CHAPTER 53

TWO-DIMENSIONAL BEACH TRANSFORMATION DUE TO WAVES

by

Tsuguo Sunamura and Kiyoshi Horikawa

Coastal Engineering Laboratory
Department of Civil Engineering
University of Tokyo
Bunkyo-ku, Tokyo
Japan

ABSTRACT

Important physical parameters controlling sandy beach transformation were clarified on the basis of the result obtained by a laboratory test. They were not only wave steepness but also beach gradient and a ratio of sand size to wave length. These parameters enabled the previously obtained laboratory beach profiles to be classified into newly-proposed three beach types. These parameters were also found to be effective in grouping the data of shoreline changes both in laboratories and in fields.

INTRODUCTION

Sandy beach transformation by waves is one of the most interesting problems for coastal engineers and also for coastal geomorphologists. Intensive and multiple studies have been conducted since the beginning of 1950's, both in laboratories and in fields. However, the physical processes have not yet been fully understood.

Table 1 Test cases and condition.

Case No.	deep water wave height (H_0)	wave period (T)	grain size of sand (d)	initial beach slope (tan β)	duration wave action (t)
1	3.4 cm	1 sec	0.7 mm	1/10	160 hr
2	3.4	1	0.2	1/10	160
3	7.6	1	0.7	1/10	160
4	7.6	1	0.2	1/10	160
5	7.6	2	0.7	1/10	160
6	7.6	2	0.2	1/10	160
7	3.4	1	0.7	1/20	160
8	3.4	1	0.2	1/20	160
9	7.6	1	0.7	1/20	160
10	7.6	1	0.2	1/20	160
11	7.6	2	0.7	1/20	160
12	7.6	2	0.2	1/20	160
13	3.4	1	0.7	1/30	160
14	3.4	1	0.2	1/30	160
15	7.6	1	0.7	1/30	160
16	7.6	1	0.2	1/30	160
17	7.6	2	0.7	1/30	160
18*	7.6	2	0.2	1/30	160

* Result of this case is not used in this paper.

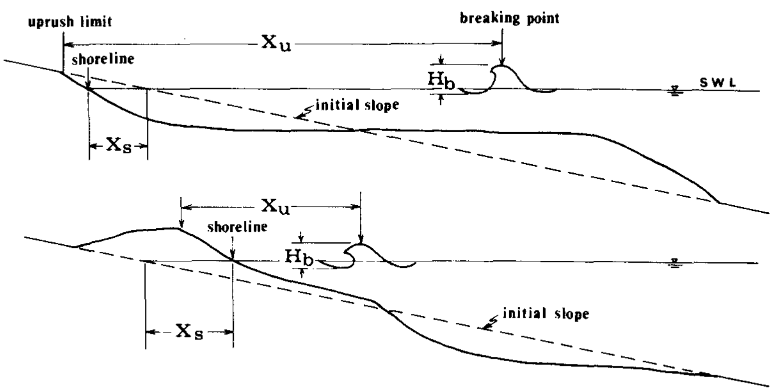

Fig. 1 Definition sketch.

Based on the result of a wave flume experiment, the present study attempted to find out important physical parameters governing shore transformation. Using the parameters, (1) laboratory beach profiles were classified according to a newly proposed criterion, and (2) shoreline changes both in laboratories and in fields were discussed.

LABORATORY EXPERIMENT

A wave flume equipped with a flap-type wave maker was used; its dimension was 25 m long, 1.5 m deep, and 0.8 m wide. The flume was divided into two equivallent parts by a splitter wall which was placed in the center of the flume. Two beaches having the same initial slope and the different mean diameters of quartz sands were set up respectively in the two parts of the flume; one was a 0.2 mm-sand beach and the other a 0.7 mm-sand beach. The specific gravity was 2.65 and Trask's sorting coefficient was 1.1, for both sands. The initial slope was uniform and three kinds of the gradient were selected: 1/10, 1/20, and 1/30. The same waves were allowed to act simultaneously on both beaches. Two kinds of wave height, i.e. 3.4 cm and 7.6 cm, and two kinds of wave period, i.e. 1 sec and 2 sec were adopted here. The total duration of wave action was 160 hours for each experimental run. Table 1 is a list of experimental cases.

In order to examine the relationship between beach profile change and wave behavior inside surf zone, the following physical quantities were measured at certain intervals of time: beach configuration, shoreline displacement, X_s, breaker height, H_b, the distance from breaking point to limit of uprush, X_u (see Fig. 1), and the time for a wave to travel from its breaking point to the uprush limit, τ. Since the beach profile was not always exactly two-dimensional, the profile measurement was done in the center of the beach.

Figure 2 shows temporal change of beach profiles; each group indicates the results obtained under the same experimental condition except for initial slope.

