WAVE ENERGY VARIATION NEAR CAPE TOWN, SOUTH AFRICA

F.A. Shillington, Physical Oceanography,
University of Cape Town,
Rondebosch 7700, RSA.

ABSTRACT

A three month time series of wave height measurements taken every six hours for twenty minutes duration at two sites (one in 24 m deep water and the other in 15 m deep water) off the South African coast have been used to examine wave energy dissipation. The rocky nature of the bottom has ruled out the possibility of dissipation due to sediment motion and percolation and only dissipation due to bottom friction has been considered. The theoretical work of Hasselmann and Collins 1968 has provided the basic technique. Average friction factors obtained have been in the range 0.17 to 0.50 but have very large scatter. Such large friction factors were not considered possible until recently (Grant and Madsen 1982) when it has been shown that if the hydraulic roughness is of the same order as the bottom orbital excursion, the friction factor tends to a value of 0.23. An attempt will be made in future work to reduce the scatter of the results by careful selection from a longer subsection of the original time series.

INTRODUCTION

In 1980 a collaborative field measuring and analysis programme was set up with participants from the departments of Oceanography at the University of Cape Town, and Ocean Engineering at the University of Stellenbosch, and help from the National Research Institute for Oceanology (NRIO) Stellenbosch and Fisheries Development Corporation (FISCOR) Cape Town, to measure wave parameters on a line perpendicular to the shore. The main objectives were:

(a) to examine processes involving wave energy dissipation in shoaling water
(b) to obtain a long term series of wave heights and wave energy spectra to establish suitable statistics for wave energy extraction design studies. (Retief et al 1982).

SITE

The site chosen for the study resulted partly from historical programmes of NRIO. A 200 m deep wave recording station near Cape Town was initiated and maintained by NRIO for a number of years as a prime

research station for S.A. waters (van Ieperen 1976). It was decided that this station should serve as the outer or deep station for this study. New stations in 24 m deep water and 15 m deep water were deployed by this project. Only records from the 24 m and 15 m deep stations are discussed in this preliminary report.

The bottom topography of the site region is displayed in figure 1. The location of the three Datawell waverider buoys is indicated. The topography is reasonably regular and both SCUBA diver inspection and a later side scan sonar survey indicated that the bottom is composed of large, smooth sandstone slabs. These rocky slabs are covered with biological growth and the kelp *Laminaria pallidae* which ranges from 1 - 2 m tall. There are relatively small patches of sand in some of the gullies.

In order to estimate the incoming wave direction, a bottom mounted OOSO direction guage (see Retief and Vonk 1974) was deployed at the 24 m deep site. This instrument was later removed when it became obvious that the tripod on which it was mounted shifted its orientation under storm conditions. An idea of the boundary roughness can be obtained from an echo sounding profile shown in figure 2.

INSTRUMENTATION ANO OATA ANALYSIS

Wave heights were measured with standard DATAWELL waverider buoys; the analogue signal being transmitted ashore to a nearby lighthouse at Kommetjie. Here the signal was received and stored simultaneously on an analogue strip chart and on cassette magnetic tape as a 17.1 minute (2048 datapoints) time series of digitised wave heights sampled once every 0.5 s. The height resolution of the digitally recorded wave heights is 4 cm. Records were taken every 6 hours at all stations. The digital data on the cassettes were then transferred to 9 track CCT at FISCOR and then put onto disc storage on the UNIVAC 1100/80 computer at UCT. Spectra were then calculated by using standard FFT algorithms together with a wave data qualification suite of programmes (Visser et al 1980) described elsewhere in these proceedings (Rossouw et at 1982). The spectra have a frequency resolution of 0.01 Hz, a Nyquist or folding frequency of 1 Herz, and 20 degrees of freedom leading to 80% confidence bands of 0.7 times the spectral estimate x and 1.6 times x where x is the expected spectral energy density value. The wave directions measured with the OOSO in the early stages of the field have not been used in this study.

WAVE OISSIPATION MECHANISMS

Shemdin et al 1980 have conveniently summarized the possible wave dissipation mechanisms into two groups:

(a) linear processes
Percolation; wave induced bottom sediment motion; bottom scattering.

