A WAVE - RECORDER FOR USE IN SHIPS

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Although sea-waves have been recorded for a number of years using shore-connected pressure-measuring instruments or inverted echo-sounders laid on the sea-bed, collection of exact information about waves, studies of the growth of waves relative to the wind, and studies of ship motion and of coastal changes relative to the waves have always been retarded by the absence of a reliable method of continuously recording waves from a ship in deep water.

Some measurements have been made by a method in which an observer stations himself at such a height that the top of a wave comes just level with the horizon when the ship is on a fairly even keel in the trough. Much more accurate measurements have been made by stereo-photogrammetric methods using cameras with a long base length mounted high on the ship.

Neither of these methods is satisfactory for obtaining a continuous picture of changing wave-conditions, and for this purpose the best method until recently has been that employed before the Second World War by the Deutsche Versuchanstalt für Luftfahrt for the study of sea-plane landings in a variety of wave conditions. In this method a pressure recorder was suspended on a steel wire 100-200 ft. below a flat lens-shaped float : because of the rapid attenuation of wave-pressure with depth, the recorded pressure fluctuations were mainly due to the recorder following the vertical movements of the float on the surface. A correction could be made for the residual wave motion at the depth of the recorder when the presence of long waves made this necessary. The pressure fluctuations were recorded by a diaphragm connected to a diamond which scratched a spiral record on a polished steel cylinder rotated and moved along its axis by clockwork. The scratch recorder has been replaced in Great Britain by an electrical pressure recorder the output of which is transmitted to the attendant ship by wireless or by a buoyant cable, but the basic idea is the same. Measurements have also been made by an apparatus attributed to Froude and which consists of a buoyant graduated pole held vertical by a weight on its lower end and kept steady in the water by a drogue of relatively large area suspended on 200 ft. of wire from the bottom of the pole. The movements of the water up and down the pole are usually observed visually or photographed, but on a recent voyage of the R.R.S. *Discovery II* satisfactory measurements were obtained by attaching a limp air-filled rubber bag to a point below the mean water-level on the pole and communicating the changes in pressure to the ship through hose-pipe.

All these methods involve laying out apparatus and recovering it, and, if the apparatus is connected to the ship by a cable or hose-pipe, it is also necessary to hold the ship stationary to prevent the apparatus being towed through the water. These operations can be difficult, particularly in bad weather, when the results may be of greatest interest, and suitable stowage of the comparatively delicate and bulky equipment may not be easy. The advantages of a recorder contained entirely inboard are apparent.

The officers of the German research vessel *Gazelle* (1874-76) used a very sensitive aneroid barometer to measure the fluctuations in air pressure caused by the waves and the movement of the ship, but the uncertainties of this method are too great to enable it to be relied upon.

The new instrument developed by the National Institute of Oceanography is contained completely within the hull of the ship and is well suited for routine measurements. In principle it measures the height of the water surface above some point on the ships hull and the height of this point above an imaginary reference plane. The sum of the two measurements gives the height of the water surface above the reference plane, and hence is independent of the movement of the ship. The height of the water surface above the point on the ship's hull is measured by the pressure transmitted through a small hole in the ships side and the displacement of the point is measured by means of an accelerometer the output of which is integrated twice electronically with respect to time. To allow for the effects of reflexion of short waves from the sides of the ship, a pressure-recorder-accelerometer unit is fitted in each side of the ship and the mean of their outputs is taken. The response of this arrangement to waves which are only partially reflected has not been rigorously calculated; but it is apparent from physical reasoning that large errors will not be introduced.

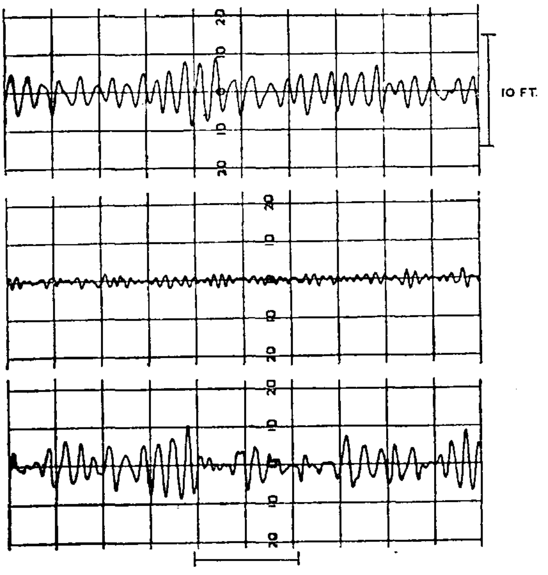

Fig. 1.