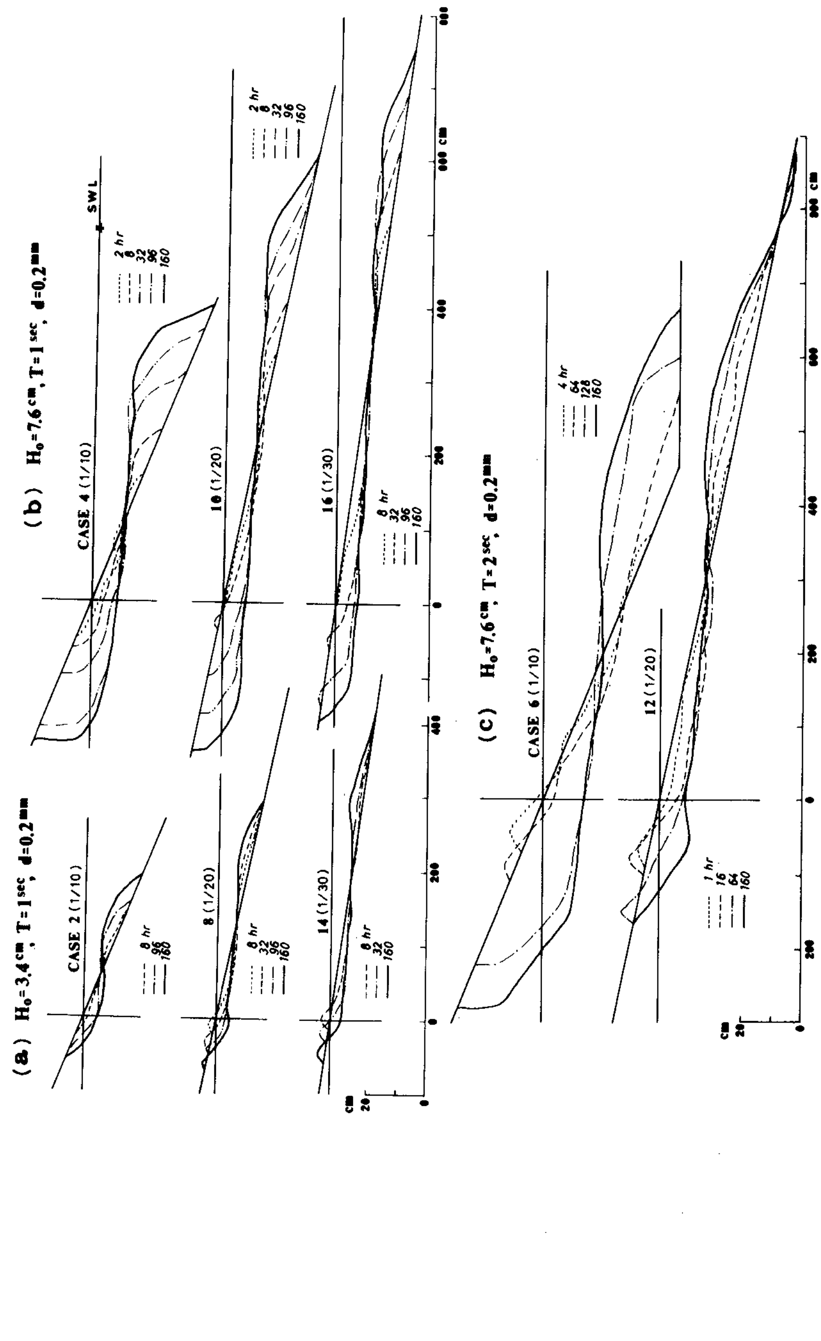

Fig. 2 Beach profile changes (1).