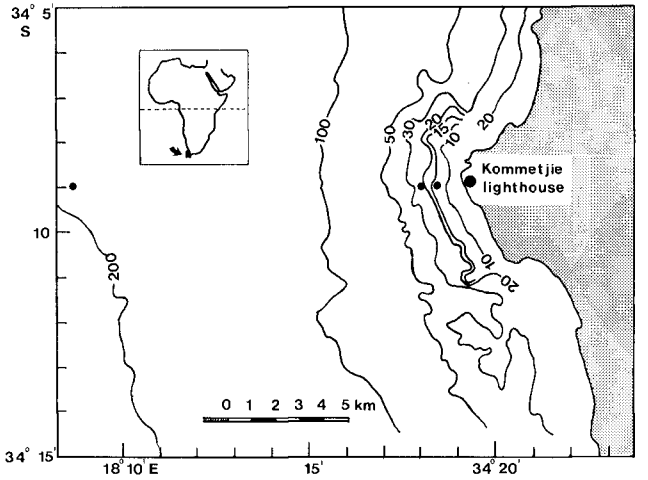

Figure 1. Site location of Datawell waverider buoys and bottom topography.

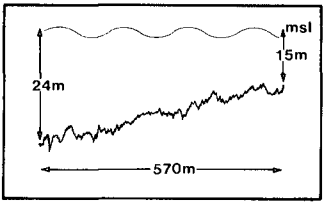

Figure 2. Typical bottom slope between shallow wave recorders from echo sounding profile.

(b) non linear processes
Bottom friction; weak non linear wave interactions in finite depth water.

In this experiment, due to the rocky bottom, it is assumed that the dominant dissipation mechanism would be bottom friction. Techniques for estimating the bottom friction coefficient have been derived by Hasselmann and Collins 1968 and Collins 1972, and have been subsequently used by various workers including van Ieperen 1975 in South African waters.

Hasselmann and Collins 1968 assume that the bottom shear stress is given by a quadratic law:

$$\tau_b = - \rho f_w \tilde{u}_b |\tilde{u}_b| \qquad (1)$$

where f_w is the friction coefficient; $\tilde{u}_b$ is the bottom orbital velocity vector due to the waves passing overhead. Since it is difficult to measure $\tilde{u}_b$ directly in the field, we use linear theory to estimate $\tilde{u}_b$ from the surface wave height measurements. (This is justified for most wavelengths and moderate wave heights in this depth of water - see for example, Swart 1978).

$$\tilde{u}_b(k) = \frac{g\ k\ \eta(k)}{\sigma \cosh (kH)} \qquad (2)$$

where $\eta(k) = A \cos (\tilde{k}.\tilde{x} - \sigma t)$, $2A$ is the surface wave height, σ the radian frequency, $\tilde{k}$ the wavenumber ($= \frac{2\pi}{L}$), H is the water depth.

We assume that there is no wind wave generation between the stations and that the wave field is steady, in which case we can write the radiative transfer equation as

$$Cg \frac{\partial E}{\partial x}(f,x) = - \Phi(f) \qquad (3)$$

where Cg is the group velocity of component frequency f, and the sink function $\Phi(f)$, is given approximately by Collins 1972 as

$$\Phi(f) = \frac{f_w\ g\ k^2 E(f) < \tilde{u}_b >}{\sigma^2 \cosh^2 (kH)} \qquad (4)$$

with $$< \tilde{u}_b > = \left\{ \int_f \frac{E(f)\ g^2 k^2\ \Delta f}{\sigma^2 \cosh^2 (kH)} \right\}^{\frac{1}{2}}$$

$E(f,x)$ is the wave energy density spectral function and $<\tilde{u}_b>$ gives the average steady bottom velocity as a linear superposition of exponentially depth decayed orbital velocities of the different wavenumbers present in the spectrum.

