CHAPTER 4

SOME RESULTS OF A DIRECTIONAL WAVE RECORDING STATION

by

J. Ploeg*

ABSTRACT

An experimental deep water wave recording station has been operated in Lake Ontario, Canada, from 1969 to 1971. The station included a triangular array with four wave sensors and a stable platform. The aim of the study was to obtain a better understanding of the usually rather vaguely defined wavelength parameter of a wind-generated sea and to record the direction of wave propagation directly in the wave generation field.

The station has also been used to test newly developed wave sensors, or to check and calibrate some of the existing wave recording systems, including staff gauges, pressure cells and accelerometers.

The paper describes briefly the mooring system of the floating stable platform and the triangular array. A comparison is made between various wave recorders, mainly by using spectral analysis, and some results of the wavelength and wave direction study are discussed.

INTRODUCTION

A general wave climate study of the Great Lakes and the Gulf of St. Lawrence for the Canadian Ministry of Transport in the late sixties resulted in some 20,000 wave frequency spectra. These wave data were presented in a report, which listed the significant wave heights and frequencies of the peak of the spectra as the two basic parameters defining the recorded sea state. ("Wave Climate Study - Great Lakes and Gulf of St. Lawrence", J. Ploeg, May 1971, NRC Report MH-107A or T- and R-Bulletin 2-17, Society of Naval Architects and Marine Engineers.) A number of other parameters was derived from the two basic parameters, such as the wavelength, which was calculated from the frequency of the peak of the spectrum, using the first order, small amplitude wave theory, \[ L = \frac{g^2 \pi}{w^2}. \]

However, it was felt that no information was available on the physical meaning of this computed wavelength parameter. In the past, the mean wave period has often been used to calculate the wavelength, mainly because spectral *Head, Hydraulics Laboratory, National Research Council, Ottawa, Canada, K1A 0R6.

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analysis was not readily available.

Just as the original significant wave height definition was chosen to correspond to the wave height estimated visually by an experienced observer, the wavelength should perhaps also be defined as a physically more meaningful parameter, possibly corresponding to the obvious periodicity of the sea, which can be observed on so many aerial photographs.

More directional information of wind generated seas in areas of limited fetch lengths, such as the Great Lakes, was also desirable.

Lake Ontario was chosen to install an experimental wave recording station, from which the above mentioned studies could be conducted. The development of new wave recorders and the calibration of some of the existing instruments was a natural extension of the main study.

Fig. 1. Location of Wave Direction Study Station
MOORING SYSTEM OF THE STATION

The station was installed near Presqu'ile Point, Ont., about 7 miles offshore in 155 ft of water, guaranteeing the recording of true deep water wave conditions. The maximum fetch was approximately 110 miles from the S.W. (Fig. 1). The station consisted of a stable floating platform, built up from 8 inch diameter tubular steel, with an 8 ft triangular cross-section and an overall length of 100 ft. The 10,000 lbs positive buoyancy was supplied by two steel tanks, housed within the triangular framework; the vertical stability of the platform was excellent. Two buffered guy wires prevented rotational movements of the platform. On top of the platform, which protruded 12 ft above the mean water level, a 60 ft high fibreglass mast was mounted to install the meteorological sensors (Fig. 2). All power supply and recording equipment was mounted in waterproof cabinets on top of the platform.

The array of wave sensors was moored to a 60 ft triangular anchor, built up from tubular steel and guy wires. It was placed about 100 ft away from the platform. Four, 60 ft long slender spar buoys, made up of steel and plastic pipes, with 600 lbs buoyancy each, were suspended from the three apexes of the triangle and from the centroid. Pressure type wave sensors were installed on top of the buoys, 15 ft below the mean water level. A small triangular framework was attached to the buoys just below the pressure cells, to guarantee the exact geometry of the array. The 60 ft dimension of the array was chosen as half the most frequently occurring wavelength on Lake Ontario.

INSTRUMENTATION AND ANALYSIS

The platform was instrumented with a step resistance type wave staff gauge, a transmission line type wave staff gauge and an absolute and differential pressure cell type wave sensor. The array was equipped with four absolute pressure cells. All these instruments were developed and built at the National Research Council. Two commercial accelerometer type wave recorders were moored a short distance away from the platform, namely a B.I. wave recorder made in Canada and a Waverider, made in the Netherlands.

The step resistance type staff gauge and the pressure cells were of fairly standard design and no details are given here. The transmission line gauge used a relatively new approach and is briefly described next.