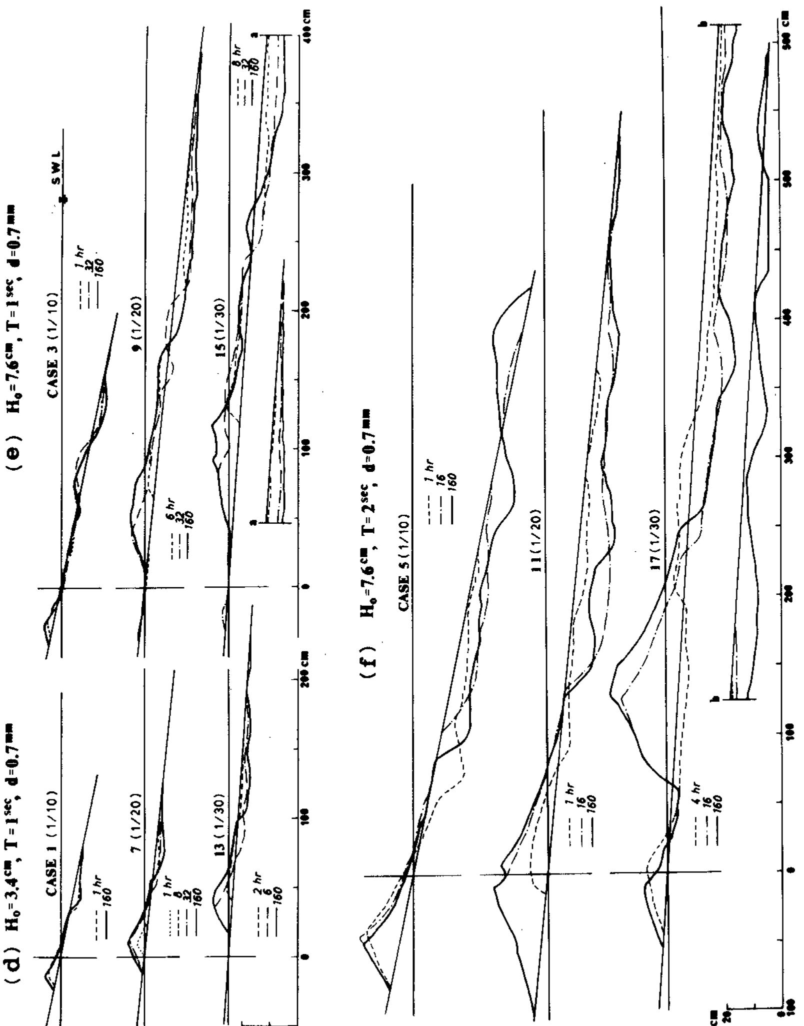

Fig. 2 Beach profile changes (2).

BEACH PROFILE CHANGE

A New Beach Profile Classification

Johnson (1949), Iwagaki and Noda (1962), and Nayak (1970) have proposed the parameters by which beach profiles could be classified into bar or step types and have provided the criteria (Fig. 3). In this figure, H_O = deep water wave height, L_O = deep water wave length, and d = grain size of beach sand. These previous studies do not take beach gradient into consideration. The present experimental cases are also plotted in Fig. 3.

According to these criteria, Cases 2, 8, and 14 must become step type. However, the final profiles of these cases show bar type (Fig. 2(a)). On the other hand, the criteria except for Nayak's one tell that Cases 3, 9, and 15 should be bar type. It is very difficult to recognize the final profile of Case 9 as a bar (Fig. 2(e)); this is typical of step type.

There are two reasons for that these criteria do not suffice: (1) the judgement of " bar " or " step " is sometimes very hard due to complexity of beach configuration, and (2) the parameters are inadequate.

The comparison among Cases 3, 9, and 15 in particular (Fig. 2(e)) shows that the initial beach slope has a great effect on the final configuration. It is clear that the initial slope is an essential factor in considering beach profile pattern. Then, this study proposes a new beach classification which is based on the displacement of topography from the initial beach slope (Fig. 4):

Type I: a shoreline retrogresses and sand accumurates in offshore zone,

Type II: a shoreline advances and sand piles up offshore, and

Type III: a shoreline progrades and no sand deposition takes place offshore.

Any beach profile can be classified into these three

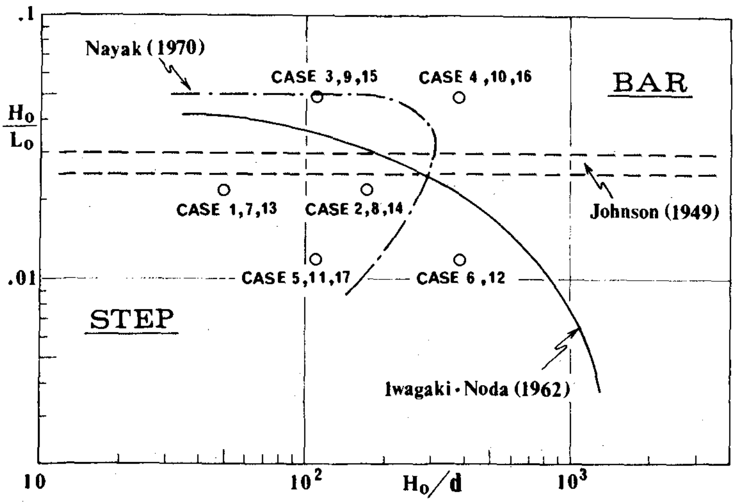

Fig. 3 Previous criteria for generation of bar and step.

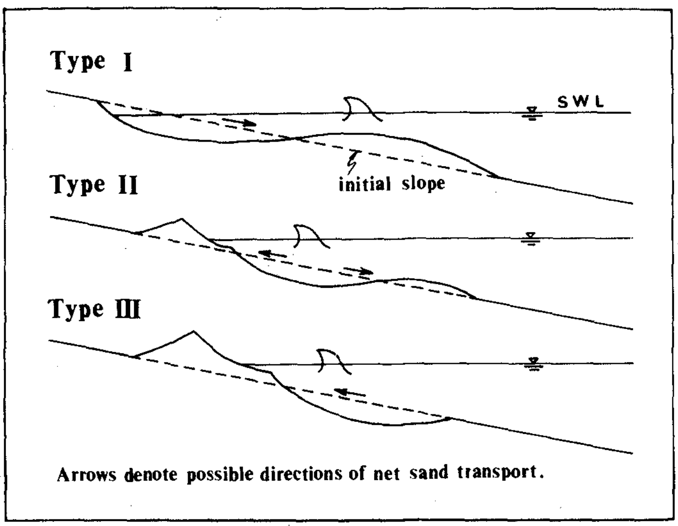

Fig. 4 New beach profile classification.

types without much difficulty. Before applying this grouping, we must clearly state major parameters dominant in shore deformation process.

