CHAPTER 114

BEACH PROFILE CHANGE UNDER VARYING WAVE CLIMATES

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Abstract

In the present paper results of experimental study of two-dimensional transformation of sandy beach under varying wave climates are presented. The varying wave climates were composed of different systems of regular waves exerted one after another on the model beach. Through experiments it was found that sandy beach transformation within surf zone could be expressed by the changes of characteristic point A and characteristic slope tan ß, and that although the expression for beach erosion-accretion criteria is dimensionless, similitude scale effects should still be taken into consideration.

I. Introduction

Beach erosion-accretion process changes with wave climates. A new beach profile is always developed from the profile created by preceding wave climate. However, previous experimental studies on beach profile change were usually carried out by assuming an initial straight beach slope i_0, which is not in conformity with the natural situation. To avoid this a series of tests on beach transformation were conducted using varying wave climates, i.e. different systems of regular waves one after another. Part of experimental results has been published(3), in which the conception of characteristic point A and characteristic slope tanß was introduced and a beach erosion-accretion criterion was proposed. In the present paper some new experimental results and advancement in the authors' research works will be given.

II. Experimental Investigation

From 1980 to 1987, experiments were performed in a wave basin, 23.8m long, 8.7 m wide and 0.58 m deep. The model stretch is separated lengthwise into six wave flumes, each 17 m long, 0.48 m wide. Ordinary quartz sand of different sizes were used and four different initial beach slopes 1/5, 1/10, 1/15 and 1/20 were moulded in wave flumes. The ground water level in the model was controlled so as to maintain its original still water level in the wave basin.

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Three kinds of waves climates were used:

1st kind: A train of regular waves with constant wave height H_0 and wave period T acting intermittently on model beach in varying durations. Through experiments the relations between initial, intermediate and equilibrium profiles can be observed. The wave climates used in 1st kind are shown in Table 1.

Table 1 Experimental conditions of 1st kind wave climates

Sand size	$d_{50} = 0.30^{mm}$				$d_{50} = 0.69^{mm}$			H_0 (cm)	T (sec)	No. of tests & durations(hr)
i_0 / Flume No. / case	No.1	No.2	No.3	No.4		No.5	No.6			
A-1	1/5	1/10	1/15	1/20		1/10		6.8	1.25	1×8
A-2	1/5	1/10	1/15	1/20		1/10		6.8	1.25	2×4
A-3	1/5	1/10	1/15	1/20		1/10		6.8	1.25	4×2
A-4	1/5	1/10	1/15	1/20		1/10		6.8	1.25	8×1
A-5	1/5	1/10	1/15	1/20		1/10		6-8	1.25	16×0.5
A-6	1/5	1/10	1/20		1/20	1/10	1/5	6.8	1.25	2
A-7	1/5	1/10	1/20		1/20	1/10	1/5	6.8	1.25	54
B-1	1/5	1/10	1/15	1/20		1/20	1/10	5.1	1.25	1×8
B-2	1/5	1/10	1/15	1/20		1/10	1/5	5.1	1.25	2×4
B-3	1/5	1/10	1/15	1/20		1/10	1/5	5.1	1.25	4×2
B-4	1/5	1/10	1/15	1/20		1/10	1/5	5.1	1.25	2
C-1	1/5	1/10	1/15	1/20		1/10	1/5	5.1	1.25	8
C-2	1/5	1/10	1/15	1/20		1/10	1/5	6.8	1.00	2×4
C-3	1/5	1/10	1/15	1/20		1/10	1/5	6.8	1.00	4×2
C-4	1/5	1/10	1/15	1/20		1/10	1/5	6.8	1.00	8×1
C-5	1/5	1/10	1/15	1/20		1/10	1/5	6.8	1.00	16×0.5
C-6	1/5	1/10	1/20		1/20	1/10	1/5	6.8	1.00	2
C-7	1/5	1/10	1/20		1/20	1/10	1/5	6.8	1.00	22
C-8	1/5	1/10	1/20		1/20	1/10	1/5	6.8	1.00	136

2nd kind: Wave climates consisting of constant regular waves and different systems of regular waves with varying wave height H_0 and wave period T. Through experimental studies of the actions of constant waves and different systems of waves on straight as well as on transformed beachs, the transformation relations for different beach configuration in surf zone can be observed. The wave climates used in 2nd kind are shown in Table 2. In Table 2(a), E-K are constant wave cases. The experiments were continued until the beach profile reaches the state of equilibrium or quasi-equilibrium. In Table 2(b), groups A and BC were performed using wave cases F, H, I, J, K, arranged in the order and for the duration shown.