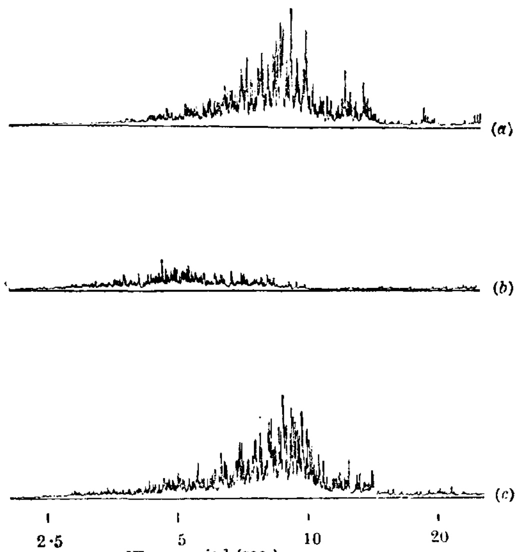

Fig. 2.

Portions of records taken with the wave-recorder (Fig. 1) and the corresponding frequency spectra (Fig. 2); (a) accelerometers only connected; (b) pressure measurements only; (c) combined output giving true wave-record. The records were taken in sequence so that the wave record is not the sum of the other two records in detail. It can be seen, however, that the spectrum of the wave record is the approximate sum of the other two.

The units have to be mounted some distance below the water-line because the point of pressure-measurement must always remain below the water surface, and they will therefore not measure very short waves. If the units are 10 ft. below the water-line, the response will drop to approximately half for waves of 4 seconds period.

To measure the true vertical accelerations the accelerometers should be mounted on gyroscopes or long-period compound pendulums ; but, to simplify design and to reduce both the space and maintenance required, they are in practice mounted on short-period pendulums which set themselves into the apparent vertical. This results in an apparent increase in gravity (that is, an increase in the mean output of the accelerometers) when the ship moves into a wave train, because the water particle motion, and hence the ship motion in the longer waves, is in circular orbits. If this increase were truly integrated the output would drift off scale ; but, by a correct choice of the time constants of the integrating circuits and by including a resistance-capacitance coupling in the circuit, the effect can be minimized and does not appear to be serious in the present instrument.

To avoid trouble from instrumental drift, the accelerometers must be very linear and give large voltage outputs. The accelerometers in this instrument have a sensitivity of approximately 30 volts/g and are linear within about 1 per cent over the range — 0.4 to +0.4 g.

The first of these wave-recorders, fitted in the R.R.S. *Discovery II*, the research ship of the National Institute of Oceanography, has been tested during a recent cruise in the North Atlantic Ocean. During this cruise, which lasted 2 1/2 weeks, a gale of force 9 was encountered and waves with a maximum height of approximately 30 ft. were measured. The instrument behaved satisfactorily during this period and developed no faults. Records from the instrument were compared with those obtained from pressure and echo-sounding wave-recorders in shallow water and with records from the electric and pole and drogue recorders as already outlined. Preliminary analyses of these results show satisfactory agreement. The overall accuracy of the instrument in itsc present form is estimated at ± 10 per cent.

Portions of three records are shown in Fig. 1 with the corresponding analyses in Fig. 2. (a) is the output of the instrument with only the accelerometers connected, (b) the output with only the pressure units connected, and (c) the combined output. The records are not simultaneous, but were taken in sequence. They demonstrate that the pressure units measure the short waves to which the ship does not respond, whereas the accelerometers measure the waves which are long enough to cause the ship to heave.

In conclusion I would like to acknowledge the help of Mr. F.E. Pierce, who was mainly responsible for the mechanical design of the instrument.