Hydraulics Research
Wallingford

THE DEVELOPMENT OF A REPEATER BUOY FOR USE WITH WAVERIDER AND SIMILAR WAVE-MEASURING BUOYS

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ABSTRACT

This report describes the development of a radio repeater buoy for use with telemetering wave buoys such as Waverider and Wavecrest. The repeater buoy helps overcome some of the transmission problems associated with the radio telemetry link, particularly in areas where it is difficult to achieve a direct line-of-sight between the wave buoy and the radio receiver.

The preliminary evaluation of various operational methods, which led to our choice of a data logging repeater system is described.

The report includes a brief technical description of the repeater buoy together with the results of laboratory tests, modifications and field trials.

The project has led to the production of a proven system for overcoming some of the radio transmission problems associated with existing wave buoys.

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1. INTRODUCTION

The Waverider system of wave measurement is in common use by Hydraulics Research (HR) whenever wave data are required for coastal and offshore applications. The basic components of the Waverider system are shown in Fig.1. A Waverider buoy is tethered to an elastic mooring and an accelerometer measures the acceleration of the buoy as it follows the changes in surface water level. These accelerations are then integrated twice electronically and the resultant measure of the displacements in water surface elevation is used to modulate a radio transmitter. A shore-based radio receiver system demodulates the radio wave and records the vertical movement of the water surface on a calibrated chart recorder and/or on a purpose built magnetic tape recording system. Both wave-height and period may be read from the records. The buoy transmits continuously and the receiver is normally programmed to record for a pre-set time at selected intervals.

The telemetry link between buoy and receiver operates in the 27MHz band. At this frequency, reliable reception is only obtained when there is a direct line-of-sight between transmitter and receiver. Under ideal reception conditions the Waverider system is capable of operating over a range of 50 km. In practice, ideal reception conditons are rarely, if ever, met. The advent of CB radio in the UK, which operates in the same 27 MHz frequency band, has exacerbated the problems of radio interference. Reliable reception is now generally limited to less than 20 km and in many instances it is less than 10 km.

In many locations, and particularly in estuaries:

(a) the line-of-sight required for reliable reception is difficult to achieve. Intervening sand banks, islands, headlands etc can block or attenuate the radiated signal.

(b) the limited operational range, referred to above, imposes severe restrictions on the siting of both Waverider buoy and the receiver station. To help overcome these operational problems HR proposed the development of a repeater buoy. This buoy would receive the incoming signal from the Waverider buoy and re-transmit this signal to the shore-station. By strategically siting this repeater buoy (see Fig.2), the Waverider signal may be redirected to clear obstructions and by employing the "double hop" technique the effective operational range may be extended.

2. SPECIFICATION OF THE REPEATER BUOY

The allocation of radio frequencies in the UK is controlled by the Department of Trade and Industry. Six specific radio frequencies, in the 27 MHz band, are allocated for transmissions from Waverider or similar scientific data buoys. These frequencies, which are in adjacent channels, have an inter-channel frequency spacing of 25 kHz. The peak emitted power of the transmitter is restricted to 200mW. DTI has consistently refused application for frequency allocation outside this restricted frequency range. The repeater buoy had therefore to be designed to work within these constraints. Discussions were held with a number of commercial organisations, who had relevant experience, with a view to drawing up a specification for the Waverider repeater buoy.

The following three options were considered in some detail:-

2.1 Duplex radio link

The most straightforward concept for a repeater station involves the use of a "duplex" radio link, ie one which receives and transmits simultaneously but on two separate frequencies, one for transmitting and the other for receiving. Commercial VHF repeater stations, which employ this technique, use two separate aerials and to avoid mutual interference a receiver/transmitter frequency spacing of 4-5% of the nominal frequency is required.

In the case of the Waverider repeater, the maximum frequency spacing possible when restricted to the six allocated Waverider frequencies, is approximately 0.5% of the nominal frequency. In addition, it was thought impractical to utilise two aerials on the buoy. It was considered, therefore, that this "simple" approach to the problem was not technically feasible.

2.2 Time division multiplexing

The Waverider buoy transmits a signal in the 27 MHz frequency band. This signal is modulated by a sub-carrier whose frequency is determined by the wave height as measured by the accelerometer circuitry. The sub-carrier, which is a 270 to 300 Hz square wave, imparts 100% amplitude modulation (ie on-off keying at the tone frequency) to the transmitted RF signal. This RF signal is shown diagramatically in Figure 3(a).

It was suggested by one manufacturer that a repeater station could be designed using a technique of time division multiplexing, whereby the re-transmitted signals are fitted into the spaces between the received signal pulses. The timing of the re-transmitted signals is illustrated in Fig.3.

With the multiplexing synchronised to the received modulation frequency, the incoming Waverider signal is effectively re-transmitted in real-time. In addition to time division multiplexing it was proposed to employ frequency changing between incoming and outgoing signals so as to increase the isolation between the receiver and transmitter in the repeater and also to avoid multipath distortion which could occur if on occasion the base station simultaneously received direct signals from the Waverider as well as re-transmitted signals from the repeater on the same frequency. It was proposed that the repeater would receive signals from the Waverider on one of the allocated channels and re-transmit on one of the other allocated channels.

This particular approach to the problem was very attractive in that, if successful, it would provide a continuous, real-time duplicate of the Waverider signals.

2.3 A data logging repeater system

In this third option, the FM signals from the Waverider buoy are received at the repeater buoy. A radio receiver in the repeater buoy is switched on by a control unit for a pre-set period. The received signal is de-modulated, converted into a digital signal and logged into a solid state memory for temporary storage. At the end of a pre-set sampling period, the buoy receiver is switched off and a 27 MHz transmitter and modulator switched on. The wave data is then read from the memory, converted back into analogue form and used to modulate the transmitter. This cycle of operation is repeated at pre-set intervals; the solid state memory being erased after each cycle.

The recording periods at the shore-based receiver station would be synchronised to the repeater buoy transmissions.

The main attraction of the data logging repeater option was the fact that it involved no unknown technology; development would therefore be relatively straightforward and success more certain.