Table 2 Experimental conditions of 2nd kind wave climates
(a) Constant regular waves

Wave Case	E	F	G	H	I	J	K
H_0 (cm)	6.80	2.96	2.32	4.96	4.28	7.00	9.42
T (sec)	1.25	2.20	2.70	1.42	1.80	1.24	0.87
Test Duration (hr)	21.0	60.0	32.5	24.0	28.0	27.0	35.0
Flume Number	1	2	3	4	5	6	
Initial Slope i_0	1/5	1/10	1/20	1/20	1/10	1/5	
d_{50} (mm)	0.30	0.30	0.30	0.69	0.39	0.69	

(b) Systems of regular waves

Wave Group	A					BC				
Case Order	K	J	I	F	H	F	I	J	K	H
Test Duration (hr)	34.5	3.0	5.0	8.0	13.0	34.5	10.5	13.0	12.5	13.0

3rd kind: Wave climates consisting of constant regular waves and different systems of regular waves with constant wave height H_0 and varying wave period T, varying H_0 and constant T as well as varying H_0 and T (Table 3). Through experiments under this kind of wave climates, we can get some more knowledge of two-dimensional transformation of sandy beach under varying wave climates.

III. Erosion-Accretion Parameters and Beach Types within Surf Zone

1. Erosion-accretion parameters

Through experiments mentioned above, it can be noted that in the course of beach transformation under a certain wave action there is a point on the beach profile, located near the wave breaking point, undergoing very little change as shown in Figure 1 and Figure 2. The same point also existed in T. Sawaragi's model test (1980)(5). We defined this point as the characteristic point A. Make use of its relative stable position, point A can be taken as a coordinate origin on the beach profile to facilitate the study of beach transformation processes. Slope $\tan\beta$ formed by connecting the characteristic point and shoreline point may be defined as the characteristic slope. Characteristics slope $\tan\beta$ changes simultaneously with advance and recession of the shoreline in the course of beach transformation, i.e. in the course of beach erosion $\tan\beta$ tends to become gentle with the recession of shoreline, conversely, in the course of beach accretion $\tan\beta$ tends to become steep with advance of shoreline. In the state of erosion-accretion equilibrium the characteristic slope will almost remain unchanged and may be denoted by $\tan\beta_c$. So by comparing the characteristic slopes before and after a certain series of wave action, we can judge whether the shoreline is advancing or receding and define the types of beach erosion-accretion accordingly. For this reason point A and $\tan\beta$ may be chosen as two important parameters to account for beach transformation within surf zone. Figure 3 shows that when a certain wave action is continued,

Table 3 Experimental conditions of 3rd kind wave climates

Flume Number	1	2	3	4	5	6	H_0 (cm)	T (sec)	Test Duration (hr)
Initial slope i_0	1/5	1/10	1/20	1/20	1/10	1/5			
d_{50} (mm)	0.40	0.40	0.40	0.54	0.39	0.40			
Wave Group	Case Order								
T	T_3						5.85	1.2	30
	T_9						6.93	1.2	23
	T_{19}						8.90	1.2	30
	T_{14}						7.96	1.2	16.6
H	H_4						6.92	0.98	13.3
	H_{35}						7.31	1.70	14.3
	H_{25}						7.42	1.53	16.3
	H_{13}						6.92	1.34	16.6
H_0/L_0	H_0/L_0 - 22						5.34	1.74	16.9
	H_0/L_0 - 34						6.31	1.84	16.2
	H_0/L_0 - 38						3.66	1.34	15.5
	H_0/L_0 - 7						3.61	1.48	17.8
S_y	S_y - 16						2.71	2.63	15.8
	S_y - 12						3.91	1.77	20.4
	S_y - 30						8.16	1.54	15.9
	S_y - 15						10.60	0.98	15.8
	S_y - 4						6.92	0.98	17.5
	S_y - 17						3.44	1.90	20.4
B - 17							3.44	1.90	20.2

the characteristic slope gradually reduces its developing speed and finally attains a state of equilibrium or quasi-equilibrium, which can be denoted by $\tan\beta_c$.

