CHAPTER 8

THE LARGE-HEIGHT RESPONSE OF TWO WAVE RECORDERS

by

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ABSTRACT

Two commonly used deep-water wave recorders which depend on acceleration measurement were calibrated on a 14 metre diameter vertical wheel, and also on much smaller laboratory test rigs, over a range of wave periods likely to be encountered at sea. The results showed that the instruments behaved according to expectations. In addition, spectra from two instruments of the same types which were deployed within one mile of each other were compared and shown to be similar.

INTRODUCTION

Instrumental wave recordings have been made all over the world for many years, and these recordings have been used to produce design criteria for coastal and offshore structures and for many other purposes. An accuracy of +10% has usually been sufficient for these purposes. However, with the advent of the North Sea oil industry, it has become necessary to reduce the errors, since overbuilding is prohibitively expensive, and underbuilding potentially dangerous. Wave heights to an accuracy of $\pm 2\%$ are often specified in the formulation of oil-rig design criteria, even though the sea's surface may be difficult to define in severe conditions.

It appeared that no accelerometer wave recorder had been calibrated over a simulated wave height of greater than 3 metres, even though waves of seven times this height are sometimes recorded, and these recordings are used to predict waves of 10 times this height and more.

It was felt that this discrepancy between calibration conditions and wave heights experienced in real life was unacceptable, and so two representative accelerometer wave recorders were tested on the Big Wheel (Ferris Wheel) at Southsea Fun-Fair. To check the instrument responses over a range of periods down to about 5 seconds, low-amplitude laboratory tests were also made. This was because the maximum speed of the big wheel gave a rotational period of 13.6 seconds. The laboratory tests also enabled a check to be made on the linearity of the recording systems.

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It appears that little work has been done to compare the spectral responses of wave recorders working under similar conditions. A comparison of the responses of the same two types of recorder has also been made.

Scope of the Experiment

Instruments used

1. I.O.S. Shipborne Wave Recorder (S.B.W.R.) (see Tucker, M.J., "A Shipborne Wave Recorder", Transactions of the Institution of Naval Architects, Vol. 98, 1956). This type of recorder has been used to obtain virtually all the I.O.S. deep-water wave records. It is one of the recorders being used by the North Sea Oceanographic Study Group, and Governmental design criteria for offshore structures are based partly on its records. The recorder consists of two sensor units (one on each side of the ship) and electronic processing circuitry. Each sensor unit consists of a pressure sensor and an accelerometer.

The position of the sea surface with respect to each unit is detected by its pressure sensor, and the position of each unit with respect to an arbitrary reference level is determined from a double integration of the accelerometer signal. A simple addition of these two outputs from each pair of sensors gives a signal proportional to wave height, from which ship motion has automatically been eliminated. The placing of identical units on each side of the vessel doubles the sensitivity and has other advantages.

A minute or so after switching on, the instrument settles down, and the output consists of fluctuations, due to the sea waves, about a mean line on the recorder. Because the pressure sensors were not subject to any hydrostatic pressure during this experiment, the chart deflexions produced were caused only by the changes in acceleration experienced by the accelerometers.

Two S.B.W.R.s were tested. Both had been used at sea, but they were completely refurbished before the experiment.

2. Waverider. The Waverider wave measurement system is also in use by the North Sea Oceanographic Study Group and is manufactured by Datawell of Haarlem, Netherlands. An accelerometer is enclosed within a surface-following, moored buoy. The accelerometer signal is integrated twice, and the resultant signal modulates a radio transmitter. Batteries, giving a working life of approximately ten months, and a voltage stabiliser, are also enclosed within the buoy shell.

The wave-modulated radio signals are received at a shore station which may be up to 50 kilometres from the buoy. The receiver demodulates the signals with a phase-locked loop circuit, and the analogue output is presented on a strip-chart.

To ensure that the experiment was carried out to the satisfaction of the manufacturers, Mr P.L. Gerritzen of Datawell attended as an observer. The instrument used was new when tested, it had not been put into the sea.

The Big Wheel and laboratory experiments gave no indication of how the two types of recorder would respond to real sea conditions; they merely measured the instrument's abilities to record their own vertical movement. An attempt has now been made to compare the performance of the two types of instrument working under similar conditions at sea.