This type of repeater station is compatible with the usual recording scheme adopted by HR, whereby Waverider signals are recorded for about 20 minutes every 3 hours.

The main inconvenience of the system is the fact that the buoy signals are not continuously available for monitoring and test purposes.

2.4 Choice of system

Having identified the possible methods of operation of the repeater station, a number of commercial organisations were invited to tender for the design and manufacture of a repeater buoy based on options (b) or (c) outlined above.

Although option (b) offered the potential advantage of real-time continuous monitoring, the areas of uncertainty were such that no manufacturer was prepared to commit themselves to a fixed price offer for this type of system. The predicted minimum developments costs were considerably higher than those for a system based on option (c).

The only fixed price offer was submitted by NBA Controls Ltd for a data logging type of repeater buoy. Although, as previously stated, this method of operation did not offer continuous monitoring, it was considered that the near real-time relaying of wave information on the pre-set cycle was an acceptable method of operation. The contract for the manufacture of the repeater station was therefore placed with NBA Controls Ltd.

The final design of the NBA model RBU-1 repeater buoy comprised a low power 27 MHz radio receiver, an electronic package which included a Z80 microprocessor control unit, a solid state memory module, and a 27 MHz radio transmitter.

A full circuit description of the repeater buoy is contained in the NBA service manual (Ref.1). Briefly, the method of operation is as follows.

The demodulated output from the receiver is fed to a phase locked loop tracking filter. It is then used to gate a 4 MHz clock signal into a counter. The result is therefore a number proportional to the period of the demodulated signal. This number is read by the microprocessor and the difference between it and the previous sample is calculated. The difference is stored as an eight-bit number. To re-transmit the signal, the stored information is interrogated using the same frequency as was sampled. This reconstituted signal is used to modulate the radio transmitter. The incoming and outgoing signals are sampled at a rate of 8 times per second to enable the higher frequency sea waves to be reproduced accurately. At the sampling frequency of 8 Hz the on-buoy storage time is limited to 34 minutes which is user selectable in 1 minute increments. The cycle time is also user selectable in 1 minute increments up to a maximum of 255 minutes.

The input sensitivity of the radio receiver is similar to the standard Waverider receiver and the transmitter power is adjusted to 200mW.

The prototype unit was housed in a 1m diameter self-coloured polyethylene buoy shell (Plate 1) similar to that used by NBA for their "Wavecrest" wave measuring system. The buoy includes a quarter-wave whip aerial, a flashing navigation light and an external on-off switching device. The battery pack supplied with the buoy had a design life of approximately 4 months.

The standard Waverider receiver/recorder unit is programmed to switch on at intervals by an electrically wound clockwork time switch. The setting accuracy of this programmer is about ±15 minutes, which is adequate for normal direct recording from the Waverider buoy, but was not sufficiently accurate for synchronising the shore station recordings with the repeater buoy transmission. The standard programmer was therefore replaced by a commercially available microprocessor controlled precision timing unit and was programmed to suit this application.

3. PRELIMINARY FIELD TRIAL

The preliminary trials of the repeater buoy were carried out on the North Cornwall coast, utilising signals from an existing Waverider which HR has maintained in Perran Bay since 1975. A location plan indicating the relevant buoy and receiver sites etc is shown in Fig.4. The shore receiving station for the Waverider buoy is situated at Perranporth some 1½ km from and in direct line-of-sight of the buoy.

An initial series of reception and transmission tests were carried out in November 1982, with a view to determining the effective reception and transmission ranges of the repeater buoy. Two mobile stations were set up, the first onboard a hired fishing vessel working from Newquay and the second installed in a Landrover. The fishing vessel carried on its deck the repeater buoy complete with its quarter-wave whip aerial and also a standard Waverider receiver unit with a quarter-wave receiving aerial. The Landrover carried a Waverider receiver unit with a quarter-wave receiving aerial. Communication was maintained between the sea and land mobile station using VHF radios.

The initial intention was for the Landrover to be stationed close to the waters edge at Watergate Bay to the North of Newquay and the fishing vessel to occupy various positions offshore with line-of-sight of both repeater buoy and the Landrover receiving station. It was discovered however that transmissions from the repeater were not received at Watergate Bay. After a series of manoeuvres of both boat and Landrover it became clear that the repeater buoy transmitter was not functioning correctly, the maximum transmission range for reliable reception at the Landrover being only 4 to 5 kilometres.

Tests on the reception range of the repeater buoy were more successful. Good reception of the Waverider signal was confirmed to a distance of at least 10km offshore. At each measurement position the relayed signal from the repeater buoy was monitored by the on-board Waverider receiver. Because of worsening weather conditions the reception tests were curtailed and the maximum reception range was not determined.

On the following day a further test was carried out ashore to determine the quality of the reconstituted wave signal. The repeater buoy was positioned at St Agnes Head some 6km from and in line-of-sight of the Waverider buoy. Direct signals from the Waverider were recorded using the Landrover receiver unit and simultaneously recorded by the repeater buoy. The relayed signals from the repeater buoy were then received and recorded by the Landrover receiver. The relayed record was found to be a very good copy of the original Waverider record. The sea conditons at the time of this test were quite rough, with maximum wave heights of up to 4 metres.

Following this short initial trial the repeater buoy was returned to the manufacturer for rectification of the transmitter fault.

The next series of tests were designed to establish:

(a) the effectiveness of the repeater buoy in re-directing the Waverider signals to clear an intervening heandland, and

(b) the long-term reliability of the repeater buoy under normal operational conditions.

The second receiver station was installed at Atlantic Hotel, Towan Head, Newquay (see Fig.4). The direct line between the Waverider buoy and this new receiver site was overland with high cliffs effectively screening the transmission path.

The site for the repeater buoy was chosen to be about 2km off Kelsey Head, giving a direct line-of-sight distance to the Waverider buoy of 8km and 5½km to the Newquay receiver.

The repeater buoy was programmed to receive and re-transmit the Waverider signals for 34 minutes on a 3 hourly cycle; the cycle times coinciding with those at the Perranporth recording station.

