Report of the National Research Center for Disaster Prevention, No. 5, March 1971

551.466:551.465:551.556.8(265.5)

"Overshooting" in Wind-Generated Waves

By

Yukio Fujinawa

Hiratsuka Branch, National Research Center for Disaster Prevention

Abstract

When waves are generated under the influence of wind, nonlinear effects are likely to become significant. Recently Barnett *et al.* asserted that wave components "overshoot" and "undershoot", as said in terms of electronics, after the phase of exponential growth. The present paper confirms this statement from a number of observations.

1. Introduction

Since Jeffreys' theory of sheltering coefficient, the generation of wind waves has been one of the most attractive problems of oceanography, but after more than forty years since him we have no satisfactory theory. Wind waves are generated and developed under the influence of wind blowing over the ocean surface, and strictly speaking, we could not solve the problem without a perfect knowledge of the wind structure over the ocean surface. But the wave-causing wind is in almost all of the cases turbulent, which is neither homogeneous nor isotropic, but a turbulence on the flexible boundary.

In the field of theoretical study of turbulence there are many investigations since Prandtl's mixing theory, but most of them are concerned with more specified turbulence such as homogeneous or isotropic one, and the turbulence near a wall is hardly said to be attacked. So it is not strange that we have practically no investigations of wind structure over a flexible boundary, the most general type of turbulence. But the wind waves are generated in fact and cause a great influence on the human life, and by some suitable assumption or from the experimental results we can properly describe the wind field over the sea and can research the mechanism of air-sea interaction, and inversely we could infer the wind structure from the wave motion. There are many investigations of the wind-wave development both in theory and observation or experiment. But usually in oceanography there are no definite results of observation. There are so many factors which influence each case of observation, and these extra terms can not be controlled by our force. In the laboratory we can not construct the experiments with an equal similarity and can only infer qualitatively, incapable of quantitative comparison with the theory. These circumstances may be a main cause which hinders the smooth development of oceanography.

O. M. Phillips (1957) proposed the resonance mechanism of water waves under the influence of the turbulent fluctuation of the air flow. This theory predicts the linear growth of wave component in resonance in time at the initial stage of wave generation. There are several observations supporting this theory, but more definite observation and consideration should be made. Miles (1957) calculated the effect of air fluctuation induced by the waves to the amplification of the waves. He assumed that this disturbance is in a neutral state, and used the stress formula after C. C. Lin (1955). But this assumption does not give serious modification and only changes the numerical constant (O. M. Phillips, 1966). Besides, there have been many observations of the amplification factor of wind waves. Some of them agree with Miles' prediction, and some give several times larger amplification rates. It is necessary to accumulate more experimental and observational results in regard to the wave development and to the influence of air flow on wind waves, before we can conclude whether or not his mechanism is correct.

Now, Miles' mechanism predicts that wave components grow exponentially

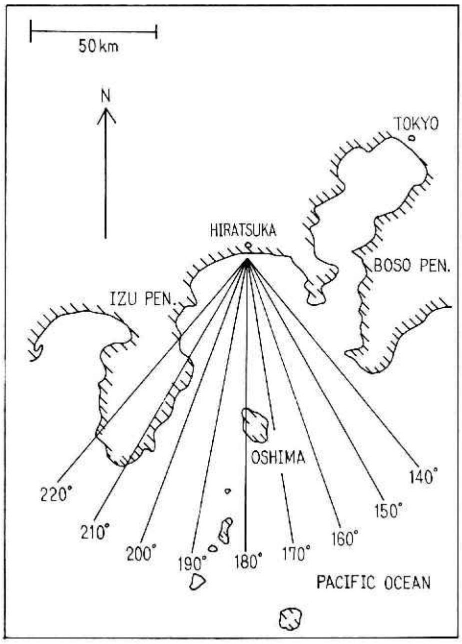

Fig. 1. Map around the Observation Tower.

