CHAPTER 263

PREDICTION OF SHORELINE CHANGE CONSIDERING CROSS-SHORE SEDIMENT TRANSPORT

Yoshimichi Yamamoto[1], Kiyoshi Horikawa[2], Katsutoshi Tanimoto[3]

ABSTRACT

Relations of cross-shore sediment transport rate with the grain size of sediment, the sea bottom slope in a surf zone and others were investigated by using data of field observation and large scale model experiments. The results are as follows :

(1) the coefficient of a cross-shore sediment transport rate varies inversely as the 1.31th power of the grain size. Then, the steeper a initial bottom slope is, the faster a beach profile reaches a state of equilibrium.

(2) The amount of a shoreline change is roughly proportional to the square root of the cross-shore sediment transport rate.

(3) The stabilized bottom slope in the surf zone increases with the grain size and the wave period, and it decreases as the breaking wave height increases.

Then, new equations to predict a beach profile change induced by cross-shore sediment transport were introduced from this investigation. Moreover, the adequate applicability of these equations to actual coasts was confirmed.

1. INTRODUCTION

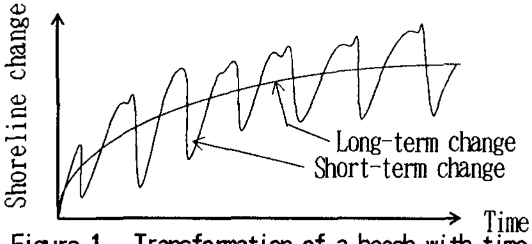

Figure 1 Transformation of a beach with time.

As practical models for predicting long-term transformation of long beaches, a shoreline change model and Uda et al.'s contour change model (1991, 1996) were proposed. However, these numerical models do not take cross-shore sediment transport rate into consideration. In designing measures to control coastal erosion and wave overtopping, it is necessary to take account of short-term beach transformation under stormy weather condition in addition to the long-term transformation as shown in Figure 1. The short-term transformation, which cannot be

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determined without considering the cross-shore sediment transport, can be predicted by means of 2 or 3 - dimensional beach transformation models combined with the computation of waves and currents (e.g., Horikawa, 1988; Sato, 1994; Shibayama et al., 1994). However, it is difficult to apply these models to long-term prediction of long beaches, because long computational time is required and numerous coefficients introduced in sand transport rate formulas have not yet been generalized.

In this study, an attempt was made to generalize the coefficient of cross-shore sediment transport rate formulas. Moreover, a convenient beach evolution model using this result was proposed and applied to actual coasts.

2. CROSS-SHORE SEDIMENT TRANSPORT NEAR SHORELINE

Sunamura (1984) proposed the following formula for calculating cross-shore sediment transport rate, Q near the shoreline per unit time and unit beach width :

$$Q = K U_r^{0.2} \phi(\phi - 0.13 U_r) w d \qquad (1)$$

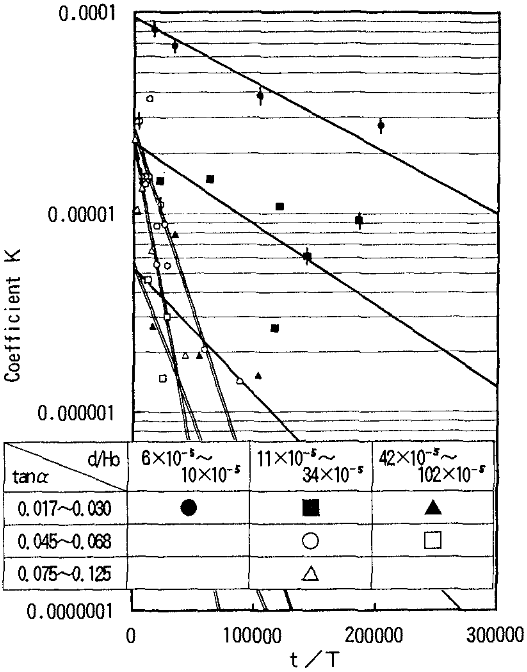
where K : a coefficient of sediment transport rate, U_r : Ursell parameter [$= gHT^2/h^2$], ϕ : Hallermeier parameter [$= H^2/shd$], w : the settling velocity of sediment, d : the median grain size of sediment, g : the acceleration of gravity, h : the wave setup height at shoreline against the still water level [$= (1.63 \tan\alpha + 0.048) H_b$, Sasaki and Saeki (1974)], H : the wave height at shoreline against the still water level [$= 2.4(\tan\alpha)^{0.3} h$ Yamamoto(1988)], T : the wave period, s : the specific gravity of sediment in water, $\tan\alpha$: the initial bottom slope in the surf zone, H_b : the breaker height.

Now, let us generalize the coefficient K of Eq. (1). As long as external forces remain constant, the rate of cross-shore sediment transport decreases with the lapse of time, and the beach profile approaches the equilibrium state. Therefore the coefficient K can be expressed by the following equation with the elapsed time t:

$$K = A \cdot e^{-Bt/T} \qquad (2)$$

where A and B are coefficients.