2. Beach types within surf zone

Beach erosion-accretion within surf zone has great influence on the stability of shoreline. According to whether the shoreline is advancing or receding and the beach is under erosion or accretion within surf zone, the beach profile within surf zone could be classified into three types as shown in Figure2:

Type I: The shoreline recedes and surf zone is under erosion.
Type II: The beach profile and shoreline have reached quasi-equilibrium state.
Type III:The shoreline advances and surf zone is under accretion.

when the wave action is continued, the beach profile would always transform from type I or type III into type II as shown in Figure 3.

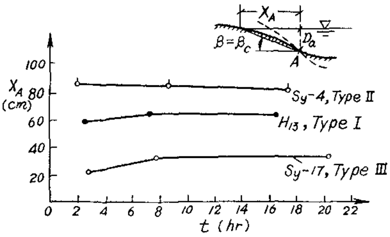

Fig. 1 Distance X_A between characteristic point A and equilibrium shoreline point versus time t

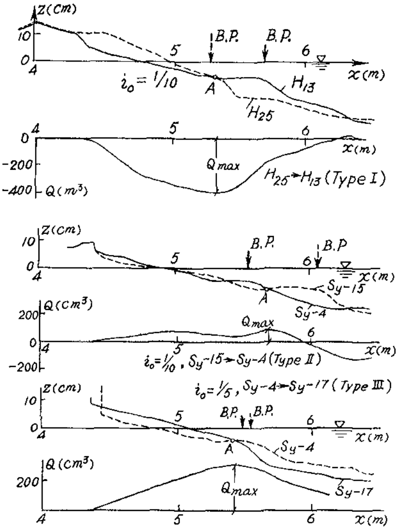

Fig. 2 Beach types within surf zone and distribution of net on-offshore sediment transport load

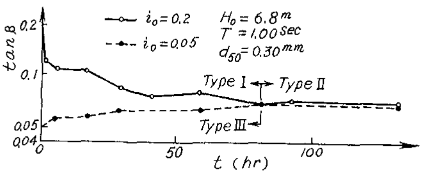

Fig. 3 Characteristic slopes $\tan\beta$ change with advance and retreat of the shoreline in the course of beach transformation and tend to attain equilibrium

IV. Beach Criterion Number

1. Model scales

The authors' experimental data are compared with Sunamura and Horikawa's criterion (1974)(8) as shown in Figure 4. The data points from 205m long large wave tank (R. Kashima et al, 1982)(2) are also shown in the figure. It shows that for Sunamura's small wave tank, the beach erosion-accretion criterion number K=4 - 8, but for the large wave tank K=18, and from the author's experiments the criterion number for the two different grain sizes are different. Although the expression for beach erosion-accretion criteria has been made dimensionless, yet the wave and grain size effects have not been eliminated. Obviously such criteria can not be used in practice.

Since beach erosion-accretion transformation is principally produced in the surf zone, a normal similarity of wave is also required in the model in order to satisfy the dynamic similarity of wave action within the surf zone, i.e. the following relations should be satisfied:

$$\left.\begin{aligned} \lambda_H &= \lambda_L = \lambda_D \\ \lambda_T &= \lambda_D^{0.5} \end{aligned}\right\} \qquad (1)$$

When prototype sand is used the beach model is a distorted model, so the following relations also should be satisfied:

$$\lambda_d = \lambda_\omega = 1 \qquad (2)$$

$$\lambda_l = \lambda_D^{\alpha} \qquad (3)$$

where λ_H, λ_L, λ_T, λ_D represent the scale of wave height, wave length, wave period and water depth respectively, λ_l is the horizontal scale: λ_d and λ_ω are the scale of sand grain size and settling veloci-

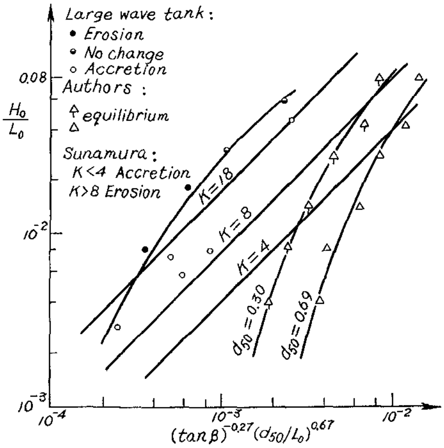

Fig. 4 Examination of similarity of T. Sumanura's erosion-accretion criterion

ty respectively. In order that the criterion number K obtained in model may be used in practice, the scale of number K must equal one in any situation, i.e.:

$$\lambda_K = 1 \tag{4}$$

If the relations in equation (1) and (3) are substituted into Sunamura's criterion, and adopt $\alpha = 1.5$, Sunamura's criterion can be rewritten as:

$$\lambda_K = \left(\frac{\lambda_H}{\lambda_d}\right)^{0.67} \left(\frac{\lambda_D}{\lambda_L}\right)^{0.27} = \frac{\lambda_H^{0.535}}{\lambda_d^{0.67}} \tag{5}$$

