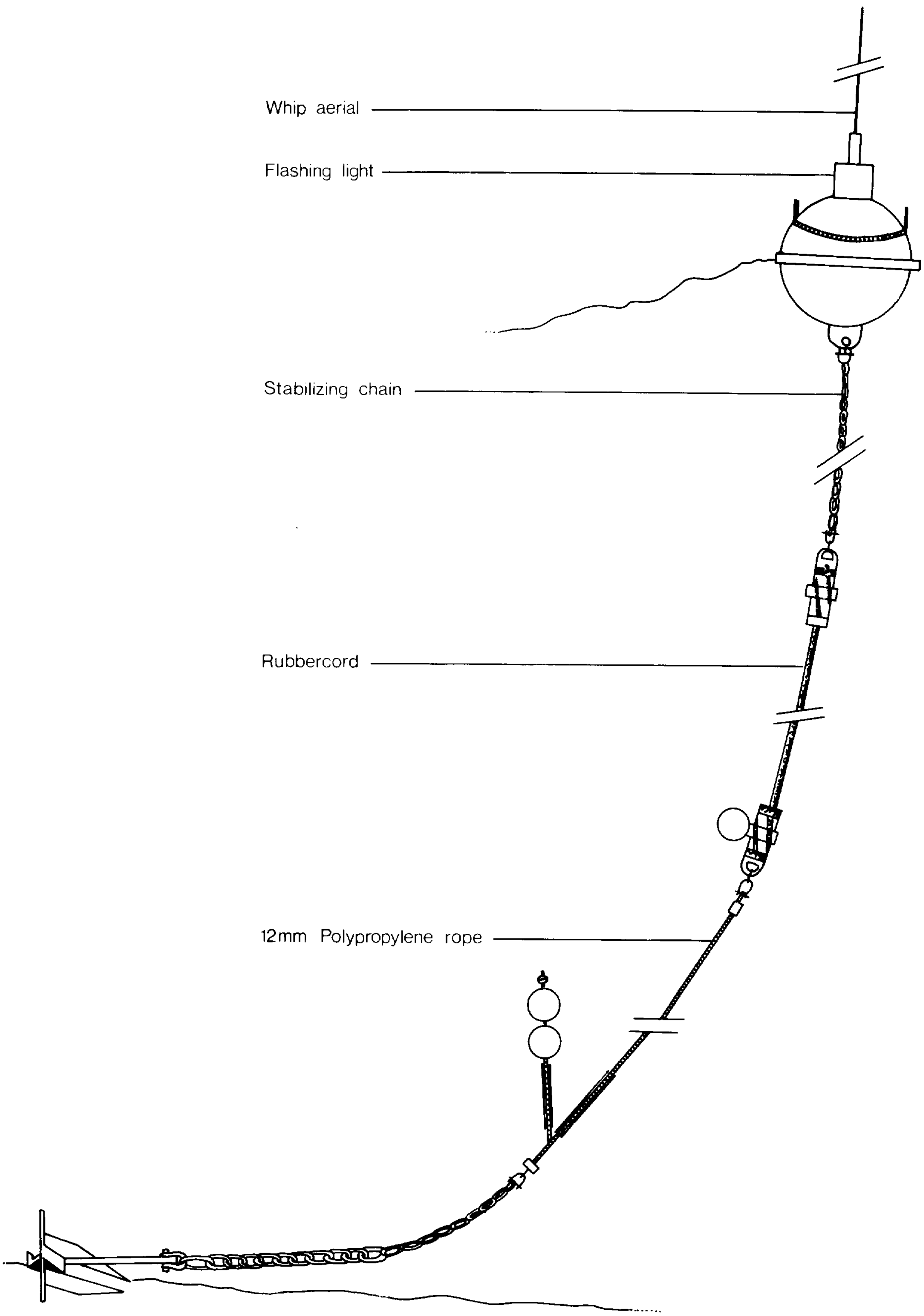


FIGURE 5 IOS 'SIMPLE' WAVERIDER MOORING

However there are, as always, some notable disadvantages:

1 The system is vulnerable to human interference.

2 Radio interference difficulties may severely limit the distance between transmitter and receiver, particularly in the presence of high waves. This problem has been getting steadily worse with the increasing illegal use of Citizens' Band radio.

3 Measuring accuracy may be significantly impaired in the presence of strong currents.

4 The effects of corrosion and wear in moorings may dictate short intervals between services in some areas.

5 Waves of period greater than approximately 25 seconds will not be recorded adequately.

Buoys with the capability of measuring a range of oceanographic and meteorological parameters are available but tend to be an expensive solution where wave measurements are required in coastal situations. In deeper water and more exposed places large data buoys with long range radio telemetry systems may be the only way of acquiring data. The cost of operating the larger type of buoy is almost certain to be very much in excess of that necessary to keep a Waverider on station.

Long vertical buoys (spar buoys) have been in wide use for oceanographic measurements but, by and large, have not successfully made routine sea wave measurements. Usually the buoy's vertical motion is monitored by an accelerometer, but since the spar has an inherently poor response to short period waves it is necessary also to incorporate a pressure transducer on the submerged portion. The response function to waves for the system as a whole then becomes complex and accurate measurements are difficult to achieve.

The Shipborne Wave Recorder (Ref 5 and 6) has also been widely used in the past. It too contains accelerometers to measure heave which in turn is a measure of the longer period waves that the ship responds to. The short period waves which do not contribute to the heave are measured by pressure transducers situated in the hull just below the waterline. The combination of a pair of heave and pressure transducers each side of the ship close to the pitch centre allows the ship pitch and roll motion to be reduced to negligible proportions. The system is rugged and easily maintained and thus allows high rates of data return at modest cost: this is possibly its major advantage nowadays. It is important that the ship should be stationary, or nearly so (< 2 knots), when measurements are taken otherwise distortion of the wave period information takes place. The system is relatively accurate for long period waves, but the pressure unit signals have to be corrected for the depth of the pressure unit below the surface. This correction factor is frequency dependent and liable to introduce significant errors in the accuracy of the instrument for the measurement of short waves. The problem is exacerbated if the instrument is fitted to very large ships.

Photographic techniques can involve, for example, the cine filming of a graduated staff. The method is obviously very limited in its ability to produce regular recordings of wave height and period over long periods, and conversion of the data into a readily usable form is a labour intensive task.

4.4 So far most of the instruments described have involved sensors that are both visible and accessible to unauthorised interference. Classification (c) is concerned with sensors that are submerged and thus largely protected against idle curiosity and deliberate interference. If water pressure is monitored a little below the surface by a sensor which gives an electrical output proportional to pressure, then analysis of the data produced can yield information about storm waves, medium frequency waves, tides and mean sea level. There is one major disadvantage: the existence of the depth attenuation effect. Fig 6 shows the theoretical relationship between wave height and period versus the depth of the measuring sensor. A useful 'rule of thumb' for bottom mounted recorders is that the instrument response will be down by 50% when the depth is 1/5 of the wavelength λ, where $\lambda \simeq 1.5T^2$ in metres. Precise calculations are difficult since the results from experiments (references 7 and 8) do not agree with the classical hydrodynamic theory. It is clear that attempts to measure short period waves (<6 secs) with mean water depths in excess of 15 m will give misleading results since very large correction factors are involved. Of course quite often it may be possible to situate the transducer close to the surface, on a support structure for examples, but substantial errors will result in the presence of a large tidal range. Nevertheless pressure measuring systems are frequently used in shallow water situations where it may not be convenient or economic to deploy a buoy or staff system. They are rugged devices and comparatively cheap: usually they are connected to the shore by means of a protected cable.

In one design (Fig 7) a change in pressure causes a change in capacitance and since the variable capacitor is in the frequency determining part of an oscillator a change of frequency results. The frequency modulated output signal is passed up an armoured cable (usually of maximum length 3 km) to the shore unit where it is

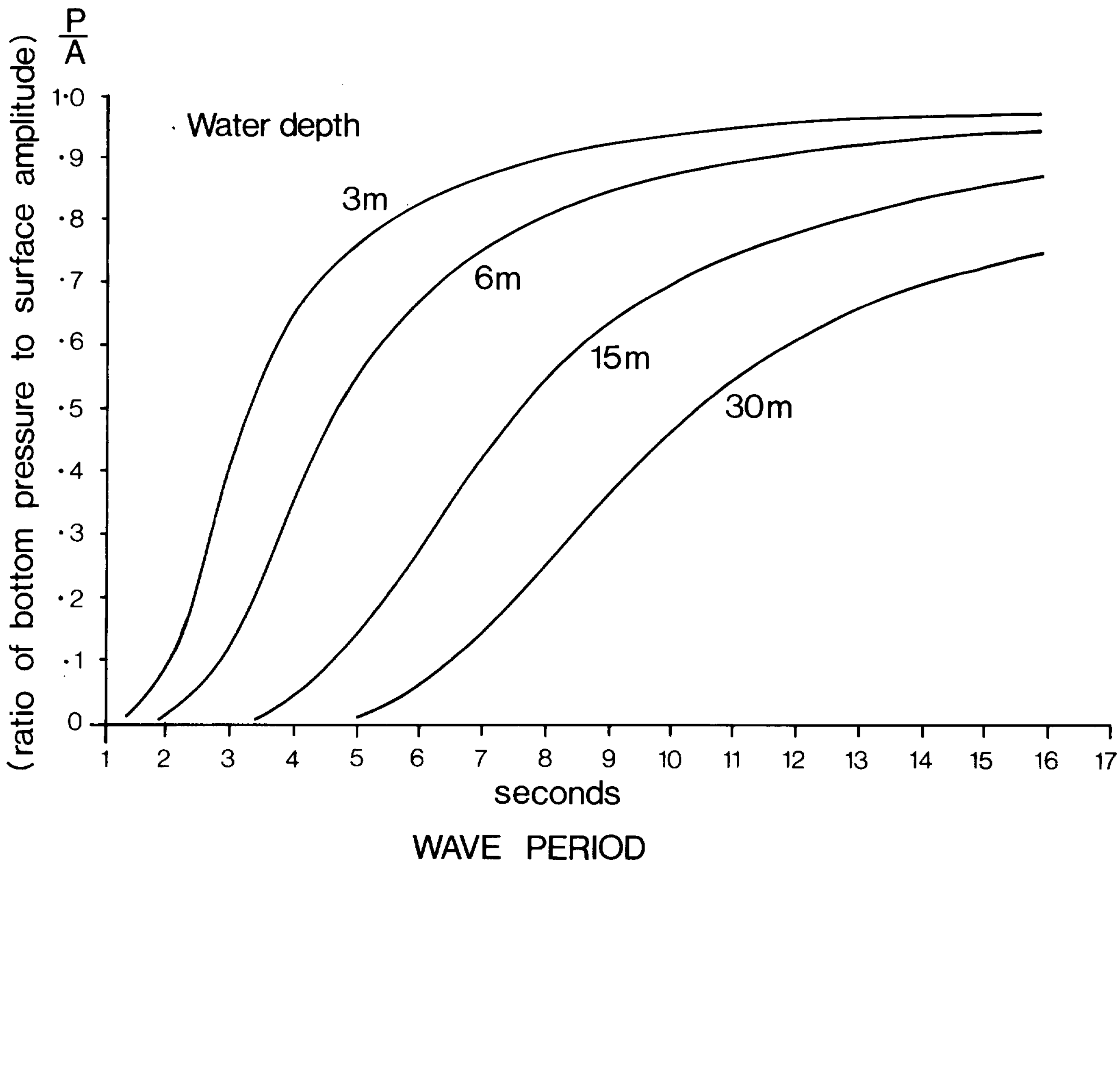


FIGURE 6 ATTENUATION OF WAVES WITH WATER DEPTH

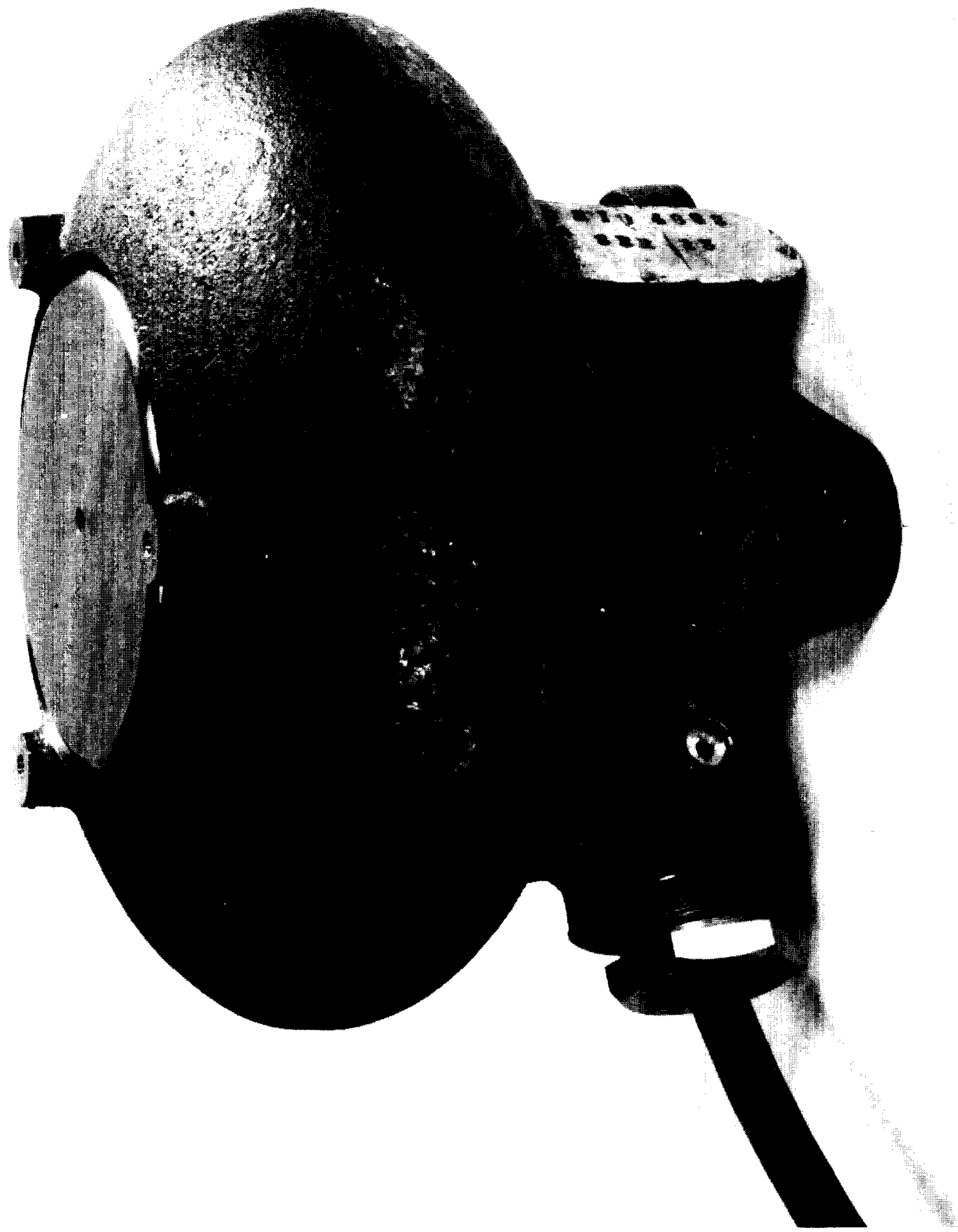


FIGURE 7 IOS FM PRESSURE TRANSDUCER

demodulated and recorded. At least one commercial equipment offers a self-contained recording option: the recorder is mounted along with the transducer in the sea making a cable to shore unnecessary. With this arrangement the sea unit must be recovered when tape/chart and battery changes are due.

Accuracies of pressure measuring systems may be better than 5% for long period waves in shallow water, but where a large correction factor due to depth attenuation is necessary then the uncertainties suggest that errors of 10% or more may be present.

The inverted echo sounder wave recorder is a subsurface instrument that apparently possesses many of the advantages of the pressure measuring principle, but does not suffer the depth attenuation problem. It employs the principle of a bottom (or mid-water) mounted transducer being used in the upward looking mode. The transducer emits a narrow beam pulsed signal and detects the echo from the sea surface. The transmit time of the pulse is considered to be directly proportional to the sea surface elevation. The frequency of operation may be as high as 700 kHz with a pulse rate of 10 Hz, and the beam width less than 5°. The height measurement accuracy of the system can be much better than 5% provided the sea/air boundary is well defined and there are not excessive salinity and temperature variations. In conditions of aeration and breaking waves the noise in the system will be considerable although some instrument manufacturers claim to compensate for this by use of digital averaging techniques. Since power consumption is relatively high it is usually necessary to provide a connecting cable to the shore.

4.5 There is an increasing requirement to gain a knowledge of wave direction. To take one particular example: the harnessing of energy from sea waves is likely to be a practical proposition only if the energy collecting devices are efficient. A knowledge of the principal directions along which the wave energy is being propagated will assist engineers to optimise the design of the devices and their mooring systems. Unfortunately wave direction is a difficult parameter to measure. Sophisticated buoys which measure sea surface slope and in some cases curvature, have been in use for many years, but these are only suitable for short-term experimental work where the presence of a research ship has been possible. More recently routine wave direction measurement has been made by a large (and expensive) data buoy in the south west approaches to the English Channel (Ref 9). Currently several attempts are being made to manufacture a smaller buoy that might be used for routine measurements of direction and most of these are based on the incorporation of a pitch, roll and heave sensor. For such a system to work effectively the buoy must be allowed to pitch and roll in sympathy with a wide range of sea conditions, but this means that its ability to resist overturning is substantially reduced. Even if these hydrodynamic problems are solved the data recording, analysis and presentation pose formidable problems; for each routine record gathered the distribution of energy both in period and direction will need to be plotted and, of course, it is likely that there will be numerous combinations of these parameters.

