SOME PROPERTIES OF SWELL IN THE SOUTHERN OCEAN

by

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SUMMARY

Records of pressure from a bottom-resident instrument deployed near the western margin of Bass Strait have been analysed. Discrete wind-sea and swell spectra have been identified and have been related to meteorological events. The spectra fit a finite-depth form of the Wallops spectrum.

1. INTRODUCTION

Research in coastal and ocean engineering at Monash University has been planned to address topics of specific relevance to Australia. The Southern Ocean, effectively with an infinite fetch, is a source of strong swell to which the whole southern half of the continent is exposed. The present project involves the collection of wave data, particularly swell, and the numerical modelling of the generation, propagation and decay of waves in arbitrary bathymetry. An instrument and moorings suitable for a single point or a directional array were designed and made for this project.

The aim of the preliminary field experiment described here was both to test the instruments and to attempt some definition of the swell field impinging on the Strait to guide future experiments.

To the south of Tasmania the strong westerly winds of the Roaring Forties prevail. At the latitude of Bass Strait the weather patterns

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are dominated by the eastward-moving succession of high and low pressure regions with its approximately four-day period. The lows are usually more strongly developed and give rise to stronger winds. The lows are often preceded by or merged with one or more cold fronts which are accompanied by strong winds but of short duration. The pattern of highs and lows moves north in winter making the northerly winds dominant from April to September, while southerlies are dominant from November to March. There is no "weather window" in Bass Strait and strong winds may be experienced in any month.

Owing to the dominant strong winds around latitude 40°S, the wave climate is particularly severe on the south-western coast of Tasmania, moderating with distance north —— towards the site of the present measurements. Strong wave and swell events reported here were generated by each of the wind systems: very large atmospheric systems south latitude 40°S, strong lows passing just south of or over Bass Strait and cold fronts passing over Bass Strait.

2. SOURCES OF DATA

Hourly wind speed and direction were obtained from the nearby Baseline Air Pollution Monitoring Station at Cape Grim with the cooperation of CSIRO. This observatory is 45 km south-east of the site of the experiment and stands on a cliff 90 m above the sea. Presently no corrections have been applied to the wind data.

The instrument used to measure the waves is a bottom-resident pressure-sensing recorder. The recorder is a micro-computer controlled digital cassette drive designed for minimum power consumption and capable of conditional sampling of the input. The instrument wakes every four hours and senses the sea state for a period determined by the firmware. If it decides there is sufficient surface activity it logs conditions as described and then enters an extended recording mode. In the present experiment this involved samples at 4 second intervals for a period of 30 minutes each.

The tape has a capacity of approximately 100 30-minute wave records. In the trial, the results of which are reported here, the instrument ran for 39 days. In this time six events reached the threshold value and resulted in wave records.

For this deployment the instrument was placed on the sea bed, though later deployments may use a taut-wire mooring system. Since the maximum depth for the instrument is 60 m, a station at the edge of the shelf was not attainable. The site selected, shown in Fig. 1, was 144° 20'E, 40° 28'S, 2.5 km north-west of Black Pyramid, a site which satisfied the above criteria although the sea bed was not as smooth as desired being a low rocky ridge rising 15 m above the general surroundings to a depth of 57 m below MWL.

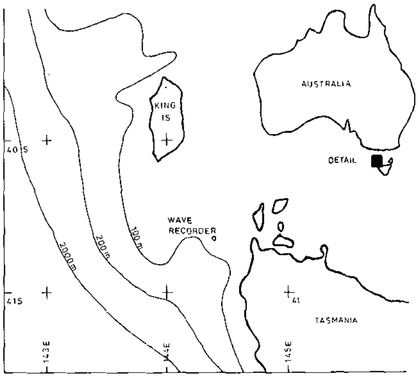

Fig. 1 Location map

3. SPECTRA

To reduce the records of bottom pressure to power spectra of the surface elevation the average of seven hanned periodograms was taken, and the correction for attenuation due to depth corresponding to each frequency component was applied to its spectral value to give the corrected spectrum at the surface. The magnitude of the depth correction factor reaches large values (~ 300) at the highest frequencies considered. For the spectra shown a filter has been applied attenuating components with periods less than 9 s.