Then, we assume that the coefficients A and B are dominated by $\tan\alpha$ and d/H_0 (H_0 is the wave height in deep water), and investigate relations of these coefficients with $\tan\alpha$



tanα \ d/Hb	6×10⁻⁵~10×10⁻⁵	11×10⁻⁵~34×10⁻⁵	42×10⁻⁵~102×10⁻⁵
0.017~0.030	●	■	▲
0.045~0.068		○	□
0.075~0.125		△	

Figure 2 Relationship of the coefficient K with t/T.

and d/H_0 by using data of field observation and large scale model experiments given in Tables 1 ~ 4 in the appendix.

Figure 2 is a semilogarithmic graph of the relationship between K and t/T based on these data. Symbols with a vertical segment mean field data and other symbols mean experimental data. Then, average values of significant waves are used for the wave height and the wave period of irregular waves, because data of significant waves are used in many countries. However, experimental data of regular waves are used in order to supplement lack of data. Each straight line in this figure shows a tendency of data of each group. When t/T is 0, K (= A) varies greatly depending on the value of d/H_0, but changes very little depending on the value of tanα. Thus, the coefficient A is dominated strongly by d/H_0. Moreover, the slope of the straight lines in this figure varies widely depending on the value of tanα, while it is little affected by the value of d/H_0. This means that the coefficient B is strongly dominated by tanα.

tanα \ d/Ho	6×10^{-5}~ 10×10^{-5}	11×10^{-5}~ 34×10^{-5}	42×10^{-5}~ 102×10^{-5}
0.017~0.030	●	■	▲
0.045~0.068		○	□
0.075~0.125		△	

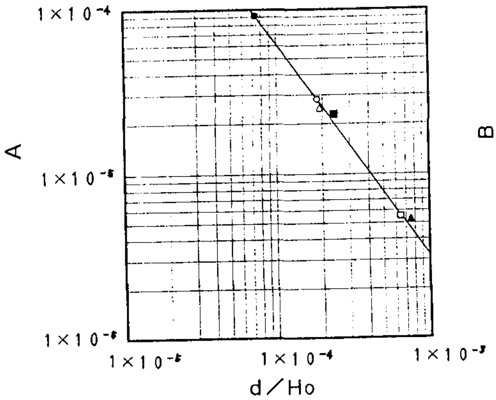


Figure 3 Relationship of A with d/H_0.

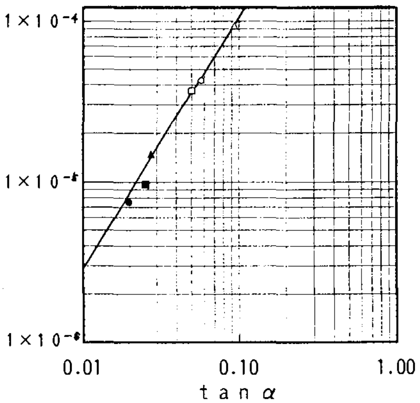


Figure 4 Relationship of B with tanα.

Figure 3 illustrates the relationship of the coefficient A with d/H_0 and Figure 4 shows the relationship of the coefficient B with tanα. As these figures indicate clearly that the coefficient A increases as d/H_0 falls and the coefficient B increases with tanα. Namely, the smaller the grain size of sediment is the larger the coefficient A is and the steeper the sea bottom slope is the faster the beach profile reaches the equilibrium state. These relations can be expressed by the following equations :

$$\left.\begin{array}{l} A = 3.61\times10^{-10}(d/H_0)^{-1.31},\quad B = 4.20\times10^{-3}(\tan\alpha)^{1.57} \\ [\tan\alpha = 0.017\sim0.125,\quad d/H_0 = 0.00006\sim0.00102] \end{array}\right\} \qquad (3)$$

The rate of cross-shore sediment transport near the shoreline can be obtained from Eqs. (1), (2), and (3). Figure 5 shows the comparison between measured values and calculated values obtained from data shown in Tables 2 and 4. This figure shows that the calculated values agree fairly well with the measured values.

3. SHORELINE CHANGE DUE TO CROSS-SHORE SEDIMENT TRANSPORT

Let us consider a simplified pattern of beach profile change, as shown in Figure 6, due to cross-shore sediment transport. Transforming slightly the continuity equation of cross-shore sediment transport, we can obtain the shoreline displacement as $\Delta y \propto (\int_0^t Q\,dt)^{0.5}$. Moreover, by using the data shown in Tables 2 and 4, the following equation can be obtained:

$$\Delta y = 2.7\,(\int_0^t Q\,dt)^{0.5} \quad (4)$$

Therefore, the shoreline displacement due to cross-shore sediment transport can be calculated by using Eq. (4).

Figure 7 compares the measured values shown in Tables 2 and 4 with the calculated values given by Eq. (4). The data marked with + mean cases that initial bottom slopes above the still water level are steep by cliffs or steps. This figure shows that the calculated values agree well with the measured values. However, since Eq. (4) is intended for the simple beach profile change due to cross-shore sediment transport, Application of Eq. (4) to shores undergone complex beach changes should be preceded by careful study.

