MEASUREMENT OF THE VELOCITY-PROFILE IN AND ABOVE A FOREST OF *LAMINARIA HYPERBOREA*

KEN HASTE ANDERSEN, MARTIN MORK & JAN EVEN ØIE NILSEN

SARSIA

ANDERSEN, KEN HASTE , MARTIN MORK & JAN EVEN ØIE NILSEN 1996 10 15. Measurements of the velocity-profile in and above a forest of *Laminaria hyperborea*. – *Sarsia* 81:193-196. Bergen. ISSN 0036-4827.

The aim of this study is to resolve the mechanism of damping of surface waves above bottom vegetation. A field experiment has been carried out, where the horizontal velocities were measured in and above a kelp forest of *Laminaria hyperborea* (GUNNERUS)Foslie, using ultrasonic current-meters. The results from the experiment are presented as periodograms of kinetic energy-density at several levels, and as the correlation of energy at two levels. The main conclusion is that the attenuation extends throughout the whole water column. The long waves exhibit only a slight (5-8 %) reduction of velocity-amplitude within the kelp forest.

Ken Haste Andersen, CATS (Chaos And Turbulence Studies), Niels Bohr Institute, The University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen Ø, e-mail: kenand@alf nbi.dk – Martin Mork & Jan Even Øie Nilsen, Department of Geophysics, University of Bergen, Allégaten 70, N-5007 Bergen, Norway, e-mail: even@gfi.uib.no.

KEYWORDS: Wave attenuation; kelp; velocity-profile; wave-energy; spectra.

INTRODUCTION

The giant kelp *Laminaria hyperborea* (henceforth referred to just as the 'kelp') is a large seaweed, which has a rigid stipe of a maximum of 3 m length, on top of which is a frond consisting of a single leaf, with a surface area of up to 2 m^2. The kelp grows in large forests in shallow waters (from the surface to about 25 m depth) on rocky bottoms, with good exposure to surface waves (FOSSÅ & SJØTUN 1993). The largest concentrations of kelp are found along the west coast of Norway. Fig. 1 shows a sketch of a kelp-forest.

In recent years, the study of the kelp has become relevant because of increased harvesting (SIVERTSEN 1991). Just as the forests on land, the kelp forests are peculiar biotopes. They serve as protection for amphipods, fry, and crabs (FOSSÅ & SJØTUN 1993). Also, attention has been drawn towards the function of the kelp forest as shore-protection (SIVERTSEN 1991), and this is the question which is addressed in this article. It seems beyond doubt that waves passing seaweed is attenuated (ASANO & al.1992; KOBAYASHI & al.1993), but it is not known to what degree this effect is able to prevent erosion of beaches.

As part of the study of the attenuation of surface-waves above kelp-forests, several models have been proposed (WANG & TØRUM 1994; ANDERSEN 1995; MORK 1996). But there is a dire need for empirical data, which can be used to validate and calibrate these models. To relieve this need, it was sought to measure the vertical profile of the horizontal velocity inside and above a kelp-forest. From this profile, information about the influence of the kelp on the flow can be extracted, both from the damping of the velocity, and from the phase-difference between the flow above and below the fronds.

FIELD EXPERIMENTS

All the measurements were done using Ultrasonic Current-Meters (UCM), which measures the velocity of the flow with a precision of 1 mm/s, and a sampling-rate of 2 Hz. The data are given as the magnitude and direction of the horizontal velocity. Two UCM's were placed on a rig, one was fixed on top of the rig (henceforth referred to as the upper meter), and the other (the lower meter) was placed in different positions below the upper meter (Fig. 2). The two meters measured series of 20 min. length. By moving the lower meter between series, and by comparing the measurements from the lower meter with the simultaneous measurements from the upper meter, it was possible to construct a velocity-profile.

The rig was placed at Lyroddane, Southwest of Bergen (N 59°10'05", E 4°59'04"), where a suitable kelp-forest was found. The forest consisted of young plants with a clean stipe, a height of about 130 cm and a total mass (wet-weight) of about 1.5 kg. The depth of the water was about 6 m.