Dominant Parameters in Beach Transformation

Figure 5 shows the relationship between $X_u^* L_o / H_{b*}^2$ and H_{b*}/d, where $X_u^* = X_u$ at the final stage, and $H_{b*} = H_b$ at the initial stage. In this paper, the " final stage " means the state after a 160-hour wave action, while the " initial stage " denotes the state immediately after wave action, i.e. at the time when the beach slope was scarecely changed.

Although the data points in Fig. 5 are widely scattered, there is a tendency as shown by the straight line, which is expressed by

$$X_u^* L_o / H_{b*}^2 = 0.018 \ (H_{b*}/d)^2 \ . \tag{1}$$

This equation indicates that X_u at the final stage can be inferable from H_b at the initial stage, L_o, and d.

In Fig. 6, open circles show the data at the final stage, while solid circles present the data at a measuring time less than 160 hours. The following relation can be established independent of time:

$$X_u / L_o = 0.39 \ (\tau / T)^{1.2} , \tag{2}$$

where T = wave period. The final stage is given by

$$X_u^* / L_o = 0.39 \ (\tau^* / T)^{1.2} . \tag{3}$$

Figure 7 shows the relationship between H_b/H_o and H_o/L_o, for various bottom slope. All the data plotted here were the results which Goda (1970) synthesized giving correction to the previous data of laboratory tests conducted on a uniform and fixed bottom slope (Bowen et al., 1968; Goda, 1964; Iversen, 1951; Mitsuyasu, 1962; Toyoshima et al., 1968).

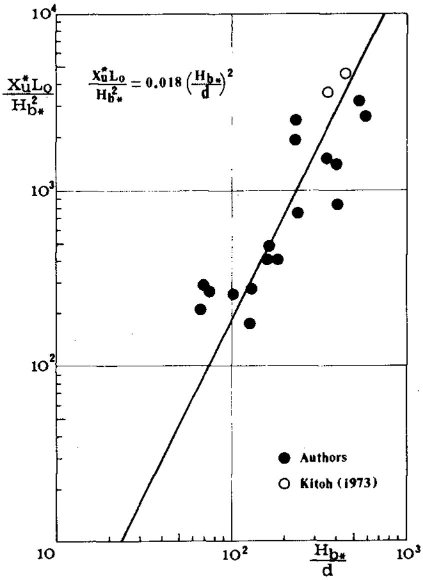

Fig. 5 Relation of $X_u^* L_o / H_b^2$ and H_{b*}/d.

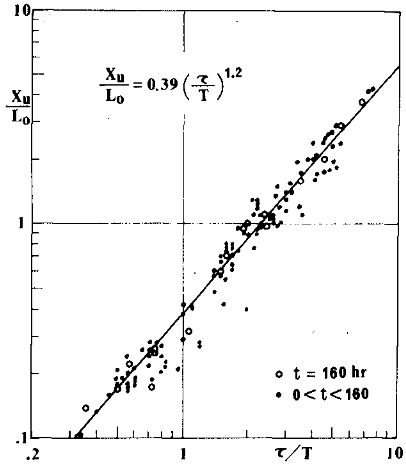

Fig. 6 Relation of X_u/L_o and τ/T.

These straight lines are shown by

$$H_b/H_o = (\tan \alpha)^{0.2} (H_o/L_o)^{-0.25}, \qquad (4)$$

where tan α = bottom slope.

Equation (4) can be applied to a uniformly sloped sandy beach at the initial stage, on the assumption that the influences of friction and percolation by sandy bottom on the breaker height could possibly be neglected. Consequently, the following equation is written:

$$H_{b*}/H_o = (\tan \beta)^{0.2} (H_o/L_o)^{-0.25}, \qquad (5)$$

where tan β = initial sandy beach slope.

From Eqs. (1), (3), and (5), we can get

$$H_o/L_o = 2.76 (\tau^*/T)^{0.4} (\tan \beta)^{-0.27} (d/L_o)^{0.67}, \qquad (6)$$

where τ^*/T = phase-difference at the final stage. The " phase-difference ", which was defined as τ/T by Kemp (1960), is an important quantity that can explain differences in beach profile.

According to the observation, the final profile showed Type I when the following condition was satisfied:

$$\tau^*/T \geqq 2, \qquad (7)$$

while Type III was formed under conditions of

$$\tau^*/T \leqq 2. \qquad (8)$$

Hence, the boundary between Types I and III is

$$H_o/L_o = 4 (\tan \beta)^{-0.27} (d/L_o)^{0.67}. \qquad (9)$$

This equation indicates that H_o/L_o, tan β, and d/L_o are dominant parameters in grouping beach profiles created under fully long duration of wave action. The validity of these parameters will be investigated below using the previous wave flume data. Before doing this, the check of temporal shoreline changes is needed, because shoreline position is one of essential criteria of the newly proposed classification.