Another principle uses an array of fixed vertical elevation detectors which may be of the staff or pressure transducer type. This approach faces difficulties on two counts: a simple array is only effective for a limited range of wavelengths, whereas in the sea the range of wavelengths of interest is 100:1, and the fixing and maintenance of an array at full scale (to cater for wavelengths of up to 1000 m) is a considerable undertaking. Measurement of horizontal water particle velocities in two dimensions combined with a surface elevation detector will allow derivation of wave directional information provided that the sensor is near the surface, and as a result this equipment is mostly only suited to making measurements in shallow water situations.

The use of horizontal scanning radar to estimate wave direction on a routine basis has met with some success (Ref 10) and although it tends to be a subjective method it may, in many circumstances, provide useful data for a modest outlay, particularly if a suitable radar already exists in the area of interest. The problem is to persuade the normal user that sea clutter - usually a nuisance - may, in fact, be a valuable source of data. However, it should be pointed out that the interpretation of radar returns from the sea surface call for a high degree of experience. It is possible that on a day with little local wind the sea surface might be 'glassy' but at the same time contain significant swell energy and the radar may show little or no return from the waves under these conditions. The use of satellite mounted radar to measure wave direction was discussed in 4. 1 and was noted as being of promise for the future.

5 DATA RECORDING

5.1 The traditional way in which wave data have been recorded in the past is by ink trace on paper chart rolls. This has the considerable virtue of enabling the operator to see what waves are being recorded and, where appropriate, to make on-the-spot comparisons with what is actually occurring in the sea. Since most chart rolls require replacement every few days, the operator will be in a position to regularly check the operation of the instrument and in this way malfunctions can be reported back very quickly. But of course there are disadvantages in this system too: charts get damp and can easily become jammed, ink dries up or gets applied at a greater rate than required, and so on. More than anything else though, the difficulty of transferring the data into a format which a computer can handle must rank as the greatest. It involves teams of dedicated staff carrying out an essentially boring and repetitive task. It is an interesting fact that the experienced human eye is an extremely effective detector of malfunctions in wave records, a sudden spike or burst of interference will very readily be apparent and compensation for an unstable mean line can easily be incorporated in the analysis. In most installations therefore there is a case for continuing to take chart records or, at least, for maintaining some kind of analogue display for fault detection. However many uses to which wave data are put require them to be in digital form and so magnetic tape logging is becoming essential for most sites, although still retaining the chart recorder for purposes already described.

For reasons of economy it is not normal to record the wave signal continuously. It would be very costly and inconvenient to provide the magnetic tape capacity to do so, and the replay and processing task would become very expensive and onerous. Instead a series of equally spaced samples is taken. In devising a suitable sampling scheme two essential requirements should be met:

1 Each sample should be of sufficient duration to allow the sea state to be described with adequate statistical reliability.

2 The time intervals between samples should be short enough so that variations of sea state with time are adequately described. IOS has adopted a scheme in which a 17-minute sample is taken every 3 hours (which should mean that at least 100 waves are recorded), but, as already indicated the design of a sampling scheme is concerned with achieving the best compromise between a number of conflicting requirements. The above scheme will not suit all situations and already it is clear that longer records are

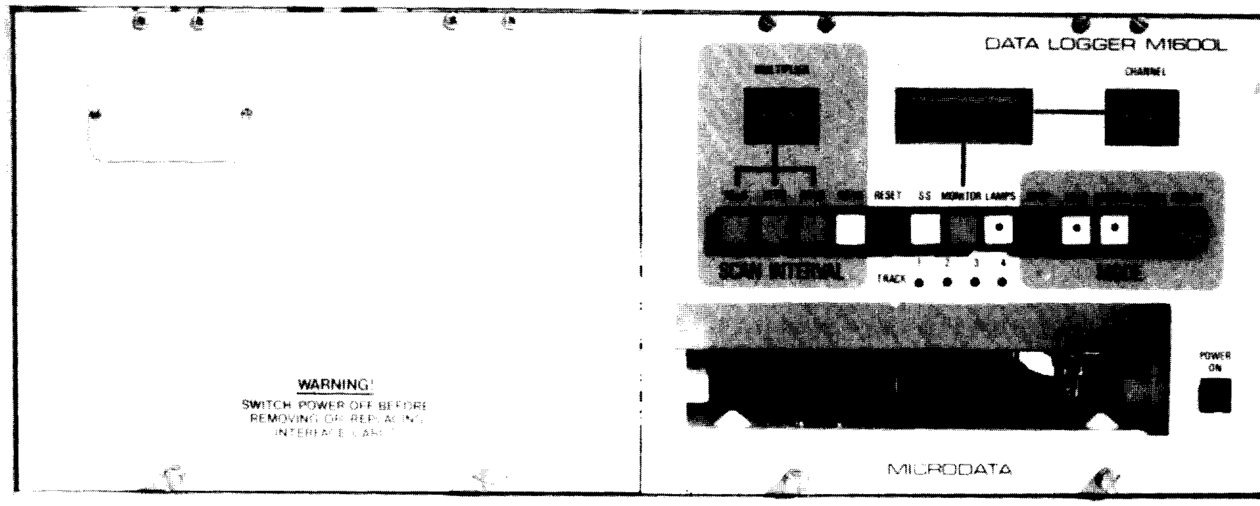
desirable and as data recording and processing becomes more reliable and cheaper, or if on-line processing is developed, this will be possible. Whatever timing scheme is operated there is great merit in standardising on the GMT system, no clock changes will need to be made during the year and the likelihood of confusion over timings will be much reduced.

5.2 The essential requirements for a digital data logger for recording wave data are seen by IOS as follows:

1) Single channel capacity adequate for tape changes at a minimum interval of two weeks using IOS sampling scheme;
2) Low power, battery and mains operation;
3) Portable and contained in a sealed case;
4) Cartridge or cassette;
5) Standard, off the shelf, requiring only minor modifications;
6) Availability of translator to allow easy interface to a computer.

At IOS the first generation machine was a modified commercially available data logger manufactured by Rapco Electronics and this recorded on standard 1/4 inch reel to reel tape. Using 5 inch reels containing 1200 feet of tape this gave a duration between tape changes of 33 days (based on 2048 0.5 second samples once every 3 hours to which 'housekeeping' data is added). All timing and programming functions were carried out by the logger including switching of ancillary equipment. More recently a second generation logger has been brought into use, again a commercially manufactured machine but by Microdata. This records on 3M data cartridges which hold about 15 days of data. The smaller capacity is more than offset by the operational convenience of cartridges and the substantially lower power requirements. Where these loggers are used to record signals from Waverider buoys a resolution corresponding to 0.1% of the range or 1 cm of heave can be achieved. Photographs of the two logging systems are shown in Figure 8.

The question of validating magnetic tape data will be discussed in the section concerned with data analysis, processing and presentation.



MICRODATA

FIGURE 8 DIGITAL DATA LOGGERS

6 SITE SURVEYS AND INSTALLATION PLANNING

6.1 The importance of careful planning has already been emphasised in Section 1. In this section some more detailed guidance will be given.

The desk study referred to earlier will likely have revealed several possible sites and approaches. In making a site survey the following points need to be considered:

For the sensor:	Water depth, currents and pollution
	Site exposure to the waves of interest
	Bottom topography
	Sediment movement
	Human interference
	Radio transmission
	Boat/diver availability
	Structure effect
For the shore unit:	Accessibility
	Accommodation and power supply
	Radio interference
	Local assistance
	Shoreline topography
	Receiver situation

Taking these one by one. The water depth will influence the type of instrument: deep water will preclude pressure sensors unless mounted on a structure: shallow water and/ or strong currents may make installation of a wave measuring buoy impossible. Is depth limiting likely to occur and will a big tidal range in a coastal situation make it advisable to record waves only at high tide? Are surges likely? This will be an important question in areas like the southern North Sea. A polluted environment (near an estuary or industrial complex for example) will adversely affect the life of mooring components and maybe the transducers themselves. Excessive marine growth might also be a nuisance and this is especially so in tropical waters.

In choosing the site for the transducer at least two approaches regarding exposure may be possible: is it required to measure waves at or close to the position of the proposed structure or might it be better to record waves further offshore and then calculate the likely conditions at several specific sites close by? As an example of the

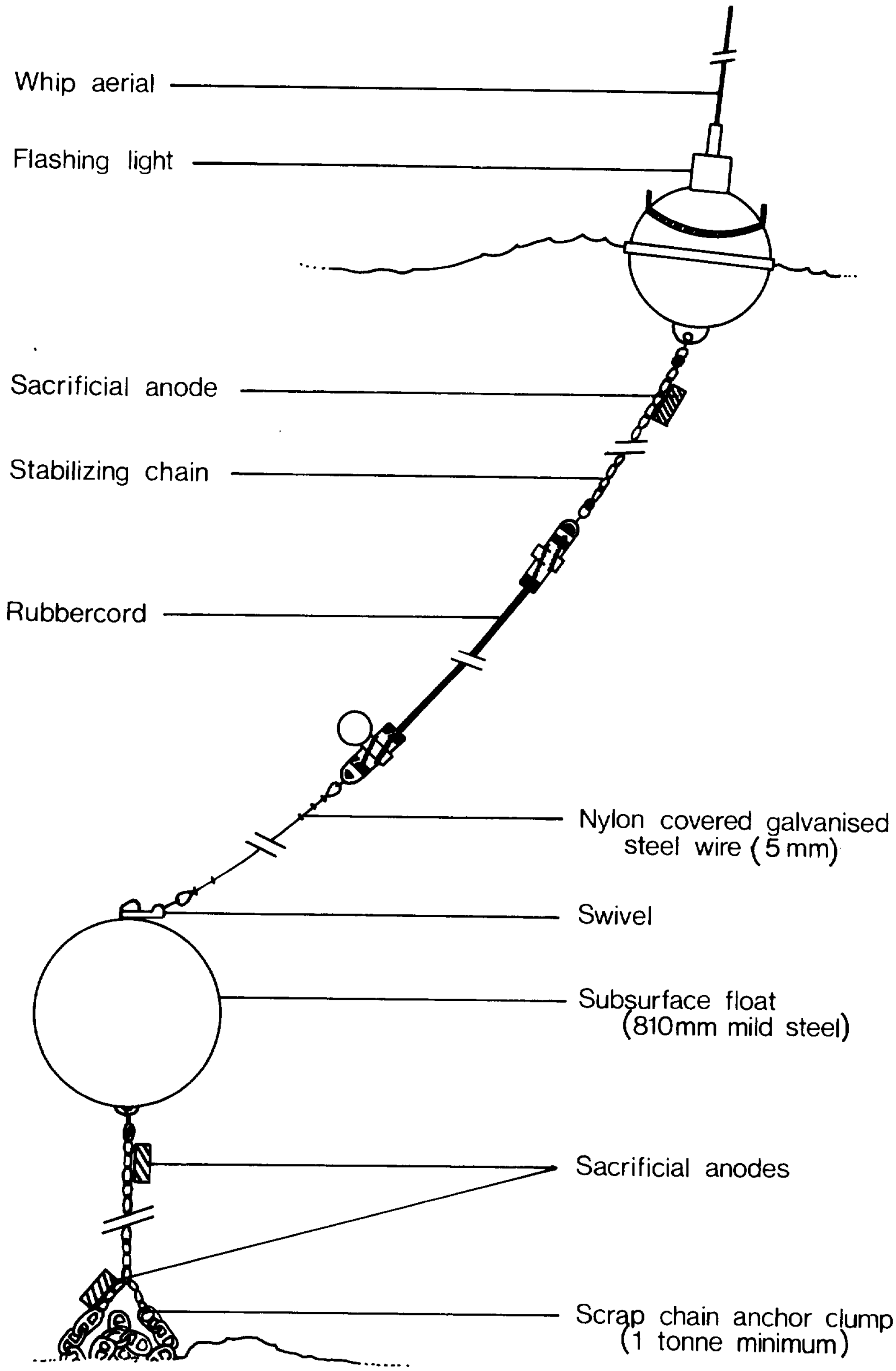


FIGURE 9 IOS 'SUB-SURFACE FLOAT' WAVERIDER MOORING

latter approach it could be that a study for the construction of a power station indicates three possible sites around a bay. In this case a wave recorder situated centrally in the bay could provide information that may be applied, after modification, to each of the sites of interest. Volume 1 Chapter 3 of Ref 2 gives guidance on this approach. When considering exposure of the site to waves, investigation of the fetch and likely source of swell input will be essential.

A knowledge of bottom topography will allow an assessment of likely refraction of waves. It could be that wave energy at a particular location is being enhanced by a focussing effect, equally a de-focussing mechanism might exist. A rough sea bed can snag and/or abrade moorings so that a very rocky bed may make incorporation of a sub-surface float assembly advisable (Figure 9). The existence of wrecks could be a positive advantage since it is unlikely that trawlers will operate in such an area. Quite often examination of charts and acquisition of local knowledge will provide the topographical information, particularly for sites close to the shore. If not, a survey operation will need to be mounted.

Unpredicted movement of sediment has caused bottom mounted sensors to be completely covered or overturned and usually this happens under storm conditions. Human interference, both deliberate and accidental, is one of the greatest sources of lost data. The most effective counter to this problem is through the building up of good relationships with local authorities, fishermen and others who have dealings with the sea. The local fisheries officer, harbourmaster, coastguard, etc., are all extremely valuable contacts and a carefully executed public relations exercise will pay dividends almost without fail. If people do not know what measurements are being made and why (although one does not need to be too specific) then curiosity will generate rumour and invariably the project will be jeopardized in some way. Often it is difficult not to place instruments in areas that are being heavily fished and outside of territorial waters this generates particularly acute problems since quite often foreign ships will suspect that wave measuring apparatus (and other oceanographic equipment) has a military role and anyway, where trawling is productive, little attention will be paid to small obstructions: the equipment may disappear without trace. It seems a contradiction to say that in several cases in recent years IOS has found it convenient to situate instruments within military weapon testing areas since the likelihood of damage from projectiles is much less than the benefits received due to the absence of civilian interference.

6. 2 It has already been mentioned that the distance between a transmitting buoy and its receiver may be severely restricted by the presence of radio interference. Such interference may not necessarily be local and is likely to be variable depending on weather and sea conditions, sunspot cycles and hours of daylight and darkness. A carefully executed survey with a sensitive, narrow bandwidth, receiver will not only provide a background to the extent of this problem but if a test transmitter is placed at the likely buoy site(s) it may well help to identify a 'pocket' of high buoy signal strength on the land at one or a variety of transmitting frequencies.

Not all installations will require the use of divers, but in most a boat will be necessary. The economics of operating divers needs to be carefully balanced against the cost of alternative approaches. As an instance it may be cheaper (and safer) to write off buoy moorings that to attempt expensive recovery and maintenance procedures, particularly when consideration is given to the difficulties of operating divers in exposed areas. However, it should be borne in mind that abandoned moorings may create long-term hazards to fishermen. The use of local boats and assistance where possible during installation and maintenance will be rewarded under the need for a good public relations philosophy put forward earlier.

6. 3 Where support structures are required for particular types of instrument careful consideration must be given to the effect of the structure on the waves in the immediate vicinity, the point is worth labouring because at least one case is known to IOS where waves have been measured within the lee of the structure (for the prevailing winds). The data collected were almost useless for their intended purpose. Some piers pose particular problems in this respect.

6. 4 Some of the items on the survey list for the sea sensor cannot be divorced from those to be considered at the shore end. Site accessibility is not the most crucial of considerations, indeed it may be very much a secondary matter if the chosen site for the shore apparatus has special advantages like a signal enhancement 'pocket'. It is, however, important to ensure within reason that easy and frequent access is possible for maintenance personnel and that proper arrangements have been made with the land-owner. Security is only likely to be a problem if the equipment is installed in a place to which the public has access. Accommodation may not exist on very remote sites and this problem is best resolved by the construction of a stout timber building. As a rule though, use of inhabited premises which are heated, dry and have people on hand to monitor the system

performance are much preferable. Official or semi-official establishments are well suited and quite often the availability of an instant read-out of wave height and period will encourage local people to participate in the data collection programme.

It is obvious that the existence of a reliable mains power supply is an advantage, but often wave recording sites are remote and if mains is available it is unlikely to be renowned for its regulation and reliability. The principle of providing battery back-up with float charging should be adopted in all long-term recording stations. The back-up should have the capacity to maintain full operational capability of the system for a minimum of 24 hours and preferably for 3 days. In the absence of a mains supply (or an adequate one) batteries will be the prime power source and the charging of these will become of concern. Petrol or diesel generator sets may be reliably employed, although the former will require more maintenance, but it may well be possible to supplement conventional generators with solar and/or wind generators. Certainly many exposed sites around UK coasts are ideal for production of electricity from wind and it is surprising how much solar energy is available for conversion by photo-voltaic cells even in the north of the British Isles. A combination of solar and wind energy may reduce the contribution by a petrol or diesel generator to that of a fill-in source for the occasional period when neither wind nor sunlight is present.