A long period of bad weather prevented deployment of the repeater buoy until late December 1982. The buoy was laid using an all-rope mooring system of a type originally developed by HR for use in high flow conditions in the Severn Estuary (Ref.2). It was thought appropriate to use this type of mooring for the high buoyancy 1m diameter repeater buoy.

Recordings were started on 28 December. From the outset, very good reception from the repeater buoy was obtained at the Newquay receiver. Comparisons of the records with those obtained directly at Perranporth confirmed the high quality of the relayed signal. An example of this comparison is shown in Fig.5.

Recordings at Newquay came to an abrupt end on 3 January 1983 when radio reception from the repeater buoy was lost. Weather conditions at the time were poor with 5m maximum wave heights at the recording site. It was assumed, at the time of loss, that the buoy had broken free from its moorings although, because of the poor weather conditions, it was not possible to visit the buoy site and confirm this until 13 January. Coastguards and local police were alerted at the time of the loss in case the buoy should be washed ashore and discovered by members of the public. No sitings were reported until an exhaustive search of the local coastline was made by HR staff on 19 January. On that date a large number of identifiable fragments of the buoy shell were discovered at Porth Mear Cove (near Trevose Head) some 14km east of the repeater buoy site. Unfortunately, none of the recovered fragments (see Plate 2) gave a clue to the cause of the buoy breaking loose. None of the mooring components nor the mooring attachment to the buoy were found. It remains a matter of conjecture therefore whether the loss was due to mechanical failure of the buoy or of the moorings or to a collision by a vessel.

The preliminary evaluation of the data logging repeater buoy confirmed that most of the electronic design objectives had been met. Waverider signals were relayed around a blocking headland and high quality reproduction of the original wave parameters was obtained. The maximum operating range of the system was not determined although good reception at the repeater buoy was confirmed over a range of 10km and a strong signal was received from the buoy transmission at a distance of 5½km.

The extent of the mechanical damage to the polyethylene buoy shell gave cause for concern. Waverider buoys have a stainless steel shell and on a number of occasions these buoys have been washed ashore and in spite of severe mechanical abuse on rocks they have survived intact. Although it was not certain that a Waverider shell would have survived the conditions met by the repeater buoy it was decided that a MkII version of the repeater buoy be housed in a Waverider type stainless steel shell.

A second electronic unit was ordered from NBA and this was housed by HR in a Waverider shell. The only modification required to the standard shell was for the top flange and seal to be re-made to suit the NBA package.

4. SECOND FIELD TRIAL

The main objective of the second field trail was to demonstrate the long-term durability of the buoy and electronic unit. The trial was undertaken in Summer 1983 at the same Perranporth/Newquay site as used for the preliminary tests. The repeater buoy was moored using a standard HR Waverider mooring (Fig. 6). This mooring, described in detail in Ref.3, incorporates an elastic element which eliminates mooring snatch and allows the buoy to follow the water surface movements under high flow and wave conditions. Durability of this mooring system is well proven.

As in the preliminary trial, synchronised wave recordings were taken at 3 hourly intervals at both Perranporth and Newquay. The repeater was deployed on 26 July. Apart from some periods of radio interference (a common occurence at the 27 MHz frequency) the relay link operated well until 8th August when signal reception was lost at the Newquay receiver station. The repeater buoy was therefore recovered for examination. It was found that individual cells in the buoy battery pack had failed. The field trial was therefore curtailed in order to investigate in the laboratory the reason for the premature battery failure.

5. LABORATORY TESTS

The battery problem was discussed with NBA and with battery manufacturers. It transpired that the particular batteries used by NBA were prone to sudden and inexplicable failure. The variable discharge cycle to which the batteries are subjected in the repeater buoy may have been a contributing factor. The battery drain varies between a very low standby current to a fairly high current when the buoy is transmitting and even higher at night when the buoy flashlight is triggered.

It was decided to carry out tests ourselves on alternative batteries in order to find a more suitable type. It was found that a set of Leclanché cells, as used to power Waverider buoys, offered an immediate answer to the problem. At the time of reporting, the repeater buoy has been running in the laboratory continuously on a three-hourly receiver/transmit cycle for four months using a set of Waverider batteries. Indications are that the reserve power left in the battery pack should be sufficient to power the buoy for at least another two months, giving an anticipated operational duration of at least six months.

6. CONCLUSIONS

The development of a repeater buoy for use with telemetering wave buoys has been completed successfully.

A series of field trials and laboratory tests has demonstrated that the main design objectives have been met.

The repeater buoy has been used to relay Waverider signals around a blocking headland and high quality reproduction of the original wave record obtained.

The repeater electronics are housed within a stainless steel Waverider shell and the buoy is moored using a standard HR Waverider mooring.

The electronics unit is powered by a set of Waverider Leclanché cells giving an anticipated deployment duration of at least six months.

7. ACKNOWLEDGEMENTS

This report describes work carried out under Contract DGR/465/32, funded by the Department of Transport from April 1982 to March 1984 and thereafter by the Department of the Environment. The DOE nominated officer was Mr A J M Harrison

The development work was supervised by Mr C B Waters, Head of the Field Services Section of Hydraulics Research. The electronic design and construction of the repeater buoy was carried out by NBA (Controls) Ltd, Farnborough. Mr M J Crickmore was the Company's nominated project officer until August 1984. Dr A J Brewer is the present nominated officer.

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3. "Experiences in the mooring of Waverider buoys in coastal waters". WATERS C B. SUT - Technology of Buoy Mooring Systems. Proceedings of a meeting held at the Institute of Mechanical Engineers, October 1975.