Figure 8 is a schematic diagram of temporal shoreline changes. There are two typical changes: (1) a shoreline does not return to its original position (Fig. 8(1)&(2)), i.e. an irreversible change can be seen, and (2) once advanced or retreated shoreline returns to its original at a time of t_1 and then retrogrades or progrades (Fig. 8(3)& (4)), i.e. a reversible change can be appreciated.

Figure 9 illustrates actual shoreline changes; Cases 6, 8, 9, and 14 present reversible changes. These cases show that $t_1 \leqq 40$ hours. After t_1, an irreversible state attains. When applying the new classification, it is necessary to use the data in which a shoreline change is in an irreversible state.

The time of t_1 would depend on experimental conditions, but the quantitative relation has not yet been obtained. The estimation of t_1 is possible if the data of temporal shoreline change is available. The previous beach profile studies do not usually provide such a data. Hence, the authors assumed here that a shoreline change was in an irreversible state if the wave duration was more than 40 hours, irrespective of test conditions.

The final beach profiles of the previous tests which satisfied the following three conditions were used: (1) a wave flume was used, (2) sand or gravel was used as bed material, and (3) wave duration was more than 40 hours (Eagleson et al., 1961; Horikawa et al., 1973; Monroe, 1969; Raman and Earattupuzha, 1972; Rector, 1954; Saville, 1957; Tsuchiya and Yoshioka, 1970; Watts, 1954).

Result of Classification

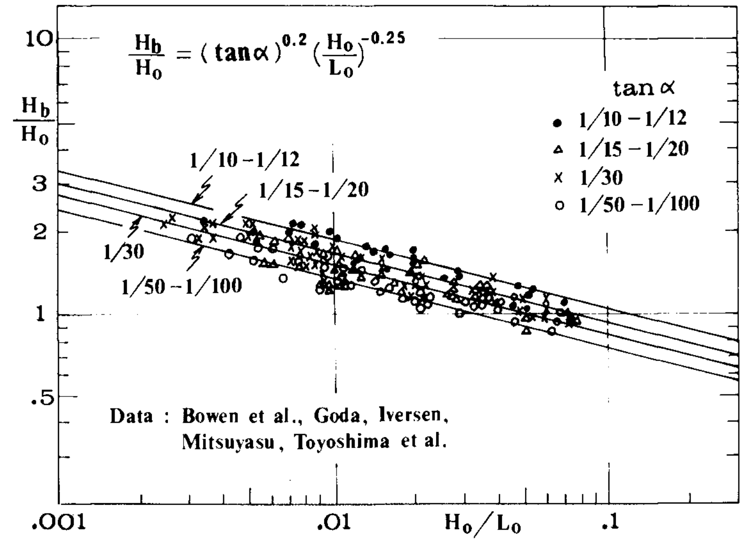

Fig. 7 Relative breaker height and deep water wave steepness for various bottom slope.

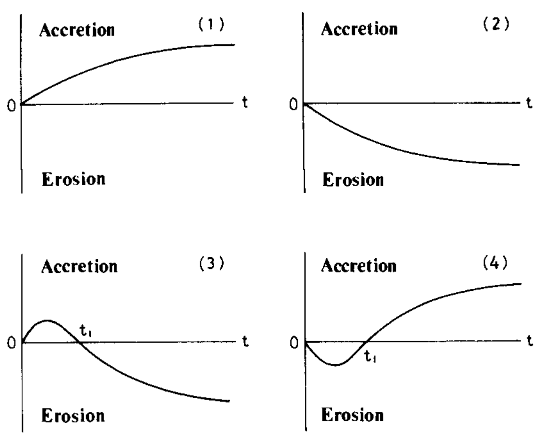

Fig. 8 Schematic diagram showing temporal shoreline changes.