By combining the above equations with a formula for calculating the stable slopes of sea bottoms, the beach pro-

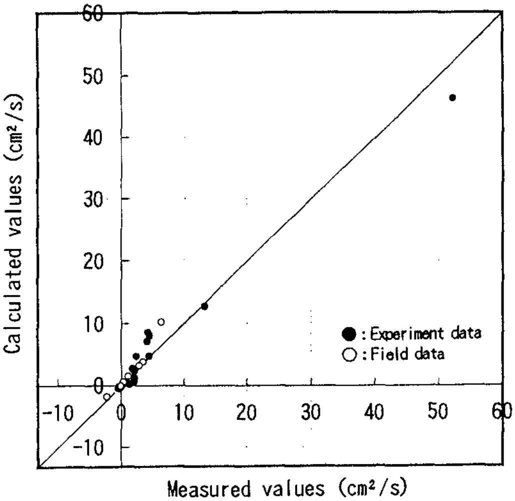


Figure 5 Measured vs. calculated values of cross-shore sediment transport rate.

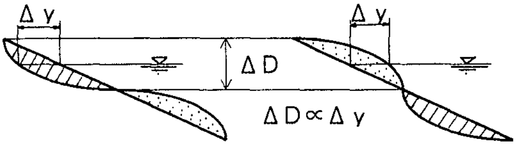


Figure 6 Patterns of beach change due to cross-shore sediment transport.

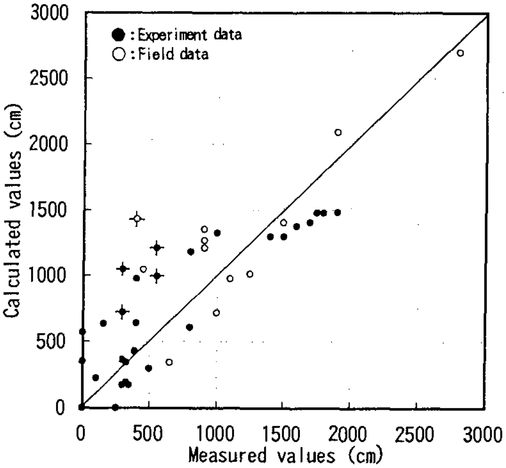


Figure 7 Measured vs. calculated values of Δy.

files after transformation can be determined.

From Eq. (1), when the beach profile reaches the equilibrium state, the following relation can be obtained:

$$\phi = 0.13\, U_r \qquad (5)$$

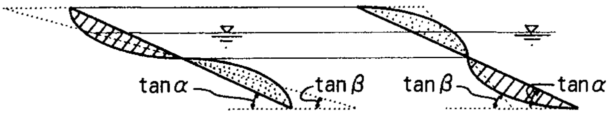


Figure 8 Image of tanβ (sea bottom slope under equilibrium state in the surf zone).

Substituting Hallermeier parameter, Ursell parameter and Eq. (6) (Yamamoto, 1988) to Eq. (5), and transforming slightly, we can obtain Eq. (7).

$$H = 2.4(\tan\beta)^{0.3}\, h = 1.9(\tan\beta)^{0.9} H_b \qquad (6)$$

$$\tan\beta = \left(\frac{0.0864\, s g d T^2}{H_b^2}\right)^{2/3} \qquad (7)$$

where $\tan\beta$ is the sea bottom slope under the equilibrium state in the surf zone, and H_b is the breaking wave height.

Then, assuming that the rate of time change of the sea bottom slope equals $e^{-Bt/T}$, the sea bottom slope of the arbitrary elapsed time t in the surf zone, $\tan\theta$, can be expressed by the following equation :

$$\tan\theta = \tan\beta + \frac{\tan\alpha - \tan\beta}{e^{-Bt/T}} \qquad (8)$$

Moreover, substituting the data shown in Tables 5 and 6 in the appendix, we can obtain Figure 9. The figure indicates that the calculated values agree well with the measured values.

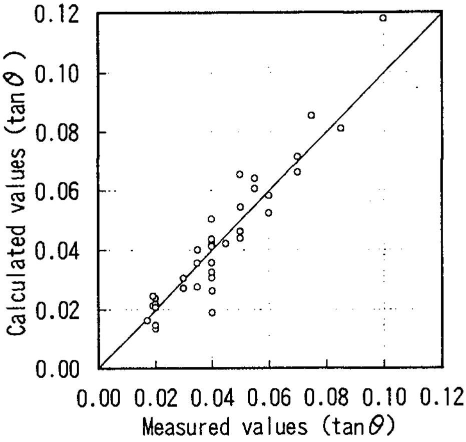


Figure 9 Measured vs. calculated values of tanθ.

4. APPLICATION OF THE PROPOSED EQUATIONS TO ACTUAL COASTS

We performed the following two beach change simulations.

