Special Contributions, Geophysical Institute, Kyoto University, No. 6, 1966, 95-99

A NOTE ON THE FRICTION COEFFICIENT OBTAINED BY THE WIND PROFILE METHOD FROM OUR WIND FLUME EXPERIMENTS

By

Norihisa IMASATO

(Received November 15, 1966)

Abstract

The effect of the zero-plane displacement of the wind profile over the wind waves on the friction coefficient is presented here by using data from our wind flume experiments. The zero-plane where the wind profile is closest to the logarithmic profile is found at a somewhat higher place than the mean wave crest and at a lower place than the mean wave trough. This fact seems to show that the wind profile over the wind waves is a little different from the logarithmic profile.

1. Introduction

The problem of shear stress over the water surface is essential in considering wave generation and growth. In 1963 Kunishi [1963] discussed this problem in a report on his wind flume experiment. He showed that the friction coefficient increased with wind speed, and that its dependence on the fetch was very slight. In 1966 Kunishi and the present author [1966] experimented on wave growth under the high wind speed (8-34 m/sec) using the high-speed wind flume of Kyoto University.

The latter results were generally considered to be an extension of the former. However, the existence of some different situations was also considered from the analyses. One difference was distinguished in the behavior of roughness length z_0. In the latter experiments, although waves were at the sea wave stage, gz_0/w_*^2 was not constant, and slowly decreased with $w_*\bar{H}/\nu_a$, depending on the fetch, where w_* is the friction velocity, $\bar{H}$ the mean wave height, and ν_a the kinematic viscosity of the air. Therefore, γ^2 increased with the wind speed obviously depending on the fetch.

In these analyses the equation which gives the relation between the mean wind speed and the height under the adiabatic condition,

$$W=\frac{w_*}{k}\ln\frac{z_0}{z} \tag{1}$$

has been used, where k is Kármán constant and zero-plane is assumed to be the mean water level. There is no difinite reason why the mean water level must be chosen as the zero-plane of the wind profile. If there were an analogy between the rough flow in the pipe and the turbulent boundary layer over the wind waves, the zero-plane of the wind profile should be taken at the mean wave trough. However, if the zero-plane is shifted from one height to another, γ^2 will have a different value, for γ^2 is another expression of z_0.

In this paper, the well-known empirically modified wind profile equation,

$$W=\frac{w_*}{k}\ln\frac{z-d}{z_0} \tag{2}$$

is used, where d is the zero-plane displacement. The relation between d and z_0, and the connection between the change of these values and the wave phenomena is studied by using data of the wind profile in our wind flume experiments (kunishi [1963], Kunishi and Imasato [1966]). If the wind profile over the wind waves takes the logarithmic form, it is important to know where the zero-plane is, when our experimental data are closest to the logarithmic profile.

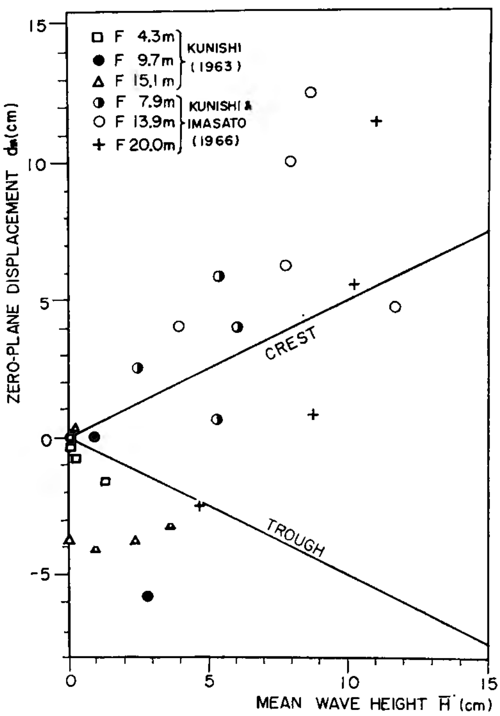

Fig. 1. Relation between the mean wave height $\bar{H}$ and the zero-plane displacement d_m which gives the minimum value of the mean square of the residual from the logarithmic wind profile. Capital letter F indicates the fetch.