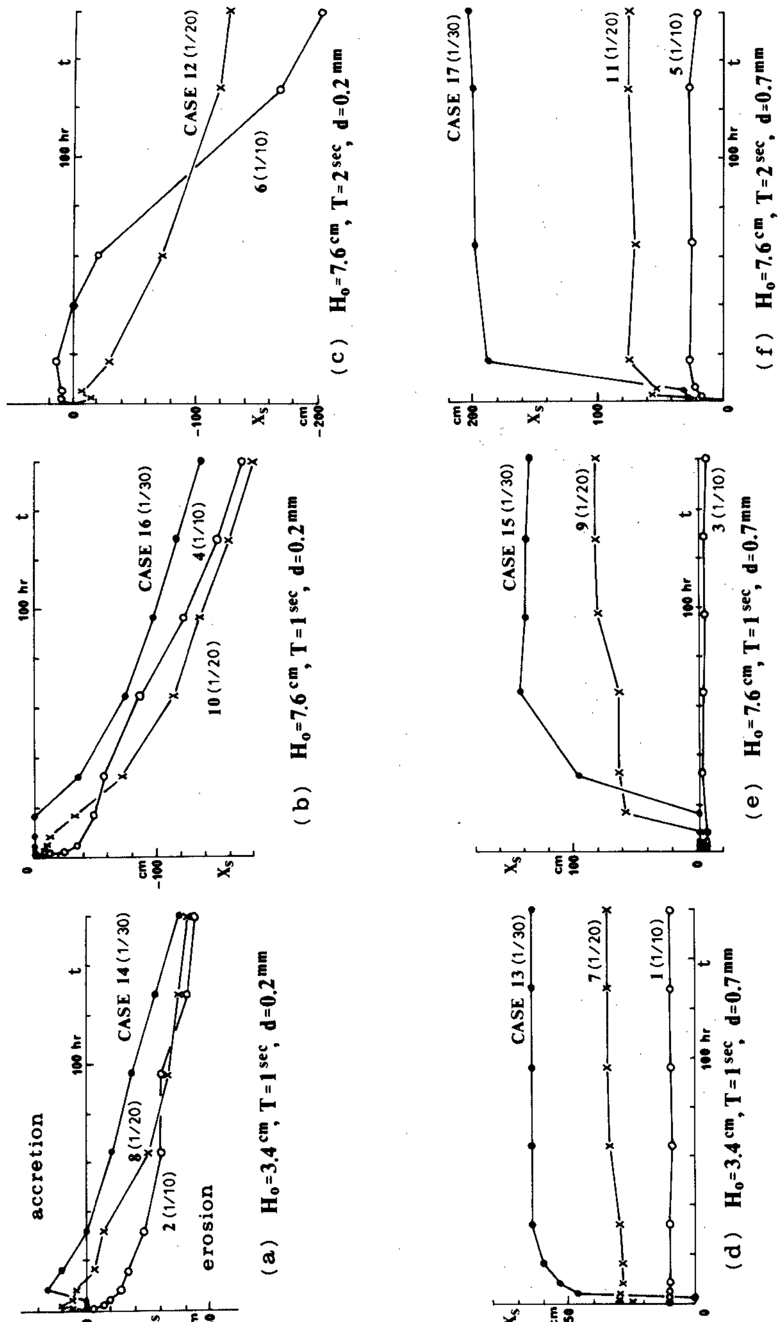

Fig. 9 Temporal shoreline changes.

As shown in Fig. 10, almost all the data points of Type III are in the following region:

$$H_O/L_O \leqq 4 \ (\ \tan\beta\ )^{-0.27} (\ d/L_O\ )^{0.67}, \qquad (10)$$

while Type I is in

$$H_O/L_O \geqq 4 \ (\ \tan\beta\ )^{-0.27} (\ d/L_O\ )^{0.67}. \qquad (11)$$

The region for Type II is given by

$$4\ (\ \tan\beta\ )^{-0.27} (\ d/L_O\ )^{0.67} \leqq H_O/L_O \leqq 8\ (\ \tan\beta\ )^{-0.27} (\ d/L_O\ )^{0.67}. \qquad (12)$$

It is interesting that fully-developed shore topography is distinguishable by these dimensionless three parameters.

SHORELINE CHANGE

Laboratory Shoreline Change

A review of Fig. 4, with special attention to shoreline change, presents that Type I shows an eroded shoreline, while Types II and III denote advanced ones. Figure 10 indicates that these parameters would be effective in grouping the data of shoreline change. To confirm this, additional data of Saville (1957), whose experiment fulfilled the above-mentioned three requirements, were also plotted in Fig. 11.

All the data points are distinctly grouped into two areas, i.e. erosion and accretion, although there is an intricate region between them.

Field Shoreline Change

Using the same parameters and assuming the existence of

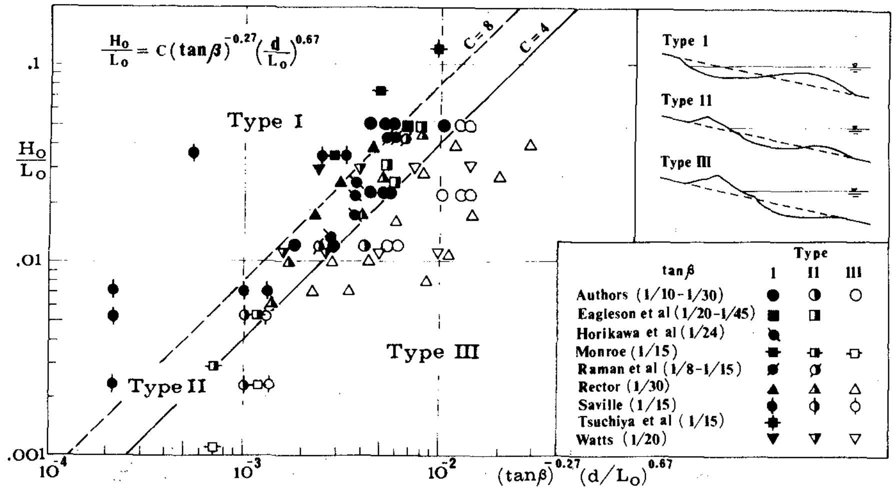

Fig. 10 Classified laboratory beach profiles.