A Waverider and a S.B.W.R. have been operated simultaneously in at least two positions: (1) at the Sevenstones Light Vessel off Land's End, and (2) the M.V. 'Edelstein', operating at 61°20'N on the Greenwich meridian. The Waverider was usually operated within a kilometre of the ship in each case. Although each pair of recorders obviously does not measure exactly the same waves, spectra can be computed from records taken at the same time.

Details of the Big Wheel (Ferris Wheel) Experiment

The wheel was made in Italy; its diameter was measured carefully and was found to be 14.0 metres. The Waverider and two S B.W.R.s were placed approximately at the apices of an equilateral triangle on the wheel. Each instrument was carefully lashed down so that it did not experience any spurious vibration which could have interfered with correct operation. When all the instruments and necessary power supplies had been fitted into the cars, the wheel was carefully balanced so that its rotational speed was constant throughout a revolution.

It was necessary to provide a 240 volts 50 Hz supply for each S.B.W.R. Although each car carried a mains supply derived from a fairground generator, it was felt that it would be unwise to use this to energise the recorders. The required supply was therefore derived from a 12 volt accumulator and an inverter.

The response of the S.B.W R. is closely linked to the stability of the 80 volt, 1000 Hz oscillator. Thus if the oscillator voltage falls by 1%, then the recorder response is reduced by 1%. To allow for voltage variations, the oscillator voltage was measured after each run. Corresponding corrections would then be made to the responses where necessary. Each S.B.W.R.'s performance was recorded in situ by its own chart recorder.

The transmitter aerial provided by Datawell for the Waverider buoy was too long for the experiment, it caught in the bracing as the wheel turned. A stub-aerial with a loading-coil was therefore used

The Waverider receiver was set up in a vehicle close to the base of the wheel. It was run from a portable generator providing 240 volts, 50 Hz. A reserve receiver was provided by the Interservice Hovercraft Unit, and was set up at I.H.U. some thirteen kilometres from the test site. Although this system worked satisfactorily, the record showed some evidence of unlocking; this was probably due to the use of a temporary aerial and the presence of interference-sources in the area.

The wheel could be rotated at constant speeds giving rotational periods between 13.6 to 30 seconds. Each experimental run was for 10 revolutions after the wheel had attained a steady speed. The period was determined as the average period for the 10 revolutions. Individual revolutions were also timed; these showed some variation, but resultant errors were insignificant

RESULTS OF THE EXPERIMENTS

Big Wheel

The results of the 14-metre height experiments are shown graphically in figure 1. The reason why part of the Shipborne Wave Recorder response is greater than unity is that, when the pressure units are in circuit, attenuation of wave motion with depth reduces the combined response of the units and a nominal sensitivity of 0.835 times the maximum is used. A full description of the rotational experiments can be found in NIO Internal Report A 63.

Shipborne Wave Recorder - Big Wheel

It can be seen that, relative to the theoretical response, the instrumental sensitivity increases slightly with increasing period. This is a phenomenon which has been known for a long time but which is not understood. Departures from the theoretical values are

Recorder No. 1	0% at 14 seconds 4% high at 25 seconds
Recorder No. 2	2% low at 17 seconds 0% at 24.5 seconds

Chart reading errors are of the order of $\pm$0.5%.

Waverider - Big Wheel

The response of the instrument was very close to the theoretical values. This instrument gave only slightly less response than was expected; at 13.5 seconds it was 0.8% low and at 30 seconds 2.4% low.

Laboratory

The Shipborne wave recorder was tested on a 1 metre diameter arm in the Institute's laboratory at Wormley and the Waverider on the 3 metre diameter calibration rig at NPL Hythe. The Shipborne recorder was tested at periods from 6 to 36 seconds and the

Waverider from 2 to 10.8 seconds. The results are shown in figure 2.

S.B.W.R. - laboratory

The agreement here between theoretical and experimental curves is similar to that in the Big Wheel experiment. The discrepancies between experimental and theoretical curves are:

At 6 seconds	0.2% high
at 15 seconds	1% low
at 25 seconds	3.3% high

Chart reading errors are of the order of $\pm$0.5%.

Waverider - laboratory

The instrument did not appear to change sensitivity over the period range of from 2 to 10.8 seconds, and the absolute response was correct to within chart reading errors.

Spectral Comparisons between a Waverider and the S.B.W.R. at the Sevenstones Light Vessel

A Waverider buoy was deployed near the Sevenstones Light Vessel for several periods between 1971 and 1972 in connection with trials being carried out in the area. The Waverider chart records were subsequently made available to us.

