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ESTIMATED VALUES OF BOTTOM FRICTION FACTORS OF SOME JAPANESE COASTS

By

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Abstract

In order to forecast shallow water ocean waves, the value of the bottom friction factor in shallow water has to be given for estimation of wave energy loss due to bottom friction.

In this paper, from the damping of the significant wave heights and the transformation of the wave spectra observed off some Japanese coasts, the bottom friction factors are computed and the relationship between the bottom friction factor and the wave Reynolds number is presented.

It should be noted that the estimated values of bottom friction factors of some Japanese coasts are much greater than 0.01, which was given by Bretschneider to be generally used in forecasting shallow water ocean waves.

1. Introduction

The relationship between the bottom friction factor in shallow water and wave characteristics with the bottom condition has to be well known in forecasting shallow water ocean waves.

The bottom friction factor f is defined by the following expression (PUTNAM and JOHNSON [1949]):

$$\tau = f\rho u_b^2, \tag{1}$$

where τ is the bottom shear stress, u_b the velocity of water particles on the bottom, and ρ the density of water. In 1952 to 1953, BRETSCHNEIDER [1954] carried out the field investigations on the loss of wave energy in shallow water in the Gulf of Mexico and obtained the values of 0.053~0.08 as the bottom friction factor. On the other hand, it was found that in his figure of $gH_{1/3}/U^2$ against gh/U^2 representing the development of wind waves in shallow water, the theoretical curves derived under the assumption that the bottom friction factor is equal to 0.01 have the best fit for the steady state wave data (BRETSCHNEIDER [1954]), where $H_{1/3}$ is the significant wave height, h the mean water depth, U the wind velocity, g the acceleration of gravity. Therefore, the shallow water wave height has been estimated by using $f=0.01$ since he proposed his figures of shallow water wave forecasting (BRETSCHNEIDER [1958]). But the applicability of the figures based on the bottom friction factor of 0.01 to the Japanese coasts is not confirmed yet and in addition, the reason why the values of the bottom friction factor obtained by the field observations are different from that used in the estimation of shallow water wind waves is not clarified. In Japan, KISHI [1954] obtained the values of 0.03~0.04 as the bottom friction factor of the Niigata coast from the wave height reduction between two stations as far as approximately 40 meters, using the wave data which Ijima obtained by the stereoscopic method, though this estimation of the bottom friction factor by Kishi seems to be questionable in accuracy.

In this paper, from the damping of both significant and mean wave heights and the transformation of the wave spectra observed off some Japanese coasts, the loss of wave energy due to bottom friction is investigated and the bottom friction factors are estimated. Finally the estimated bottom friction factors are plotted against the wave Reynolds number and it is shown that the bottom friction factor is dependent upon the wave Rynolds number.

2. Formula for estimation of bottom friction factor

BRETSCHNEIDER and REID [1954] proposed the following expression of the bottom friction factor f from the energy equation of steady state waves considering the effects of bottom friction, percolation, refraction, and change of group velocity for the bottom condition of constant slope m:

$$f=\frac{\{H_1(K_pK_rK_s)_2/H_2(K_pK_rK_s)_1\}-1}{\dfrac{H_1}{(K_s)_1 mT^2}\displaystyle\int_{(h/T^2)_1}^{(h/T^2)_2}\frac{\phi_f K_p K_r}{(K_pK_r)_1}d(h/T^2)}, \tag{2}$$

where suffix 1 denotes the conditions at the offshore-side station, suffix 2 the conditions at the onshore-side station, H the wave height, K_p the wave height reduction factor due to percolation (REID and KAJIURA [1957]), K_r the refraction factor, K_s the shoaling factor, h the water depth, T the wave period, and

$$\phi_f=\frac{64\pi^3}{3g^2}\left(\frac{K_s}{\sinh 2\pi h/L}\right)^3, \tag{3}$$

where L is the wave length.

In estimating the bottom friction factor, Eqs. (2) and (3) are used in this paper.