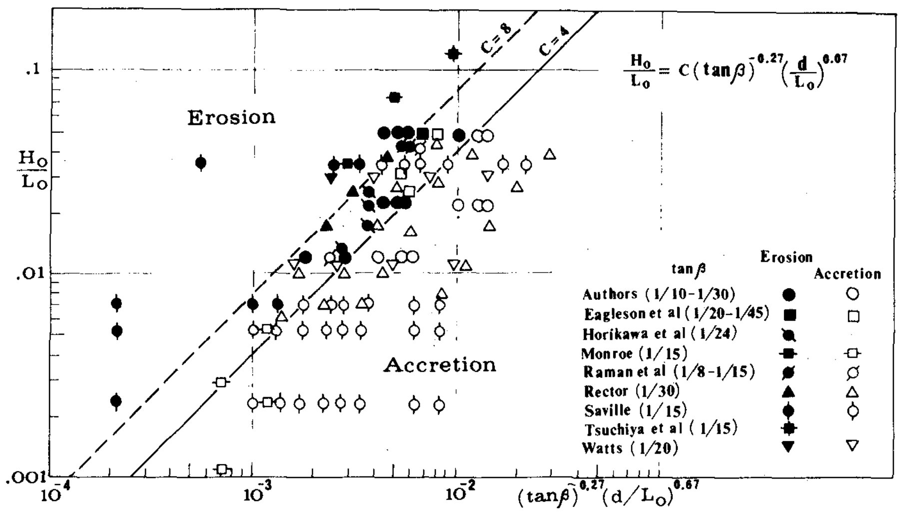

Fig. 11 Shoreline change in the laboratory.

two-dimensionality in nature, the authors attempted to analyze the previous field data (Agemori, 1967; Chang and Tang, 1970; Darling, 1960; Japan Atomic Power Co., 1960; Ministry of Transport, 1962; Ozaki, 1972; 1973; Rao and Kassim, 1970; Saville, 1957; Sonu, 1968; Wiegel et al., 1953). Figure 12 shows the result. The judgement of " erosion " and " accretion " was based on the shoreline deviation from its position at the beginning of an investigation term. Maximum wave height during that term was adopted for H_0 (or H); wave period corresponding to this height was used for calculation of L_0. Mean grain size of subaerial beach sand was taken as a representative value of d. In Fig. 12, tan $\overline{\beta}$ stands for the averaged submarine slope from shoreline up to a water depth of about 20 m; this value was tentatively taken here.

The data points in parentheses are the results of prototype experiment conducted by Saville (1957). It is interesting that these results and the field data showing erosion are in the same region.

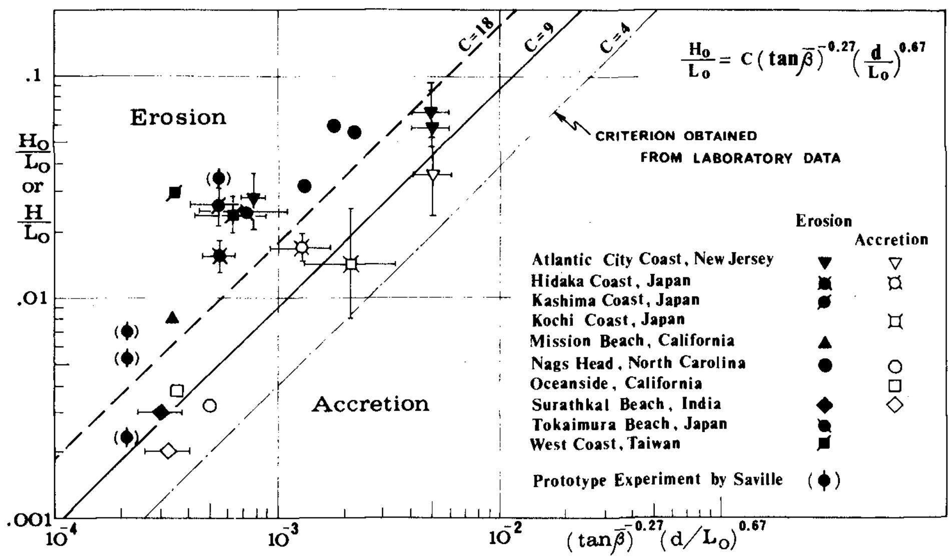

Fig. 12 Shoreline change in the field.

Figure 12 indicates that there is a similar trend to the laboratory result in Fig. 11, although the boundary between erosion and accretion shifts leftwards as a whole. One reason for this shift would probably be scale effect.

There are several problems in such a treatment of field data: (1) the check of two-dimensionality in nature, (2) the investigation of time effect on actual beach transformation under varying wave field, (3) the treatment of sand grain size which is generally a function of time and space, (4) the definition of " initial " beach slope, and (5) the examination of tidal effect on shoreline change. The clarification of these points is necessary for the future development of this study.

CONCLUSION

Major parameters governing sandy beach transformation were found to be not only wave steepness but also beach slope and a ratio of sand grain size to wave length. These parameters were effective in classifying fully-developed beach topography, and also helpful to grouping the data of shoreline changes both in laboratories and in fields.