6.5 The only aspect of radio interference not so far discussed is that of the locally generated type. If the receiving equipment is sited close to a powerful transmitter (which may happen in a military establishment, and to some extent in a coastguard or harbour-master's office) then trouble should be anticipated. Impulsive interference from ignition systems and devices switching loads at frequent intervals are quite likely to interfere with sensitive receiving and digital logging equipment, so a site surveyor must be mindful of all these possibilities.

6.6 Although local assistance has been mentioned, it must be emphasised that to have one or two people responsible for chart/tape changing and day-to-day maintenance who have some inherent interest in the data collection programme is probably the greatest guarantee of a high data reutrn. It is incumbent on the project coordinator that he cultivates and maintains these contacts throughout the programme, the importance of so doing cannot be too highly emphasised.

6.7 Most pressure transducer and inverted echo sounder systems require a cable to be brought ashore and quite often this will turn out to be the weakest link in the system. If the breaker region is comprised of sand or fine gravel then trenching the cable at low spring tide with a mechanical digger will provide adequate protection if the coastline is relatively stable. In fact, armoured cables usually bury themselves in soft sand a week or two after laying. A rocky beach is a different proposition, even a heavily armoured cable will survive only for a short time unless it is trenched and concreted between the rocks. The site surveyor must take great care in choosing the most sympathetic route for the cable. For systems where the reception of a radio signal is involved it is generally good practice to avoid sharp discontinuities in the signal path so a route involving cliffs would be avoided. Strictly this applies to transmission frequencies of less than 30 MHz where the ground wave is being received. Also greater attenuation of the signal takes place over land as compared to the sea so it is advisable to minimise the dry ground path. Different rules apply to line of sight propagation and reception, here an unobstructed line of sight is the main criterion and the receiving aerial might with advantage be placed as high as possible above sea level.

6.8 So far in this section no mention has been made of the Shipborne Wave Recorder. The fact that it is completely contained within a ship dictates a quite different surveying approach. Both pressure and heave sensors should be sited as near as possible to the pitch axis of the ship and be symmetrically placed on the port and starboard sides to within 300 mm. The openings in the hull for the pressure transducers must be as shallow as possible (to minimise the depth attenuation effect) but must rarely be exposed to air when the ship rolls. For example, a ship of displacement 2000 tons might have the units mounted between 2 and 3 metres below the water line. It is not important if the hull is not vertical at the transducer mounting point, but the openings must be at least 600 mm away from the bilge keels. Often the best position will be found to be in the engine room and accessibility for servicing will be a consideration.

The recording unit will normally be sited in the wheelhouse or instrument room. The risks of r.f. pick-up will be greatly reduced if the instrument is sited away from the main transmitters and aerial feeders: the length of cables between transducer and recorder are not often a problem. It is sensible to check the stability of the ship's power supplies (both frequency and voltage) as well as the likely change of draught (or position of water line) during a voyage.

7 OPERATIONAL TECHNIQUES

7.1 Documentation

The matter of good relationship and communications with site personnel has already been emphasised but it is also very desirable to initiate simple, clearly understood site documentation. The operator, who is unlikely to be an engineer or scientist, will be encouraged to show enthusiasm and interest in the equipment if he has a good basic description of the objects of the measurement programme and the way the equipment works. A site log sheet upon which all routine maintenance is recorded, together with malfunctions and observations of extreme climatic conditions, is essential. If it is possible to make a visual estimate of wave height and period from the sea and to compare this with the chart record, then a first order check on equipment performance will be available.

The engineer responsible for the wave recording project should also keep a detailed diary of all site events, calibrations, weather reports and so on. A well documented record of this kind may turn out to be invaluable when errors in data are discovered perhaps a year or more later.

7.2 Instrument Calibration

Calibration of instrument systems is particularly important since although much commercial equipment is reliable and will be calibrated before delivery, the effect of operations in the sea for a few months and servicing of the shore system by relatively unskilled personnel can introduce errors in height and frequency response that will not easily be detected by the data analyst or data validation operations. As a general principle, equipment should be calibrated at least once a year, but where transducers are exchanged at more frequent intervals it is good practice to calibrate the new transducer immediately before deployment and the old one as soon as possible after recovery.

Calibration techniques will, of course, depend on the principle of operation of the instrument. A radar or laser can easily be checked by interposing a solid target: measurements of various transducer-target distances may be plotted against output signal and should yield a linear relationship. Additionally the target may be moved sinusoidally at various rates of oscillation and this will allow an assessment of the frequency response of the system.

Similar techniques may be employed with wave staffs, but here it is usual to move the staff in and out of a tank of (saline) water. It is advisable to be aware of effects likely to be introduced by structures: a variable capacitance staff might have stray capacitances imposed by the surrounding metalwork which will not be present if the staff is calibrated in a separate tank or situation.

Heave measuring buoys require to be calibrated in special rigs that will generate sinusoidal motions either by rotational means or by vertical reciprocating motion. The accuracy of a heave sensor may thus be measured to better than 1% over the period range of, say, 3 to 30 secs. This method, although the most widely used, must be treated with some reservations. Most rigs are only able to apply maximum heave or displacement excursions of between 2 and 5 metres and often the calibration is of most importance when wave heights in excess of 20 m have been, or will be, measured in the sea; no account is taken of the ability of the buoy to accurately contour the sea surface. Purchase and maintenance of a carefully calibrated reference receiver is strongly advised where the calibration of several buoys over a period of time is involved.

The Shipborne Wave Recorder heave sensors (accelerometers) may also be calibrated on rotating rigs and their small mass makes this physically much easier to do, but this must be carried out on shore or with the ship in a dock with negligible wave motion present. These calibrations should be applied at yearly intervals. The same problem of only calibrating for relatively small sinusoidal heave excursions exists however.

Pressure transducers for use with both the shipborne equipment and for separate land based installations are easily checked in, or connected to, a pressure vessel to enable a plot of output voltage versus applied pressure, but dynamic calibration is much more difficult. The generation of a sinusoidal variation of pressure requires fairly complex control systems and the accurate measurement of the peak-to-peak excursions is difficult to make. Therefore static calibrations are accepted as being the best compromise, and have the additional advantage of being easy to reproduce in the sea if a fair tidal range is present. For example, a graduated staff can be placed vertically in the water in the vicinity of the transducer (since usually a coastal situation is involved) and if a mean water level is read off say every 15 minutes over a tidal cycle and compared to the transducer output signal, a graph may be plotted and its slope will represent transducer sensitivity. Static calibration of an echo sounder may be achieved in the same way or an underwater moving target may be used to simulate the sea/air interface to give a dynamic calibration. The ability of the device to correctly measure wave height and period in the presence of aeration is rather more difficult to verify.

Wave staffs should be checked weekly for marine fouling and abrasion by fishing lines etc., and could also be monitored for excessive calibration errors if 10 cm marks were made on an adjacent vertical stanchion although this means of comparison would become of limited value in the presence of high winds and waves.

Wave direction sensors are best initially checked for direction sensing by testing them in tanks containing at least two wave makers on different orientations, but their behaviour in the sea is not so easily assessed. As with more routine wave height measuring systems it is often helpful to compare the signal(s) being recorded with other wave recorders, meteorological conditions, and visual observations of the sea, although considerable experience and skill is required to carry out the latter with any precision, particularly from ships where fixed reference points are not available.

An important principle in all wave recorder calibration schemes is that where possible the whole system should be calibrated as a unit. This means, for example, that if an accelerometer is being subjected to a rotating rig test then the receiving and logging equipment should also be connected. Translation of the magnetic tape resulting from the calibration will allow derivation of a correction formula for wave height over a range of wave frequencies. Of course, often it is not possible to maintain the same buoy/receiver/logger combination throughout the life of an installation, hence the recommendation to maintain a reference receiver. It is also useful to verify the polarity of the wave signal to ensure that crests and troughs are properly identified in the analysis. It is conventional for crests to be indicated by pen excursions to the left when viewing a chart recorder from the front (most electrical meters and recorders indicate increasing quantities to the right).

7.3 Transducer Deployment

The installation of equipment in the sea will be much facilitated by the application of practical experience. The choice of materials will be dictated by an understanding of electro-chemical corrosion effects and a knowledge of the stresses likely to be imposed. Certainly buoy moorings need to be very carefully designed and assembled, screw threads must be 'seized', and great attention must be paid to the reduction of crevice corrosion in stainless steel fittings by ensuring that surfaces are exposed to flowing water (and therefore not greased). Buoy hulls should be painted both with corrosion preventing epoxy paint and anti-fouling compound with no 'pin holes' or unpainted areas. Regular inspection and servicing is essential particularly in polluted and warm water. A six-monthly buoy change is recommended in UK waters. The rubber cord in Waverider moorings is potentially very dangerous and during deployment it is advisable to place the buoy in the water first and quickly release the remainder of the mooring: a stretched cord contains a large amount of potential energy and can, if accidentally released or pulled from its termination, cause great damage. Similarly, recovery of the buoy is best achieved by pulling the lower part of the mooring inboard first, followed by the buoy, but at no point allowing the ship to tow the buoy via the rubber cord. Monitoring the buoy signal at the time of deployment will give an indication of how well the equipment is working and may save a return visit by boat if, for example, the aerial has not been properly seated in its threaded socket. The acquisition of, or access to, a direction finding set will greatly assist in locating a drifting buoy. A very useful and easy site check on Waverider buoy signal strength is achieved by inserting a switched attenuator box between the aerial plug and the receiver aerial input socket. Increasing the attenuation until the receiver 'unlocks', and repeating this several times, will give rise to a characteristic value and it should be possible to reproduce this figure to an accuracy of, say, $\pm$ 2dB throughout the installation. The presence of strong radio interference will give misleading results however, and it is assumed that all buoys radiate a similar strength signal when first deployed. Recovery of a buoy from a third party who may claim salvage is the cause of many a dispute, quite apart from any other consideration the local salvage laws will have to be taken into account. It should be pointed out that the value of a 'lost' wave measuring buoy will depend on whether its accelerometer assembly has been irreparably damaged; the buoy may only be of scrap value. Offering high rewards for buoy recovery is not recommended since it may encourage the removal of operational buoys. Gaining the cooperation of local fishermen etc is the best guarantee of the return of equipment in reasonable condition at a reasonable price.

Instruments connected to shore by cable can be deployed in two ways:

1 The cable drum may be mounted on the shore and the cable pulled out by a boat which is carrying the sensor and its mounting structure, and this may require buoying up the cable every 10 metres or so.

2 The cable may be flaked out on to the deck of the boat and then laid after the transducer has been deployed.

The latter method is usually best, but care must be taken to flake the cable out in figure of eight loops as it comes off the drum sothatkinks are avoided. Whenever assembling equipment for underwater use, cable glands and 'O' ring seals must be scrupulously clean and greased with the correct lubricant/sealant; petroleum jelly is useful in this respect and graphite grease for mild steel threads. Tripods must be anchored on the seabed with 'stretched out' chains since in shallow water wave action may overturn them. If the position of the structure can be identified by reference to landmarks rather than marker buoys then the possibility of illegal interference will be reduced. Armoured cable once used is rarely economically recovered and re-used, since any subsequent problems due to leakage etc. will usually cost more to remedy that procurement and laying of a new cable in the first place.

7.4 The shore installation

It was earlier observed that electronic equipment mostly prefers to be in a dry and warm environment. Given that many wave recorder sites are unable to offer such amenable conditions the alternatives should be considered. One that has been adopted by IOS with success is the procurement of a waterproofed equipment container, preferably incorporating a window in the access door. If desiccant is included and replaced at regular intervals and if the container is not left open unnecessarily, the effects of damp on the equipment will be negligible. The container should be sited in a stout wooden hut, some designs of garden sheds may be found suitable.

Most instruments incorporate simple monitoring facilities that enable the site operator to check for correct functioning of transducer, recording system and power supplies. A more sophisticated approach is to procure (or construct) a simple transducer simulator (test signal generator) which, when a malfunction occurs or is suspected, can be inserted instead of the aerial or transducer cable; this will facilitate an early diagnosis as to which end of the system the fault lies. In the case of a buoy, a diagnosis of this kind may allow early detection of a mooring failure and a rescue operation can quickly be initiated. Without regular site checks it can easily be a month before a chart or tape is received for analysis and a fault discovered, and that is a month of data lost regardless of the type of wave recorder, and more than likely a buoy lost if a Waverider is in use.

Chart recorder running speeds should typically be 50 or 60 mm/minute, but in situations where long period waves predominate or the chart is a secondary source of data 30 mm/minute may suffice. Charts will normally need to be changed about every two days in the former case and possibly only twice a week in the latter.

7.5 Data transfer from site to base

Having spent a good deal of time, effort and money in acquiring the data tapes and charts, it is vital to ensure that they are well packaged and securely transported when returned from site to the place of analysis and storage; the loss of one tape could wreck a complete year's data. Use of one of the commercial delivery services that specialise in quick and secure transport is recommended.

8 DATA VALIDATION, ANALYSIS AND PRESENTATION

Not surprisingly there are many methods of analysing and presenting wave data, but this section will be confined to a simple description of the more commonly used IOS procedures.

8.1 Data Validation

Whatever analysis system is used, some form of data validation must be the first step, and it is very desirable to apply the initial stages of this the moment the data is received from site. To begin with it may simply be a question of examining chart rolls by eye to detect mean line variations, uncharacteristic profiles, chart speed variations and so on. These checks will act as a second filter on the chart data (hopefully the site operator will have provided the first) and can be very effective. Where magnetic tapes are involved then validation will usually be applied during or after the translation of the data into a computer compatible format. At this stage quite sophisticated checks may be carried out and some of these will now be described with reference to digital data obtained in records of duration 17.07 minutes (2048 half second samples of sea surface elevation) taken once every three hours.

The tests are designed to check for timing or tape formatting errors in addition to detecting characteristics not normally associated with records of this type. The assumption is made that the wave record should display certain simple properties consistent with the behaviour of a random process with an approximately normal distribution of its ordinate, and that the water surface should conform to certain well-established steepness criteria.

The tests are as follows:

1 Test for character legibility and loss of data points due to formatting errors or data transmission failure, also check record timing and length.

2 Check for the occurrence of ten consecutive points of equal value (instrument failure test).

3 Check for an interval between successive up-crossing (Tz) of the record mean level of greater than 25 seconds (wandering mean test).

4 Comparison of the difference in magnitude between successive data points with a test value based on maximum probable water slope.

5 Comparison of absolute magnitude of data points with a test value equal to four times the standard record deviation.

The test programme will take the following actions:

Single lost data points, up to a maximum number of fifteen per record, identified by the first test are replaced by the average value of the two neighbouring points. Two or more adjacent lost points cause the record to be rejected.

Failure of either test 2 or 3 causes the record to be rejected.

Faulty points, up to a maximum number of five, identified by test 4 are replaced by the average value of the two neighbouring points. Two or more adjacent faulty points cause the record to be rejected.

No alterations to the record are made on failures of test 5. Six failures, up to three of which could be consecutive, are allowed before rejecting the record.

The results of these tests are recorded with each record written to the data (time history) file as a group of ten error flags, KFLAG (1-10):

KFLAG (1) not used

(2) not used

(3) not used

(4) not used

(5) record start not at correct nominal time

(6) time interval between start of current and previous records not three hours

(7) not used

(8) not used

(9) record rejected (if set to zero the record may be assumed to be valid)

(10) record length incorrect

For chart recorded analogue data the validation that follows the initial simple checks referred to earlier requires some knowledge of the analysis techniques. References 11 and 12 describe how A, B, C and D (respectively the highest crest on the record, the second highest crest, the lowest trough and the second lowest trough measured positively from the mean line position) and Tz are measured from a record, the validation checks must therefore be restricted to use of these parameters and result in listing these records for which any of the following statements are true.

a) A is less than B

b) C is less than D

c) Incorrect time sequence

When the above errors have been corrected, or the records flagged, and Hs (the significant wave height) and Tz computed, the data are screened for potential errors by selection and examination of records in which:

a) H1/H2 is greater than a predetermined value

b) Hs or Tz increase or decrease by more than a predetermined value between consecutive records and then increase or decrease by more than half that value on the following record.

c) The lowest 10 values of Tz occur

d) The highest 10 values of Hs steepness occur

e) The highest 10 values of Hs occur

f) The highest pair of Tz values within each 0. 5 metre increment of Hs occur

g) The highest and lowest 25 values of instrument depth occur (pressure sensors only)

Tests (a) and (b) may require test runs to determine a reasonable magnitude of 'predetermined value' so that only the most extreme cases are selected. Tests (c) to (g) are repeated, if necessary, following correction of erroneous records detected.

8. 2 Analysis of data

This may be divided into two categories:

1) The reduction of analogue records into five parameters (as already indicated) followed by the application of statistical techniques developed some years ago (references 11 and 12) to yield a description ot the data in terms of Hs and Tz.

2) The derivation of the 'Energy Spectrum' which may be described as the way the wave energy is distributed according to the wavelength or frequency which carries it. This is a convenient operation when data have been collected in a digital form, but becomes onerous (and expensive) if analogue data have to be digitised first.