(1) SHORELINE CHANGE AT HAZAKI COAST

The first one is the time series hindcast for 18 days at Hazaki coast in Ibaragi Prefecture, Japan, based on the data given in Katoh and Yanagishima's paper (1988). In their paper, time series data of the daily mean wave energy flux, and limited data of the maximum significant wave height $[(H_{1/3})_{max}]$ and period on stormy days were given. Therefore, time series data of the significant wave height $(H_{1/3})$ from the data of the square root of the daily mean wave energy flux $(E^{1/2})$ were calculated by using the following empirical relations :

$$H_{1/3} = (H_{1/3})_{max}/1.5 \qquad (9), \qquad E^{1/2} = (H_{1/3})_{max} \qquad (10)$$

Eqeation (10) can be obtained from Figure 10 drawn by limited data under stormy weather. However, as the offshore bars exist and the mean water depth at the bar crown is about 2.9 m, the significant wave height of waves acting on the shoreline is less than approximately 2.2 m due to wave breaking. Therefore, the breaking wave height heigher than 2.2 m is reduced to 2.1 m. Then, the time series data of the wave period are calculated by using Eq. (11) obtained empirically in their paper.

$$H_{1/3}/L^{1/3} = 0.25 \times E^{0.37} \qquad (11)$$

where L is the wavelength.

However, as larger waves are diminished in this case, the breaking wave height is cut down, the wave period in this case should be shortened by using the following equation based on Bretschneider's formula [$T = 3.86\,(H_{1/3})^{0.5}$] :

$$T_a/T_b = C\,(2.1/H_{1/3b})^{0.5} \qquad (12)$$

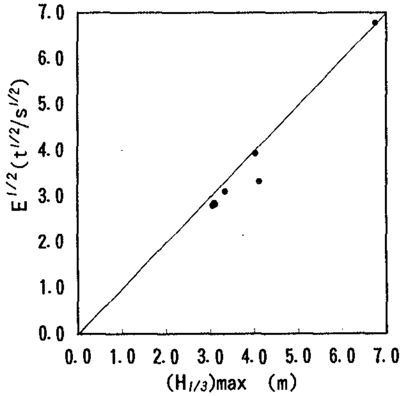


Figure 10 Relation between maximum significant wave height and square root of daily mean wave energy flux.

where the suffix a means the values after wave breaking, while the suffix b means the values before wave breaking, and C is a proportional coefficient (= 1.1 from a few field observation data).

Because the shoreline of Hazaki coast is straight and no coastal structure like a groin exists along this coast, the shoreline change due to longshore sediment transport can be neglected. Therefore, the shoreline change on this coast can be simulated by using Eqs. (1) ~ (4), (7), and (8). The calculated result of shoreline change agrees well with the measured result as shown in Figure 11.

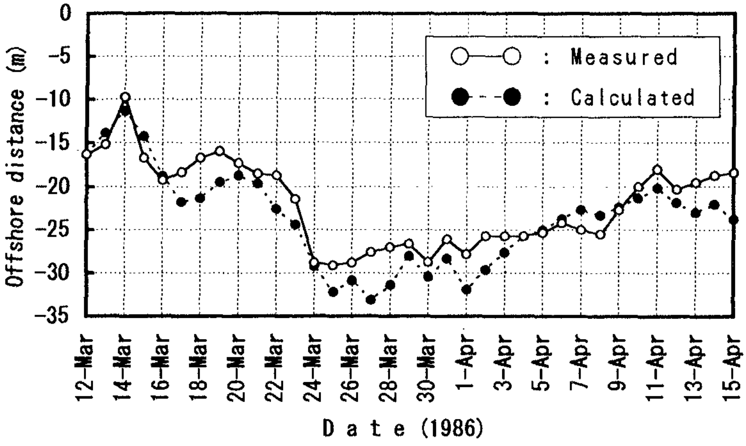


Figure 11 On-offshore changes of shoreline position (D.L.+ 1.4 m).

(2) SHORELINE CHANGE AT MISAWA PORT COAST

Another example is the simulation for one year at Misawa Port coast in Aomori Prefecture, Japan, based on data of Hashimoto and Uda's paper (1979).

A remarkable shoreline change occured during the period of one year from 1976 to 1977, when the offshore breakwater at Misawa Port became long enough to bring about remarkable diffraction effect (refer to Figure 12). It is likely that the diffraction effect of the breakwater made the wave height small in the water area sheltered by the breakwater, thereby the rate of onshore sediment transport increased in this area as shown in Figure 13. Hashimoto and Uda applied an empirical eigenfunction expansion method to predict shore transformation at and around Misawa Port and pointed out the existence of cross-shore sediment transport. Thus, the probable mechanism of this shoreline change was that alongshore transport sediment entered the port area due to influence of the diffraction effect of the breakwater, then the waves in the port transported the sediment onshore, therefore the shoreline advancement occured.

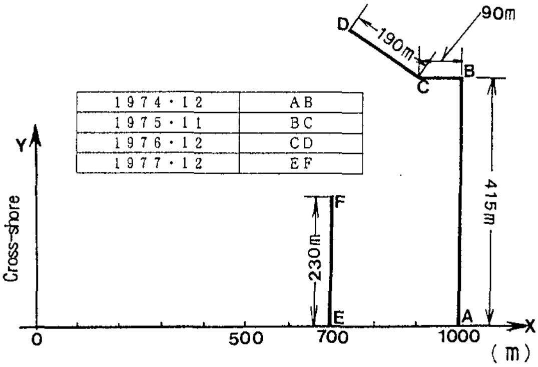


Figure 12 Configuration of breakwaters at Misawa port.