3. Estimated values of bottom friction factors of some Japanese coasts and their relationship against wave Reynolds number

Using the wave data obtained by the field observations, the bottom friction factors of the Akita coast (IWAGAKI and KAKINUMA [1963]), the Izumisano coast (IWAGAKI and KAKINUMA [1965]), the Nishikinohama coast (IWAGAKI, KAKINUMA and MIYAI [1965]), the Hiezu coast (IWAGAKI and KAKINUMA [1965]), and the Takahama coast have been calculated based on Eq. (2).

Teble 1 presents the conditions of the coasts corresponding to run numbers of wave observations and **Table 2** shows the values of bottom friction factors estimated by the significant wave method together with the data of significant

Table 1. Conditions of each coast

Location	Water depth		Bottom slope	Median diameter of bottom material (mm)	Run No.
	h_1(m)	h_2(m)			
Akita coast	15.0	3.2	5.83×10^{-3}	0.41	A-1~4
Izumisano coast	5.7	4.3	4.27×10^{-3}	2.08	I-1
Hiezu coast (63)	11.8	3.4	1.10×10^{-3}	0.17	H-1~10
Nishikinohama coast	8.6	7.1	3.66×10^{-3}	0.28	N-3~5
	8.6	6.2	〃		N-1′~2′
	7.0	6.1	〃		N-1″~6
	6.0	2.4	1.81×10^{-2}		N-6′~7′
Hiezu coast (64)	13.5	9.8	6.03×10^{-3}	0.17	H′-2~9
Takahama coast	9.8	6.3	5.74×10^{-3}	0.17	T-1~12

Table 2, Values of bottom friction factors of some Japanese coasts by significant wave method

Run No.	Date	Time	Significant wave				Bottom friction factor, f	Wind above land		Wave direction
			H_1 (m)	T_1 (sec)	H_2 (m)	T_2 (sec)		Speed (m/sec)	Direction	
A-1	3rd Dec. 61	1300	1.02	7.4	0.80	—	0.058	5.0	NW	NW
A-2	〃	1500	0.82	7.2	0.74	—	0.033	5.5	NNW	WNW
A-3	4th Dec. 61	1100	0.60	7.1	0.47	—	0.090	2.0	N	NNW
A-4	〃	1300	0.50	7.8	0.46	—	0.049	2.3	NE	NW
I-1	24th Feb. 63	1220	0.86	3.7	0.77	3.8	0.14	13.5	WNW	WNW
H-1	3rd Oct. 63	1209	0.67	5.1	0.53	5.5	0.13	10.1	NNE	NNE
H-3	〃	1414	0.82	5.2	0.72	6.0	0.083	11.2	〃	〃
H-4	〃	1521	0.93	5.2	0.69	6.2	0.061	10.5	〃	〃
H-5	〃	1614	0.82	4.9	0.71	6.3	0.096	10.1	〃	〃
H-7	5th Oct. 63	1042	1.11	5.5	0.96	5.0	0.027	7.8	NE	〃
H-8	〃	1103	1.03	5.6	0.81	5.2	0.12	7.8	NNE	〃
H-9	〃	1156	0.97	5.1	0.83	6.1	0.091	9.0	〃	〃
H-10	〃	1215	0.92	5.7	0.85	6.2	0.058	8.0	NE	〃

N-3	1st Feb. 64	1130	0.76	3.9	0.72	3.7	0.53	7.3	WNW	WNW
N-4	〃	1230	0.86	3.9	0.81	3.6	0.37	9.4	NW	〃
N-5	〃	1420	0.89	3.9	0.80	4.6	0.37	7.5	WNW	〃
N-1′	31st Jan. 64	1620	0.77	3.4	0.65	3.4	1.16	8.5	〃	〃
N-2′	〃	1710	0.78	3.9	0.76	3.8	0.32	11.1	NW	〃
N-1″	〃	1620	0.72	3.3	0.65	3.4	0.89	8.5	WNW	〃
N-2″	〃	1710	0.88	3.9	0.76	3.8	0.33	11.1	NW	〃
N-6	4th Feb. 64	1140	0.77	3.5	0.70	3.5	0.92	6.9	NNE	NNW
N-6′	〃	1140	0.70	3.5	0.57	3.3	0.28	6.9	〃	〃
N-7′	〃	1540	0.51	3.0	0.42	3.1	0.37	6.2	〃	NW
H′-2	2nd Dec. 64	1405	1.95	10.0	1.85	10.0	0.06	0.3	E	N
H′-3	〃	1434	2.36	10.6	2.13	10.5	0.07	2.5	〃	〃
H′-5	〃	1527	2.02	10.1	1.98	9.6	0.04	1.3	〃	〃
H′-6	〃	1546	1.92	9.3	1.91	10.3	0.03	1.1	〃	〃
H′-7	3rd Dec. 64	1349	2.31	13.0	2.15	14.0	0.06	7.1	〃	NNE
H′-8	〃	1414	2.32	12.4	2.41	13.6	0.01	6.5	〃	〃
H′-9	〃	1434	2.47	14.6	2.23	15.5	0.06	4.8	〃	〃
T-1	10th March 65	1141	1.26	7.4	1.25	7.8	0.03	0.5	W	NNE
T-7	〃	1551	1.49	10.0	1.35	10.2	0.06	0	〃	N
T-9	11th March 65	1100	1.39	11.4	1.38	12.5	0.03	0	〃	〃
T-12	〃	1530	1.44	11.4	1.16	11.5	0.08	0	E	NNE