Figures

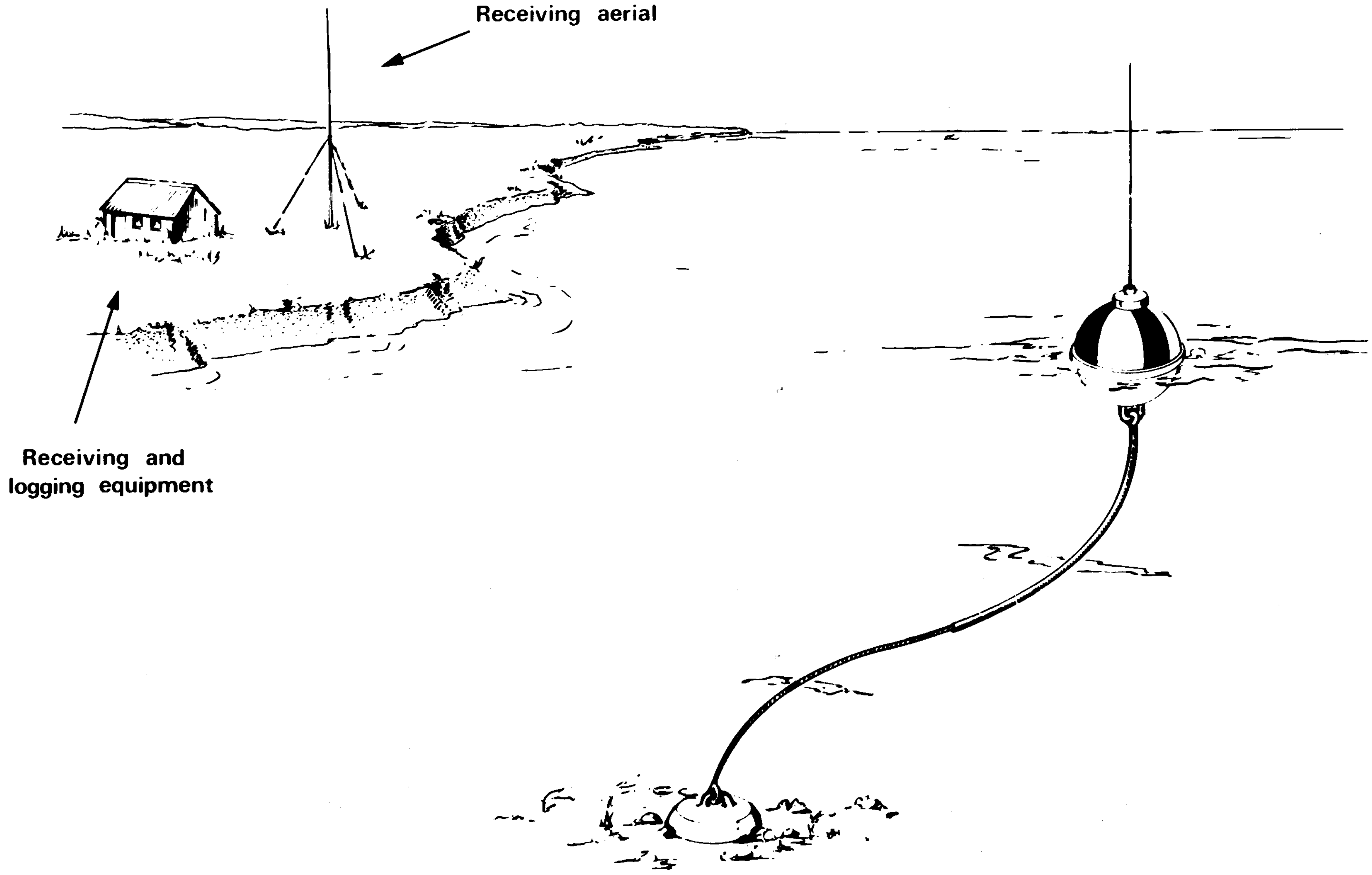
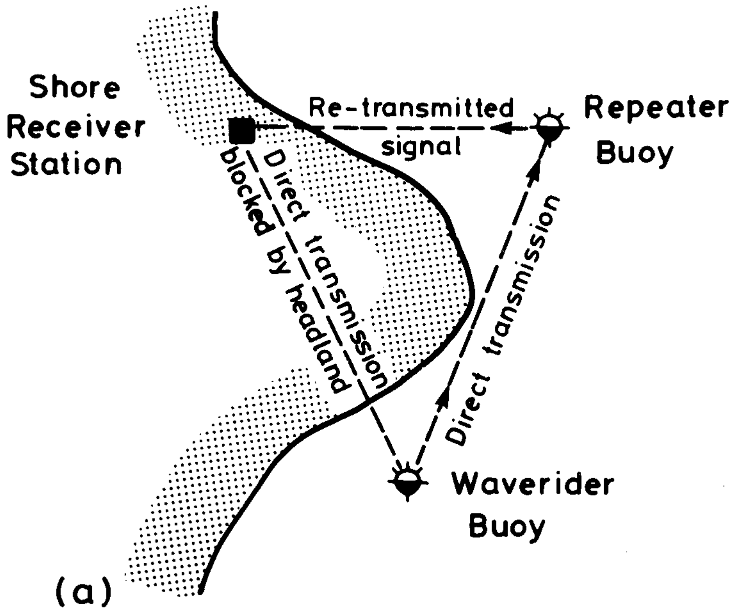