The hindcast of the shoreline change in this area was performed by combining Eqs. (1) ~ (4) with the shoreline change model.

First, the shoreline change model was applied under the following conditions on the basis of the Hashimoto and Uda's paper :

(a) The height of the longshore sediment transport zone was 11 m .

(b) Ozasa and Brampton's formula (1979) was used to calculate the longshore sediment transport rate, and the figure 0.2 was selected as a coefficient in

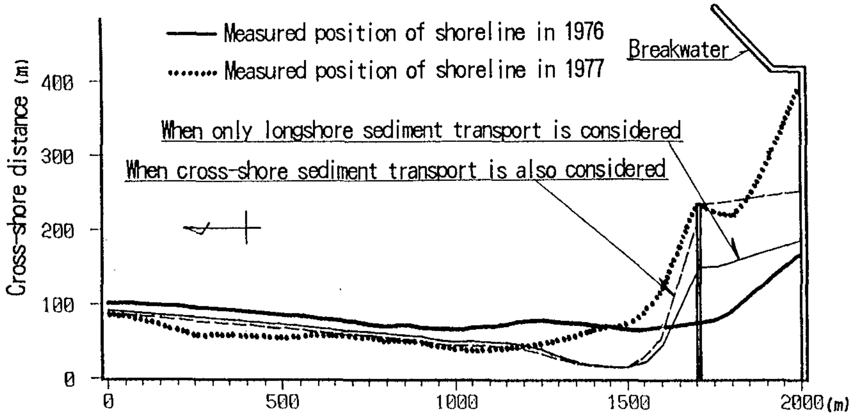


Figure 13 Result of shoreline change simulation.

the formula.

(c) The wave height, period and direction are shown in Table 7 in the appendix.

(d) The sea bottom slope was 1/50.

The result of this simulation was plotted in Figure 13 by a solid line. This result, which was the same as that calculated by Hashimoto and Uda, did not agree with the measured result shown as a dotted line.

Then, the shoreline change due to the cross-shore sediment transport was taken into account by using Eqs. (1) ~ (4). The influence of the wave hysteresis on the shore transformation seems to be great. However, the available data were not the time series data of waves but the statistical data shown in Table 7. Therefore, we adjusted the median grain size of sediment so as to obtain reasonable shoreline displacement. Because the natural beach change after one year induced by cross-shore sediment transport is regarded as small, the shoreline change due to the cross-shore sediment transport near the 0 m point, which is far from the breakwater, can be deemed small. Namely, the median grain size of sediment must be selected so as to obtain a small shoreline change due to the cross-shore sediment transport near the 0 m point. When the figure 0.43 mm was selected as the median grain size from usual grain size at Misawa Port coast, the shoreline displacement near the 0 m point became small as shown in Table 7. Therefore, the calculation by Eqs. (1) ~ (4) was performed under the condition of the median grain size 0.43 mm. By combining this result with the result obtained by the shoreline change model, the significantly improved shoreline displacement was obtained as shown in Figure 13 by a broken line.

5. CONCLUSIONS

Main conclusions are as follows :

(1) The relations among $\tan\alpha$, d/H_0 and the coefficient K of cross-shore sediment transport rate (in Sunamura's formula) can be expressed by Eqs. (2), (3) based on the analyses of data obtained by field observation and large scale experiments.

(2) The formulas [Eqs. (4), (7) and (8)] were proposed for calculating the shoreline displacement and the bottom slope change in the surf zone due to the cross-shore sediment transport. Then the effectiveness of these formulas against actual coasts was demonstrated by the simulation results of shoreline change on two actual coasts.

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APPENDIX

H_o : significant wave height in deep water.
T : wave period.
L_o : wavelenght in deep water.
H_o/L_o: wave steepness in deep water.
tanα: initial mean bottom slope in the surf zone.
H_b : breaking wave height.
h : wave setup on shoreline against the still water level.
H : wave height on shoreline against the still water level.
d : median grain size of sediment.
ϕ : Hallermeier parameter.
Ur : Ursell parameter.
Ar : cross sectional area of erosion part near shoreline.
t : observation time.
Q : rate of cross-shore sediment transport.
w : settling velocity of sediment.
K : coefficient in the cross-shore sediment transport rate formula.
Δy : shoreline displacement due to cross-shore sediment transport.
tanβ: mean bottom slope under the equilibrium state in the surf zone.
tanθ: mean bottom slope of the arbitrary elapsed time in the surf zone.
α : wave direction.
Tp : frequency of incoming waves.

Suffix c means the calculated value.

Table 1 Field observation data (No.1).