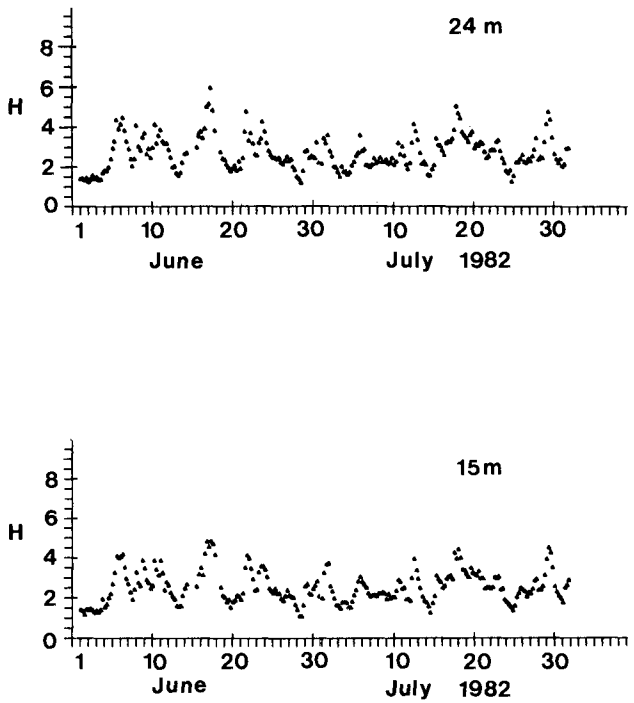

Figure 3. Time series of average significant wave height in 24 m and 15 m depth for June and July 1982.

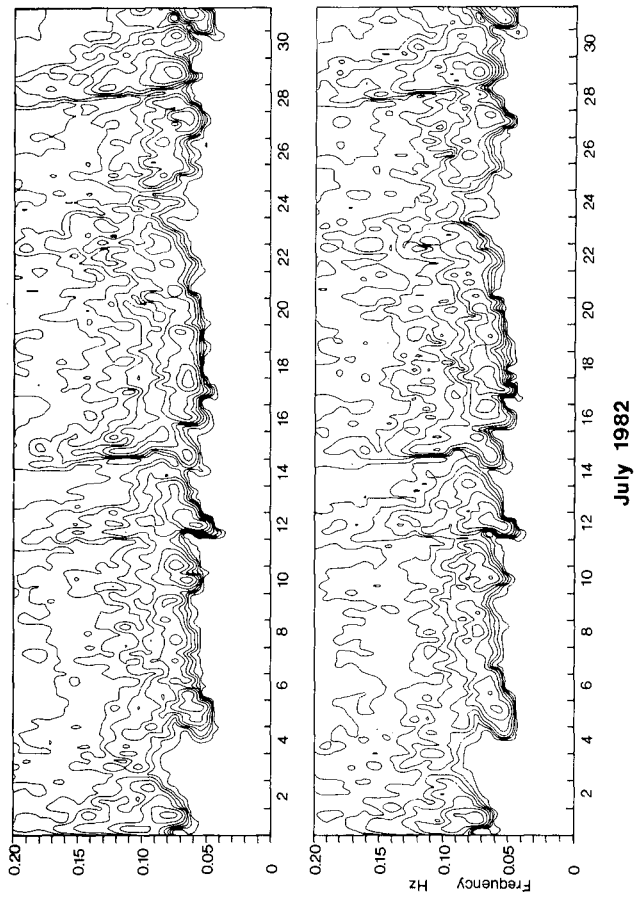

Figure 4. Energy, frequency, time diagram for 24 m (above) and 15 m (below) stations off Kommetjie, South Africa. Energy contours in decibels above 1 m^2sec with contour levels at -2.5, 0, 2.5, 5, 7.5 etc decibels.

RESULTS

As a preliminary analysis, a three month subset of the data for June, July, August 1982 has been used. Figures 3 and 4 show respectively the average significant wave height during June, July 1982 at the 24 m and 15 m depths and the energy-frequency time contour diagram for July 1982, also at both depths. The spectra were computed four times per day for both the 24 m and 15 m stations. Equation (4) was used to compute the friction factor f_w at each of the twenty frequencies

$$f(i) = (0.006 + \frac{5i}{1024}) \text{ Hz} \qquad \text{for } i = 0, 1, \ldots 19.$$

The friction factors for the entire data set (322 values at each frequency) were averaged in time and are shown in brackets in Table 1. The main data shown in Table 1 were selected using a criterion that H_s at the 24 metre deep station should be greater than H_s at 15 metres depth. As can be seen from the scatter diagram in figure 5, sometimes the shallower station experiences larger waves than the deeper one. This is considered to be due to convergent refraction of energy under southerly wave directions.

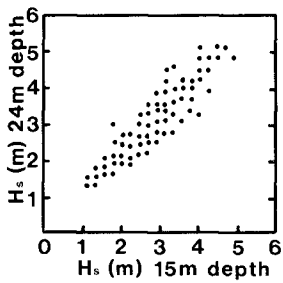

Figure 5. Plot of significant wave height in 24 m versus wave height in 15 m deep water.

Figure 6 shows a percentage occurrence diagram of friction factors f_w at selected frequencies. There is some tendency for the friction factor to increase in magnitude with increasing frequency, but the large scatter in the results makes it difficult to place confidence in such a conclusion.