Fig. 1 Schematic diagram of the waverider system



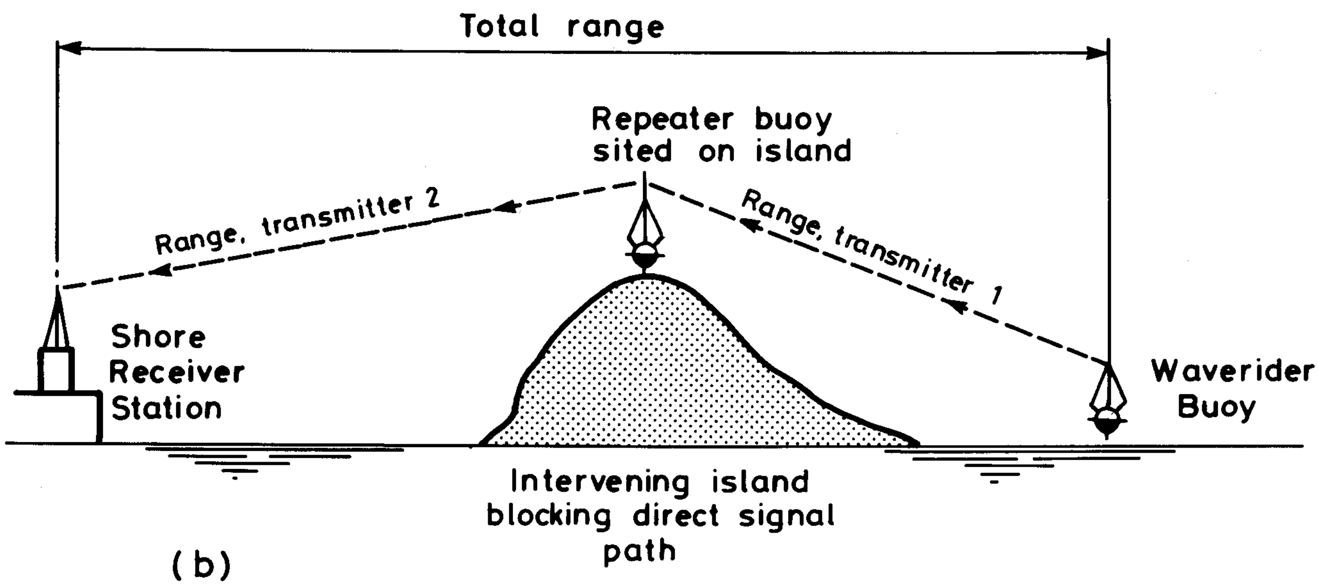


Fig 2 Typical applications of the repeater buoy

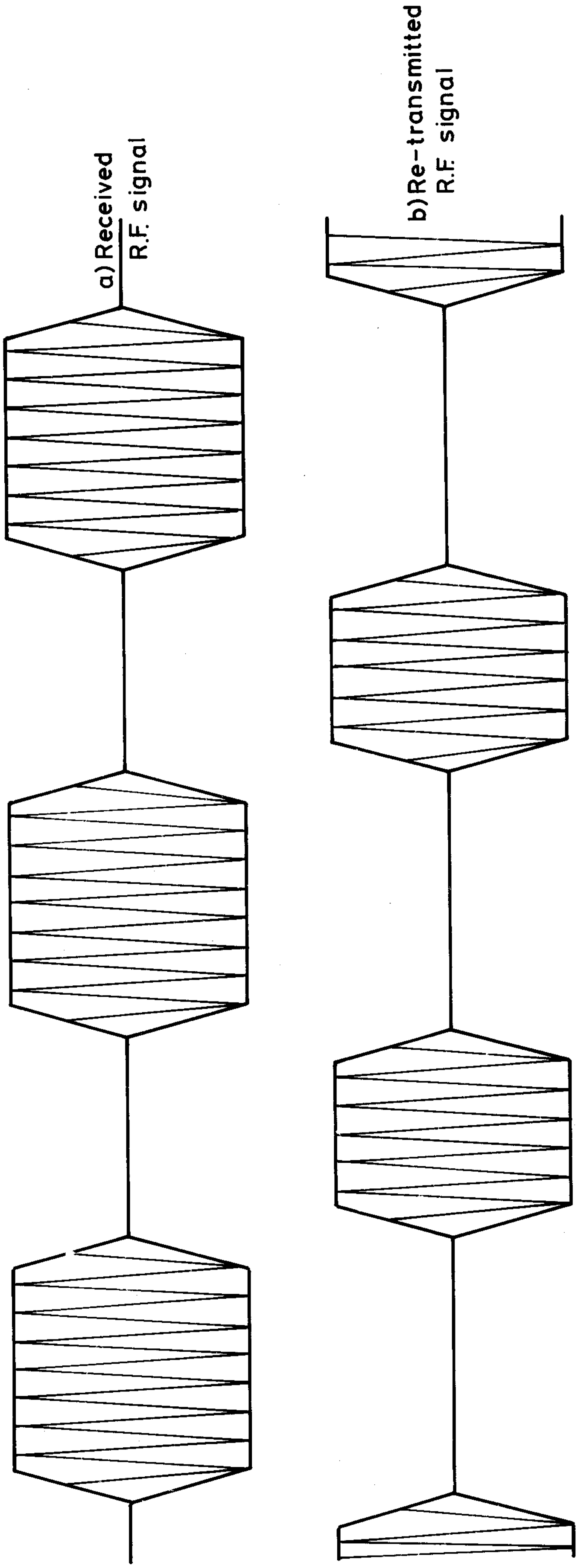