Ho(cm)	T(s)	Lo(cm)	Ho/Lo	tan α	Hb(cm)	h(cm)	H(cm)	d(cm)	Φ	Ur	Ar(cm²)	t(s)	Researcher
100	13.5	28431	0.004	0.040	216	24.4	22.3	0.030	440	6684	-200000	88620	Sonu, 1960
170	6.0	5616	0.030	0.045	219	26.6	25.2	0.030	515	1256	150000	133260	Sonu, 1960
120	8.5	11271	0.011	0.025	179	15.9	12.6	0.030	216	3544	-270000	1209600	Uda, 1982
250	9.0	12636	0.020	0.020	305	24.6	18.2	0.020	439	2398		172800	Sunamura et al., 1983
250	9.0	12636	0.020	0.020	305	24.6	18.2	0.027	325	2398		172800	Sunamura et al., 1983
300	10.0	15600	0.019					0.076			280000	1036800	Takeda et al., 1985
280	9.5	14079	0.020					0.026			130000	259200	Takeda et al., 1985
290	10.0	15600	0.019	0.017	346	26.0	18.3	0.018	463	2646	380000	1036800	Kuriyama, 1991
180	8.5	11271	0.016	0.017	223	16.8	11.8	0.018	298	2965	-220000	1728000	Kuriyama, 1991
130	7.0	7644	0.017	0.017	159	11.9	8.4	0.018	212	2828	-70000	1296000	Kuriyama, 1991
230	9.0	12636	0.018	0.045	337	40.9	38.7	0.026	913	1839	275000	43200	Nairn, 1991
300	10.5	17199	0.017	0.023	388	33.2	25.7	0.020	644	2520	600000	172800	Katoh et al., 1992
300	10.5	17199	0.017	0.023	388	33.2	25.7	0.020	644	2520	1000000	345600	Katoh et al., 1992

Table 2 Field observation data (No.2).

Q(cm²/s)	W(cm/s)	K	d/Ho	t/T	Kc	Qc(cm²/s)	Δyc(cm)	Δy(cm)	Researcher
-2.257	4.490	0.0000153	0.00030	6564	0.0000125	-1.846	1207	900	Sonu, 1960
1.126	4.490	0.0000111	0.00018	22210	0.0000146	1.479	1046	450	Sonu, 1960
0.223	4.490	0.0000061	0.00025	142306	0.0000030	-0.111	1403	1500	Uda, 1982
	2.178		0.00008	19200	0.0000707	0.812	1011	1250	Sunamura et al., 1983
	3.558		0.00011	19200	0.0000477	0.093	342	650	Sunamura et al., 1983
0.270	14.793		0.00025	103680			1429	400	Takeda et al., 1985
0.502	3.087		0.00009	27284			973	1100	Takeda et al., 1985
0.367	2.008	0.0000382	0.00006	103680	0.0000580	0.556	1664		Kuriyama, 1991
-0.127	2.008	0.0000274	0.00010	203294	0.0000158	-0.074	1266	900	Kuriyama, 1991
-0.054	2.008	0.0000092	0.00014	185143	0.0000117	-0.068	714	1000	Kuriyama, 1991
6.366	3.087	0.0000287	0.00011	4800	0.0000458	10.158	1416		Nairn, 1991
3.472	2.178	0.0000816	0.00007	16457	0.0000887	3.773	2091	1900	Katoh et al., 1992
2.894	2.178	0.0000680	0.00007	32914	0.0000737	3.136	2700	2800	Katoh et al., 1992

Sunamura et al.'s Δy is the calculated value by using Qc.
Nairn's data is based on information by Kriebel and Dean's paper.

Table 3 Experimental data in large wave tanks (No1).

Ho(cm)	T(s)	Lo(cm)	Ho/Lo	tan α	Hb(cm)	h(cm)	H(cm)	d(cm)	Φ	Ur	Ar(cm²)	t(s)	Researcher
141	11.3	19920	0.007	0.066	200	31.1	33.0	0.022	1034	4270	300000	144000	Saville, 1957
108	11.3	19920	0.005	0.066	170	26.4	28.1	0.022	879	5024	300000	144000	Saville, 1957
48	11.3	19920	0.002	0.070	110	17.8	19.3	0.022	614	7585	0	144000	Saville, 1957
171	5.6	4892	0.035	0.066	220	34.2	36.3	0.022	1137	953	300000	144000	Saville, 1957
46	6.0	5616	0.008	0.050	100	13.0	12.7	0.047	170	2662	-18000	72000	Simizu et al., 1984
95	9.0	12636	0.008	0.050	128	16.6	16.2	0.047	218	4679	-130000	250200	Simizu et al., 1984
85	3.0	1404	0.061	0.050	88	11.4	11.1	0.047	150	756	0	75600	Simizu et al., 1984
176	6.0	5616	0.031	0.030	199	19.3	16.2	0.047	187	1534	-7000	126000	Simizu et al., 1984
73	9.0	12636	0.006	0.030	147	14.2	11.9	0.047	138	4671	-50000	140400	Simizu et al., 1984
71	3.1	1499	0.047	0.030	82	7.9	6.7	0.047	77	993	-5000	105840	Simizu et al., 1984
96	9.1	12918	0.007	0.050	190	24.6	24.0	0.027	564	3222	55000	255600	Simizu et al., 1984
110	6.0	5616	0.020	0.050	180	23.3	22.8	0.027	534	1479	55000	353160	Simizu et al., 1984
65	12.0	22464	0.003	0.050	160	20.7	20.2	0.027	475	6654	-44000	288000	Simizu et al., 1984
162	3.1	1499	0.108	0.050	160	20.7	20.2	0.027	475	444	25000	273960	Simizu et al., 1984
34	3.5	1911	0.018	0.030	47	4.6	3.8	0.027	77	2209	-4000	360000	Simizu et al., 1984
106	4.5	3159	0.034	0.030	132	12.8	10.7	0.027	216	1300	17000	280800	Simizu et al., 1984
161	3.1	1499	0.107	0.030	159	15.4	12.9	0.027	260	512	16000	360000	Simizu et al., 1984
30	5.8	5248	0.006	0.020	62	5.0	3.7	0.027	66	4896	-12000	313920	Simizu et al., 1984
80	3.1	1499	0.053	0.020	91	7.3	5.4	0.027	97	953	-4000	370800	Simizu et al., 1984
178	5.0	3900	0.046	0.100	191	40.3	48.5	0.027	1400	731	270000	212400	Simizu et al., 1984
110	7.5	8775	0.013	0.100	137	28.9	34.8	0.027	1004	2294	230000	109800	Simizu et al., 1984
150	6.0	5616	0.027	0.075	221	37.6	41.5	0.033	900	1035	70000	15480	Dette et al., 1986
151	5.4	4549	0.033	0.075	211	35.9	39.6	0.023	1258	879	150000	36000	Vellinga, 1986
200	5.6	4892	0.041	0.068	230	36.5	39.1	0.022	1235	901	230000	54000	Kraus et al., 1988
200	5.6	4892	0.041	0.068	230	36.5	39.1	0.022	1235	901	260000	108000	Kraus et al., 1988
200	5.6	4892	0.041	0.064	230	35.0	36.9	0.040	628	923	240000	54000	Kraus et al., 1988
200	5.6	4892	0.041	0.064	230	35.0	36.9	0.040	628	923	190000	108000	Kraus et al., 1988
140	6.0	5616	0.025	0.085	215	40.1	46.0	0.022	1552	1007	200000	15120	Nairn, 1991
150	6.0	5616	0.027	0.125	245	61.6	79.3	0.033	2002	736	135000	2590	Southgate, 1991