It is obvious that, the above equation is not simultaneously in accord with the prerequisites indicated in equation (2) and (4). If $\lambda_d=1$, then $\lambda_K \neq 1$, λ_K is directly proportional to $\lambda_H^{0.535}$, i.e. criterion number K will be increased with increase in wave force; while if $\lambda_H=1$, λ_K is inversely proportional to $\lambda_d^{0.67}$, i.e. the criterion number K will be increased with decrease in sand size. So that, Sunamura's criterion for large wave tank, small wave tank and different sand grain sizes exhibited non-identity as shown in Figure 4.

The criterion expression of CERC (1975)[9], $K=H_0/\omega T$, was vertified. The scale of the criterion can be written as

$$\lambda_K = \lambda_H^{1/2} / \lambda_\omega \tag{6}$$

when $\lambda_\omega=1$, then $\lambda_K = \lambda_H^{1/2}$. Obviously, in CERC's criterion λ_K is a value affected by wave height or wave length, the value K increases with the wave height or wave length, so the criterion of CERC is rather limited for use.

2. Beach erosion-accretion criterion

A beach erosion-accretion criterion was presented in 1986 by authors, which is:

$$\frac{H_0}{L_0} = K\left(\frac{\omega}{gT}\right)^{1.3}\left(\frac{U_c}{\omega}\right)^{0.4}(\tan\beta)^{-1.5}, \quad K = Cf_w^{0.2} \tag{7}$$

In this formula several points are worthy to mention. First, the conception "characteristic slope" $\tan\beta$ is introduced instead of initial straight slope i_0, to make the criterion applicable to any stage of beach evolution and irregular beach profile under varying wave climates.

Second, the critical velocity for incipient movement of the sediment U_c is introduced which is an important factor in determining the net sediment transport on the beach under wave actions. Moreover, the ratio of bottom frictional velocity of wave motion to settling velocity U_*/ω indicates the direction of net sediment transport on the beach (T. Sawaragi, 1982)(6) and reflects what kind of sediment movement is dominant between suspended load and bed load. The tendency of beach to attain equilibrium state is shown by the value of U_* to approach $\sqrt{2f_w}\,U_c$. Thus, on an equilibrium beach $\sqrt{2f_w}\,U_c/\omega$ could be used instead of U_*/ω, where f_w is the frictional coefficient.

Third, the criterion formula satisfies the scale relations. After analysing over 100 data sets of the authors' as well as other researchers' experiments the following results were obtained: A beach will be in the state of quasi-equilibrium when $0.32 \leqslant K \leqslant 0.83$, with average value $K=0.5$, in erosion state when $K > 0.83$; and in accretion state when $K < 0.32$. The data extent is: $H_0=2.32 \sim 176^{cm}$, $T=0.87 \sim 12^{sec}$, $D_{50} = 0.2 \sim 6.1^{mm}$ (3) .

V. Characteristic Point and Equilibrium Characteristic Slope

1. Characteristic point A

In the paper of 1986(3), it has been indicated that on model beach composed of a certain kind of sand under the action of different systems of waves run in succession, a new characteristic point will be produced when one wave system is changed into another, whatever the previous beach transformation process may be. The position of point A (relative to the equilibrium shoreline) created by a certain wave case on any beach profile (irregular beach profile or simple straight beach) is generally the same. That is to say, the relative position of point A is closely related to wave parameters and sediment properties only and is almost irrespective of the previous processes of evolution of beach transformation.

Based on the above analysis a statistical formula for calculating water depth D_a at point A was obtained:

$$D_a/L_0 = 0.52\,(H_0/L_0)^{0.96}\,(U_c/\omega)^{0.33} \tag{8}$$

the data extent is: $H_0=2.32 \sim 176^{cm}$, $T=0.87 \sim 12^{sec}$, $d_{50}=0.2 \sim 6.1^{mm}$.