Fig 3 Receive/transmit signals multiplex timing

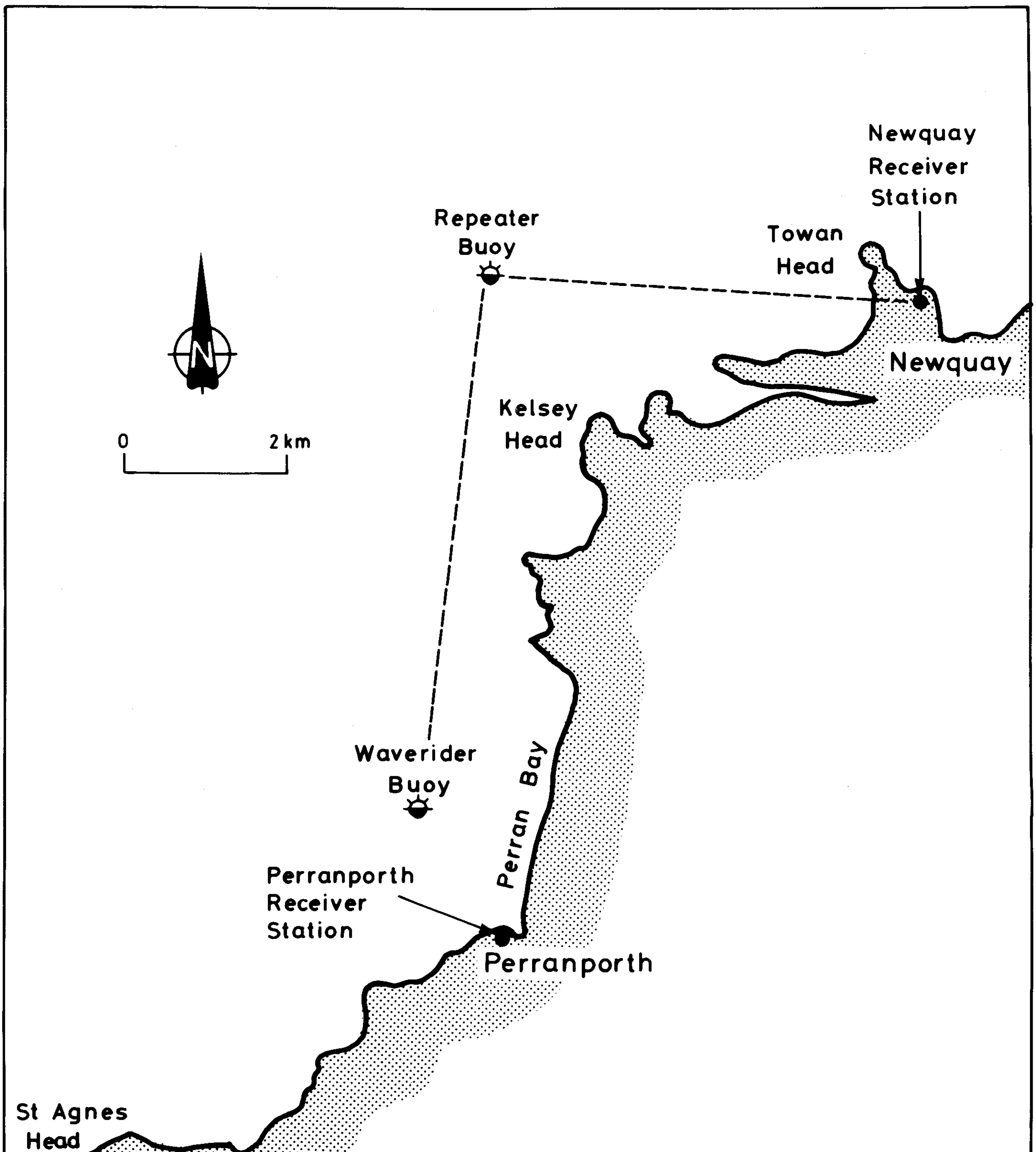


Fig 4 Location plan for the field trials