The time history of the surface elevation was reconstructed by transforming the whole pressure record, making the depth correction in frequency space, and transforming inversely. The power spectrum of the surface elevation can also be obtained from this history; as expected the results are similar to those obtained from the pressure signal directly, as described above.

4. RESULTS AND DISCUSSION

Records of the hourly wind data from Cape Grim and the four-hourly wave data from Black Pyramid were combined as shown in Fig. 2 to represent a time history of wind and wave parameters during the 39-day period of the experiment. The wave height parameter used in the time history was based on the maximum crest-to-trough pressure difference observed during a 5-minute period. The units are metres of water. Because the wave recorder senses bottom pressure at a depth of 57 m, the description of the sea state obtained from it corresponds principally to swell conditions.

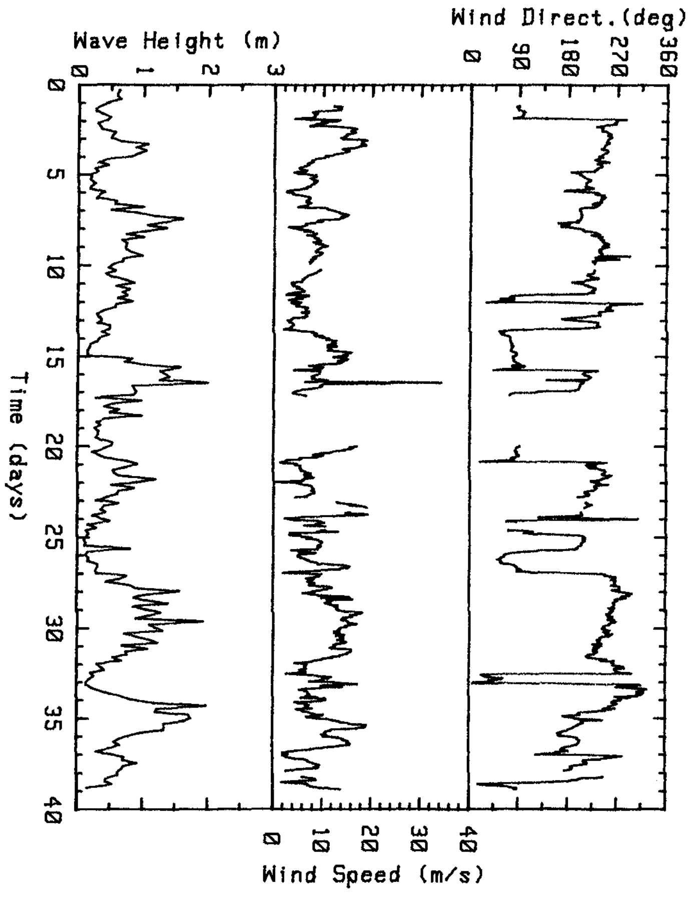

Fig. 2 Time series of measured sea state with wind speed and direction at Cape Grim

Some features of the time history are worthy of note. During the period of the experiment the wind blew mainly from the south-west and only on one occasion exceeded 20 m/s. The significant wave height varied between about 10 cm and 2 m and the periods of high and low swell activity are clearly shown in Fig. 2. The first significant swell started to build up after day 6 (14 November 1982) and reached a peak between days 7 and 8, then gradually decayed until day 15 at which time it grew considerably. On day 16 (24 November 1982) of the experiment, between 0600Z and 1200Z wind from the SSW reached speeds of 34 m/s. This storm produced a wind sea, which in conjunction with the significant existing swell, was sufficient to trigger the instrument into the extended recording mode.

The first 30-minute wave record was taken during this intense but short-lived frontal storm. Analysis of the wave record obtained indicated a 14.2 s period swell peak in the surface elevation spectrum with an estimated significant wave height H_s of 2.1 m. The spectrum is shown in Fig. 3; clearly evident is a separate peak due to the wind sea.