During two expeditions, 16 and 29 March 1995, a total of 10 series of 20 minutes were made. On the first expedition four series were made, labelled 1-1 to 1-4, and on the second expedition six series were made labelled 2-1 to 2-6. Fig. 1 and Table 1, show the height above the bottom of the lower meter, for each series. The height of the swell-component of the waves was about 0.5 m.

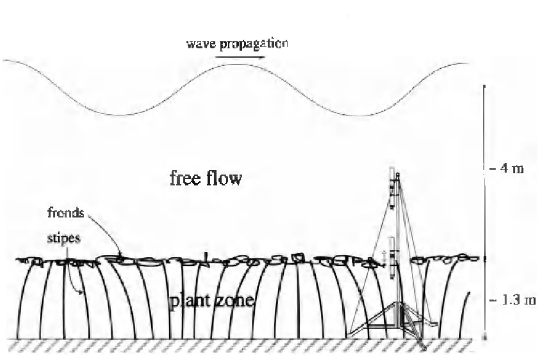

Fig. 1. Sketch of a kelp-forest. It is possible to define an upper layer, which is undisturbed by the presence of the kelp, and a lower layer, dominated by the kelp; the plant-zone. When the forest is influenced by surface-waves, the plants oscillate with the same period, but not necessarily the same phase, as the waves.

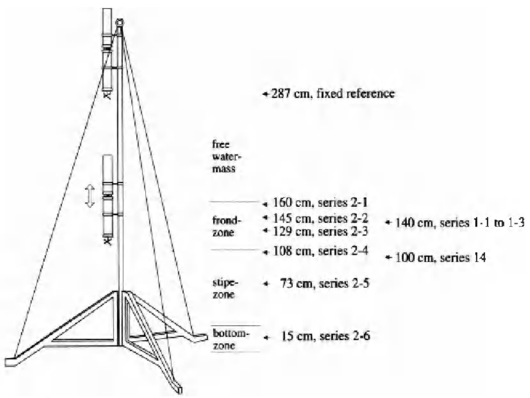

Fig. 2. The rig with the two UCM's, and the positions of the lower meter. The upper meter was fixed at 287 cm above the sea-floor, while the lower meter was moved between the series.

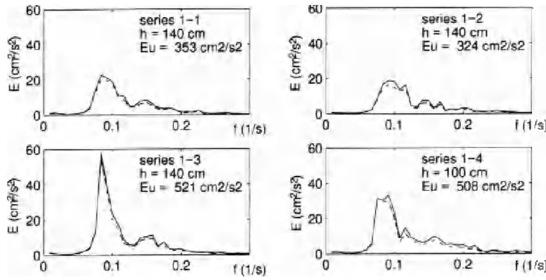

Fig. 3. Periodograms from the first expedition, showing kinetic energy-density as a function of frequency. The variable h is the height above the bottom for the lower meter, and E_u is the sum of the squared horizontal velocities at the upper meter. The full line represents the upper meter, while the broken line represent the lower meter.

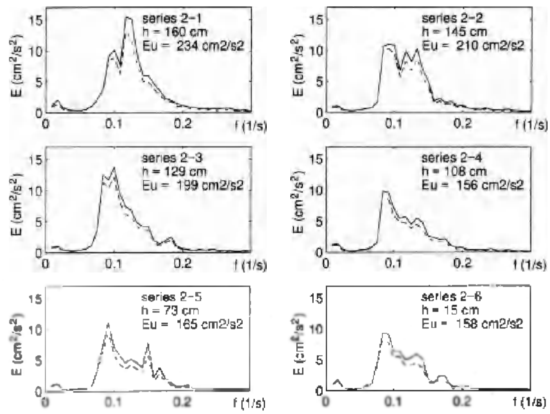

Fig. 4. Periodograms from the second expedition, showing kinetic energy-density as a function of frequency. Legends as in Fig. 3.

DATA ANALYSIS

Figs 3 and 4 show periodograms of the horizontal velocities. The energy P_n at each frequency n was calculated as

$$P_n = \frac{2}{N^2}(U_n^2 + V_n^2),$$

where U_n and V_n are the Fourier-transforms of the u- (east) and v- (north) components of velocity, respectively. Furthermore a method of splitting the data into segments was used, described in detail by Press & al.(1992). Each segment contained 240 measurements (one tenth of a whole series), with an overlap of 50 %. To each segment was applied a Bartlett window (*ibid.*).