The gauge consisted of two concentric metal tubes, the outside one 2 inches in diameter, the inside one 1 inch in diameter. The outside tube was perforated to allow the
Fig. 2. Mooring Diagram of Offshore Wave Recording Station
water level inside the tube to follow the wave profile. The two tubes formed a coaxial transmission line. An electromagnetic wave generated at the top of the gauge and guided by this transmission line, reflected upon the water surface, where the permittivity changed by a ratio of 1:81 (air/water). The reflected wave travelled back to the top of the gauge, where it was used to generate a new wave, but of opposite polarity. The result, of course, was a square wave oscillation with the period linearly proportional to the wave height. The frequency of the oscillation was typically several megahertz and had to be scaled down to be recorded on tape.

Output signals of all wave recording instruments were transmitted by cables to the recorders on the platform to eliminate noise problems. The pulse frequency or period modulated signals were simultaneously recorded on a multi-channel tape recorder. Only the Waverider system was transmitted to a shore station and recorded separately as an analog signal on an F.M. tape recorder.

The analysis of the recorded data was done on a small digital computer, which had an extensive analog to digital interface. A special programme was written, which allowed the analysis to be carried out as a one-pass computation, with a minimum of manual intervention from the operator. The programme allowed a simultaneous input of up to four channels. Demodulation of the signal into an analog voltage preceded the power spectral density analysis, which used the Fast Fourier Transform technique. The spectra were displayed to enable the operator to select frequency limits, if so desired, to compensate the 'pressure spectra' using the Airy theory to obtain wave height spectra. Filtering of the data to specific bands of frequency could be done next. The computation of the RMS values of the four records was used to normalize the data, before the cross-correlation functions were computed.

The various calculations were done for the spectra as a whole as well as for different filtered portions of the spectra, with the filter limits selecting the frequency bandwidth defined by the location of peaks in the spectra. The bandwidths of the filtered spectra were typically 0.1 to 0.2 rad/sec. The time delays, resulting from the 6 cross-correlation functions were then used to compute the direction of wave propagation and the wave celerity. The wavelength was obtained by multiplying this wave celerity with the period corresponding to the frequency of the peak of the unfiltered or filtered spectrum. A flow chart of the programme is shown in Fig. 3.

COMPARISON OF WAVE RECORDERS

Although a comparison of wave recorders was originally not the reason for this study, it certainly turned out to be
Fig. 3. Flow Chart of Directional Wave Analysis
an integral part of the programme. The entire facility lent itself pre-eminently for this purpose and the results were rather interesting.

The two different types of staff gauges yielded nearly always identical results in the power spectral densities, as well as the demodulated analog signal of the wave heights. Figure 4 is a typical example of the excellent comparisons obtained between the two instruments. The distance between the two gauges on the platform was approximately 4 ft. The transmission line wave staff gauge will be developed further by the National Research Council within the next year, because the cost and maintenance requirements turned out to be much less than any of the known staff gauge type wave recorders.

The differential pressure cell showed generally also good agreement with the wave staffs, except for frequencies higher than 0.3 Hz. The time history of wave heights from a pressure cell record was obtained by doing a Fourier transform on the recorded pressures, a compensation and conversion from pressures to amplitudes and a subsequent inverse Fourier transform to give wave height (Fig. 5).

The absolute pressure cell was slightly less accurate than the differential cell, probably because of the depth of submergence term, which had to be supplied from estimates of the mean water level. The differential cells, were of course not sensitive to the long term changes of the mean water level. Figure 6 shows an example of the typical results of a comparison between an absolute pressure cell and a wave staff gauge.

The B.I. wave recorder is not available anymore, but since it had been used extensively in the earlier quoted Wave Climate Study, this evaluation was extremely useful and a number of corrections were indeed applied to the original data as a result of this study.

The Waverider system could not be recorded on the same tape recorder with the other instruments and a direct comparison was therefore not possible. However, spectra recorded over the same time intervals compared reasonably well, both in spectral shape and in RMS values, the latter mostly within 10% of those of the wave staffs. It should be remembered that Lake Ontario does not have any high currents, which may in other locations affect some of these floating and moored wave recording systems severely.

RESULTS OF THE DIRECTIONAL ANALYSIS

The principal aim of the study was to determine a realistic wavelength parameter in a wind generated sea. The flow chart in Fig. 3 showed briefly how the outputs of the four sensors of the triangular array were used to
Fig. 4. Comparison of Step Resistance and Transmission Line Gauges

Fig. 5. Wave Record from Pressure Cell Through Inverse Fourier Transform

Fig. 6. Comparison of Staff Gauge and Pressure Cell
calculate the wave celerity and the direction of wave propagation.