ACKNOWLEDGEMENT

The authors express their appreciation to Mr. K. Kondo, Coastal Engineering Laboratory, University of Tokyo, for his co-operation in doing the laboratory test. This study was partly supported by Science Research Fund of the Ministry of Education.

REFERENCES

Agemori, C. (1967): On littoral transport along the Kochi coast. Proc. 14th Jap. Conf. Coastal Eng., pp.280-285. (in Japanese).

Bowen, A. L., D. L. Inman and V. P. Simmons (1968): Wave set-down and set-up. Jour. Geophys. Res., 78, pp. 2569-2577.

Chang, K. S. T. and F. L. W. Tang (1970): Studies on the shore process and wave features of the Western coast of Taiwan. Proc. 12th Conf. Coastal Eng., pp.729-737.

Darling, J. M. (1960): Seasonal changes in beaches of the North Atlantic coast of the United States. Proc. 7th Conf. Coastal Eng., pp.236-248.

Eagleson, P. S., B. Glenne and J. A. Dracup (1961): Equilibrium characteristics of sand beaches in the offshore zone. B.E.B. Tech. Memo., 126, 66p.

Goda, Y. (1964): Wave forces on a vertical circular cylinder: experiments and a proposed method of wave force computation. Rep. Port and Harbour Res. Inst., Ministry of Trans., 8, 74p.

Goda, Y. (1970): A synthesis of breaker indices. Proc. Jap. Soc. Civ. Eng., 180, pp. 39-49. (in Japanese).

Horikawa, K., T. Sunamura and H. Kitoh (1973): A study of beach transformation by wave action. Proc. 20th Jap. Conf. Coastal Eng., pp.357-363. (in Japanese).

Iversen, H. W. (1951): Laboratory study of breakers. Proc. Symposium Gravity Waves, U.S. Bur. Stds., Cir. 521, pp. 9-32.

Iwagaki, Y. and H. Noda (1962): Laboratory study of scale effects in two-dimensional beach processes. Proc. 12th Conf. Coastal Eng., pp.194-210.

Japan Atomic Power Co. (1960): Report of field investigation on the Tokaimura beach. Rep. 2, 77p. (in Japanese).

Johnson, J. W. (1949): Scale effect in hydraulic model involving wave motion. Trans. A.G.U., 30, pp. 517-525.

Kemp, P. H. (1960): The relationship between wave action and beach profile characteristics. Proc. 7th Conf. Coastal Eng., pp. 262-277.

Kitoh, H. (1973): A basic study of beach processes. Unpub. M.Sc. Thesis, Univ. of Tokyo, 119p. (in Japanese).

Ministry of Transport (1962): On the physical condition of Kashima Industrial Port. 294p. (in Japanese).

Mitsuyasu, H. (1962): Experimental study on wave force against a wall. Rep. Trans. Tech. Res. Inst., 47, 39p. (in Japanese).

Monroe, F. F. (1969): Oolitic aragonite and quartz sand: laboratory comparison under wave action. C.E.R.C. Misc. Paper 1-69, 22p.

Nayak, I. V. (1970): Equilibrium profiles of model beaches. Proc. 12th Conf. Coastal Eng., pp.1321-1340.

Ozaki, A. (1972): A study of countermeasure for sand deposition in small harbor. Proc. 19th Jap. Conf. Coastal Eng., pp.47-51. (in Japanese).

Ozaki, A. (1973): On the effect of initial beach slope on equilibrium shore profiles. Memoir 28th Annual Conv. Jap. Soc. Civ. Eng., pp.88-89. (in Japanese).

Raman, H. and J. J. Earattupuzha (1972): Equilibrium conditions in beach wave interaction. Proc. 13th Conf. Coastal Eng., pp.1237-1256.

Rao, P. S. and P. Kassim (1970): Field study of Surathkal beach. Proc. 12th Conf. Coastal Eng., pp.1365-1381.

Rector, R. L. (1954): Laboratory study of equilibrium profiles of beaches. B.E.B. Tech. Memo., 41, 38p.

Saville, T., Jr. (1957): Scale effects in two dimensional beach studies. Proc. 7th Meeting I.A.H.R., pp.(A3)1-8.

Sonu, C. J. (1968): Collective movement of sediment in littoral environment. Proc. 11th Conf. Coastal Eng., pp. 373-400.

Toyoshima, O, M. Tominaga and H. Hashimoto (1968): Experimental study of wave deformation after breaking. Rep. Inst. Pub. Works, 133, pp.121-129. (in Japanese).

Tsuchiya, Y. and S. Yoshioka (1970): Experimental study of beach deformation by wind waves (1). Memoir 25th Annual Conv. Jap. Soc. Civ. Eng., pp.97-98. (in Japanese).

Watts, G. M. (1954): Laboratory study of effect of varying wave period on beach profiles. B.E.B. Tech. Memo., 53, 19p.

Wiegel, R. L., D. A. Patrick and H. L. Kimberley (1953): Wave, longshore current and beach profile records for Santa Margarita River Beach. IER, Univ. of Calif., Ser. 3, Issue 357, 6p.