Wave heights of Saville's, Simizu et al's, Dette et al's, Kraus et al's, and Southgate's data are not significant values but mean values, because of experiments carried out by using regular waves.

Table 4 Experimental data in large wave tanks (No2).

Q(cm^2/s)	W(cm/s)	K	d/Ho	t/T	Kc	Qc(cm^2/s)	Δyc(cm)	Δy(cm)	Researcher
2.08	2.354	0.0000153	0.00016	12743	0.0000165	2.25	1479	1750	Saville, 1957
2.08	2.354	0.0000369	0.00020	12743	0.0000117	0.66	1479	1900	Saville, 1957
0.00	2.354	0.0000000	0.00046	12743	0.0000037	-0.26	0	250	Saville, 1957
2.08	2.354	0.0000089	0.00013	25714	0.0000099	2.33	1479	1800	Saville, 1957
-0.25	7.947	0.0000046	0.00102	12000	0.0000019	-0.10	362	300	Simizu et al., 1984
-0.52	7.947	0.0000030	0.00049	27800	0.0000027	-0.46	973	400	Simizu et al., 1984
0.00	7.947	0.0000000	0.00055	25200	0.0000026	0.03	0	0	Simizu et al., 1984
-0.06	7.947	0.0000146	0.00027	21000	0.0000121	-0.05	226	100	Simizu et al., 1984
-0.36	7.947	0.0000027	0.00064	15600	0.0000042	-0.55	604	800	Simizu et al., 1984
-0.05	7.947	0.0000079	0.00066	34142	0.0000029	-0.02	191	330	Simizu et al., 1984
0.22	3.558	0.0000055	0.00028	28088	0.0000056	0.22	633	400	Simizu et al., 1984
0.16	3.558	0.0000021	0.00025	58860	0.0000021	0.16	633	150	Simizu et al., 1984
-0.15	3.558	0.0000015	0.00042	24000	0.0000039	-0.40	566	0	Simizu et al., 1984
0.09	3.558	0.0000014	0.00017	88374	0.0000011	0.07	427	390	Simizu et al., 1984
-0.01	3.558	0.0000015	0.00079	102857	0.0000007	-0.01	171	300	Simizu et al., 1984
0.06	3.558	0.0000149	0.00025	62400	0.0000064	0.03	352	0	Simizu et al., 1984
0.04	3.558	0.0000026	0.00017	116129	0.0000044	0.07	342	330	Simizu et al., 1984
-0.04	3.558	0.0000019	0.00090	54124	0.0000022	-0.04	296	500	Simizu et al., 1984
-0.01	3.558	0.0000109	0.00034	119613	0.0000043	0.00	171	350	Simizu et al., 1984
1.27	3.558	0.0000019	0.00015	42480	0.0000003	0.20	1403	1700	Simizu et al., 1984
2.09	3.558	0.0000065	0.00025	14640	0.0000037	1.18	1295	1500	Simizu et al., 1984
4.52	4.709	0.0000105	0.00022	2580	0.0000185	7.95	714	300	Dette et al., 1986
4.17	2.459	0.0000135	0.00015	6667	0.0000230	7.11	1046	300	Vellinga, 1986
4.26	2.354	0.0000153	0.00011	9643	0.0000305	8.52	1295	1400	Kraus et al., 1988
2.41	2.354	0.0000086	0.00011	19286	0.0000168	4.70	1377	1600	Kraus et al., 1988
4.44	6.349	0.0000140	0.00020	9643	0.0000147	4.68	1323	1000	Kraus et al., 1988
1.76	6.349	0.0000055	0.00020	19286	0.0000086	2.73	1177	800	Kraus et al., 1988
13.23	2.354	0.0000290	0.00016	2520	0.0000278	12.68	1207	550	Nairn, 1991
52.12	4.709	0.0000235	0.00022	432	0.0000208	46.27	992	550	Southgate, 1991