For any type of beach profile, the point A corresponds also to the point where the net sediment transport rate or net sediment load reached a limiting value as shown in Figure 2.

Using net on-offshore sand transport formula of Watanabe (1981)(2,7), $\phi = 3(\psi - 0.12)\,\psi^{0.5}$, taking its limiting value, and then considering the correction for the effects of beach slope and sand size, another formula for calculating water-depth D_a at point A is obtained:

$$\frac{D_a}{L_o} = 0.192\left(\frac{\rho_s-\rho}{\rho}\right)^{-0.8}\left(\frac{U_c^2}{g\,d_{50}}\right)^{8/15}\left(\frac{H_o}{L_o}\right)^{0.8} \qquad (9)$$

where ϕ is the non-dimensional transport rate and ψ is the Shields parameter. If the wave parameters H_o and L_o as well as beach sand size d_{50} (cm) are known, the value of D_a can be calculated.

Formula (9) is compared with formula (8) by 56 experimental data obtained from large and small wave flumes. The relative error for formula (9) is 0.28 and for formula (8) is 0.43. It is clear that formula (8) is simpler than formula (9), but the latter seems to be more accurate and rational in theory.

2. Equilibrium characteristic slope

Equilibrium characteristic slope $\tan\beta_c$ can be calculated from formula (7) using average value K=0.5.

It is interesting to note that in the course of beach transformation under varying wave climates, although the initial and intermediate beach profile or characteristic slope $\tan\beta$ are not the same, yet when a certain wave action is continued, the beach always tends to transform into the same equilibrium or quasi-equilibrium characteristic slope as shown by the black data points of group S_y - 12, S_y - 15, S_y - 4 and S_y - 17 in Figure 5.

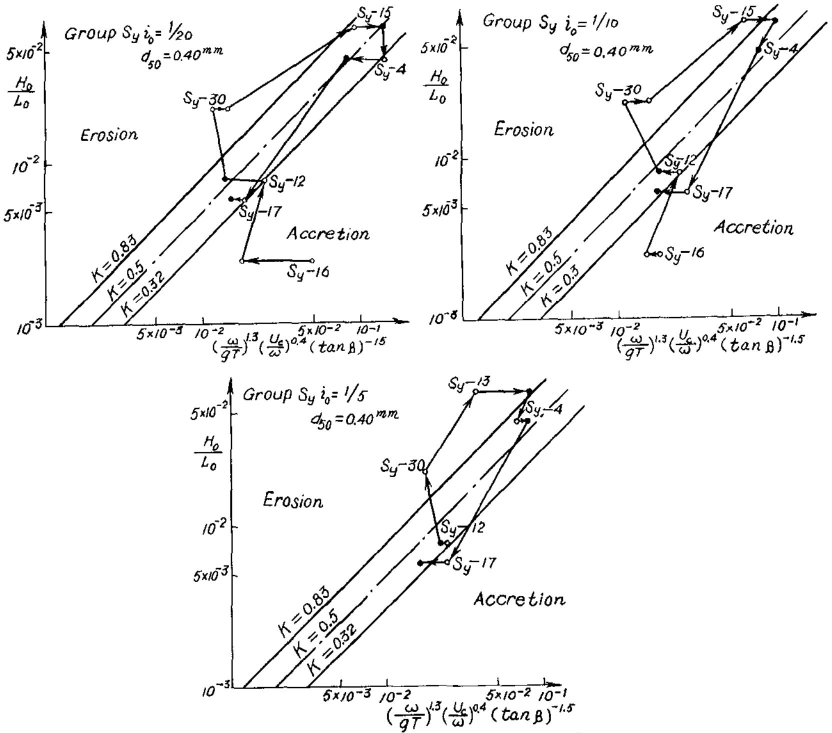

Fig. 5 H_o/L_o versus $(\omega/gT)^{1.3}(U_c/\omega)^{0.4}/(\tan\beta)^{1.5}$ for wave climates of group S_y

Conclusion

1. Based on the shoreline recession-advance and beach erosion-accretion, the beach profile within surf zone could be classified into three types.

2. Two-dimensional beach transformation under varying wave climates could be expressed by the changes of characteristic point A and characteristic slope tanß. Point A and slope tanß are closely related to wave characteristics and sediment properties only and could be obtained from formule (7) and (9).

3. Although the expression for beach erosion-accretion criteria is dimensionless, similitude scale effects should still be taken into consideration. Without similarity consideration the criterion may not be available for use.

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