DISCUSSION

Traditionally it is assumed that friction factors of order 10^{-2} are typical on sandy bottoms under waves. However, more recent work has

TABLE 1

f (Hz)	$\tilde{f}_w$	σ	n	% of total records	
0,006 *	0,53 (,65)	1,8 (0,9)	81 (302)	95,3	(93,8)
0,016 *	0,32 (0,43)	1,3 (0,7)	85 (316)	100	(98,1)
0,025 *	0,24 (0,30)	1,2 (0,6)	85 (319)	100	(99,1)
0,035 *	0,83 (0,11)	0,9 (0,5)	85 (312)	100	(99,7)
0,045	0,17 (0,27)	1,3 (0,7)	85 (317)	100	(98,4)
0,055	0,27 (0,47)	1,8 (0,9)	83 (299)	97,6	(92,8)
0,064	0,28 (0,50)	2,0 (1,0)	80 (298)	94,1	(92,5)
0,074	0,24 (0,70)	1,9 (0,9)	85 (296)	100	(91,9)
0,084	0,31 (0,63)	1,8 (0,9)	84 (304)	98,8	(94,4)
0,094	0,32 (0,67)	1,8 (0,9)	84 (298)	98,8	(92,5)
0,104	0,45 (0,64)	1,8 (0,9)	82 (300)	96,5	(93,2)
0,113	0,27 (0,49)	1,8 (0,9)	84 (304)	98,8	(94,4)
0,123	0,28 (0,43)	1,7 (0,9)	84 (306)	98,8	(95,0)
0,133	0,21 (0,38)	1,7 (0,4)	84 (308)	98,8	(95,6)
0,143	0,33 (0,40)	1,9 (1,0)	82 (300)	96,5	(93,2)
0,152	0,33 (0,54)	2,0 (1,0)	81 (297)	95,3	(92,2)
0,162	0,35 (0,49)	2,3 (1,2)	81 (293)	95,3	(91,0)
0,172	0,37 (0,44)	2,8 (1,4)	77 (284)	90,6	(88,2)
0,182	0,17 (0,18)	3,4 (1,7)	78 (259)	91,8	(80,4)
0,191	0,50 (0,50)	4,1 (2,1)	65 (241)	76,5	(74,8)

* Waverider response at these frequencies does not allow a meaningful estimate to be made.

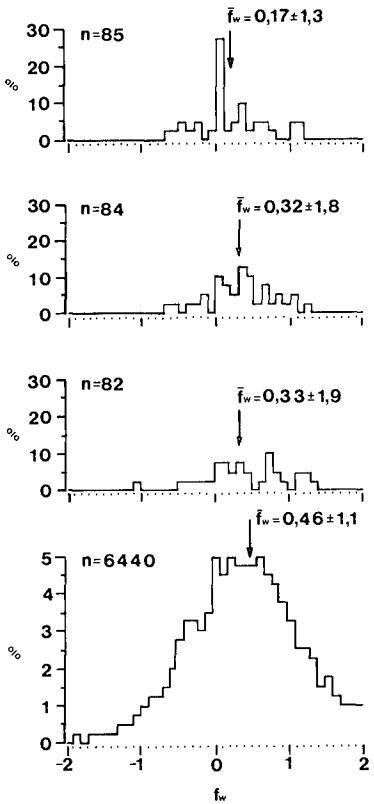

Figure 6. Percentage occurrence of friction factor f_w for frequencies from top: (a) 0.045 Hz, (b) 0.094 Hz, (c) 0.143 Hz and combined for all frequencies, bottom.