A total of twelve pairs of simultaneous S.B.W.R. and Waverider records were digitized and the spectra computed. An example of these spectral comparisons are shown in figure 3, as well as the equilibrium spectra proposed by Phillips.

It will be seen that at longer periods the spectra from the two instruments agree well, and lie within the 95% confidence limits for the calculation.

However, on several of the spectra the S.B.W R. gives more energy than does the Waverider at periods of around 10 seconds. Also, at short periods, the S.B.W.R spectra contain more energy than do the Waverider spectra. This is due to errors in the S.B.W.R. response correction at higher frequencies and can be overcome for many purposes by substituting a theoretical spectrum at periods of less than about 5 seconds.

CONCLUSIONS

The outcome of the project is a highly satisfactory one in that the instruments perform well within the limits of error normally ascribed to wave recording in general. As the bulk of wave information from British and adjacent waters has come from these two types of instrument it is encouraging that their responses differ so little from the theoretical values. The major questions still remaining to be resolved are how well the devices

sense the true position of the sea surface, and also the unresolvable problem of what is meant by the position of the sea surface when, in a storm, the vertical distance between 100% water and 99% air could be of the order of 1 metre.

ACKNOWLEDGEMENTS

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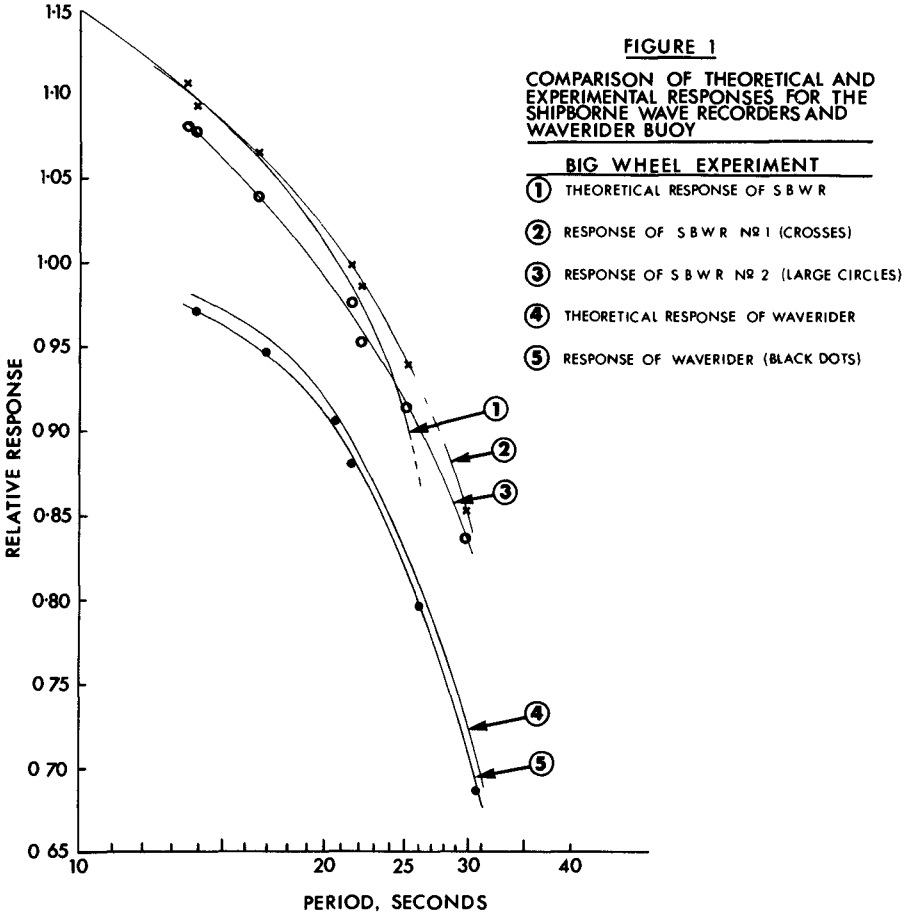