8. 3 To deal with the first case, the method referred to for the analysis of analogue records is commonly known as the Tucker-Draper analysis. Application of it allows presentation of Hs, $Hmax_{(3\ hr)}$ (the most probable height of the highest wave in the three-hour interval) and Tz in various ways: Figure 10 is an exceedance diagram for Hs and $Hmax_{(3\ hr)}$, Figure 11 shows the percentage occurrence of Tz and Figure 12 scatter diagram for which wave steepness may be inferred. Both persistence of calms and storms can be plotted as shown in Figure 13 and predictions of maximum wave height for return periods longer than the duration of the wave recording station may be made using the graph illustrated in Figure 14, although it should be pointed out that this latter plot is just one example of at least four different cumulative distribution formulae. References 13 and

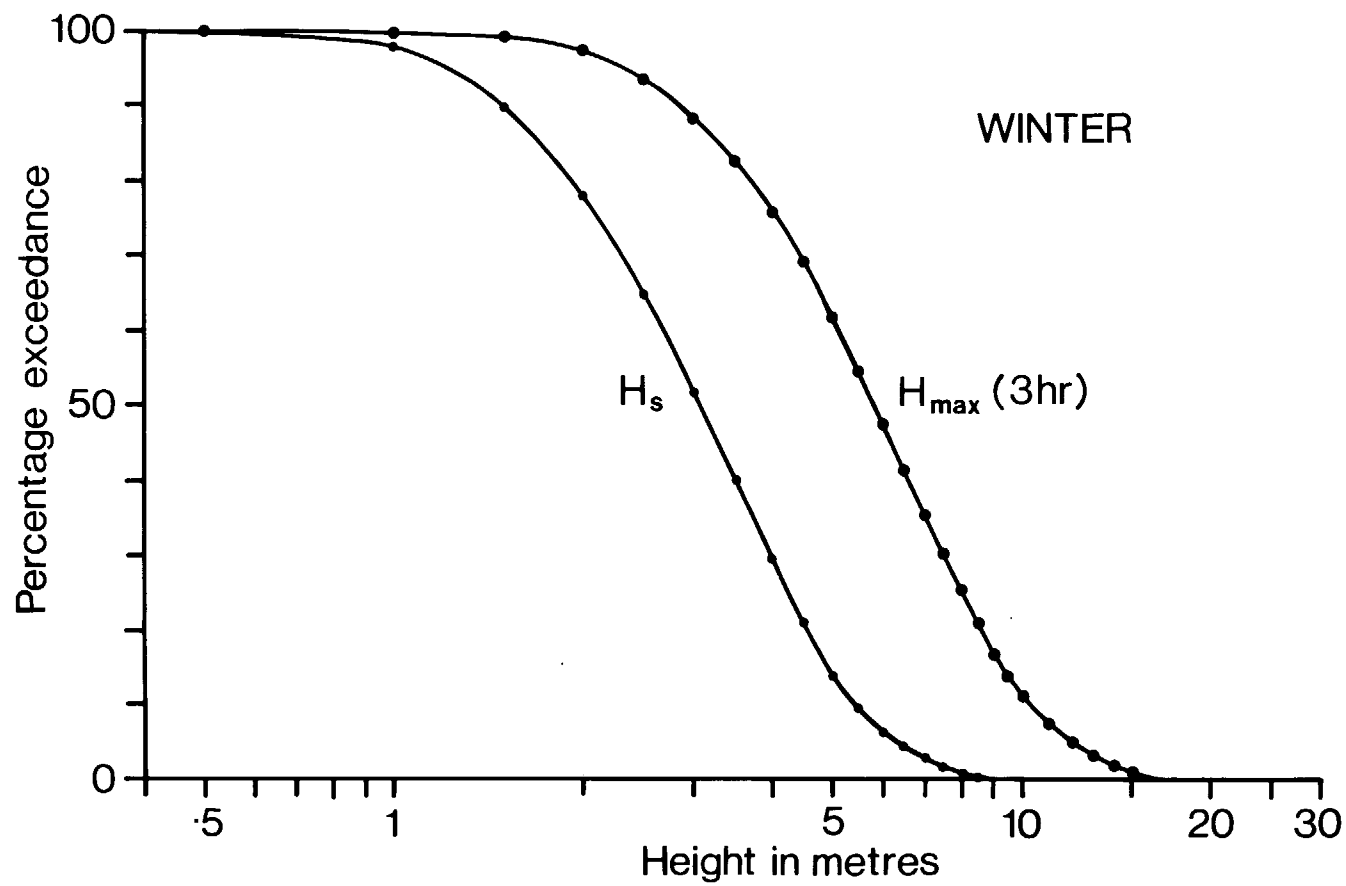


FIGURE 10 PERCENTAGE EXCEEDANCE OF H_s AND H_{max} (3 hr) - WINTER

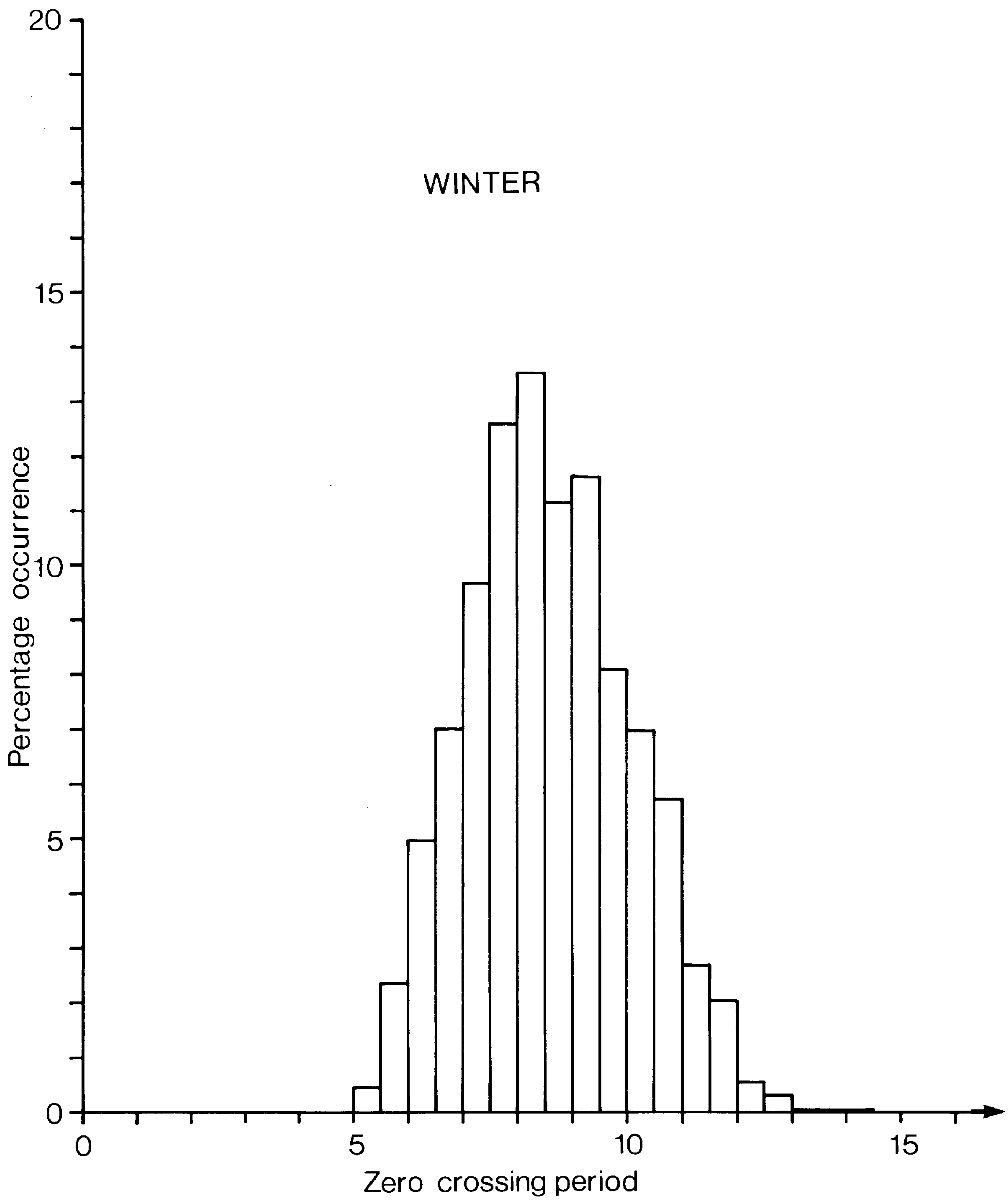


FIGURE 11 FREQUENCY HISTOGRAM FOR ZERO-CROSSING PERIOD - WINTER

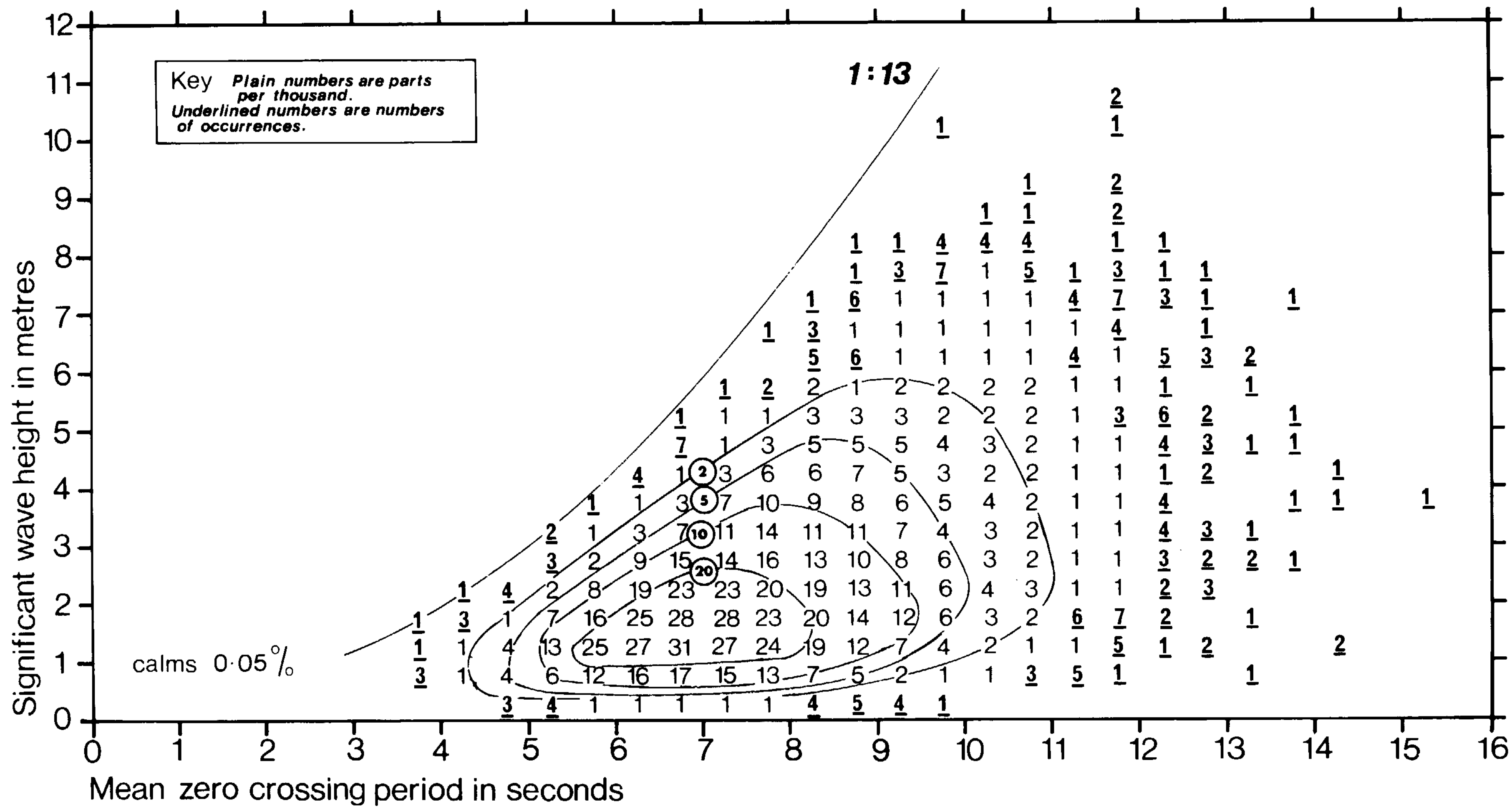


FIGURE 12 SCATTER DIAGRAM IN PARTS PER THOUSAND - WHOLE YEAR

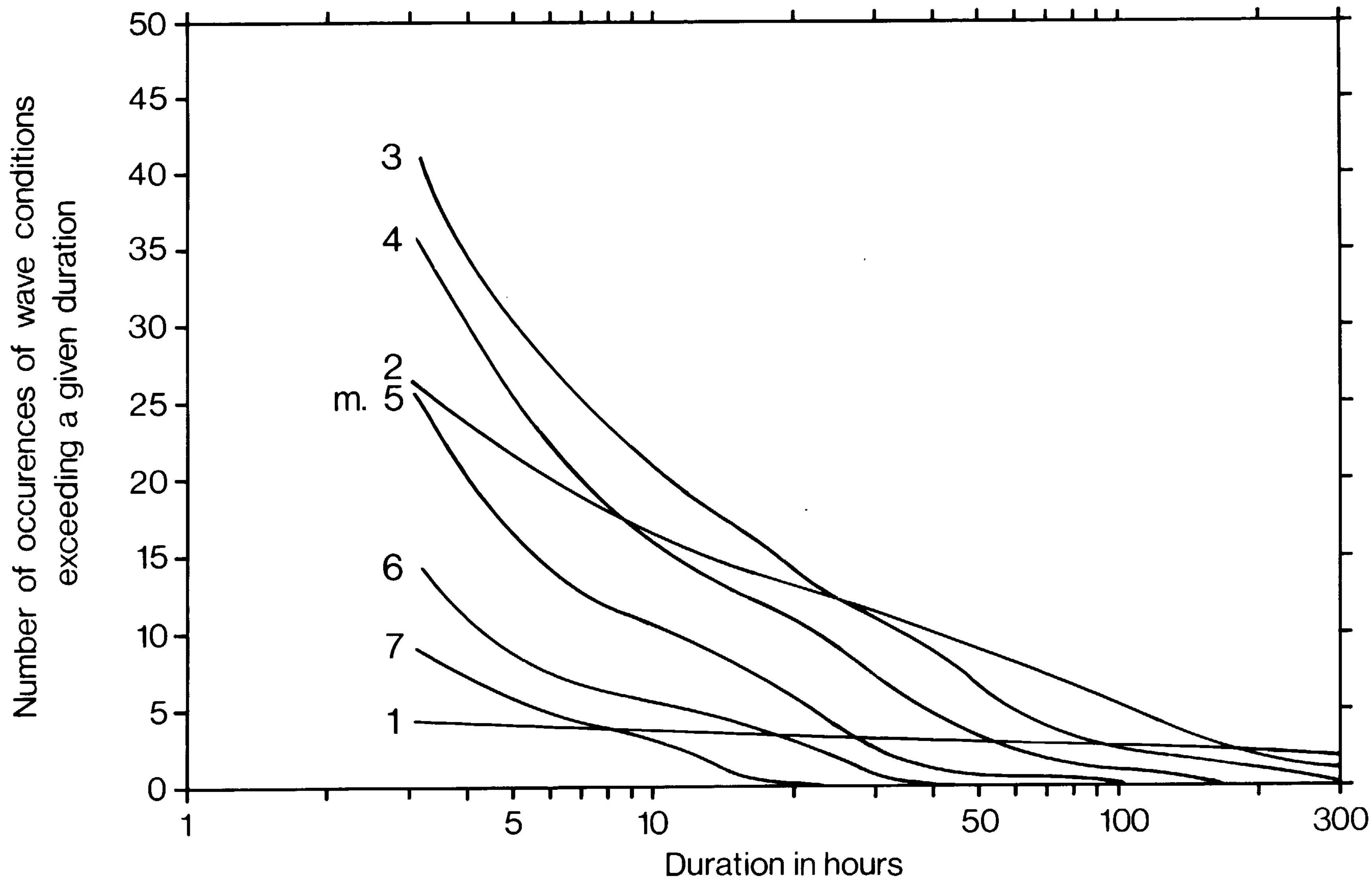


FIGURE 13 PERSISTENCE OF STORMS - WINTER

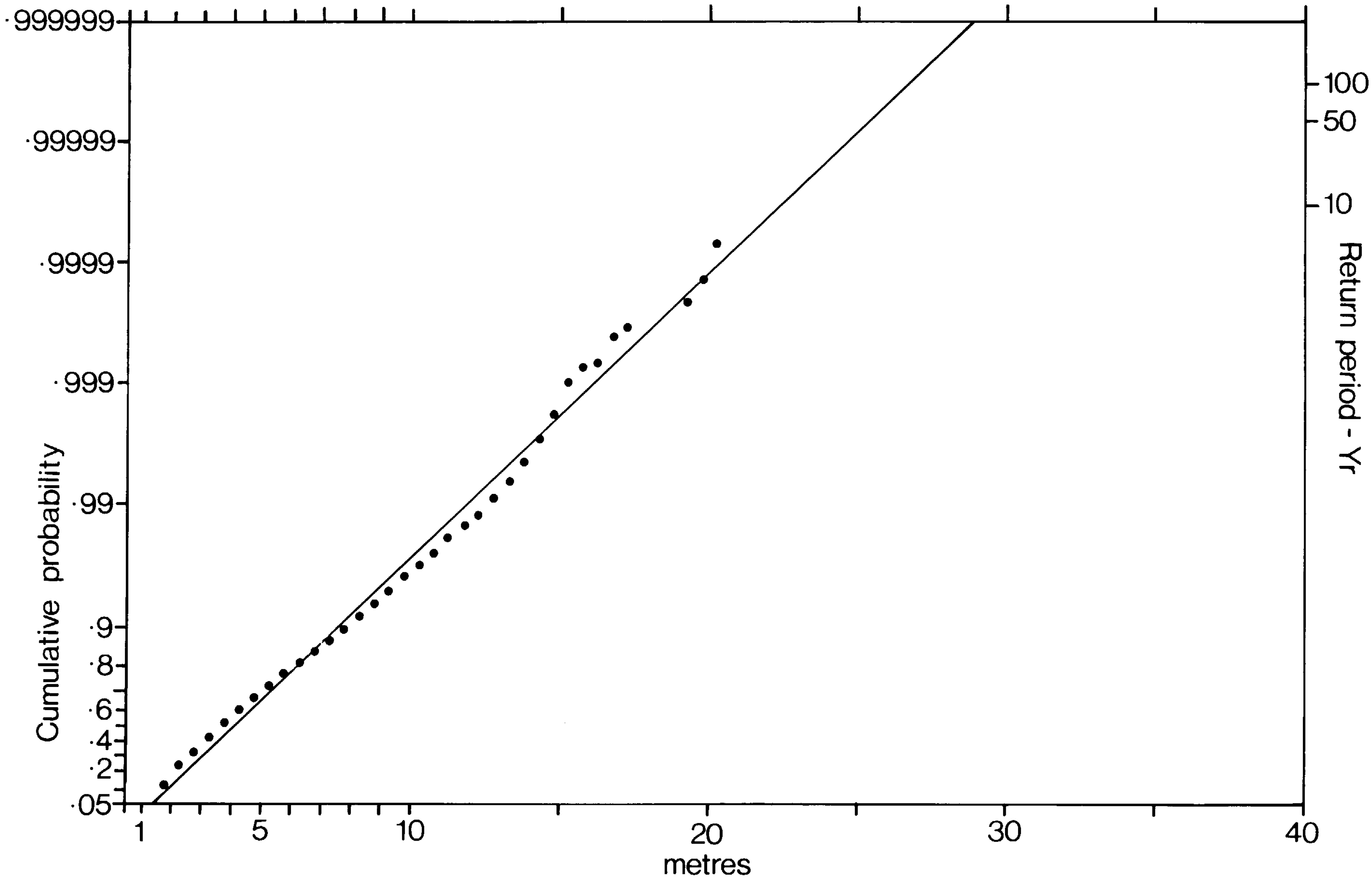


FIGURE 14 CUMULATIVE DISTRIBUTION OF H_{max} (3 hr) GUMBEL I SCALE

14 are recommended for further study of this aspect of predicting extremes and reference 15 is an example of the result of a Tucker-Draper analysis of several years of data from a Shipborne Wave Recorder. These presentations are clearly useful for planning and design purposes, but to be statistically reliable a long and essentially unbroken time series of data is required.

8.4 With regard to the second case, recent developments in miniaturised solid state electronics have made possible the manufacture of comparatively small, low power, rugged digital data loggers for site use, some examples of which were discussed in Section 4. There has long been an interest in wave spectra and the availability of these digital recording systems has been responsible for the gradual adoption of a completely new approach to analysing routine wave data. The new techniques employ Fourier analysis to allow estimates of the energy associated with each frequency component of the wave system to be made. In the usual method the discrete Fourier transform of the wave record is computed using a Fast Fourier Transform technique. This yields values of a_n and b_n, the cosine and sine amplitudes of the Fourier series representation of the record, and from these the spectrum of the record is estimated as $T/2\ (a_n^2 + b_n^2)$ where T is the length of record analysed. These spectral estimates are arranged to produce the final estimates of the spectrum. A more detailed discussion of spectral analysis techniques can be obtained from reference 16. A plot of energy (more correctly: the variance of the height fluctuation of the sea surface) against frequency is shown in Figure 15, this is from a record taken from the Waverider site west of the Outer Hebrides and clearly shows two peaks, one associated with low frequency swell at around 0.07 Hz and the other due to waves generated by local wind. The variance spectrum can be used to calculate power with an obvious application to research into wave power generation - reference 17. Figure 16 demonstrates how the spectra from one week of recording may be plotted as a matrix of spectral densities and then contoured to reveal characteristic patterns associated with local storms and the arrival of swell from distant events. Such an event is shown in the centre of this figure and has been projected back to the base line where the intersection at t_o indicates the date of origin of the storm. From a knowledge of propagation velocities it is possible to calculate how far away the point of origin is (but not necessarily its geographical position, since direction will not always be known).

8.5 The analysis and presentation of directional data was referred to earlier as presenting a formidable problem; reference 18 gives a good insight into the theoretical

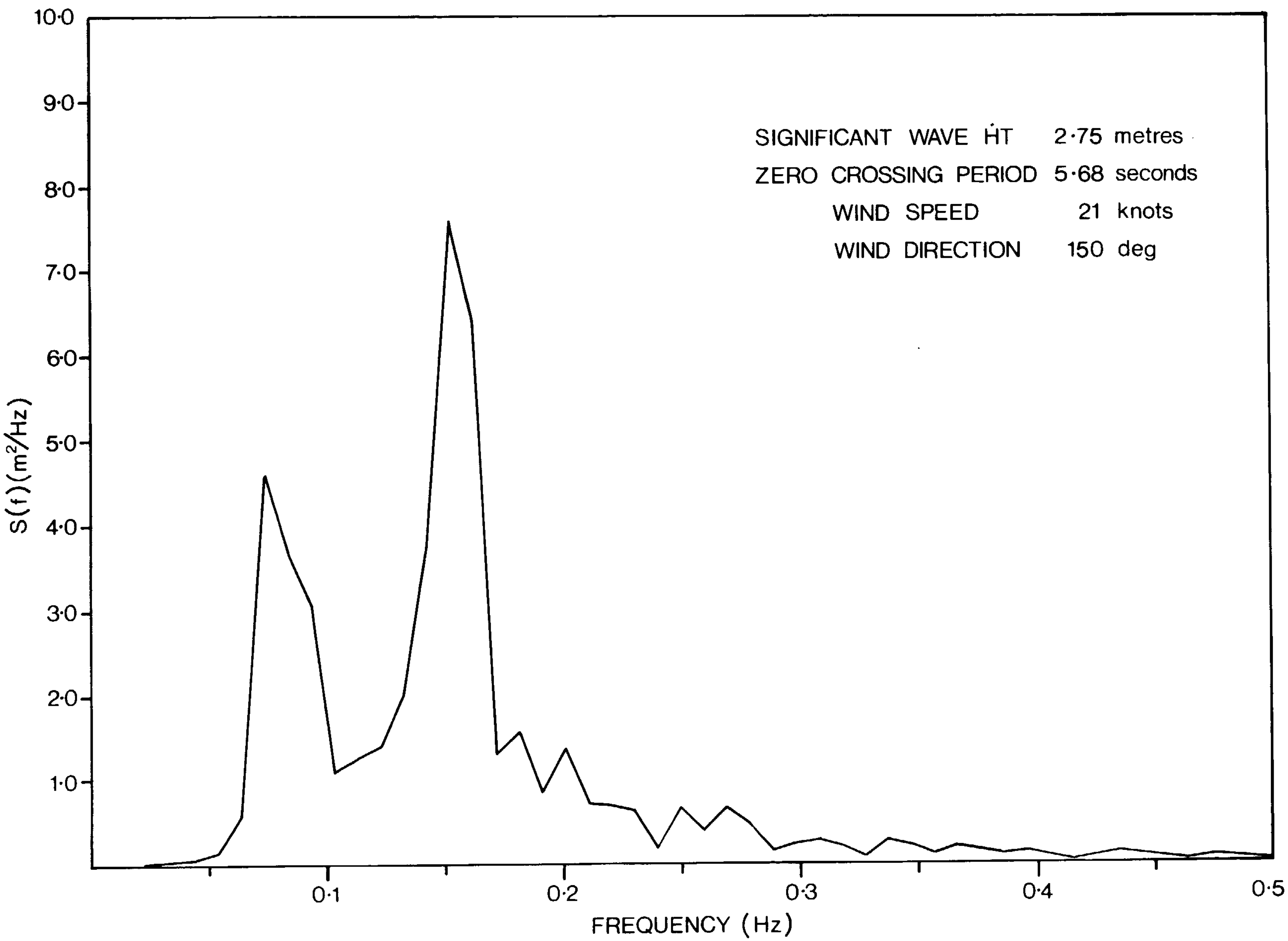


FIGURE 15 VARIANCE SPECTRUM OF WAVE RECORD

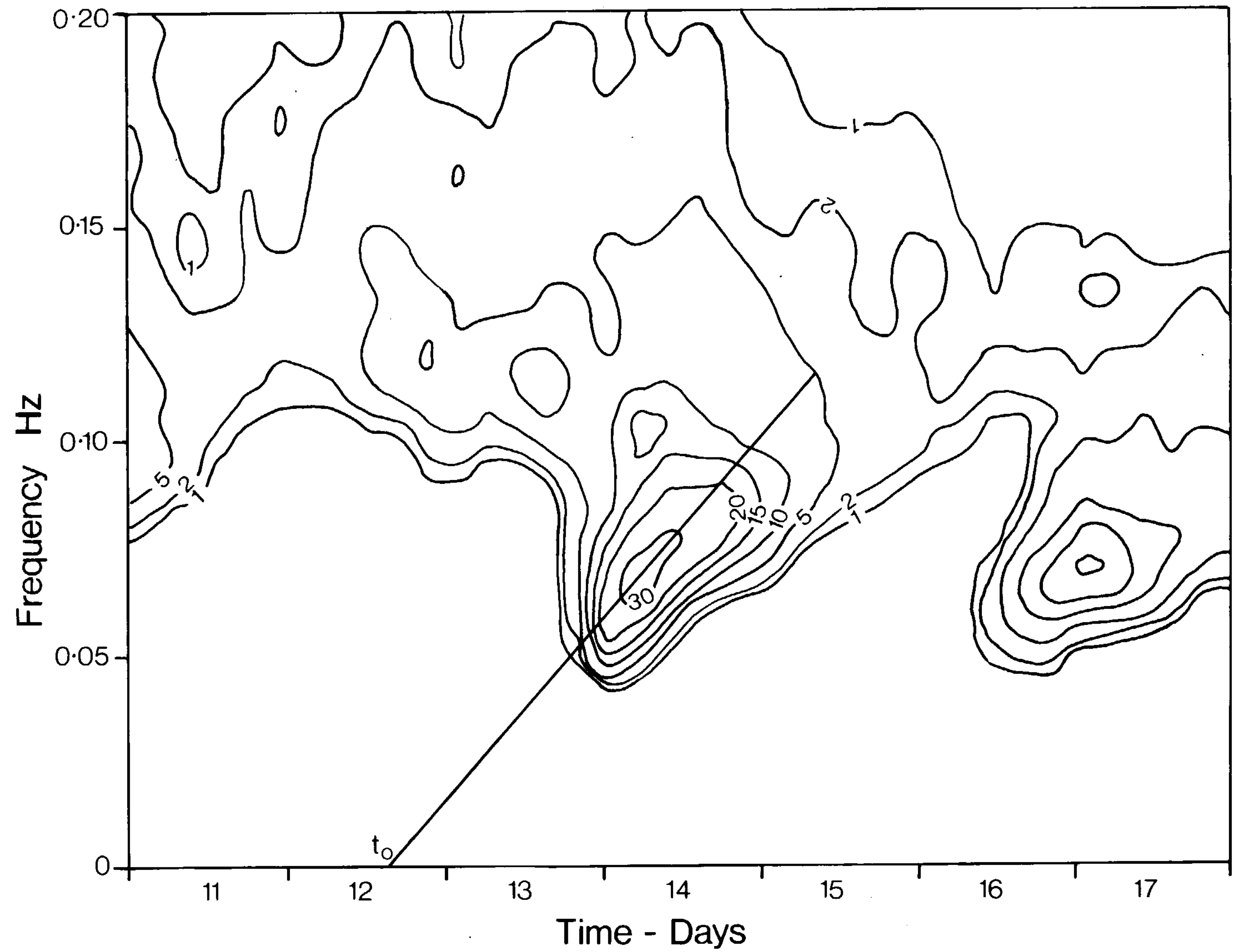


FIGURE 16 ILLUSTRATING THE USE OF CONTOURED SPECTRAL DATA AS AN AID TO THE IDENTIFICATION OF A SWELL SOURCE

considerations and experience from operating a direction recording, free floating buoy. A discussion of the results obtained from DB1 are contained within references 9 and 19.

Although there are many considerations to be taken into account when deciding how wave data should be analysed and presented, this section will be concluded with just one more: if the data collection programme has been carefully thought through and executed, and if proper validation has been applied, then the use of a well-proven and widely adopted analysis and presentation suite will make the data applicable not just for the project in hand but for future studies (and generations). There exists a substantial amount of data which is barely adequate for the original purpose, let alone for wider application because of lack of adequate attention to such details.