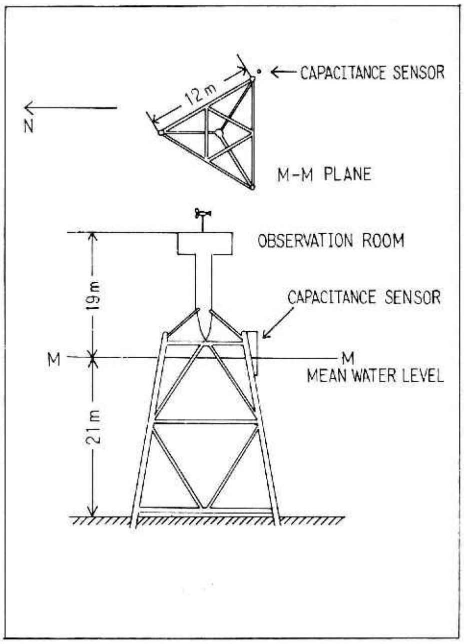

Fig. 2. Sketch of Marine Observation Tower.

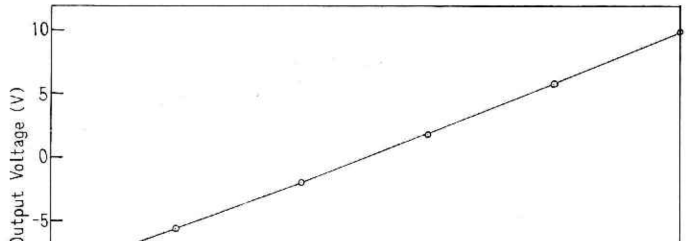

Fig. 3. Calibration curve of capacitance wave measuring system.

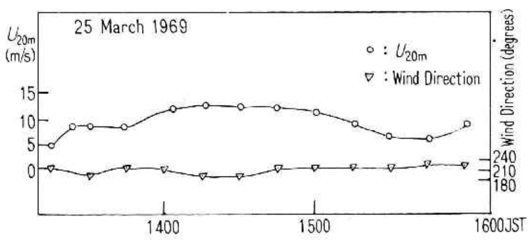

Fig. 4.1 Wind speed and direction at the height of 20 m from the mean water level.

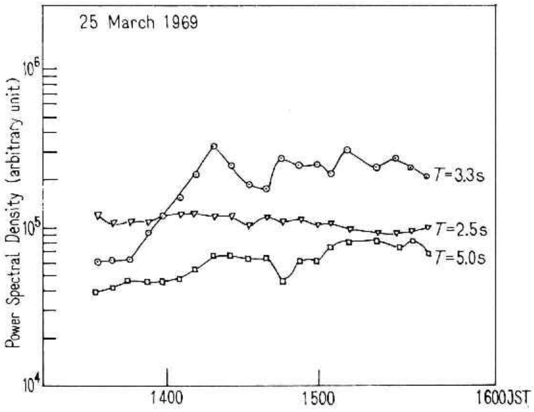

Fig. 4.2 Wave growth curve. Parameter T shows the wave period.

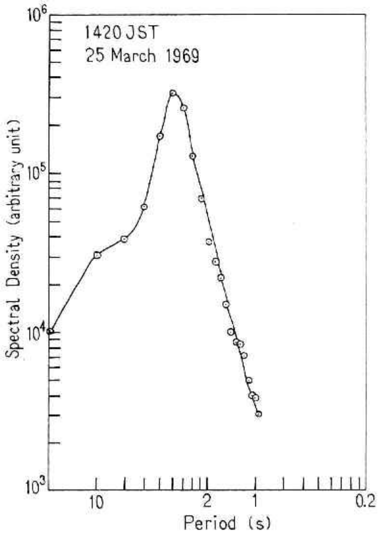

Fig. 4.3 Wave spectrum.

in time, but they can not grow indefinitely and are limited by the stability criterion. The wave number range, where the energy input from wind and the output by the breaking are equal, is called the equilibrium range, and the power spectral density $\Phi(n)$ is:

$$\Phi(n)=\beta g^2 n^{-5} ,$$

where n is the frequency, g the gravitational acceleration and β a constant (O. M. Phillips, 1958). But recently, Mitsuyasu (1969) asserts that β is not a constant but depends on the fetch or duration. Revealing of this fact will suggest the mechanism of equilibrium range which was usually treated only from dimensional analysis except Longuet-Higgins (1969).