In all the series, a large peak is seen at a frequency of a little less than 0.10 Hz, and a lower peak at about 0.12 Hz. This corresponds to wave-periods of about 11 and 7 s, which represents swell and wind-waves, respectively. The wave-climate changes from series to series, and in some series the wind-waves are dominating (Series 2-1). It is also seen that the energy measured at the lower meter corresponds to that measured at the upper meter, while at the same time being a little less than that measured at the upper meter for all frequencies. The lines falling together at low frequencies does not imply absence of damping at these wavelengths, but are due to the steepness of the graph at this point.

In order to be able to calculate the difference between the measured energy at the upper- and the lower meter, including the phase difference, a correlation analysis was applied between the energy at the corresponding series from the upper- and lower meter. Before the correlation analysis, the data was filtered to cut off all frequencies outside the domain 0.05-0.17 Hz.

The discrete correlation between the magnitudes of the upper and the lower velocities, u_k^u and u_k^L respectively, is defined as:

$$Corr(u^U,u^L)_j = \frac{1}{N}\sum_{k=0}^{N-1} u^U_{k+j}u^L_k,$$

where $j = 0,...,N$ is the displacement (discrete) in time between the two series, each of a length N. With a sampling rate of 2 Hz, each value of k corresponds to a time of 0.5 s. The calculation of the correlation can be greatly simplified through the use of the discrete correlation theorem (PRESS & al. 1992),

$$Corr(u^U,u^L)_j \Leftrightarrow \frac{1}{N}U^U_j U^{L*}_j,$$

where the arrow symbolises Fourier-transformations, and U^U_j and U^L_j are the Fourier-components of the magnitude of the upper- and the lower velocities, respectively. The star symbolises complex conjugate. In other words, this means that the correlation can be calculated for all values of j by first Fourier-transforming u^U and u^L into U^U_j and U^L_j, respectively, thereby making the inverse Fourier-transform of the product between U^U_j and the complex conjugate of U^L_j. The result is normalised by dividing with the mean energy measured at the upper meter ($\bar{E}_U = \sum(u^U)^2$), so as to make the final result the ratio between the energy (squared velocity) at the upper- and the lower meter:

$$R_{UL} = \frac{Corr(u^U,u^L)_j}{\bar{E}_U}.$$

Figs 5 and 6 show the results of the correlation-analysis.

The important results of the correlation-analysis are the characteristics q and dt. The value of q is the factor by which the horizontal energy at the lower meter is less than the corresponding energy at the upper meter, while dt is the difference in time between the two series and consequently is a measure of the phase difference. It should be noted that the uncertainty on the phase difference is about 0.5 s. The results are summarized in Table 1.

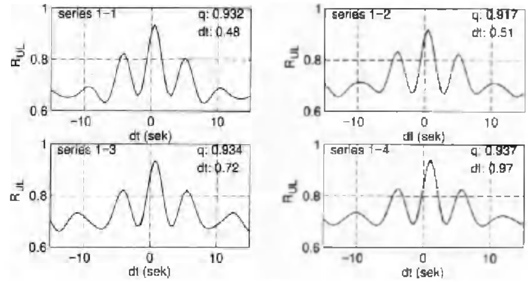

Fig. 5. Correlation between the energy at the upper- and lower meter, for the first expedition. The highest peak corresponds to the primary correlation, while the lesser, neighboring peaks result from a displacement of half a period. The value of q is the correlation at the highest peak, which corresponds to the factor between the squared velocity at the upper and the lower meter, and dt is the phase-shift between the two series.

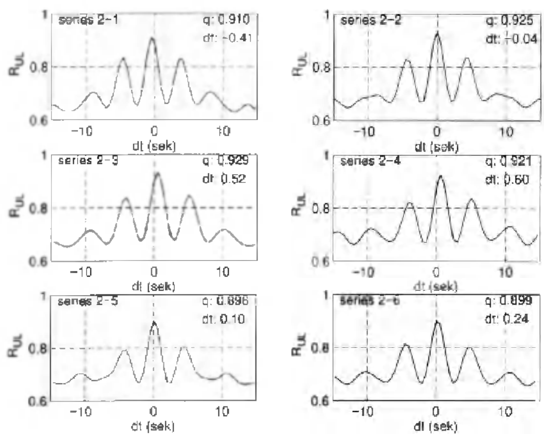

Fig. 6. Correlation between the energy at the upper- and lower meter, for the second expedition. Legends as in Fig. 5.