9 TWO EXAMPLES OF WAVE RECORDER SELECTION

9.1 In 1971 a requirement to measure waves arose in connection with a feasibility study for a freshwater storage scheme on the foreshore of the Wash - a 25 km square bay on the East Coast of England. An assessment of wave characteristics was required for the design of surface protection on the seaward facing slopes, and in planning construction. The situation in the Wash was particularly difficult as a tidal range of over 8 m acted over an area of complex topography with extensive drying banks.

Three types of instrument were considered as possibilities for this situation:

1) Surface piercing (wave staff)
2) Accelerometer buoy
3) Sub-surface transducer

The first system was not chosen because of its vulnerability to damage and fouling. However, in this situation in particular the ability of such a system to measure both short period waves and tides would have been a major advantage.

The buoy measuring systems, perhaps best exemplified by the Waverider, would also have adequately measured the short period waves, but not the tides. However, the difficulties of mooring wave buoys in narrow channels precluded their use.

Two types of pressure transducer were ultimately chosen on the grounds of their rugged and proven designs and also their availability, bearing in mind that the installation was programmed to take place within six months of defining the requirement. They were:

1) The Van Reijsen-Boersma Seawave Meter
2) The Institute of Oceanographic Sciences F. M. wave recorder.

Both systems could be connected to shore by cable link.

The use of radio transmission for relaying the signals to shore would have been ideal but no suitable equipment was available, neither was the use of a transmitting aerial at the sea end considered a reliable proposition. Having thus chosen the instruments it became necessary to site both sea units and shore recording stations in such a way that the maximum cable lengths for each site should not exceed about 7 km. All transducers were mounted in protective housings and were installed on sandbanks, but near deepwater channels. The laying of long cables in an intertidal area was a major achievement and the work was undertaken by a specialist contractor who had successfully carried out a similar operation in the Dee estuary. Cable lengths in the Wash were 5600 m, 6600 m and 6400 m for the three sites and had to be routed across areas where conditions varied from firm sand to soft silt. The nearest source of mains power was 5 km from the shore station so an inverter system was designed to provide a 240 volt 50 Hz supply from a 12 volt Nickel Cadmium battery pack. The batteries were replaced about once every two weeks with a freshly charged set. A clock was also designed to ensure that wave sampling took place only at, or around, high water.

Several years of data were collected from this remote site and although for much of the time the conditions were calm, a number of significant storm events were recorded and analysed.

9.2 The second example involved the setting up of a project to measure the wave climate, initially from one position, to the west of the Outer Hebrides. The whole west coastline of these islands is exposed to some of the most severe waves in the world and the desk survey indicated that the use of recorders close to the shore and connected by cable would not be reliable, furthermore the requirement was to monitor waves in a water depth of at least 30 m. No offshore structures existed. Two areas appeared worth surveying: the west coast of Lewis and that of South Uist or Benbecula. The survey team investigated the topography and likely shore station sites and concluded that an area some ten miles west of South Uist would be most suitable for deploying a Waverider buoy. The reasons were that it was part of a military weapon testing range and large scale fishing was not likely, also good shore facilities were available in the military complex. A subsurface float mooring was required to prevent mooring damage because of the rocky seabed. Concern was also felt about the effect of the Monach Isles on waves being propagated from the north to north west sector. The site appeared to be the best compromise and has since turned out to be a satisfactory source of extremely useful digitally recorded wave data. Two buoys at different distances from the shore but approximately on the same bearing have now been deployed and a third one further offshore is planned.

Acknowledgement

The author wishes to thank his colleagues at IOS, in particular Dr J A Crabb and Mr E G Pitt, for their help and advice in producing this report. The production of this document was undertaken with the support of the Department of Industry.

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WAVE RECORDING INSTRUMENTS
FOR CIVIL ENGINEERING USE

L. Draper and J. S. Driver

Appendix to IOS Report 103

1980

NB. L.Draper said that this appendix was very out of date (prior to his departure in 1989)

This work was supported by the
Departments of Energy and Industry

Institute of Oceanographic Sciences

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GU8 5UB
U. K.