Thus, as waves grow, nonlinear effect will emerge and a new fact will occur. Recently, Barnett *et al.* (1968) reported that waves do not reach the equilibrium value gradually, but "overshoot" and "undershoot", as said in terms of electronics. Our observation has confirmed this result. In the next paper we will try to explain this fact, taking account of nonlinear properties of wave field.

2. Observation

All the observations of this series have been done at the Marine Observation Tower of National Research Center for Disaster Prevention. The tower is situated at almost the center of the coast of Sagami Bay of the Pacific Ocean (Fig. 1). Mean water depth at the site of the tower is about 20 m and the tower is about 1 km distant from the coast (Fig. 2). The wave measuring detector is a capacitance wave measuring system, whose sen-

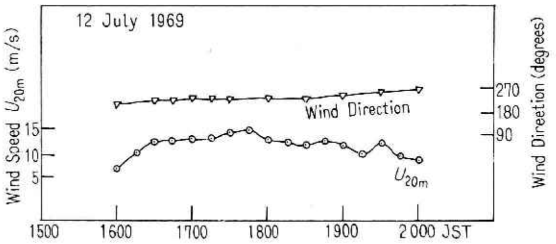

Fig. 5.1 Wind speed and direction at the height of 20 m from the mean water level.

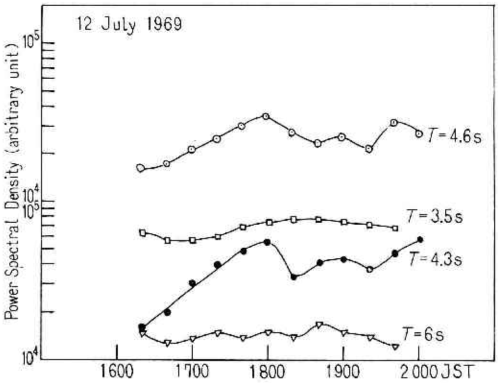

Fig. 5.2 Wave growth curve.

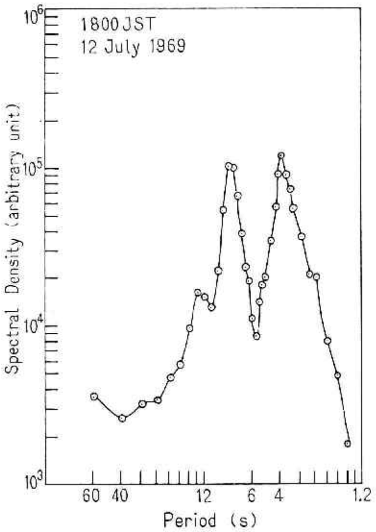

Fig. 5.3 Wave spectrum.

sor has a diameter of 5 mm. Its position of installation is shown in Fig. 2. Means of wind speed and direction are measured by the aerovane shown also in Fig. 2. Analog output voltage has been digitized and transmitted to the laboratory through cable and received by computer as paper tape.

Calibration of the wave measuring system is shown in Fig. 3, and the relation between the output voltage and the length of the probe immersed in the water is fairly linear.

3. Results

Observational results are shown from Fig. 4.1 to Fig. 7.3.

In the figures of Fig. 4 there are shown the observational results of 25 May 1969. Fig. 4.1 shows the wind speed at the height of 20 m from the mean water level U_{20m} and its direction, when wind began to blow relatively suddenly and blew constantly during the time concerned. Fetch can be inferred from Fig. 2 and wind direction. Fig. 4.2 is the growth curve of three wave components whose wave periods T are respectively 2.5, 3.3 and 5.0 sec. The wave component of $T=3.3$ sec does not increase in the early stage when wind speed is not strong, and as wind blows strong it increases exponentially and takes the appearance of "overshoot" and attains to maximum and minimum several times. On the other hand, the component $T=2.5$ sec remains nearly constant and may be in equilibrium state. And the longer component $T=5.0$ sec does not develop so fast, and seems to increase moderately. Power spectral density of wave field, almost at the time when the component $T=3.3$ sec over-

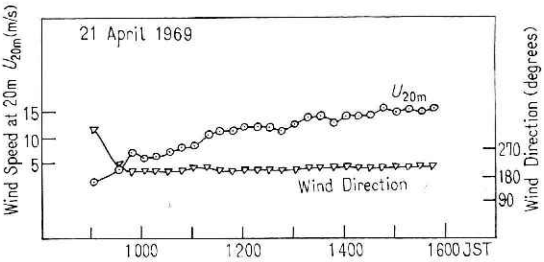

Fig. 6.1 Wind speed and direction at the height of 20 m from the mean water level.