2. Analysis

From equation (2) and our data the mean square of residual from the logarithmic wind profile for an arbitrarily given d can be calculated by the method of least square; then d_m which gives the minimum value of this mean square of residual can be found. Therefore, d_m gives the position of the zero-plane where the wind profile is closest to the logarithmic one. The relation between d_m and the mean wave height $\bar{H}$ is shown in Fig. 1. Two lines are given; one corresponds to the mean wave crest and the other to the mean wave trough.

From this figure, we find that the points of d_m's from Kunishi's experiment lie below the mean wave trough and those from Kunishi-Imasato's lie above the mean wave crest.

As is well-known, the relationship over the rough surface is expressed as the equation,

$$W=\frac{w_*}{k}\ln\frac{z}{K}+A_r\left(\frac{w_*K}{\nu_a}\right), \tag{3}$$

where K is the roughness height. From equations (1) and (3), we can derive the quantity C_r, which is the function of w_*K/ν_a alone and can be written as follows;

$$C_r=-5.75\log\frac{w_*z_0}{\nu_a}. \tag{4}$$

It is clearly found to be another expression of z_0. Kunishi [1963] used this relationship and showed that the wave height can be considered the roughness height. If we assume $K=\bar{\mathrm{H}}$ as he did, we get Fig. 2, which gives the relation between d and z_0.

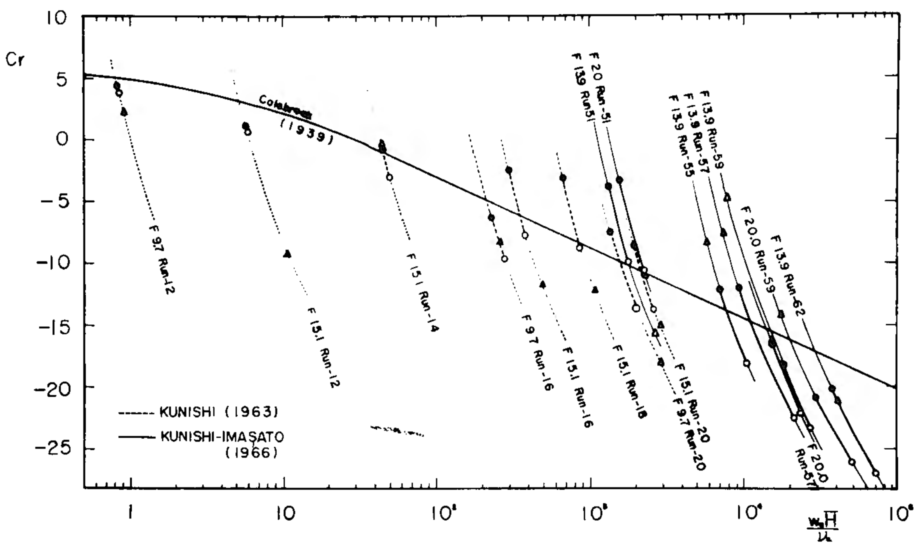

Fig. 2. Change of the roughness length z_0 with the zero-plane displacement d.

In this figure, the broken lines show the relation obtained from Kunishi's experiment, and the full lines from that by Kunishi and Imasato; these lines will be called z_0-lines in this paper. Also black circles, open circles and triangles show values of C_r obtained when the zero-plane is taken at the mean wave crest, at the mean wave trough, and at the height of $d=d_m$, respectively. The curve established by Colebrook [1939], which is shown in this figure, crosses each of the z_0-lines between the open circles and black circles, when $w_*\bar{\mathrm{H}}/\nu_a$ is smaller than 1.5×10^4. Each of these cross points gives the zero-plane displecement d_0 to be taken in cases where the waves are considered to give wholly the same effect as the roughness of a solid rough surface. It looks similar to a case where zero-plane d_0 is found between the mean wave crest and trough, but the wind profile for this displacement d_0 is different from the closest logarithmic profile.