Crossway,
Taunton,
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TA1 2DW
U. K.

CONTENTS

WAVE RECORDING INSTRUMENTS FOR CIVIL ENGINEERING USE

L. Draper and J.S. Driver
Institute of Oceanographic Sciences

INTRODUCTION

This list is the latest in an occasional series which first started in 1961 as an appendix to a paper[1] on wave recording techniques. The paper was superseded in 1970 by another[2] and in its turn is being replaced by a comprehensive Guide to Sea Wave Recording[3].

It has been prepared by writing to all companies listed in the previous Appendix, and to all others known to have offered wave recording instruments for sale. There have been several companies which have withdrawn from the wave recorder market, and many models which are not now produced, but several new companies and models have appeared. The net result is about a twenty percent reduction in the number of models available.

The authors have tried to be diligent in locating manufacturers of wave recorders, but it is perhaps inevitable that some manufacturers or models have been omitted. In cases where the information has not been supplied in the classifications (1 to 8) requested, the authors have attempted to do so themselves, but may not always have interpreted the wealth of publicity material correctly. In all such cases the authors apologise for any difficulties which may arise as a consequence. They would be most grateful if any omission or error could be notified to them.

The wave recording and associated systems which are described in this list are nearly all standard systems which are available commercially. For convenience they are classified into six groups:

a) Instruments which measure waves from above the surface
b) Instruments which measure waves at the surface
c) Instruments which measure waves from below the surface
d) Instruments which measure wave directions
e) Instruments which measure waves in laboratories
f) Ancillary equipment

Within each group, instruments are listed under each manufacturer's name (arranged alphabetically), and information about each instrument is summarized in the following form:-

1) The model
2) The principle of operation of the instrument
3) Types of recording available
4) The types of waves it is suitable for measuring, and operational environment
5) The various components which comprise the system
6) The price and delivery time (where available) at 1 June 1980
7) Any other information
8) The representative in the United Kingdom, or, in some cases, in Europe.

The information given here about equipment has been supplied by the manufacturers, and any enquiries for further information should be addressed to them.

Data logging systems have been included for the first time under section f). Some are selected from a list compiled by R.A. Haine (IOS); it is by no means exhaustive and comprises only a brief description of some of the more well known (at IOS) equipment. The addresses of manufacturers cited from the IOS list are given on page 38.

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In a number of sections the answers have been numbered sequentially instead of according to the number of the question to which the answer relates.
This irritation is regretted, but it does not invalidate the information given.

SECTION A

a1 EMI ELECTRONICS LTD. (UK)

1. Infra-red wave height monitor
2. Infra-red light pulses reflected from surface
3. Digital or analogue
4. Storm and swell
5. Sensor head and processor

a2 DR. FAHRENTHOLZ (W. GERMANY)

1. Wave recorder type 161
2. A transducer, working in the air, is installed on a boom held above the surface. The distance from the transducer to the surface is measured by echo sounding. The transducer and the recorder are connected by cable.
3. Analog recording on 200 mm - electro-sensitive paper, option: Analog or digital outputs for data logging.
4. Short and long sea waves.
5. Transducer, cable, recorder
6. Price: depends on the specification. Time of delivery: about 6 months
7. Max. distance from the surface: 25 m, Max. length of cable 20,000 m.

a3 KRUPP ATLAS ELEKTRONIK (W. GERMANY)

1. ATLAS LARA 10 Survey Laser Range Finder
2. This instrument is designed as an active Laser diode ranging laser. It is suitable for dynamic range measurements against natural reflectors such as the water surface.

   It may be used to measure the height of waves, by installing the Laser Range Finder mounted above the surface, allowing the laser pulses to be reflected by the water surface.
3. Digital display
   Digital output for a printer, punched tape puncher, or magnetic tape unit.

SECTION A

a3 (cont'd) ...

4. All kinds of waves at distances between the laser optics and the water surface from approx. 0.5 to 30 metres under nearly all weather conditions. Accuracy depending on turbulences on the water surface, typically 0.1 metre ± 0 1% of measured distance.
5. ATLAS LARA 10 Survey Laser Range Finder consisting of
   a) Control and Readout Unit 220 V AC, 12 V DC
   b) Optical Head
   c) Connection Cable
6. Approx. DM 15,000 - delivery typically 6 weeks after receipt of your order
8. Krupp International United Kingdom

SECTION B

b1 LOUIS C. ADAMO INC. (USA)

1. WRANSAC
2. Accelerometer buoy (Waverider)
3. Various
4. Storm and swell
5. Modified Waverider buoy with satellite communication

b2 DATAWELL BV (NETHERLANDS)

1. Waverider, stainless steel buoy with spherical hull, diameter 0.7 metre.
2. Vertical accelerations of the buoy are measured with an accelerometer mounted on a gravity stabilised platform (natural period of 40 sec). The acceleration signal is integrated twice to give waveheight which is converted into a fm square wave signal at a scale of 1.86 Hz per metre displacement, centre-frequency is 259 Hz.

SECTION B

b2 DATAWELL BV (NETHERLANDS)

2. (cont'd)
This fm square wave modulates the transmitter carrier of 27 MHz (100% am modulation).
The transmitter range is 50 km for waveheights less than 10 metres and 30 km for a waveheight of 25 metres.

3. The 6 channel (not simultaneously) receiver, Warep, is provided with a programming unit.
Available are 2 analog outputs, paper chart recorder and electrical (1 Volt/metre), and a fm output, centre frequency 259 Hz and 10.36 Hz deviation per metre displacement. A digital magnetic tape recorder, Dima, can be connected to the fm output.

4. Waveheight range, minimum: noise peak-peak (bandwidth 1 Hz) eq. 0.02 metre, maximum: 40 metres peak-peak.

Wave frequency range: 0.065 Hz - 0.50 Hz (3%)
0.035 Hz - 0.65 Hz (30%)
The wave amplitudes with frequencies between 0.035 Hz and 0.065 Hz can be corrected within 3% of their true value from the response given.

Waverider scale accuracy: better than 3%.
With the use of a rubber mooring line the Waverider buoy will remain afloat under the combined action of a 20 metre high wave and a current of 2 knots.
For higher currents a 0.9 metre diameter hull is available.

5. 6. Waverider buoy (including batteries with a life of at least 9 months) Dfl. 14,000.
Waverider buoy with flashlight Dfl. 16,000.
Warep receiving system (including antenna) Dfl. 16,500.
Standard mooring system (rubbercord, Nylon coated steel wire rope (100 m), Polypropylene rope (200 m) and terminals). Dfl. 2,330. Servicekit Dfl. 4,250.
A wide range of spare parts is available.

SECTION B

b2 DATAWELL BV (NETHERLANDS)

5. 6. (cont'd) ...

Prices are FOB Shipol (airfreight) or Amsterdam/Rotterdam (surface freight). Delivery is normally from stock.

8. Datawell has no representatives, direct contact with users is preferred. Users might wish to see section f.

b3 ETROMETA BV (NETHERLANDS)

1. Slender Step Gauge
2. Resistance
3. Waves, swell and tides
5. Wave Staff, Electronics, Monitor.

b4 DR. FAHRENTHOLZ (W. GERMANY)

1. Wave and Wave-run-up recorder type 162.
2. 48 pressure sensors are installed in a long line on a beach or dike. When the water gets over the pressure sensors a relay contact will be switched on and this fact will be recorded. The sensor system and the recorder are connected by cable.
3. Analog recording on a 200 mm electro-sensitive paper, option: Analog or digital outputs for data logging.
4. Short and long waves and their wave run-up on beaches, dikes and so on.
5. Pressure sensor system, cable, recorder.
6. Price: depends on the specification.
   time of delivery: about 6 months.
7. Max. water depth: 20 m. Max. cable length 10,000 m.

b5 HYDROWERKSTATTEN (W. GERMANY)

1. Type 433
2. Float
3. Wax paper at maximum cable distance of 500 m.
4. Sea waves.
5. Sensor, cable and shore unit.
6. FOB DM 20,050 plus cable cost.

SECTION B

b6 INSTITUTE OF OCEANOGRAPHIC SCIENCES (UK)

1. Shipborne Wave recorder type IOS 5254.
2. The equipment comprises accelerometers to measure longer waves and pressure units to measure the shorter ones. The two transducer sets are installed one each side of the ship 1-3 m below the water-line. All equipment is contained within the ship.
3. Paper chart recorder and buffered analogue output for data logging.
4. Sea waves in all exposed locations up to 30 m height and 25 sec period. Short period wave response depends on depth of installation of pressure units.
5. Two sets of accelerometers and pressure transducers connected by cable to the electronic signal processing and chart recording unit. The latter offers choice of manual or automatic record sampling.
6. Price: Electronics unit: £2,500 Transducers: £5,500 - ship fitting and cabling extra. Delivery normally within 6 months of receipt of order.
7. Ship must be stationary or nearly so when records are taken. A portable calibrator is available at £2,500 and an installation service can be provided if required.

b7 KELK (CANADA)

The following specification for this model has been revised in June 1976. The revision is available from the manufacturers or the agents.

1. Model P116 Zwarts Gauge
2. A co-axial transmission line, having a strong aluminium or copper pipe as its outer conductor, is the tuning element of an electronic oscillator. When immersed in water, a sharp change in the electrical impedance of the transmission line occurs at the water surface. The period of the output pulse is proportional to the length of transmission line which is not immersed.

SECTION B

b7 KELK (CANADA) cont'd ..

3. Sea and fresh water waves of up to 30 m crest to trough.
4. i) Wave height sensor, in 3 m line sections
   ii) A simple voltmeter and calibration network for direct connection to the sensor.
5. Basic model P116 $3,536 ; additional 3 metre line sections $645; delivery time is stock to 8 weeks A.R.O. for 1 unit, and longer for larger quantities.
6. The sensor produces a digital output (which can be transmitted over lines up to 10 to 50 km or by radio).
   Analogue conversion is provided by Model P146 Signal Converter.
   Accuracy ± 0.2% of range.
   Power requirement 12-18 d.c., 20 mA.
   Analogue output ± 5.0v; load resistance 500 ohms (min).
   With P146/digital output 5v pulse train; load resistance 500 ohms (min). Approx. frequencies 1250 Hz at top level, 557 Hz at 9.1 metres.
7. Rees (Mechanical Equipment) Ltd.

b8 SEAWAVE RECORDERS - METRITAPE (USA)

For wave gauging metritape can provide sensing element and signal conditioner supply 0-1 mA to drive recorder supplied by others. In addition signal conditioner will provide aux output (4-20 mA, 1-5 mA or 1-5 VDC) for other use.

1. Model - Sensing element type LS
   signal conditioner 701D
2. Sensor is precision wound resistive element.
   Resistance output directly corresponds to liquid level.
3. Recorder not available. Supplied by others.
4. All waves, all environments. Cannot be flooded
   Frequency response - 36 feet/12 seconds is fastest available.

SECTION B

b8 (cont'd)...

5. In general, sensor type LS, MTG Box MB/FRP176, Sigcon 701D, protective stilling pipe. This is dependent on specific installation details.
6. Delivery 16 weeks.
   Price - dependent upon length of sensing element required, installation details (i.e. on a pier, part of a ship, etc.)
7. None.
8. Marine Ventures, Ltd. London.

b9 N.B.A. (CONTROLS) LTD. (UK)

1. Wavecrest.
2. A wave contouring buoy incorporating an acclerometer suspension system electronic package, radio transmitter and appropriate supplies. The accelerations experienced by the buoy are electronically integrated twice to produce a voltage output proportional to sea surface deviation. This signal is transmitted to a shore- or ship-based receiving system.
3. The receiving system can be supplied with chart recorder outputs which show real time wave profiles or alternatively data can be logged on magnetic tape cassettes. Internal buoy loggers recording data in standard MIAS format can be supplied.
4. Surface waves over the range 0.06 Hz to 0.6Hz in all oceanographic environments.
5. In a standard single sphere of 0.63 m diameter. Various mooring systems are available. Optional receiving equipment is available.
6. £3,450.00. Delivery 4/5 weeks.
7. The mooring point attachment design of the wavecrest is such that it is possible for 3 buoys to be mounted in a triangular frame with a buoy at each apex. Coherent

SECTION B

b9 N.B.A. (CONTROLS) LTD. (UK)

7. (cont'd)...
outputs can be computer analysed to calculate wave front direction.

8. Manufactured in Great Britain.

b10 NOVA SCOTIA RESEARCH FOUNDATION (CANADA)

1. Flexible wavestaff
2. The wave sensor consists of a helix of resistance wire supported by a grooved plastic tube with an insulated return wire connected to the bottom of the helix. As the water level changes, there is a corresponding resistance change between the sensor's terminals.
3. Waves in the sea, and also in freshwater provided that at least ten feet of staff is immersed.
4. (i) The wave sensor, which is of a flexible, one-piece construction and which can be rolled into a coil three feet in diameter.
   (ii) An electronic circuit board, A, which produces a a direct analogue output between 0 and 5 volts d.c. (also available with power supply for operation from 115v).
   (iii) An electronic circuit board, B, to convert the direct analogue output to a varying frequency output in the range 30-90 Hz or 1-2 KHz. It is suitable for simple telemetry or recording on tape.
5. £900-£1,100 from Colnbrook, UK, depending on staff length; 6 weeks A.R.O.
6. The wave sensor is available in whatever length required, but standard lengths are 20, 30, 40, 60 and 80 feet. (Range of resistance is 100 to 1000 ohms). When installed the flexible staff (diam. 5/8 inch) is supported by threading it onto a stainless steel cable (diam. 3/16 inch). The power requirements are 25.5 ± 1v d.c., 20 mA, or 115v a.c., 10 watts.

SECTION B

b10 (cont'd)....

7. Colnbrook Inst. Development Ltd.

b11 VAN ESSEN B.V. (NETHERLANDS)

1. Model WR67 (improved Wemelsfelder).
2. This instrument is a float-operated wave recorder. The float is contained within a perforated tube, and follows the water surface; it is connected to a a recording mechanism by a nylon thread.
3. Sea waves up to 12 metres high.
4. (i) The float-operated sensor.
   (ii) Paper chart recorder.
   (iii) Power supply.
   (iv) A switch clock to control the sampling periods. The recorder paper is 240 mm wide, and the paper speed is 0.25 mm/sec or 1 mm/sec. With a paper speed of 0.25 mm/sec and 2 hours recording each day, the instrument can remain unattended for one month. For longer expanded records during storms, the instrument can be equipped with a radio-receiver. With a special radio-transmitter the instrument can be set in and out of action from the shore. In this case larger batteries are necessary.
5. Dfl. 17,600. F.O.B. Rotterdam; about one month. (Price of radio equipment on request, delivery about 5 weeks).
6. The chart drive is provided by a small electric motor, which is supplied by 6 primary cells, each 1.5 volts. The sensor needs to be installed on a pole.

SECTION C

c1 APPLIED MICROSYSTEMS LTD. (CANADA)

1. MODEL: Model 750A Wave and Tide Height Recorder
2. The Principle of Operation: Fast sampling of total hydrostatic pressure.
3. Types of recording available: Digital recording on 1/4" magnetic tape wound on 5" diameter spools.
4. Type of waves: Short or long period waves depending on moored depth.
5. Components comprising the system: Quartz crystal pressure sensor in situ accuracy 0.005% of range, precision time base, sequencing electronics, digital magnetic tape recorder, 18 alkaline D cells, 6" ID x 1 metre long pressure case.
6. Price $7,355 CDN., delivery 4 weeks-- F.O.B. Victoria, British Columbia, Canada.
7. Other Information: Measuring sequence includes once hourly samples of mean hydrostatic pressure interlaced with 7.5 minute (or 15 minute) bursts of wave data. Mean hydrostatic pressure is derived from a 4 minute signal average and wave data consists of ½ second samples of same signal. Wave data may be collected at any elapsed hour up to 10 hour interval. 'Tide' samples are every 1/4, 1/2, or 1 hour interval. Time code and and temperature are also recorded.
8. Representative: Nearest to U.K. is Norway, A.s Tekno-Team.

c2 DR. FAHRENTHOLZ (W. GERMANY)

1. Wave recorder W 2001/5 C; W 2001/5 D
2. A transducer is mounted on the sea bed in a large iron frame (type C) or in a floating buoy (type D). The vertical distance to the surface will be measured by echo sounding. Connection to the recorder by armoured sea cable.
3. Analog recording on 200 mm - electro-sensitive paper, option: Analog or digital outputs for data logging.

SECTION C

c2 (cont'd)..