Table 1. Results from the ten series. The height above the bottom is for the lower meter. The differences in the depth of the water are due to tidal effects. The energy-density per. unit mass (E_U) is calculated as the sum of the squared horizontal velocities at the upper meter. The value of q is the factor between the squared horizontal velocity measured at the upper and at the lower meter.

Series no.	Lower-meters height above bottom (cm)	Water-depth (cm)	E_U (cm^2s^{-2})	q	dt (s)
1-1	140	595	353	0.93	0.48
1-2	140	587	324	0.92	0.51
1-3	140	567	521	0.93	0.72
1-4	100	535	508	0.94	0.97
2-1	160	620	234	0.91	-0.41
2-2	145	608	210	0.93	-0.04
2-3	129	589	199	0.93	0.52
2-4	108	582	156	0.92	0.60
2-5	74	583	165	0.90	0.10
2-6	15	583	158	0.90	0.24

RESULTS AND DISCUSSION

In all cases, the energy measured at the lower meter is about 5 to 8 % less than the energy measured at the upper meter (Table 1). There does not seem to be any appreciable difference between the velocity at any of the positions between 15 and 160 cm above the bottom. This indicates that the velocity-profile is uniform in the forest and that the change in profile takes place above the canopy, between 160 and 287 cm above bottom, which means that the effect of the kelp extends up into the water-column above the fronds.

In Figs 5 and 6 there does not seem to be any appreciable phase difference between the velocity measured by the lower meter and the velocity measured by the upper meter, although one would suspect the flow in the forest to lag behind the free flow. The little shift seen in some graphs are in the same order of magnitude as the uncertainty. This result is not conclusive, since it may quite possibly be due to an inaccurate synchronisation of the internal clocks in the two instruments. Further studies are planned in late summer 1995, where closer attention will be given to collecting more accurate measurements of phase characteristics.

ACKNOWLEDGEMENTS

We are indebted to stud. scient. Jan Erik Stiansen and the crew onboard the R/V *Hans Brattström* for their assistance during the expeditions to Lyroddane. We also thank Anita Jacobsen and Inge B. Johannessen for their constructive criticism of the manuscript.

REFERENCES

Andersen, K.H. 1995. *Dæmpning af overfladebølger over bladtang*. – M.Sc. thesis from IMFUFA, Roskilde University, Denmark. 121 pp.

Asano, T., H. Degushi & N. Kobayashi 1992. Interaction between water waves and vegetation. – *Proceedings of the 23 rd ICCE conference ASCE*, Venice :2710-2723.

Dubi, A. & A. Tørum 1994. Wave damping by kelp vegetation. – *Proceedings of the 24 th International conference on coastal engineering*, Kobe, Japan, 1994.

Fosså, J.H. & K. Sjøtun 1993. Tareskogsøkologi, fisk og taretråling. – *Fiskets Gang* 2.

Kobayashi, N., A.W. Raichle & T. Asano 1992. Wave attenuation by vegetation. – *Journal of waterway, port, coastal and ocean engineering, ASCE* 119:30-48.

Mork, M. 1996. The effect of kelp in wave damping. – *Sarsia* 80: 323-327.

Press, W.H., S.A. Teokolsky, W.T. Vetterling & B.P. Flannery 1992. *Numerical recipes. The art of scientific computing*. 2ed. – Cambridge University press. 963 pp.

Sivertsen, K. 1985. *Taretråling en mulig årsak til økt erosjon av sandstrender på Jærkysten*. – NDH-rapport 1985:6. 17pp.

— 1991. Høsting av stortare og gjenvekst av tare etter taretråling ved Smøla, Møre og Romsdal. – *Fisken og havet* no.1.

Wang, H. & A. Tørum 1994. *A numerical model on beach response behind coastal kelp fields*. – Rapport no. STF60 A94092, SINTEF, Norwegian hydrotechnical laboratory.

Accepted 15 June 1996.