In all cases the wavelengths resulting from this calculation turned out to be very close to the wavelength parameters obtained from the frequency of the peak of the unfiltered or filtered spectra and the small amplitude wave formula

\[ L = \frac{2\pi \cdot g}{\omega^2} \]

An interesting observation was that the deviations which occurred always indicated the wavelengths observed with the array to be longer than those calculated from the standard linear formula. The maximum difference was of the order of 10%. This discrepancy might be real, or might have been caused by a slight movement of the mooring system of the array. A further survey will be done in the near future to examine this in detail.

It appears reasonable to use the frequency of the peak of the spectrum to calculate a wavelength parameter, using the linear formula. This wavelength will indeed have a very real physical meaning, since it almost certainly corresponds to the length dimension between the crests of successive waves, which is so obvious when flying over a wind generated sea. It might be useful to refer to this wavelength parameter in the future as the "dominant wavelength".

As far as directional information is concerned, the results of the analysis indicated that the propagation of waves with frequencies close to the peak of the spectrum was parallel to the average wind direction, after the wind had been blowing sufficiently long from the same direction. There was some doubt about the accuracy of the observed wind direction by the meteorological mast on the platform, due to a possible rotational movement of the platform over ±10°.

The triangular array in Lake Ontario was not very sensitive for the higher frequency components of the spectra. Directional and wavelength resolution beyond 0.3 Hz was not very good, although improvements in the results can be obtained by a more sophisticated analysis technique, which is presently being programmed.

From the results so far it appears that no definite trend in the spread of the wave direction occurred over the various bands of frequency of the spectra. It is expected that next year's study will resolve this question.

However, it should be noted that Lake Ontario has limited fetch lengths and swell does not develop. Only locally wind generated waves are observed at a recording station. In the oceans, swell will often start reaching a wave recording station long before the actual storm arrives which causes the locally generated waves. The low frequency
components of an ocean wave spectrum (the swell) will usually have a directional component different from the direction of the wind driven sea. Therefore, less spread should be expected in the Lake Ontario spectra than in the ocean spectra reported in the literature.

SOME OTHER ANALYSIS RESULTS

A number of other analyses were performed on the wave data from the Lake Ontario station and some of the preliminary results are briefly reported here because of their general interest.

Wave and meteorological data were observed and recorded continuously during an average storm on October 24 and 25, 1971. The record of a wave staff gauge was used to carry out some 200 spectral analyses over 16 minute intervals, with the starting points only 4 minutes apart, covering a total of about 13 hours of the storm. Figure 7 illustrates the spectral history of the storm, showing the familiar pattern of the build-up to a fully developed sea state with the peak of the spectrum continuously shifting to the lower frequencies and increasing its power spectral density value.

One of the conclusions to be drawn from this presentation pertains to the degree of stationarity of the input signal in the various frequency bands. Figure 8 is a plot of the power spectral density values at 13 different frequencies versus time. Typically the analysis had 20 degrees of freedom, giving a spread in the estimates of the spectral density values of about ±50%, using the 90% confidence limits of the Chi-square distribution. Figure 8 reveals that at most frequencies the spectral density values are within the ±50% band and therefore the process can be considered to be stationary. Only at the lower frequencies does the non-stationarity of the record become obvious and conclusions from spectral analysis techniques should thus be drawn with the necessary care.

The final figure, Fig. 9, is a plot of the RMS values, the peak frequencies and the meteorological data versus time for the length of this particular analysis. The RMS values over the 16 minute periods at 4 minute intervals show excellent continuity and give added confidence in the use of the RMS value for the estimation of wave heights even if the process is somewhat non-stationary as demonstrated earlier. Evidently, spectral analysis techniques are often employed to obtain RMS values because of compensation requirements.

The peak frequency curve seems to show a tendency to jump between discrete frequencies. No satisfactory physical interpretation has been found so far.
Fig. 7. History of a Storm as Power Spectral Density Curves
Fig. 8. Power Spectral Density Values at Different Frequencies During a Storm
Fig. 9. Wave and Wind Parameters of a Lake Ontario Storm

The wind data were recorded 10 m above the mean water level; no attempt has been made yet to correlate the wave and wind records.

CONCLUSIONS

The study has probably up to now presented more problems than it has solved, although the question of a definition of the wavelength appears resolved. It is intended to improve on the mooring and recording aspects of the station in the coming years so that the many other questions which have arisen may also be answered, such as the up to 10% difference between measured and calculated wavelengths, the spread in the direction of wave propagation in a wind generated sea, the possibility of the occurrence of discrete frequencies in a wave spectrum and also, a further correlation between the wind and wave records.