Table 5 Field observation data (No.3).

tan β (-)	tan θc(-)	tan θ (-)	Researcher
0.062	0.044	0.040	Sonu
0.021	0.032	0.040	Sonu
0.043	0.040	0.035	Uda
0.017	0.020		Sunamura et al.
0.021	0.020		Sunamura et al.
			Takeda et al.
			Takeda et al.
0.016	0.016	0.017	Kuriyama
0.023	0.021	0.019	Kuriyama
0.028	0.024	0.019	Kuriyama
0.018	0.041	0.040	Nairn
0.015	0.022	0.020	Katoh et al.
0.015	0.021	0.020	Katoh et al.

Table 6 Experimental data in large wave tanks (No.3).

tan β (-)	tan θc(-)	tan θ (-)	Researcher
0.044	0.054	0.050	Saville
0.054	0.060		Saville
0.097	0.085	0.075	Saville
0.015	0.026	0.040	Saville
0.079	0.061	0.055	Simizu et al.
0.097	0.081	0.085	Simizu et al.
0.037	0.042	0.045	Simizu et al.
0.031	0.030	0.030	Simizu et al.
0.081	0.042	0.040	Simizu et al.
0.043	0.036	0.035	Simizu et al.
0.040	0.044	0.040	Simizu et al.
0.025	0.028	0.035	Simizu et al.
0.073	0.064	0.055	Simizu et al.
0.012	0.013	0.020	Simizu et al.
0.073	0.065	0.050	Simizu et al.
0.026	0.027	0.030	Simizu et al.
0.012	0.015	0.020	Simizu et al.
0.098	0.050	0.040	Simizu et al.
0.026	0.024	0.020	Simizu et al.
0.018	0.019	0.040	Simizu et al.
0.048	0.058	0.060	Simizu et al.
0.022	0.066	0.070	Dette et al.
0.016	0.052	0.060	Vellinga
0.014	0.044	0.050	Kraus et al.
0.014	0.031	0.040	Kraus et al.
0.021	0.046	0.050	Kraus et al.
0.021	0.036	0.040	Kraus et al.
0.017	0.072	0.070	Nairn
0.019	0.118	0.100	Southgate

Table 7 Calculated shoreline position at Misawa Port coast.

α	Ho(cm)	T(s)	Lo(cm)	Ho/Lo	Tp(%)	t(s)	t/T	tanα	Hb(cm)	h(cm)	H(cm)	d(cm)	Φ	Ur	d/Ho	Kc	W(cm/s)	Qc(cm /s)	Δyc(cm)
ENE	150	9.0	12636	0.012	25.0	7884000	876000	0.020	208	16.7	12.4	0.043	139	3517	0.00029	0.000000006	7.689	-0.00043	158
ENE	250	9.0	12636	0.020	7.0	2207520	245280	0.020	305	24.6	18.2	0.043	204	2398	0.00017	0.000003362	7.689	-0.11586	1365
ENE	350	9.0	12636	0.028	2.8	883008	98112	0.020	392	31.6	23.5	0.043	263	1863	0.00012	0.000019746	7.689	0.15718	-1006
ENE	450	9.0	12636	0.036	0.2	63072	7008	0.020	474	38.2	28.3	0.043	317	1543	0.00010	0.000062500	7.689	3.31069	-1234
E	150	9.0	12636	0.012	28.0	8830080	981120	0.020	208	16.7	12.4	0.043	139	3517	0.00029	0.000000002	7.689	-0.00017	104
E	250	9.0	12636	0.020	6.0	1892160	210240	0.020	305	24.6	18.2	0.043	204	2398	0.00017	0.000004615	7.689	-0.15901	1481
E	350	9.0	12636	0.028	1.9	599184	66576	0.020	392	31.6	23.5	0.043	263	1863	0.00012	0.000026254	7.689	0.20899	-955
E	450	9.0	12636	0.036	0.1	31536	3504	0.020	474	38.2	28.3	0.043	317	1543	0.00010	0.000064510	7.689	3.41716	-886
ESE	150	7.5	8775	0.017	20.0	6307200	840960	0.020	190	15.3	11.3	0.043	127	2676	0.00029	0.000000008	7.689	-0.00036	128
ESE	250	7.5	8775	0.028	3.0	946080	126144	0.020	278	22.4	16.6	0.043	186	1824	0.00017	0.000009864	7.689	-0.13885	979
ESE	350	7.5	8775	0.040	0.1	31536	4205	0.020	358	28.9	21.4	0.043	240	1417	0.00012	0.000046121	7.689	0.86454	-446
																		Σ	-313