CHAPTER 115

REPRODUCTION MODELS OF BEACH CHANGE BY STORM WAVES

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ABSTRACT

This paper presents a technique to reproduce, by a two-dimensional moveable-bed model, beach change due to the time-dependent storm waves which are generated by the passage of an atmospheric depression. In the model test, scaling conditions for sand grain-size, vertical and horizontal lengths, and wave height and period characteristics were established by applying the authors' scale-model relationship which was reported; and wave duration time also was decided. A method of employing regular waves in the model to represent irregular waves in the field is proposed. From the results, it was shown that the model can reproduce well the beach change in the field using the regular waves having the mean wave properties in the irregular waves.

1. INTRODUCTION

Coastal disasters, such as a beach erosion and seawall collapse which are caused by rapid sediment transport that occurs during storm conditions, continue to be frequently reported. One very important method used to approximate the coastal disaster, in hopes of preventing it, is the movable-bed model which can very closely approximate the beach change processes under the conditions of time-varying waves. However, because the scale-model relationship was not properly, we could not extrapolate the quantitative results which were obtained by the moveable-bed scale model test to the actual prototype, and therefore the results were applied qualitatively. It is necessary to establish the scale-model relationship and the experimental technique for the moveable-bed model test which is applicable for short-term beach change by unsteady time-dependent waves, as occur in the field.

As an example of a moveable-bed model investigation, Vellinga (1982) tried to reproduce, by a two-dimensional model, erosion of a coastal sand dune on the Dutch coast, the Netherlands due to wave action during an extreme storm surge. In the model test, vertical and

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horizontal scales were distorted, and the model sediment grain-size was determined by a new parameter which was composed of both the dimensionless sediment-settling parameter proposed by Dean (1973) and the vertical scale. Also, Hughes (1983) examined the application of Dean's dimensionless parameter, Froude's time scale of vertical scale, and the distorted model between the vertical and horizontal scales. The relationship which Hughes proposed was verified by results which reproduced the coastal dune erosion in the Florida Panhandle, USA caused by the 1975 Hurricane Eloise, using two-dimensional model test and regular waves. Tsuchiya et al. (1985) considered experimentally how to efficiently control beach erosion due to the T-type groin and the artificial headland works at Shirarahama, Wakayama, Japan using a three-dimensional movable-bed model and regular waves. The model test condition was established using the modified author's scale-model relationship for length and grain-size scales, Froude's scale for time scale, and an undistorted scale for vertical and horizontal scales.

In these previous experimental studies, the reproduction of filed beach profiles by model test are not only defined quantitatively, but also in how to determine set the optimum regular waves for the model. Therefore, as the first step, the approach due to regular waves is hoped strongly rather than use of the time-dependent irregular waves as are found in the field, due to the lack of an adequate irregular wave scaling relationship.

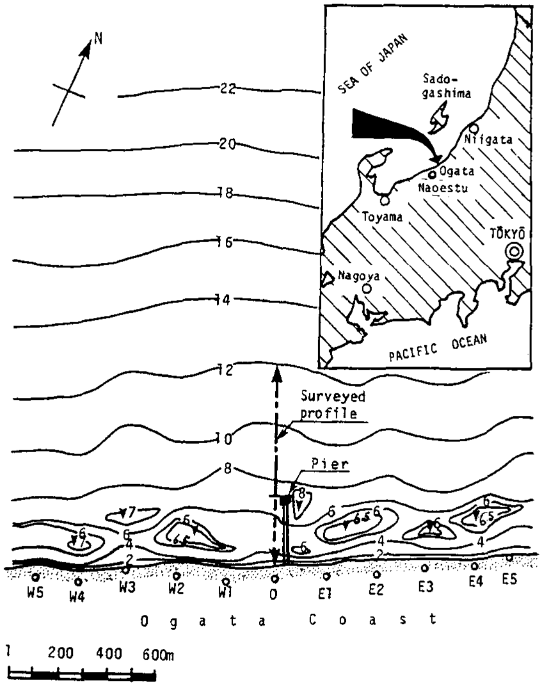


Figure 1 Bottom topograhpy of Ogata coast and study site.