1·15
1·10
1·05
1·00
0·95
0·90
0·85
0·80
0·75
0·70
0·65
RELATIVE RESPONSE
10
20
25
30
40
PERIOD, SECONDS
FIGURE 1
COMPARISON OF THEORETICAL AND EXPERIMENTAL RESPONSES FOR THE SHIPBORNE WAVE RECORDERS AND WAVERIDER BUOY
BIG WHEEL EXPERIMENT
① THEORETICAL RESPONSE OF S B W R
② RESPONSE OF S B W R Nº 1 (CROSSES)
③ RESPONSE OF S B W R Nº 2 (LARGE CIRCLES)
④ THEORETICAL RESPONSE OF WAVERIDER
⑤ RESPONSE OF WAVERIDER (BLACK DOTS)

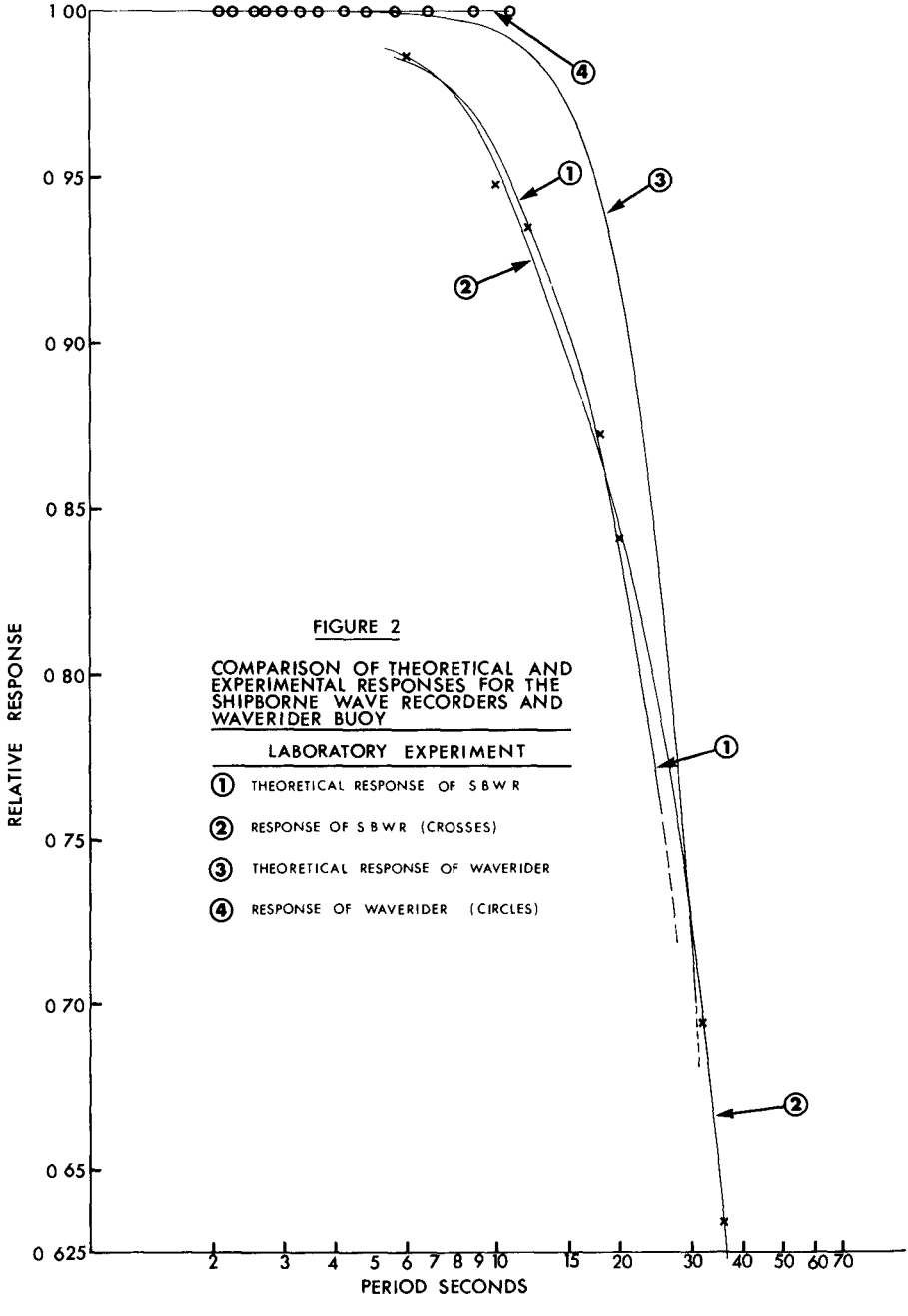
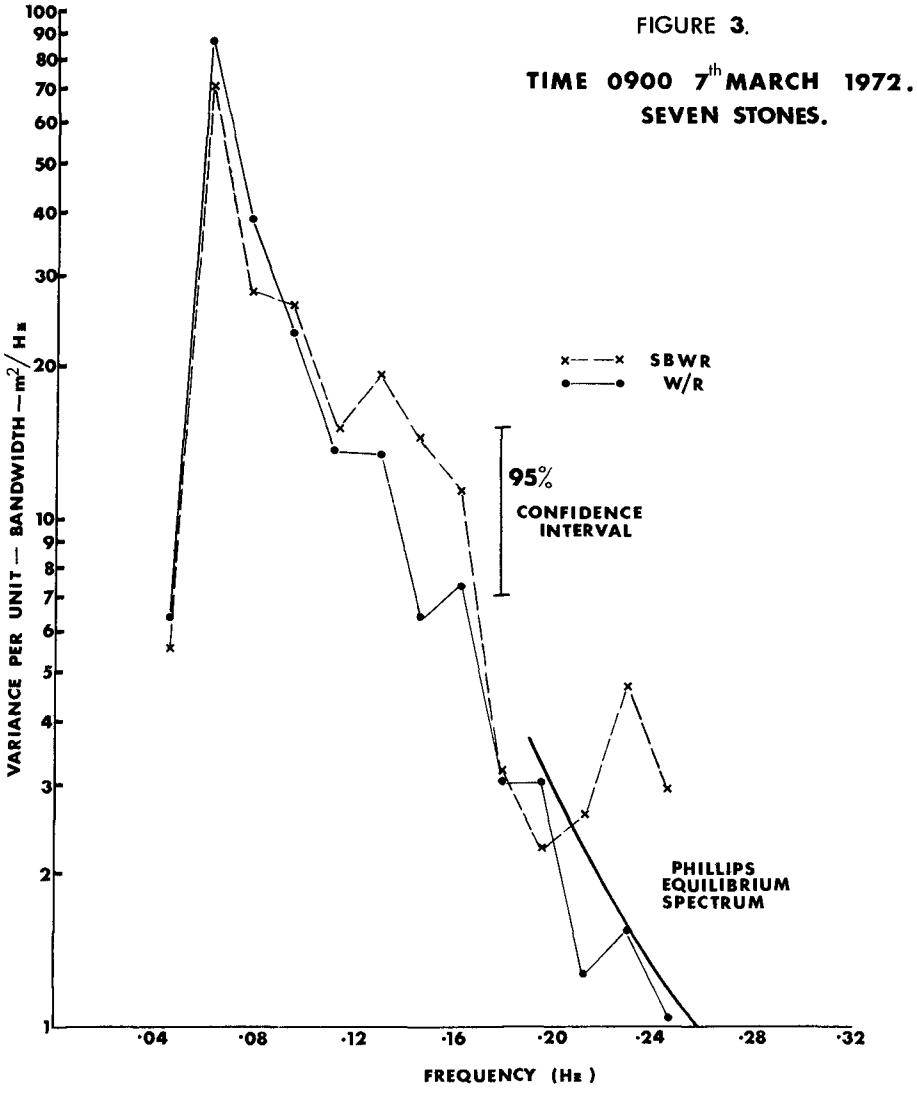

1 00
0 95
0 90
0 85
0 80
0 75
0 70
0 65
0 625
RELATIVE RESPONSE
2 3 4 5 6 7 8 9 10 15 20 30 40 50 60 70
PERIOD SECONDS
FIGURE 2
COMPARISON OF THEORETICAL AND EXPERIMENTAL RESPONSES FOR THE SHIPBORNE WAVE RECORDERS AND WAVERIDER BUOY
LABORATORY EXPERIMENT
① THEORETICAL RESPONSE OF S B W R
② RESPONSE OF S B W R (CROSSES)
③ THEORETICAL RESPONSE OF WAVERIDER
④ RESPONSE OF WAVERIDER (CIRCLES)

FIGURE 3.


TIME 0900 7th MARCH 1972.
SEVEN STONES.
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W/R
95%
CONFIDENCE
INTERVAL
PHILLIPS
EQUILIBRIUM
SPECTRUM
VARIANCE PER UNIT — BANDWIDTH — m²/Hz
FREQUENCY (Hz)
100
90
80
70
60
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