Note: $h_2/L_2<0.4$ and the relative error of bottom friction factor is smaller than 50%.

waves and wind.

Fig. 1 shows the relationship between the estimated bottom friction factor and the wave Reynolds number R_{eT}, which is defined by $u_b{}^2{}_{max}T/\nu$ (ν: the kinematic viscosity of sea water) and in this case $R_{eT}=[(R_{eT})_1+(R_{eT})_2]/2$. The relationship based on the laminar wave boundary layer theory (Eagleson [1962])

$$f=2.08R_{eT}{}^{-1/2} \tag{4}$$

is also presented for comparison in this figure.

4. Conclusion

From the result of the wave observations off some Japanese coasts, the bottom friction factors were estimated and the relationship between the bottom friction factor and the wave Reynolds number was found.

It should be noted that the estimated values of bottom friction factors of some Japanese coasts are much greater than 0.01, which was given by Bretschneider to be generally used in forecasting shallow water ocean waves.

It is concluded that the estimated values of the bottom friction factors of some Japanese coasts f are

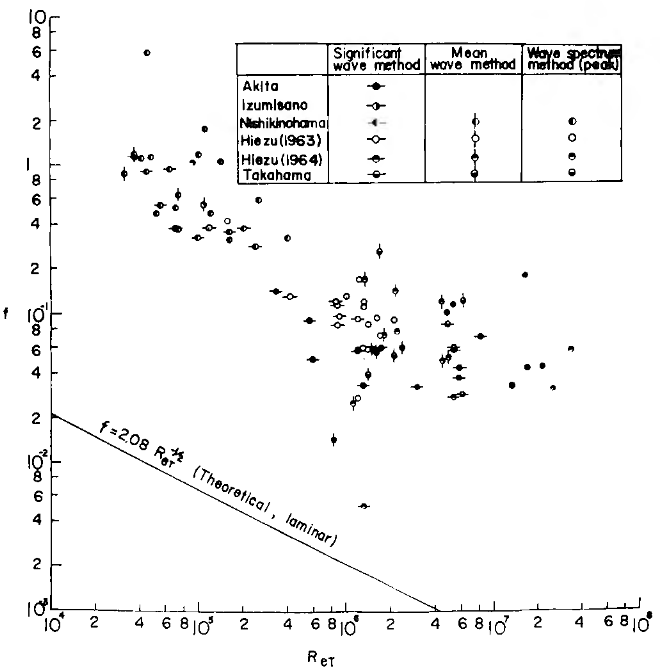

Fig. 1. Bottom friction factors of some Japanese coasts.

(1) in the case of the significant wave method,
$f=0.027\sim0.091$ for $10^{6}\leqq R_{eT}<8\times10^{6}$ (quadratic drag region),
(2) in the case of the wave spectrum method (spectral peak only),
$f=0.032\sim0.18$ for $(1\sim2)\times10^{6}<R_{eT}<3.3\times10^{7}$ (quadratic drag region), and
(3) for $R_{eT}<10^{6}$, the bottom friction factors increase with decrease in the wave Reynolds number.

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