2. CONDITIONS IN STUDY SITE

(1) Coastal morphology

The Ogata coast facing the Sea of Japan is about 100km southwest from Niigata-city, Japan and has a considerably straight shoreline as shown in Figure 1. The sediment grain-size of this coast becomes gradually fine in the offshore direction, and its medium grain-size diameter, d_{50}, is 1. 5 to 0. 2mm. The beach profiles ranging from shoreline to about 300m offshore had been surveyed at one week intervals using a rod along an observation pier known as the Ogata Wave Observatory of the Disaster Prevention Research Institute, Kyoto University. The beach profile father than 300m offshore, that is, deeper than a water depth of 8m, had been surveyed occasionally by using an ultrasonic sounding instrument. The sea bottom father than 300m offshore has an average slope of 1/100. A longshore exist bar within the zone from the shore to about 300m offshore, beyond this 300m offshore distance the seabed contours remain fairly strait and parallel to the shoreline. Therefore, the topography of this coast may be considered almost two-dimensional in the on-offshore direction.

(2) Wave climate

Wave conditions in this area are usually observed at the offshore end of the observation pier in a depth of 6m, and Naoetsu Port Office, about 10km distance from the Ogata, in a depth of about 21m.

The Naoetsu Port Office continues to perform daily wave observations. From March 14-18, 1981 a large-scale lower atmospheric depression passed through the Sea of Japan, off the Ogata coast. Figure 2 shows the weather chart on the 15th when the Ogata coast wave attack was most severe. In Figure 3, time histories for significant wave height and period during the 15th to the 17th at the observation pier are shown using heavy solid and broken lines, respectively, while those at Naoetsu harbor are shown using shin solid and broken lines, respectively. As shown in this figure, the wave period records observed at the two positions agree well with each other. Whereas, records of wave height at the two positions do not completely agree with each other. This discrepancy of wave height higher than 4m is attributed to the generation of wave breaking because the measurement station of observation pier is relatively shallows. However, there was a good agreement for waves smaller than 4m height. Because the time history of waves observed at the two positions agreed well with each other, we choose to use the wave records which were observed in Naoetsu instead of Ogata. Figure 4 shows the time history of the maximum wave height, H_{max}, the significant wave height, $H_{1/3}$, and the mean wave height, H_{mean}, for 1 hour, which were calculated using the wave records observed at Naoetsu during the storm from the 10th to the 18th. During this period, the dominant incident waves at the Ogata coast attacked at nearly normal incidence to the shore, so that the coastal condition could be considered two-dimensionally.

3. SCALE-MODEL RELATIONSHIP USED

The scale-model relationship was used to design the model such that the Ogata coast beach change processes, due to storm waves, could be reproduced. The scale-model relationship, which is indicated as the similitude zone in Figure 5, had been earlier defined by the authors (1984) by considering experimentally the similarity between the

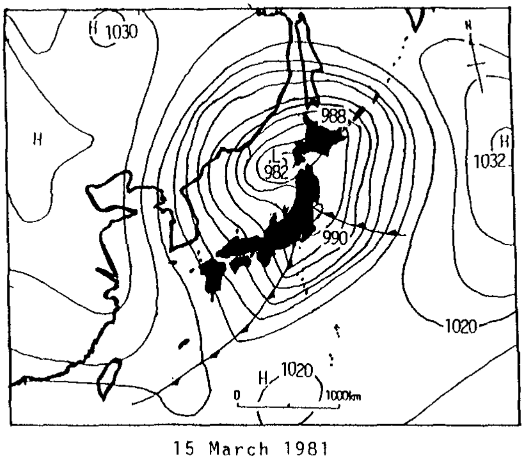


Figure 2 Weather chart of the storm at maximum intensity attacked to the Ogata coast on 15 March 1981.

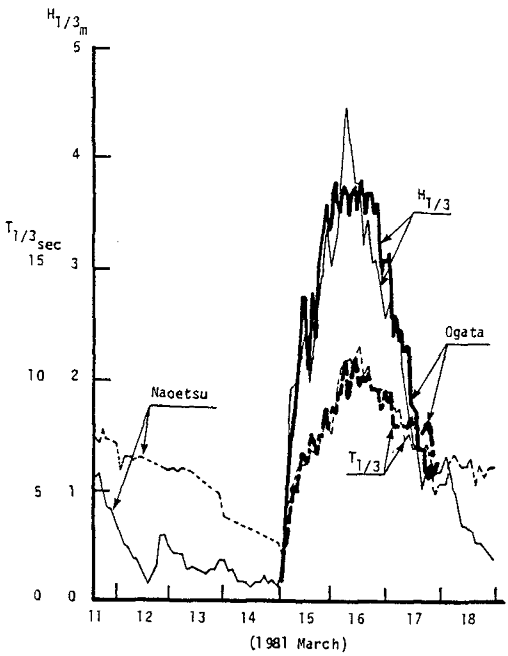


Figure 3 Time history of the significant wave height and period for 1 hour observation averaging at the tip of Ogata's pier and in Naoetsu harbour during 15 March 1981 to 17.