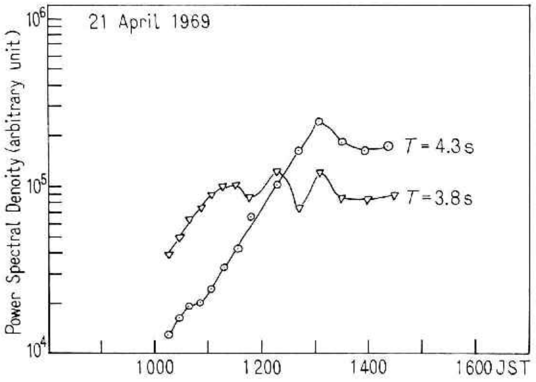

Fig. 6.2 Wave growth curve.

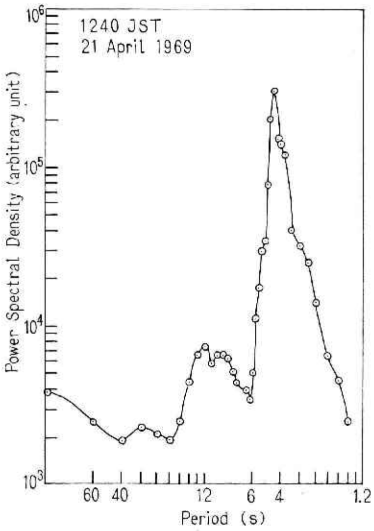

Fig. 6.3 Wave spectrum.

shoots, is shown in Fig. 4.3. This shows that the overshooting component has a period a little shorter than an optimum wave.

The figures of Fig. 5 show the results of data of 20 July 1969. Wind direction is nearly constant, but fetch is rather small. Fig. 5.2 represents the time change of four wave components of $T=6$, $T=4.6$, $T=4.3$ and $T=3.5$ sec, respectively. Two wave components of $T=4.6$ and $T=4.3$ sec show large overshoot and the component of $T=4.3$ sec has a significant undershoot. Other two components remain rather constant because of a state of equilibrium or very low energy input from wind field. Fig. 5.3 shows the wind wave spectrum at the time when overshoot is evident; in this case two overshooting components have longer periods than the optimum component has.

The figures of Fig. 6 show the results obtained on 2 April 1969. The wind blew in a very constant direction, but wind speed tended to be stronger (Fig. 6.1). Growth curves of two wave components are shown in Fig. 6.2. The component of $T=4.3$ sec develops in a linear manner in time at the early stage, and then grows exponentially and overshoots. On the other hand, shorter components faster reach the equilibrium range and take their maximum larger than the value at the time of overshooting in the late stage. Fig. 6.3 shows the wind wave spectrum at 12 h 40 m JST, and can be said to be a typical spectrum with a small swell component.

The figures of Fig. 7 show the results obtained on 11 May 1969. On that day the wind began to blow suddenly as is seen from Fig. 7.1, and the fetch was longest in the

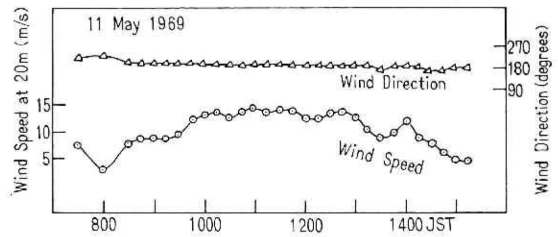

Fig. 7.1 Wind speed and direction at the height of 20 m from the mean water level.