4. Short and long sea waves.
5. Transducer, armed sea cable, recorder.
6. Price: depends on the specification. Time of delivery: about 6 months.
7. Max. water depth: 100 m; Max length of cable 20,000 m.

c3 DR. FAHRENTHOLZ (W. Germany)

1. Wave recorder W 6301/5 C; W 6301/5 D
2. A transducer is mounted on the seabed in a large iron frame (type C) or in a floating buoy (type D). The vertical distance to the surface will be measured by echo sounding. The connection between the transducer and the recorder is an armoured sea cable.
3. Analog recording on 630 mm - electro-sensitive paper, option: analog or digital outputs for data logging. The recorder can record the measurements of three transducers simultaneously.
4. Short and long sea waves.
5. Transducer, armoured sea cable, recorder.
6. Price: depends on the specification.
   Time of delivery: about 6 months.
7. Max. water depth: 100 m; max. length of cable 20,000 m.

c4 DR. FAHRENTHOLZ (W. GERMANY)

1. Pressure sensor type 4025 A 5.
2. A pressure sensor is installed on the seabed. The water waves are measured by the pressure of the water. The sensor and the recorder are connected by an armoured sea cable.
3. Analog recording, option: analog or digital outputs for data logging.
4. Sea waves, wave length and wave period which can be

SECTION C

c4 Dr. FAHRENTHOLZ (W. GERMANY)

4. (con'td)...
   measured depend on the water depth.
5. Contents of one equipment: Pressure sensor, armoured sea cable, recorder.
6. Price: depends on the specification. Time of delivery: about 6 months.
7. Max. water depth: 60 m. Max. length of the cable 20,000 m.

c5 INSTITUTE OF OCEANOGRAPHIC SCIENCES (UK)

1. F.M. Wave recorder, type I.O.S. 4882/5255.
2. The sea unit uses a pressure sensitive diaphragm to vary the gap of a parallel plate capacitor. The wave information is transmitted by cable to shore as a frequency modulation of a nominal 100 kHz carrier.
3. 100mm chartrecorder and magnetic tape cassette (C90). Also buffered analogue output for external logger.
4. Wave height ranges from 5 m to 20 m, and period from 4 sec. to 25 sec. (Due to attenuation, the highest frequencies which can be recorded depend upon depth of immersion); Suitable for operation in rugged situations with armoured cable connection between transducer and shore electronics. Maximum cable length 2 km but may be increased by special arrangement. The unit has a power consumption of 20 va on mains and incorporates a float charged battery which will allow normal operation during mains failure for up to 36 hours. May also be operated from 12 volt car battery.
5. (i) Pressure transducer
   (ii) Shore electronics unit
   (iii) Armoured cable.
6. £3,500 plus cable. Delivery normally within 6 months. Instruments may be purchased or hired.
7. Site survey and installation service available if required.

SECTION C

c6 INTERSEA RESEARCH CORPORATION (USA)

1. Wave recording system A-2/Q-6
2. The system employs the A-2 wave pressure sensor for underwater installation at a maximum of 60 ft. depth.
3. Paper chart recorder and 0 to ± .5 VDC analog output for data logging.
4. Sea waves to 22 feet (standard), other heights by special order, periods to 100 seconds. Short period response depends upon sensor installation depth.
5. Differential pressure transducer with hydraulic filtering to eliminate the effect of tide and long period seiches, connected by cable to a recorder unit which also contains the power supply and signal conditioning circuitry.
6. Price: Sensor - \$1,650.00
   Recorder - \$3,450.00
   Cabling - Extra

   Delivery normally within 30 days of receipt of order. (Prices are in U.S. dollars, F.O.B. the plant).
7. Recorder has built-in test circuit for recorder circuitry and cable fault detection.
8. U.K. representative: Offshore Environmental Systems Ltd.

c7 INTEROCEAN SYSTEMS INC (USA)

1. WG/7500 Wave Gauge (self-contained or remote)
2. The sensor is a high resolution, temperature compensated differential transducer (silicon semi-conductor strain gauge). One side of the differential transducer has a low pass hydraulic filter to compensate for the effect of tide and it therefore reads waves directly.
3. Very high precision (± 5 mm) measurement of waves with a range of ± 5 metres, or ± 10 metres, or others upon request.
4. Self-contained models are powered with standard "D" size (flashlight) batteries, and store measurements on a

SECTION C

c7 INTEROCEAN SYSTEMS INC (USA)

4. (cont'd) ...
programmable digital magnetic cassette or miniature analog strip chart recorders. Unattended operating time varies from 20 days to one year depending upon selected program. Remote models have the power supply and recorders built into one case and the sensor in another, and both are connected via a submersible electro-mechanical cable with connectors.

6. The instrument may rest on the sea bed, or be attached to a structure or a taut line mooring, at a maximum depth of 75 metres. Gauge is insensitive to clogging, biofouling or silting over because sensor is isolated from direct contact with water by an oil filled chamber with a 10 cm diaphragm interface.

c8 KAIJO DENKI (JAPAN)

1. Ultrasonic Wave Height Meter, Model USW-132B.
2. The equipment is used together with a bottom mounting transducer, from which the sonic pulse is emitted to the surface water. The time required for its round-trip is measured for wave height observation.

$$H = \frac{C}{2} \Delta t$$

Δt = change in the round-trip time
C = propagating velocity of underwater sonic pulse
H = wave height value

3. The pulse received to the recorder from the electric unit is converted into a DC electric and analog recorder. It is also transmitted from the main unit to the output terminal of the data processor.
4. Capable of sensing the wave height with 200 kHz beam at the 9 - 50 m bottom. High sensitivity to fluctuating depths and wave cycles. No complex wave height processing.
5. Main unit (consisting of: Electric Unit, Control Unit, Recording Unit and Rack) Transducer.

SECTION C

c8 KAIJO DENKI (JAPAN)

5. (cont'd) ...
   Connecting cable to Transducer and Main unit.
6. Price: Main unit and Transducer: F¥ 5,300,000.-
   Connecting cable: depending on customer's specifications
   Above price not including Installation Charges.
   Delivery: within 5 months upon receipt of order.
7. Options: Significant Wave Processor is available at F¥ 5,000,000.- Real time processing of significant, mean, max. wave height, and 1/10 peak wave per observation. Data printing per measurement cycle.

c9 KRUPP ATLAS-ELEKTRONIC (W. GERMANY)

1. Atlas Deso 20 Survey Echosounder
2. This instrument is designed as a dual channel survey echosounder. It may be used to measure the height of waves, by installing the transducer assembly on the sea-bed or on the leg of a drilling rig, and allowing the sound waves to be reflected from the water surface. The second echosounder channel may be used to measure a fixed distance so that the sound velocity can be determined for later correction of the wave height measurements.
3. (a) Analog recording on paper of both sounding channels simultaneously;
   (b) Digital display of either one sounding channel;
   (c) Digital recording of both sounding channels on either printing paper, punched paper tape, or magnetic tape cassettes, directly or after preprocessing in a computer.
4. All kinds of waves in water depth from 0.3 - approx. 100 metres wave resolution and accuracy depending on water depth, transducer beam width, and turbulences on the water surface. Accuracy typically 0.12% of measuring range scale.

SECTION C

c9 (cont'd)....

5. 1(a) ATLAS DESO 20 Survey Echosounder, single channel 210 KHz 24 v DC
   (b) Transducer assembly
   (c) 210 KHz transducer, ± 1.5 degree beam width
   (d) transducer cable (length tbd)
   2 OPTIONS
   (a) Second frequency channel (210 KHz or 33 KHz)
   (b) Calibration transducer 210 KHz
   (c) Wide beam transducer 33 KHz, approx. 20 degrees beam width
   (d) 1st channel digitizer and digital display
   (e) 2nd channel digitizer
   (f) Remote control assembly
   (g) Digital printer w. clock
   (h) Magnetic tape recorder
   (i) Punched tape recorder
   (k) Processing system
6. Depending on configuration: Price approx. DM 30,000 delivery typically 12 weeks after receipt of your order.
7. The system can also be used as standard survey echosounder.
8. Krupp International United Kingdom.

c10 KYOWA SHOKO CO. LTD.

1. Direct waveheight recorder, pressure type DW-III.
2. Pressure sensor.
3. Paper chart.
4. Storm waves and swell.
5. Recording unit, Pressure receiving tube and Protection frame, Stable Wheel, tripod.
7. Maximum depth 15 m, measuring range 8 m, weight 75 kg.

C11 N.B.A. (CONTROLS) LTD. UK

1. Model DNW-5, self contained recorder.

SECTION C

C11 (cont'd)....

2. A piezo resistive pressure transducer in an underwater pressure housing senses the changes in water pressure twice a second (standard) and records the required information in a digital form on an integral magnetic tape cassette.
3. The data logger is a memodyne model 201 magnetic tape cassette recorder. A range of tape readers is available to assist processing of data into analogue and digital formats.
4. Duration and frequency of sample periods are pre-selectable by the operator. Duration can be from 10 seconds up to 64 minutes and frequency from 10 seconds up to 255 minutes. The instrument is therefore suitable for measuring all wave and tide movements.
   The instrument must be fixed mounted either on the sea bed or to a structure.
5. Self-contained instrument.
6. £3850.00. Delivery 2/3 weeks.
7. The NBA (Controls) Ltd. data processing division offers a full suite of analysis programmes for both wave and tide data at a turn around of approximately 10 days. Additional facilities include the provision of suitable mounting frames and the inclusion of optional additional parameters - temperature, conductivity, dissolved oxygen etc.
8. Manufactured in Great Britain.

C12 N.B.A. (CONTROLS) LTD. UK

1. DNW-6.
2. Operation as per model DNW-5. Model DNW-6 is a remote Recording version with a connecting length (up to 3000 metres) of cable between the sensor unit and the surface cassette recorder package.

SECTION C

C12 (cont'd)....

3. As per model DNW-5 except that cassette logger is located on the surface. A 0-1V analogue output is continually provided.
4. As per model DNW-5.
5. Underwater sensor unit in tubular pressure case, connecting cable and surface rack mounted or free standing recorder package.
6. £5500.00 + cable at £3.40 per metre. Delivery approximately 8/10 weeks.
7. As per model DNW-5.
8. As per model DNW-5.

C13 NEREIDES (FRANCE)

1. Pressure Gauge self recording wavemeter HR-3
2. This equipment measures water level from below the surface with an accurate pressure sensor (PAROSCIENTIFIC). Signal is digitalized twice per second - water level on 2 byte words - waves on one byte - instrument is preprogrammed by operator to adjust frequency and duration records.
3. Data are recorded on magnetic tape cassette on ECMA 34 mode. Day, hour, minute are also recorded. Each record contains 2 bytes for water level or a 2 minute wave sample.
4. Equipment can be moored by 50 m depth and measures waveheight up to 30 m and very long periods. Short waves are difficult to measure by 20 m depth and more.
5. PVC container containing rechargeable batteries. High accuracy pressure sensor (0-100 PSI). Electronic PCBS - TAD cassette recorder.
6. Price: 62,000 F.F.
   Option: static currentmeter for wave direction measurements.
   Delivery: within 6 months.

SECTION C

c13 (cont'd)....

7. Option: static currentmeter for wave direction
min-max code - instead of recording waves every 0.5 second, we record each wave amplitude and period; ECMA 34 standard: 1000 x 2 minutes = 33 hours, 2 track cassette recorder = 66 hours.

c14 SEA DATA (USA)

1. Model 635-8 Pressure Recorder Waves.
2. Pressure cell.
3. Digital Magnetic Tape. Sea Data 15 Megabit Cassettes.
4. Sea waves of 2.5 sec period and upwards; 45 m height.
5. Self-contained. Optional remote sensor with cable.
6. US$ 10,200 - 60 days.
7. Temperature recorder included.
8. Bruce Swale, Explorocean.

c15 SEA DATA (USA)

1. Model 635-11 Pressure Recorder, Waves and Tides
2. Pressure cell
3. Digital Magnetic Tape. Sea Data 15 Megabit Cassettes.
4. Sea waves of 2.5 sec period and upwards including tides. Tide accuracy 0.1 cm, 45 m height.
5. Self contained. Optional remote sensor with cable.
6. US$ 12,000 - 45 days
7. Temperature recorder included.
8. Bruce Swale, Explorocean.

c16 SIMRAD (NORWAY)

1. Model Simrad HW Wave Height Sensor
2. The instrument is basically a very high frequency narrow beam inverted echosounder operating at a frequency of 710 KHz.
3. In its basic version the instrument outputs a DC voltage

SECTION C

c16 SIMRAD (NORWAY)

3. (cont'd)....
   0-10 VDC, proportional to the distance from the transducer to the sea surface. The DC output can be scaled to meet particular requirements. A version with a BCD digital output is also available.
   Processing power can be included in the instrument to perform data analysis and to output data according to user requirements. Digital filtering will, for instance, make the instrument into an accurate tide meter in addition.
4. The system can be used to measure all types of waves provided a stable transducer mounting arrangement can be found in less than 100 metres depth. Because of its very narrow beam and rapid sampling rate the instrument allows relatively accurate measurement of wave profiles to be made. A useful feature in the near shore wave zones.
5. The basic system consists of a cabinet containing the electronics and a transducer connected to it by cable, which can be several hundred metres long. The cabinet is prepared to take one user-specified interface card.
6. Price F.O.B. Oslo, Norway.
   HW, Basic version: N.kr. 29,000 (approx. £2,590).
   Transducer, 2^{o} beam angle: N. kr. 6,000 (approx. £536). Delivery: approximately one month after order.
7. The instrument is virtually unaffected by aeration and turbulence near the surface.
8. U.K. Source: Simrad Seatronics Ltd.

SECTION C

c17 VAN ESSEN B.V. (NETHERLANDS)

1. Ospos
2. This is a self-contained pressure recorder mounted in a fibre-glass reinforced polyester tank.
3. Waves and tides with measuring ranges from 6 to 12 metres.
4. The polyester tank contains the pressure transducer, a switch clock to control the sampling periods, power supply, and waxed paper recorder. The waxed recorder paper is 80 mm wide, and the paper speed may be 0.25 or 1 mm/sec. With a paper speed of 0.25 mm/sec. and 2 hours recording each day, the instrument can remain unattended for one month.
   In shallow water the instrument can be fixed on a steel tripod.
5. Dfl. 17,700 (tripod Dfl. 850) F.O.B. Rotterdam; 1 week.
6. The pressure-measuring spring can be pre-stressed for half the measuring range, so that the instrument can be installed in deeper water where currents may be less strong.

c18 VAN REIJSEN (NETHERLANDS)

1. Boersma - van Reijsen Seawave Meter with Acoustic FM pressure cell.
2. The submerged pressure sensor measures pressure change by a change in frequency of a mechanical resonant member.
3. Chart recorder on audio tape recorder. Spectrum analyser for a number of spot frequencies is available. Records 15 min every 3 hours.
4. Sea Waves and Tides.
5. Sensor, cable and shore units.
6. Quoted on receipt of detailed enquiry. 3-4 months.
7. The unit can be provided with a radio telemetry link.

SECTION D

d1 ENDECO (USA)

1. Endeco Wave-Track™ Buoy - Type 949
2. The standard Type 949 configuration includes a fibreglass reinforced buoy, programmable crystal timer, accelerometer, double integator, self-contained batteries, and FM transmitter.
3. Receiver has a built-in chart recorder along with a RS232C output for further computer processing. Also, internal magnetic tape recording of 150 autocovariances and wave statistics.
4. System can measure waves of .02 m to 30 m having a period of 2-30 seconds or longer. Buoy can operate in water temperatures of -5° to +45°C.
5. The system comprises of a floating sensor/transmitter buoy and a base receiver/recorder station.
6. The Type 949 Wave-Track Buoy is priced at $9,150.00 U.S. dollars and the receiver is priced at $1,725.00 U.S. dollars. Both available on either a lease or straight sale basis from stock. An optional processing software program is available at a price of $2,625.00 U.S. dollars.
7. Additional Wave-Track systems are available for wave direction sensing. Satellite links are also available.
8. O.R.E. Ltd.

d2 MAREX (UK)

1. Marex Wave Direction Buoy
2. The buoy uses a Datawell Hippy 40 or Hippy 120 sensor, mounted in a hull designed to follow wave slope.
3. On board cassette recorders. Shore station recorders according to project requirements.
4. No upper sea state limit. Short period wave response down to 3 seconds.

SECTION D

d2 (cont'd)

5. Datawell Hippy 40 or 120 sensor, Marex microprocessor data system;
   Power supply;
   Transmitter Racal TRA 906 (HF) or Motorola 300 series (VHF/UHF);
   Marex wave direction hull;
   Mooring.
6. | | |
   |---|---|
   | Hull | £9,750 |
   | Data Module | £9,950 |
   | Battery Modules | £370 each |
   | Wave Module | £6,500 |
   | Transmitter Module | £1,895 |

   These are the main items. There are additional costs for cables/connectors and items which depend on system specification, e.g. mooring, shore station, software, system engineering.
7. The buoy can make other measurements, such as temperature, barometric pressure, wind speed/direction and tide in addition to wave direction.

d3 NEREIDES (FRANCE)

1. WADIBUOY - Wave Direction and Amplitude Buoy
2. This 2.5 m diameter toroidal buoy, made of reinforced fibreglass, follows sea surface. Heave, pitch, roll and heading are measured and transmitted by VHF to the shore, twice per second, on digital form continuously. Oceanometeorological parameters also available on the buoy can be transmitted by satellite as well as wave energy spectrum.
3. Data can be used as follows:
   - Recorded on programmed cassette datalogger CORMORAN model (ECMA 46 model); H1/3, THI/3, H. max, Tz are computed and printed on TETARD wave processor.