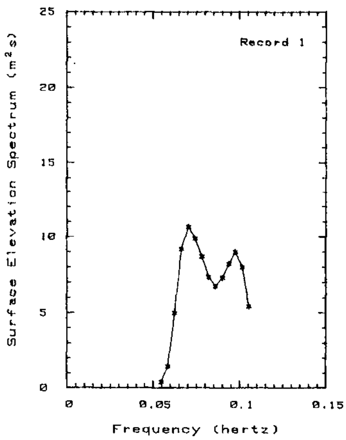

Fig. 3 Surface elevation spectrum showing separate swell and wind-sea peaks

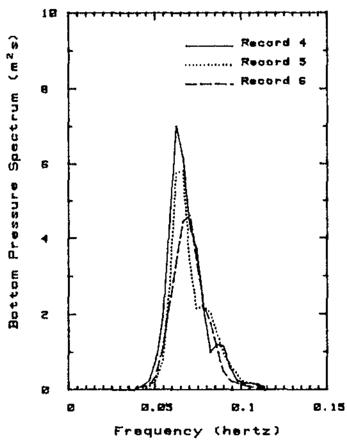

Fig. 4 Bottom pressure spectra showing evolution with time

A further 13 days passed before the second 30 minute record was taken. The swell level decreased from day 16 (24 November) until about day 20 (28 November); it increased slightly before falling to its lowest level on day 25 (2 December). Under the influence of strong west winds the wave activity then built up steadily; record 2, taken on day 30 (7 December), coincided with the passage of a storm of extended duration with winds up to 18 m/s from the west. The surface elevation spectrum corresponding to this record contained a single peak at a frequency of 0.1 Hz. Although the frequency range of the data obtained from the pressure transducer is limited, an estimate of the H_s was found by fitting the experimental data to a Wallops spectrum modified to account for finite depth. This procedure yielded a H_s of 6.3 m. A Jonswap spectrum with a peak enhancement factor of 4.2 yielded essentially the same result.

Wave activity subsided after day 30 (7 December) to a new low level on day 33 (10 December), it then rose sharply and the swell reached a high level. Records 3, 4, 5 and 6 were taken during this period after which the swell again fell to a low level. The last three wave records obtained were taken successively at 4-hour intervals, commencing on day 35 (12 December) at 1600Z. An increase with time of the frequency associated with the peak in the swell spectrum is clearly evident in Fig. 4, where the bottom pressure spectra of records 4, 5 and 6 are presented. A distance of about 950 km to the source of the swell in these records was inferred from the frequency shift. Although limited in detail, the synoptic weather charts issued by the Australian Bureau of Meteorology indicate a likely storm source located some 1000 km SSW of the site of the experiment.

No swell peak was observed in the spectrum of the storm sea of record 2, but all the other spectra from the records obtained displayed prominent swell peaks, which, with the exception of record 6, were accompanied by locally generated wind-sea peaks.

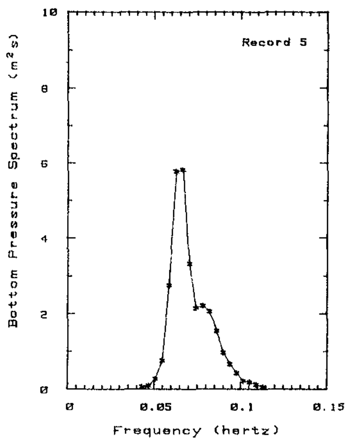

Fig. 5 Typical bottom pressure spectrum - Record 5

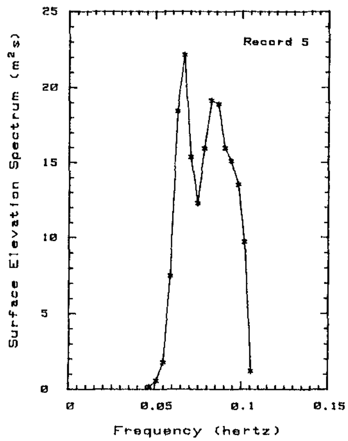

Fig. 6 Typical surface elevation spectrum - Record 5

The period of the swell peaks ranged from 14.2 to 15.3 s, and estimated values of H_s ranged from 2.1 to 3.1 m. Wave record 5 is typical and Figs. 5 and 6 represent respectively bottom pressure and surface elevation spectra for this record; in both representations swell and wind-sea peaks may be identified.