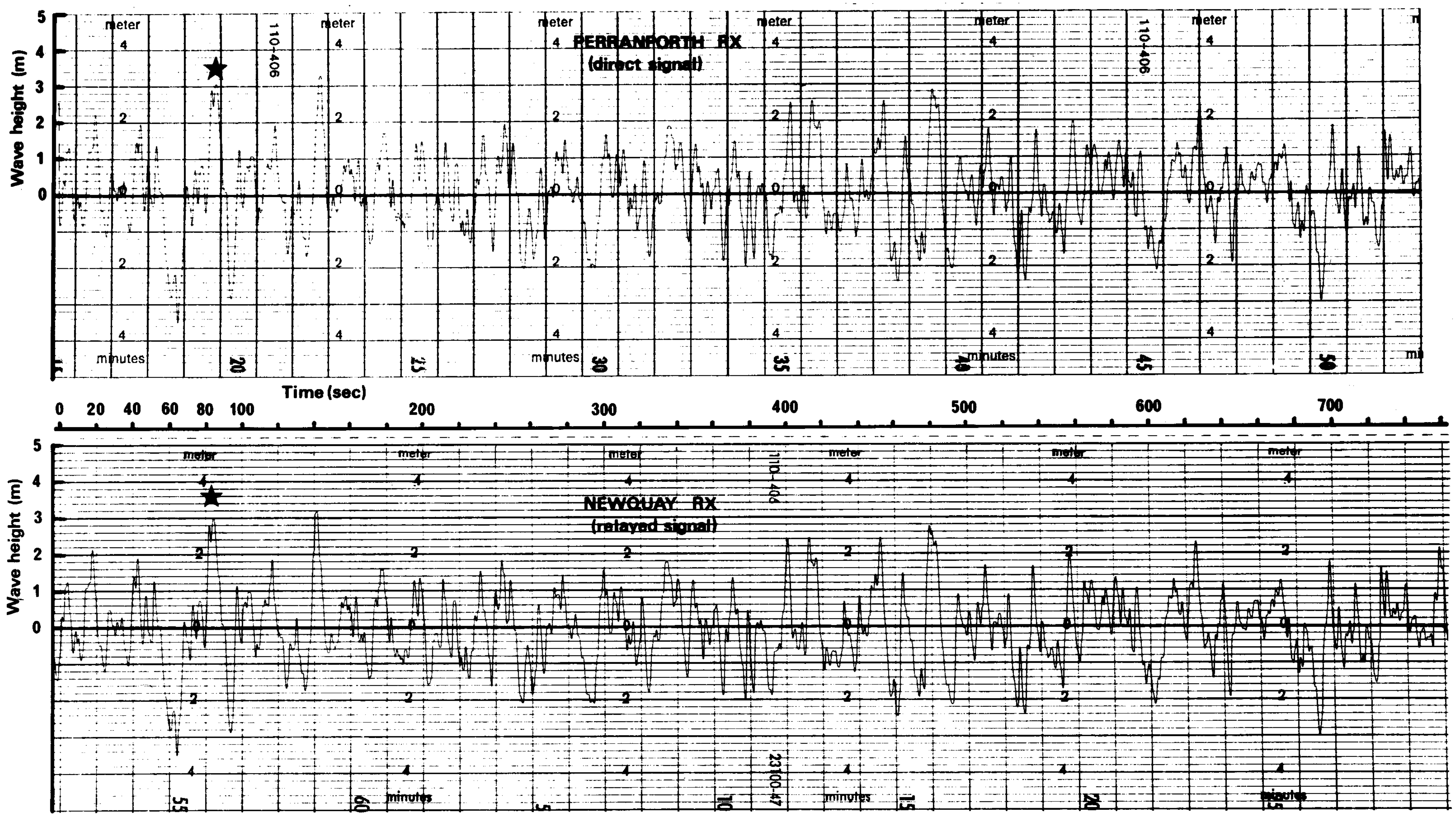


Fig.5 Comparison of direct and relayed wave records

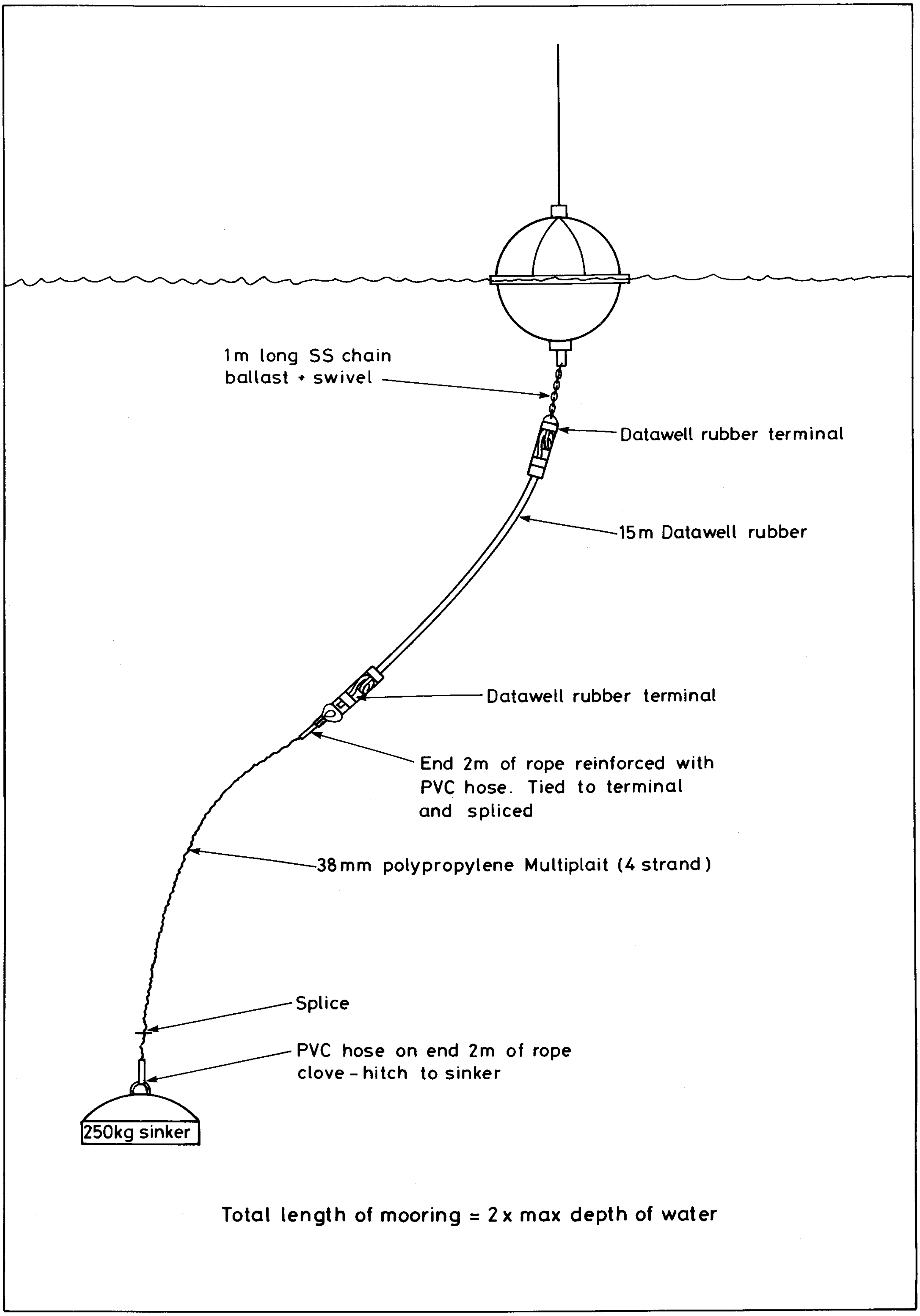


Fig 6 Standard HR waverider mooring