SECTION D

d3 NEREIDES (FRANCE)

3. (cont'd)
   - Processed on HP 9845T with complete software to obtain real time wave directional spectrum.
4. All waves from 2 to 20 sec period.
5. The buoy is delivered with a battery rack, flasher, radar reflector and a four legged mast.
   Climatological sensors for on a vertical mast (wind, temperature, barometric pressure ...), oceanographical sensors for under the buoy (current, water quality sensors, hydrophone, temperature profile line....).
   On shore station: WADIBUOY receiver connected either to CORMORAN, TETARD, THETIS system or to HP 9845 computer.
6. PRICE depends on configuration from 130,000 to 400,000 F.F. Delivery time from one to six months depending on configuration and stock.
7. Satellite transmitter available for all parameters. However, wave directional spectrum analyser now in development will be in production only by the end of 1980.

d4 SEA DATA (USA)

1. Model 635-9 Directional Wave Recorder
2. Pressure cell and E-M current sensors
3. Digital Magnetic Tape, Sea Data 15 Megabit Cassettes.
4. Sea waves of 2.5 sec and upwards: 45 m height.
5. Self-contained. Optional remote sensor with cable. E-M sensor on end of short cable.
6. US$ 19,500 75 days.
7. Standard wave recorder and temperature recorder included.
8. Bruce Swale, Explorocean.

d5 SEA DATA (USA)

1. Model 635-12 Directional Wave Recorder
2. Pressure cell and E-M current sensors.

SECTION D

d5 (cont'd)

3. Digital Magnetic Tape; Sea Data 15 Megabit Cassettes
4. Sea waves of 2.5 sec period and upwards including, tides, 45 m height.
5. Self-contained. Optional remote sensor with cable.
   E-M sensor on end of short cable.
6. US$ 22,500 - 90 days.
7. Standard wave recorder and temperature recorder included; mean current recorded.
8. Bruce Swale, Explorocean.

SECTION E

e1 CHURCHILL CONTROLS (UK)

1. Wave monitor
2. The equipment uses conductivity probes which comprise a pair of stainless steel wires or rods depending on the length of probe required. The probes are connected by twin cable to the electronics which can be up to 100 metres away.
3. The basic instrument provides an output signal of up to +10v-0- -10v for input to a chart recorder or data logger. Proprietary galvanometer type recorders can be supplied as part of a complete system.
4. The basic instrument is suitable for the measurement of wave heights up to one metre in a laboratory environment. A special version is available for the measurement of waves in sea water up to two metres amplitude.
5. The system comprises the probes of various lengths and associated electronics which is engineered on plug-in modules.

SECTION E

e1 CHURCHILL CONTROLS (UK)

5. (cont'd)....
Alternative power supply modules are available for A.C. mains supply or for operation from a rechargeable 12v battery. Instrument cases and rack mounting frames are available for different sizes of system from one to seven probes.

6. Prices for complete assemblies are as follows:

WMA100 single probe assembly -	£ 384.00
WMA200 2 probe assembly -	£ 583.00
WMA300 3 probe assembly -	£ 801.00
WMA700 7 probe assembly on rack mounting frame -	£1634.50

Prices for sea water probes on application.
Delivery is normally ex-stock.

7. Controls are incorporated to enable the output signal to be adjusted to suit any type of chart recorder or data logger. Controls are also provided to enable compensation to be made for the resistance of the probe connecting cable to maintain an overall linearity of better than 1%.

e2 VAN REIJSEN (NETHERLANDS)

1. Model Wave Meter M70
2. Partially immersed vertical conductors
3. Optional
4. Model waves up to 50 cm (higher optional)
5. Sensor, cable & electronics unit
6. Quoted on receipt of detailed enquiry 3-4 months.

SECTION F

f1 DATEL (USA)

1. Modular data logging system
2. Magnetic tape 2 track NRZ1 format
3. 2 x 10^6 bits on cassette
4. Sea waves
8. Datel (UK) Ltd.

f2 HURST EQUIPMENT (UK)

1. DLM.278 modular data logging system

2, 3, 5.
Microprocessor-based main frame with various input/output modules and peripherals

4. Sea waves, interface available for Waverider and survey parameters.

f3 KAIJO DENKI (JAPAN)

1. Significant wave digitaliser
2. Binary digitization of analogue signal
3. Digital printout
4. Sea waves
5. Electronic unit

f4 MEMODYNE (USA)

1. Modular data logging system type 201
2. Magnetic tape 2 track NRZ 1 format
3. 2 x 10^6 bits on cassette
4. Sea waves

f5 MICRODATA (UK)

1. Portable digital data logger

2, 3.
4 track magnetic tape recorded in ANZI/ECMA format on 3M cartridge. Capacity 20 x 10^6 bits.

4. Sea waves.

SECTION F

f6 NEREIDES (FRANCE)

1. Environment Data Acquisition System CORMORAN
2. This equipment, designed to record wave data on programmed magnetic cassette, is also available for oceanographic, hydrographic and meteorological parameters up to 12 data inputs.
   Before starting the equipment, the operator has to initialize CORMORAN, fixing:
   - Day, hour, minute
   - Record features for each channel (frequency and duration) which will be activated
3. Records are written on ECMA 46 ANSI magnetic cassette. If recording blocks are 2048 bytes long, capacity is 2.3 megabytes.
   Equipment is also available as an option using ECMA 34 cassette with 1 to 256 byte recording block length maximum and a 2.5 kilobyte capacity.
   Cassette reader is available with HPIB or RS 232 output.
4. Availability for main wave sensors including radar, DATAWELL receiver, wavestaff, WADIBUOY receiver, pressure gauge system.
5. The system includes:
   - Magnetic cassette recorder and serial formatter
     $p = n + m$ data input PCB
     $p \leq 12$ standard version
     $n = 0$ to 12 analog input
     $m = 0$ to 12 digital 32 bit inputs
   - Electronic PCB including CMOS microprocessor, RAM and PROM memory.
   - supply voltage 50-60 Hz - 110 to 220 volts and internal rechargeable battery for supply failures
6. PRICE of standard equipment complete with display, etc. is 56,000 F.F.
   Delivery time is from stock up to 3 months.

SECTION F

f7 NEREIDES (FRANCE)

1. Wavespectran
2. This equipment, installed on waverider models 6000 or 6900 on Wadibuoy or other equipments, records 17 minutes of wave signal every 1 - 2 or 3 hours and analizes it, using FFT to obtain wave amplitude or energy spectrum.
   Spectrum is processed for 32 frequencies but only 28 are available to be transmitted by satellite. 32 bytes of ARGOS satellite message are organized as follows:
   - 2 bytes available for pressure sensor
   - 1 byte available for temperature
   - 1/2 byte used for battery voltage
   - 1/2 byte determines gain of spectrum
   - 28 bytes corresponding to 28 frequencies of spectrum
3. This equipment is designed to transmit spectrum by satellite but it can be also recorded on:
   - 4 to 16 K byte static memories (on patented EDELWEISS system) ECMA 34 cassette recorder
   - (onshore) on printer or plotter
4. Designed mainly for DATAWELL buoy or sensor, this equipment processes wave outputs from these instruments.
5. System includes clock, analyser, supply voltage and in option:
   - ARGOS transmitter, antenna, cover (for waveriders)
   - Pressure sensor
   - temperature sensor
   - battery pack
6. PRICE of basic system is 45,000 F.F.
   Delivery time from 3 to 6 months.
7. Simplified system using digital filter and CMOS microprocessor will be probably in production in June.
   A wave direction spectrum analyser (WADIAN) is now under development.

SECTION F

f8 NEREIDES (FRANCE)

1. (Onshore or in board) Wave Computer TETARD
2. This equipment, connected to a wavestaff, a DATAWELL system or a pressure sensor, measures in real time H.max, H1/3, TH1/3, Tz, processed data available on BUS are displayed every 15 minutes and/or transmitted.
3. Processed data are printed on alphanumerical printer, every 15 minutes if tempest, every hour if difficult sea state, every 12 hours if calm sea state (depending on comparison to 2 thresholds fixed by operator).
4. No computation is done if $H1/3 < 0.3$ m or $TH1/3 < 1.6$ sec.
5. Motorola microprocessor with 5 k byte Prom, 4 K byte RAM Printina alphanumerical printer.
6. Price:

TETARD 1 for one wave sensor	39,500 F.F.
TETARD 2 for two wave sensors	41,600 F.F.
TETARD P for wave pressure sensor	44,000 F.F.
TETARD S to install on buoy for satellite transmitter	37,000 F.F.

Price on January 1st 1980.
Delivery time: from stock up to 6 months.
7. Very useful for DATAWELL equipment (unlock is taken in charge). Compatible with PELICAN wave programmed cassette recorder.

f9 RAPCO (UK)

1. Purpose built digital data loggers
2, 3. Various magnetic tape options, for example 3M cartridge with ECMA 46 format.
4. Sea waves.

f10 SEA DATA (USA)

1. Burst-recording data logger model 651-8.
2. Magnetic tape.

SECTION F

f10 (cont'd) ...

3. 1,250,000 12-bit numbers
4. Sea waves
7. 15 Megabit model also available
8. Explorocean

f11 SUBER (FRANCE)

1. Significant wave computer for any analogue sensor.
2. Digital processor
3. Print-out
4. Storm waves and swell
7. Three models 1) Standard: H_{max}, H_s, T
   2) Print-out & crystal clock
   3) Print-out, crystal clock & data receiver.
8. O.E.S.

f12 SUMMIT (LAWSON & TRELOAR PTY. LTD.) (AUSTRALIA)

1. Processing receiver for Datawell Waverider Buoys.
2. Flexible multi-function receiver & data processor.
3. Chart, digital magnetic tape or on-line to computer.
4. Sea waves
5. Combined receiver and processor
6. 10-18 weeks depending on required specification.
7. The basic equipment employs 3 receivers plus a spare so that 3 waveriders can be monitored simultaneously.
8. European representative Technisch Bureau Meijwaard BV.

Addresses of Manufacturers

Louie C. Adamo Inc.,
Suite E26,
533 Stevens Ave.,
P.O. Box 2,
Solana Beach,
California 92075
Tel: (714) 755 9754
Twx: 9103221736
(Entry No. b1)

Applied Microsystems Ltd.,
769 Lily Avenue,
Victoria B.C., V8X 3R7
Canada.
Tel: (604) 479 8034
(Entry No. c1)

Churchill Controls Ltd.,
Headley Road East,
Woodley,
Reading,
Berks. RG5 4TR
Tel: Reading (0734) 692488
(Entry No. e1)

Datawell bv
Zomerluststraat 4,
2012 LM Haarlem,
Netherlands
Tel (023) 316053
Tx: 41415 DATEL NL
(Entry No. b2)

EMI Electronics Ltd.,
Albert Drive,
Sheerwater,
Woking, Surrey GU21 5RU
Tel: (04862) 76123
Tx. 859615
(Entry No. a1)

ENDECO,
Marion,
Massachusetts 02738
Tel: (617) 748 0366
Tx: 929451
(Entry No. d1)

ETROMETA BV,
P.O. Box 132,
8400 AC Gorredijk,
Netherlands.
(Entry No. b3)

Dr. Fahrentholz,
Grasweg 4-6,
2300 Kiel 1,
W. Germany
Tel: Kiel (0431) 54 20 49
Cables: ECHOSYSTEME KIEL
(Entry Nos. a2, b4, c2, c3, c4)

Hydrowerkstatten,
Uhlenkrog 38,
2300 Kiel - Hassee,
W. Germany
Tel: Kiel (0431) 68 25 11
(Entry No. b5)

Institute of Oceanographic Sciences,
Wormley,
Godalming,
Surrey GU8 5UB
Tel: (042879) 4141 Tx: 858833
(Entry No. b6, c5)

Interocean Systems Inc.,
3540 Aero Court,
San Diego,
California 92123
Tel: (714) 565 8400
Tx: 69-5082
(Entry No. c7)

Intersea Research Corporation,
11760 Sorrento Valley Road,
San Diego,
California 92121
Tel: (714) 453 5200
Tx: 69-7901
(Entry No. c6)

Kaijo Denki Co. Ltd.
19, 1-chome,
Kanda-Nishikicho,
Chiyoda Ku,
Tokyo
101 Japan
Tel: 03(294)7611/03(295)5609
Tx: J-28582 Kaijoden
Cables: KAIJO-SONIC TOKYO
(Entry No. c8, f3)

George Kelk Ltd.,
48 Lesmill Road,
Don Mills,
Ontario M3B 2T5
Canada
Tel: (416)445 5850
Tx: 06-966670
Cables: KELLEX TORONTO
(Entry No. b7)

Krupp Atlas-Elektronik,
Postfach 448545
2800 Bremen 44
West Germany
(See Krupp under UK Reps.)
Tel: 0421/457-0
(Entry No. a3, c9)

Kyowa Shoko KK,
24-1, 4 chome,
Mejiro,
Toshima-Ku,
Tokyo 171,
Japan
Tel: (03)952-1376
(Entry No. C10)

Marine Exploration Ltd.,
MAREX House,
High St.,
Cowes,
I.O.W., U.K.
Tel: Cowes (0983)296011
Tx: 86262
(Entry No. d2)

METRITAPE Inc.,
33 Bradford St.,
Concord,
Massachusetts 01742
USA
Tel: (617)369 7500
Tx: 923492
(Entry No. b8)

NBA (Controls) Ltd.,
Invincible Road,
Farnborough,
Hants. GU14 7QU
Tel: (0252) 514335
Tx: 858510
(Entry Nos. b9, c11, c12)

NEREIDES
66 Boulevard de Mondetour,
91400 Orsay,
France
Tel: (1) 907 2048
Tx: 691518 F NERED
(Entry Nos. c13, d3, f6, f7, f8)

Nova Scotia Research Foundation,
100 Fenwick Street,
Box 790,
Dartmouth,
Nova Scotia B2Y 3Z7
Canada
Tel: (902) 424 8670
Tx: 019 22719
(Entry No. b10)

SEA DATA,
153 California Street,
Newton,
Massachusetts 02158
USA
Tx: 951107 SEA DATA NEW
(Entry No. c14, c15, d4, d5, f10)

SIMRAD Seatronics Ltd.,
49 High Street,
Kingston-upon-Thames,
KT1 1LQ
Tel: (01) 549 9200
Tx: 8954665
(Entry No. c16)

SUBER
Sainte Anne du Portzie,
29200 Brest,
France
Tel (98) 80 18 45/80 12 43
Tx: 940675 (Public Brest)
(Entry No. f11)

SUMMIT,
Lawson & Trealoar Pty. Ltd.,
Suite 601 6th floor,
144 Pacific Highway,
P.O. Box 799,
North Sydney 2060 N.S.W.
Australia
Tel: (02) 92 1399
(02) 997 3647
Tx: AA 23976
(Prefix all telex messages "Lawson Treloar")
(Entry No. f12)

VAN ESSEN BV,
2624 AA Delft,
Westlandseweg 7,
Netherlands
Tel: (015) 120025
(Entry No. b11, C17)

VAN REIJSEN
Postbus 5005,
2600 GA Delft,
Netherlands
Tel: (015) 569216
Tx: 38126
(Entry No. c18, e2)

Addresses of UK Representatives:

Colnbrook Instrument Development Ltd.,
Poyle Road,
Colnbrook,
Buckinghamshire SL3 OAJ
Tel: Colnbrook (02812) 2371

Explorocean,
Charwell House,
Lincoln Way,
Windmill Road,
Sunbury-on-Thames,
Middx. TW16 7HN
Tel: Sunbury (09327) 87411
Tx: 261234 Telesystems

Krupp International UK,
Krupp Atlas-Elektronik Division,
Survey Section,
Unit 12 Kirkhill Place,
Kirkhill Industrial Estate,
Dyce, Aberdeen,
Scotland.

Marine Ventures,
8 Waterloo Place,
London SW1Y 4BE
Tel: 01 930 0515
Tx: 24760 Marven G

O.E.S.,
17 West Street,
Farnham,
Surrey GU9 7DB
Tel: Farnham (0252)714812
Tx: 858132

O.R.E. Ltd.
16 Bessemer Way,
Gt. Yarmouth, NR31 OLX
Tel: Gt. Yarmouth (0493) 58833 & 59050
Tx: 97208

~~Rees (Mechanical Equipment) Ltd~~.
~~6 Park Grove~~,
~~Cardiff~~,
~~Glamorgan CF1 3BN~~

Addresses of European Representatives (where none exists in the UK)

As. Tekno Team,
Box 313,
5051 Nesttun,
Bergen,
Norway
Tel: (05) 22 02 62

Technisch Bureau Meijwaard BV,
Leeghwaterstraat 13,
Sliedrecht,
Netherlands.
Tel: 01840 2155

Addresses of data logger manufacturers cited from the IOS list

Datel (UK) Ltd.
Stephenson Close,
Portway Industrial Estate,
Andover,
Hants.
Tel: (0264) 51055
(Entry No. f1)

Hurst Equipment Ltd.,
134 North Lane,
Aldershot,
Hants.
GU12 4QN
Tel: (0252) 311011
(Entry No. f2)

Memodyne Corporation,
385 Elliot St.,
Newton Upper Falls,
Massachusetts 02164,
USA
(Entry No. f4)

Microdata Ltd.,
Monitor House,
Station Rd.,
Radlett,
Herts.
WD7 8JX
Tel: (09276) 3141
(Entry No. f5)

Rapco Electronics Ltd.,
10 Joule Rd.,
Houndmills,
Basingstoke
Hants. RG21 2XF
Tel: (0256) 25454
(Entry No. f9)