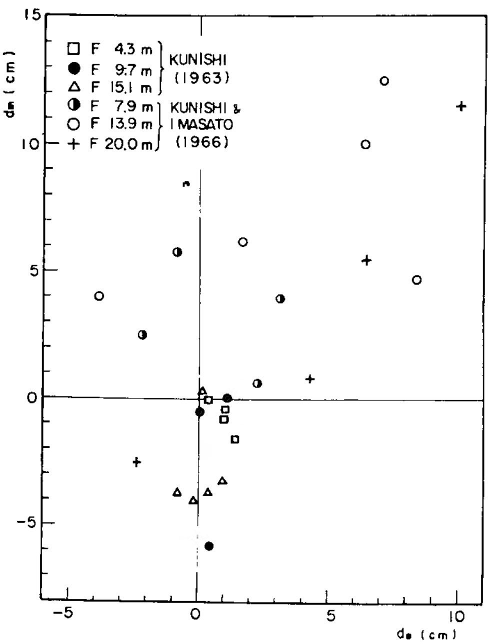

Fig. 3. Relation between d_m and d_0.

Fig. 3 shows the relation between d_m and d_0. Data scatter widely and d_m does not seem to have any correlation with d_0 except for the large value of d_0. In the region where $w_*\bar{H}/\nu_a$ is larger than 1.5×10^4, the zero-plane d_0 does over the mean wave crest, and d_0 seems to come near to d_m. This value of $w_*\bar{H}/\nu_a$ corresponds to the state in which the wind speed is more than about 20m/sec in the center of the wind tunnel and the wind begins to cause a strong spray from the water surface.

3. Conclusion

As is above described, the zero-plane which gives the wind profile closest to the logarithmic form is found at a rather lower position than the mean wave trough from Kunishi's experimental data and at a rather higher position than the mean wave crest from Kunishi-Imasato's.

There seem to be two possibilities in explaining this difference. If the logarithmic wind profile is valid in the boundary layer over the wind waves, we must consider the wind waves have not wholly the same nature as the roughness of the solid wall. In this case, friction coefficient γ^2 becomes larger by some 50-80% in Kunishi's experiment and smaller by some 40-60% in the Kunishi-Imasato's than in the case when the zero-plane is taken at the mean water level. It seems, however, in Fig. 2, to be natural to consider that the waves have the analogous nature of Colebrook's natural roughness at least in the region $w_*\bar{H}/\nu_a$ $<1.5\times10^4$. Concerning this point of view, the author is of the opinion that the wind profile over the wind waves is a little different from the logarithmic form, though he cannot now decide what expression is the most suitable for the wind profile. If the wind profile can be approximated to be logarithmic and the zero-plane is taken at $d=d_0$, friction coefficient γ^2 will change within about 20-30% of that in the case $d=0$.

In order to settle these problems and to solve the mechanism of wave generation and growth, it is necessary to evaluate shear stress by other ways such as the flux method etc. It is also necessary to compare our experimental data with theories about this problem such as those of Miles or Phillips. We are now starting to do this work by calculating the energy spectra of waves obtained from our experiments.

Acknowledgements

The author wishes to express his heartfelt thanks to former Prof. Hayami, and also to Prof. Kunishi for his encouragement and the use of his experimental data.

References

Colebrook, C. F., 1939 ; Turbulent flow in pipes, with particular reference to the transition region between the smooth and rough pipe lows, J. Inst. Civil Engrs., **11**, 133-156.

Kunishi, H., 1963 ; An experimental study on the generation and growth of wind waves, Bull. Des. Prev. Res. Inst. Kyoto Univ., No. 61, 1-41.

Kunishi, H. and N. Imasato, 1966 ; On the growth of wind waves by high-speed wind flume, Annuals, Des. Prev. Res. Inst. Kyoto Univ., No. 9, 667-676 (in Japanese).