Plates

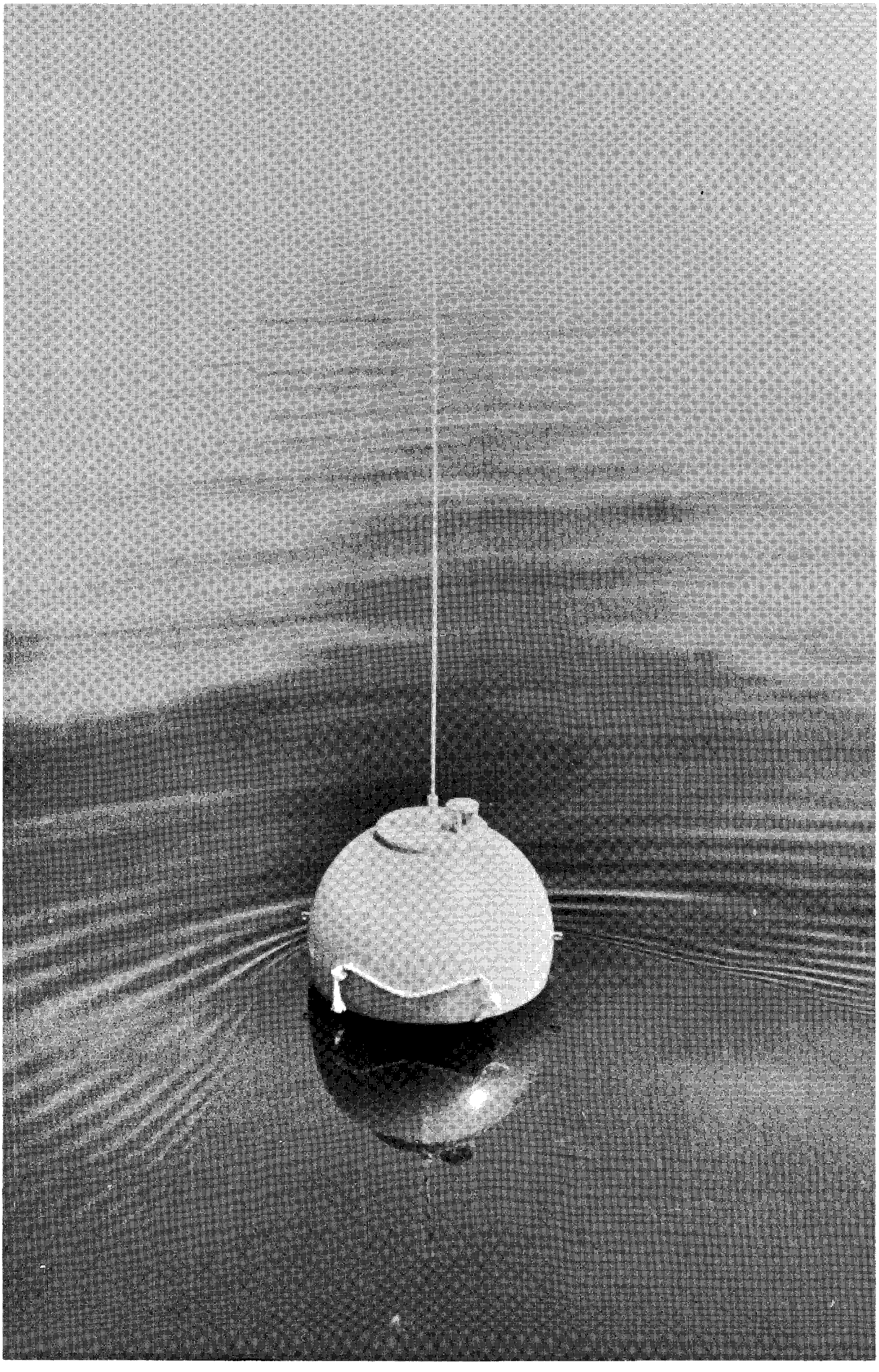


Plate 1 The repeater buoy

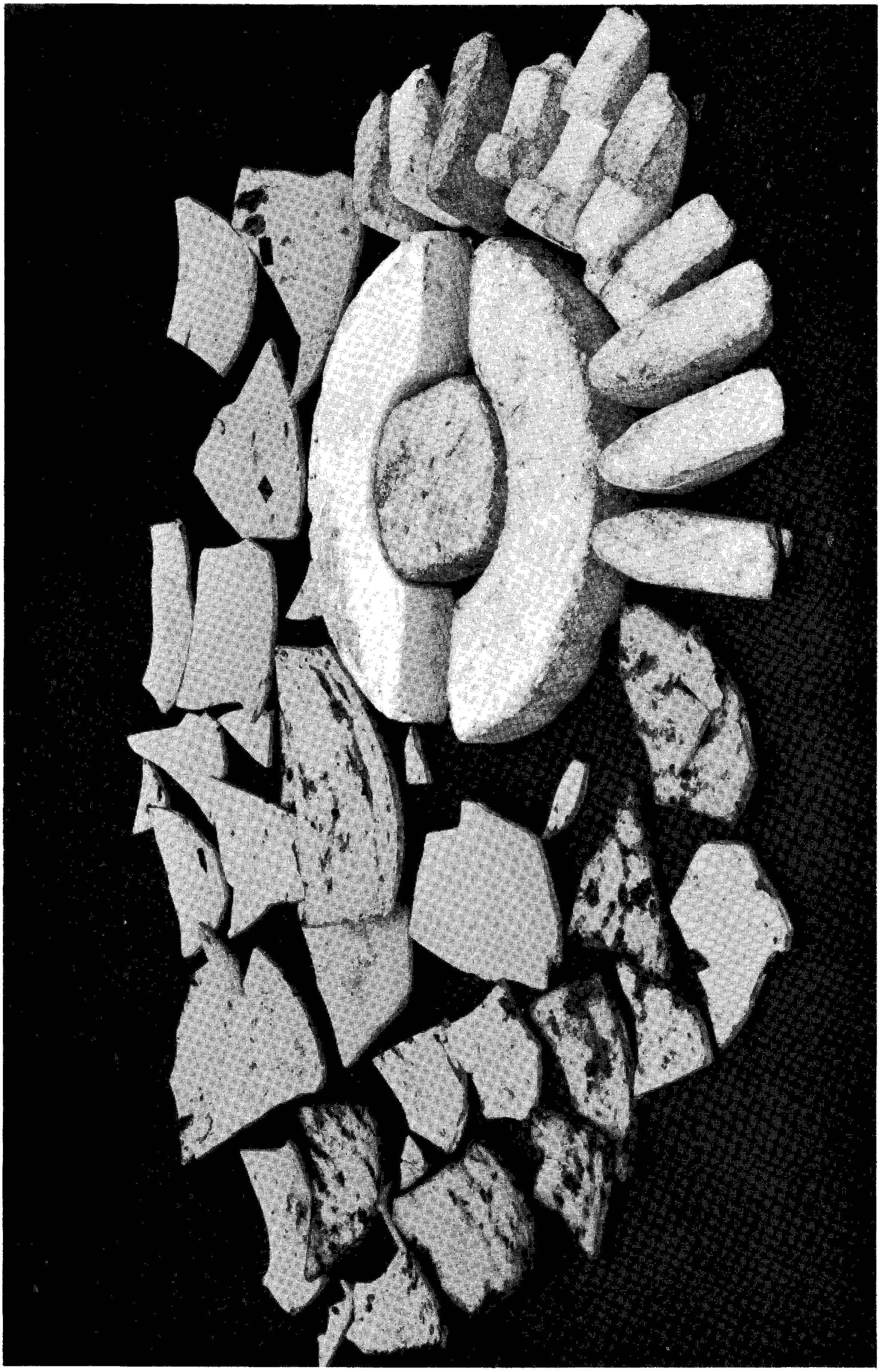


Plate 2 **The remnants of the repeater buoy**