Record 6 was taken soon after the local wind sea had subsided and represents swell resulting from the events of 12 December. In an effort to describe theoretically swell we have modified the recently proposed Wallops spectrum to account for finite depth effects. The Wallops equation for the spectrum of surface elevation given by Huang et al (1981) is:

$$\Phi(f) = \frac{\beta g^2}{(2\pi)^4} \cdot \frac{f_p^{m-5}}{f^m} \cdot \exp\left\{-\frac{m}{4}\left(\frac{f_p}{f}\right)^4\right\} \tag{1}$$

where f and the frequency of the spectral peak are now measured in Hertz.

As originally given the equation was suitable for deep water conditions. We have modified the functions β and m for intermediate depth water; the derivation of these forms is given in Lleonart, Blackman and Hinwood (1983).

$$\beta = \frac{\{2\pi S[\tanh(k_p d)]\}^2 \cdot m^{\frac{m-1}{4}}}{4^{\frac{m-5}{4}}\,\Gamma\left(\frac{m-1}{4}\right)} \tag{2}$$

$$m = \left|\frac{\ln(\sqrt{2}\pi S)^2\left[\frac{\cosh(k_p d)}{\sinh^3(k_p d)}\left\{1 + \frac{1}{2}\cosh(2k_p d)\right\}\right]^2}{\ln 2}\right| \tag{3}$$

where

$$S \equiv \frac{(\bar{\eta}^2)^{1/2}}{\lambda_p}$$

$\bar{\eta}^2$ is the mean square surface elevation,
λ_p is the wave length corresponding to the spectral peak,
k_p is the corresponding wave number, and
d is the still-water depth.

These forms differ from those in Huang et al by the inclusion of the factors in square brackets.

Fig. 7 shows good agreement between the field data and the spectrum for surface elevation based on eqns (1) to (3). We have also developed a theoretical description of the spectrum of the swell in terms of bottom pressure, and a comparison of observations with the predictions is presented in Fig. 8. Further comparisons have been made with data from other sources as well as more recent data of our own. We have found agreement to be consistently good. Huang et al suggested it may be possible to apply the Wallops spectrum to cases where the spectrum contains multiple peaks and we have indeed found, for reasonably separated peaks, that two independent Wallops spectra may be combined to describe the full spectrum.

The derived time series of surface elevation were analysed to establish probability distributions and the extent of wave group formation among larger waves. Unlike the Pierson-Moskowitz spectrum, the Wallops spectrum has a variable bandwidth parameter and it should therefore be a valuable tool in characterising the statistics of wave groups.

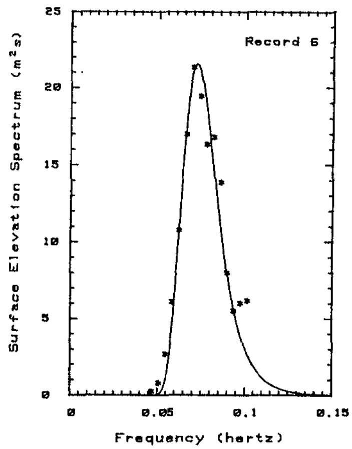

Fig. 7 Comparison of measured surface elevation spectrum with modified Wallops spectrum

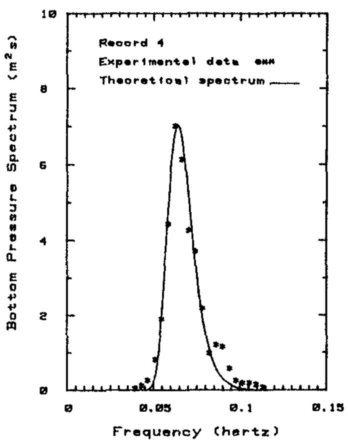

Fig. 8 Comparison of measured bottom pressure spectrum with modified Wallops type spectrum

5. CONCLUSIONS

The data obtained confirm that there is significant swell generated by identifiable meteorological events within the Southern

Ocean. The surface elevation spectra obtained fit a Wallops spectrum modified for the effects of shallow depth. Using the variable bandwidth property of the Wallops spectrum an analytical expression for the length of runs of high waves has been obtained and compared with field data.

6. REFERENCES

HUANG, N.E., LONG, S.R., TUNG, C.-C., YUEN, Y., and BLIVEN, L.F. (1981). A unified two-parameter wave spectral model for a general sea state. J. Fluid Mech., 112: 203-24.

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