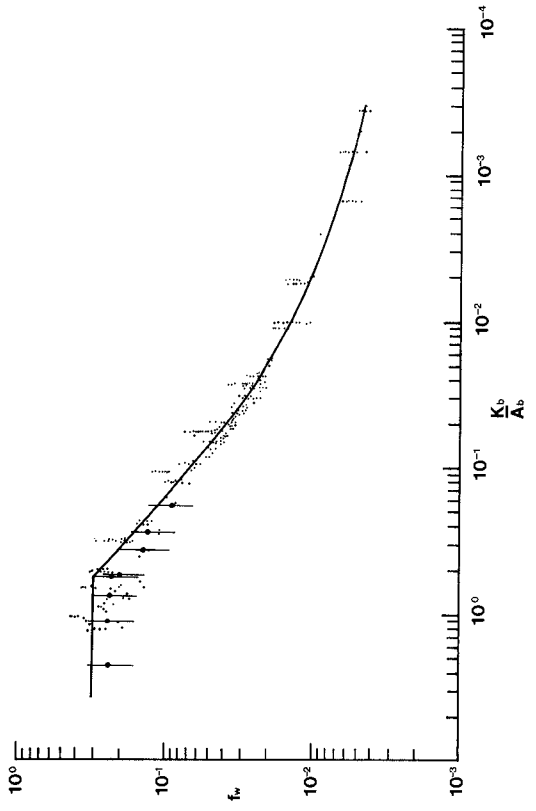

Figure 7. Friction factor f_w for wave tank observations at different hydraulic roughness lengths k_b as a function of $\frac{k_b}{A_b}$ where A_b is the bottom orbital excursion amplitude. (After Swart, unpublished, see also Grant and Madsen 1982).

shown that larger values of the friction factor are being obtained under various conditions. It appears from figure 7 (after Swart, pers comm.) that a limiting value for the friction factor is 0.3. This is also confirmed in recent work of Grant and Madsen 1982. In these instances the high friction factors result when the hydraulic roughness is of the same order as the bottom orbital excursion amplitude. Thus, in this experiment, it is assumed that the large values of the friction factor are due to a large hydraulic roughness. Grant and Madsen show that for values of $\frac{k_b}{A_b} > 1$ (where k_b is the hydraulic roughness length, A_b the bottom orbital excursion amplitude) that friction factor $f_w = 0.23$.

The main problem with the results is the large scatter. This scatter has been attributed to changes in wave direction as the storm pass to the south of the Cape, which then result in changes of energy due to refraction. It is anticipated that the scatter can be reduced by carefully selecting portions of the data set that might be expected to arrive from a particular direction.

No attempt has yet been made to model the effect of the large kelp on dissipating energy. Considering a boundary layer with a scale the same order of magnitude as the size of the kelp, one could consider the kelp in the sense of a percolation model. One would imagine that the kelp would be transparent to low frequency energy, but not so to high frequency energy.

ACKNOWLEDGEMENTS

The author would like to thank the SANCOR division of CSIR for the funding required by this project. The work would also not have been possible without the help of Mr R.C. Wyness in the maintenance and smooth operation of the wave recording equipment. Computer and diving assistance was obtained from the Fisheries Development Corporation.

REFERENCES

COLLINS, J.I. 1972. Prediction of shallow water spectra. *J.G.R.*, 77, 2693-2707.

GRANT, W.D. and O.S. MADSEN. 1982. Movable bed roughness in unsteady oscillatory flow. *J.G.R.*, 87, 469-481.

HASSELMANN, K. and J.I. COLLINS. 1968. Spectral dissipation of finite-depth gravity waves due to turbulent bottom friction. *J. Mar. Res.*, 26, 1-12.

RETIEF, G. DE F., G.K. PRESTEDGE and F.P.J. MULLER. 1982. A proposal for wave energy conversion near Cape Town. *18th ICCE* (ABSTRACTS).

RETIEF, G. DE F. and A.P.M. VONK. 1974. Low cost in shore wave direction indicator. *Proc. 14th Int. Coastal Engineering conference*, Copenhagen, 212-224.

ROSSOUW, J., L.W. COETZEE and C.J. VISSER 1982. A South African wave climate study. *18th ICCE* (ABSTRACTS).

SHEMDIN, O.H. et al 1980. Mechanisms of wave transformation in finite depth water. *J.G.R.*, 85, 5012-5018.

SWART, D.H. 1978. Vocoidal water wave theory. Volume 1: Derivation. *CSIR Research Report 357*, pp 137.

VAN IEPEREN, M.P. 1975. The bottom friction of the sea bed off Melkbosstrand, South Africa: A comparison of a quadractic with a linear friction model. *Deut. Hydrogr. Zeits.*, 28, 72-88.

VAN IEPEREN, M.P. 1976. Characteristics of wave fields recorded along the western coast of Southern Africa. *First Interdisciplinary Conf. on Mar. and Fresh Water Res. in S.A.*, Port Elizabeth, paper 45, pp 24.

VISSER, C.J., M. ENNIS and J. ROSSOUW 1980. Data qualification and spectral analysis of sea wave data. Paper 8 in: *Workshop on digital time series analysis with geophysical applications*, April 1980, Hermanus, South Africa.