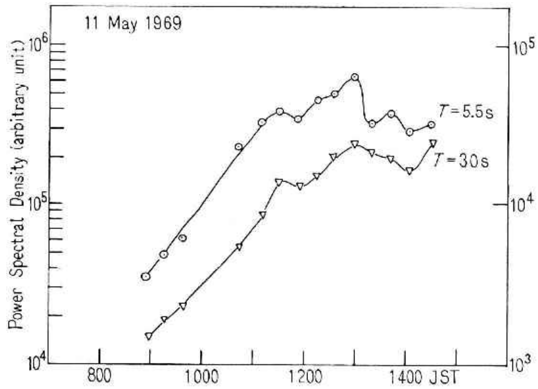

Fig. 7.2 Wave growth curve. Right-hand ordinate shows the component of $T=30$ s.

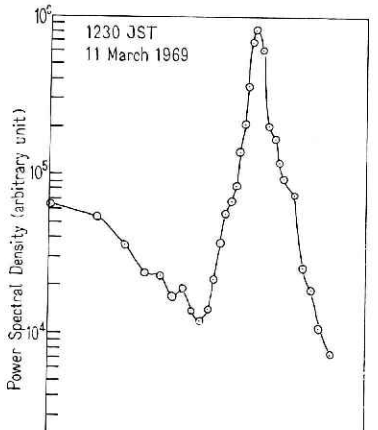

Fig. 7.3 Wave spectrum.

series. Growth curves of two wave components are represented in Fig. 7.2. The component of $T=5.5$ sec has a rather small amount of overshoot and some time later a larger overshoot can be seen. However, this may be due to the weakening of wind as is seen from Fig. 7.1. The very long wave component of $T=30$ sec shows an extraordinarily large growth rate that can not be explained by Miles' mechanism. Such a situation occurred only once in the series and more data should be accumulated, if we wish to decide whether or not this is a natural phenomenon. Fig. 7.3 shows the spectral density at the time of evident overshoot.

4. Conclusion

From several observations described above, we might say that overshooting and undershooting in the wave development really exist. Observations show that the wave component, which is thought to be in a state of equilibrium, does not always remain constant but fluctuate in time under the influence of wind. Usually this fluctuation is treated as a noise, but if we take account of the overshooting and undershooting, this fluctuation will become physically significant and some suggestion will be obtained as to the equilibrium constant β.

References

1) Phillips, O. M. (1957): On the generation of waves by turbulent wind. *J. Fluid Mech.*, **2**, 417-445.
2) Miles, J. W. (1957): On the generation of surface waves by shear flows. *J. Fluid Mech.*, **3**, 185-204.
3) Lin, C. C. (1955): *The Theory of Hydrodynamic Stability*. Cambridge Univ. Press, London, 155 p.

4) Phillips, O. M. (1966): *The Dynamics of the Upper Ocean.* Cambridge Univ. Press, London, 261 p.
5) Phillips, O. M. (1958): The equilibrium range in the spectrum of wind generated waves. *J. Fluid Mech.*, **4**, 426-434.
6) Mitsuyasu, H. (1969): On the development of wind wave spectrum (2). *Nippon Kaiyō Gakkai Shūki Taikai Kōen Yokōshū.*
7) Longuet-Higgins, M. S. (1969): On wave breaking and the equilibrium spectrum of wind generated waves. *Proc. Roy. Soc. A*, **310**, 151-159.
8) Barnett, T. P. and Sutherland, A. J. (1968): A note on an overshoot effect in wind-generated waves. *J. Geophys. Res.*, **73**, 6877-6885.

(Manuscript received 10 December 1969)

風浪における行過ぎ量

藤縄幸雄

国立防災科学技術センター平塚支所

波浪の発達において初期段階でフィリプス (O. M. Phillips) の，また主発達段階ではマイルズ (J. W. Miles) の機構が，量的にはともかく，作用しているらしいといわれている．主発達段階から平衡領域に近づくにしたがって波浪場の非線形性が顕著になると思われるが，最近，電子工学の用語でいう行過ぎの現象があるのではないかといわれはじめた．ここでは観測からその存在を確かめた．