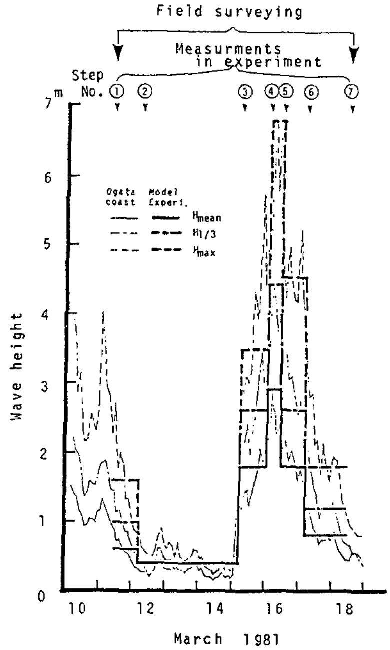


Figure 4 Variation of wave height during storm and experimental waves used.

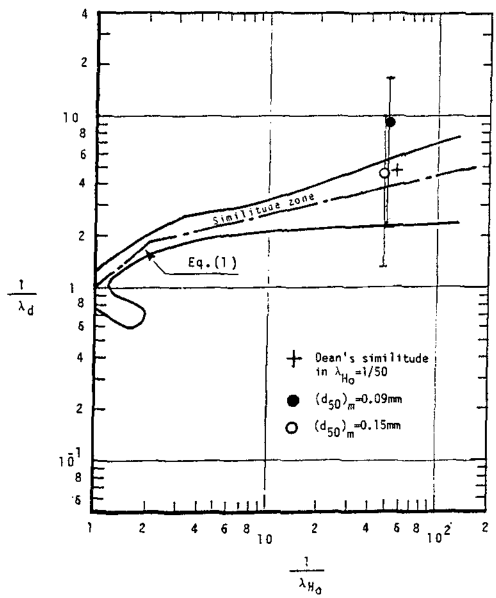


Figure 5 Scale-model relationship and experimental conditions set up in model.

large-scale beach profile and medium to small-scale ones under equilibrium conditions. Also, the wave duration time scale used in the model test was determined by using the authors (1986). This time scale was introduced from experimental results which were derived under conditions established according to the authors' scale-model relationship. These scale-model relationships are summarized as follows:

(1) The vertical and horizontal length scales of the beach profile are taken as the same (i. e., undistorted or geometric similarity).

(2) Wave characteristics such as wave height and period are determined by the Froude law.

(3) The beach sediment used in the model should be the sand or silica-sand which has the same specific gravity as the sea-bottom sediment of the prototype.

(4) The grain-size scale $\lambda_d = (d)_m / (d)_p$ between the grain-size of model sand, $(d)_m$, and prototype, $(d)_p$, is determined by the relationship indicated by the dot-dashed line in Figure 5. This relationship is given by

$$\frac{1}{\lambda_d} = 1.7^{a} \left(\frac{1}{\lambda_l}\right)^{b} \tag{1}$$

where a=1, b=0.87 for the range of experimental scale $1 \geq \lambda_l \geq 1/2.2$; a=0, b=0.2 for $\lambda_l < 1/2.2$, and λ_l is the scale of length $(1/n)$, that is, experimental scale.

(5) Time scale, λ_t, is given by

$$\frac{1}{1.6}\sqrt{\lambda_l} \leq \lambda_t \leq \frac{1}{0.65}\sqrt{\lambda_l} \tag{2}$$

Then we use the time scale which is indicated the average tendency of Eq. (2), given as

$$\lambda_t = \sqrt{\lambda_l} = 1/\sqrt{n} \tag{3}$$

This relationship is none other than the Froude's time scale.

4. MODEL TEST CONDITION

The experimental scale of the model was set at 1/50, and the sand-grain size scale was then determined by Eq. (1) to be $\lambda_d = (d)_m / (d)_p = 1/3.7$. The median grain-size of on-offshore direction in the Ogata coast ranges from $(d_{50})_p = 1.5 \sim 0.2$mm, therefore, according to Eq. (1), the model sand grain-size should range from $(d_{50})_m = 0.41 \sim 0.05$mm. Especially, the sediment grain-size, where the beach profile at the Ogata coast changes remarkably, is $(d_{50})_p = 0.4$mm, therefore, two kinds of silica-sands were used, $(d_{50})_m = 0.09$ and 0.15mm, which have a uniform grain-size distribution. The sorting coefficient of these silica sands are 1.32, and the specific gravity in the air is 2.71. The grain-size scale between the two kinds of silica-sands and the field sediment are shown in Figure 5. The value of sediment grain-size in the field are scattered, so that their representative values and scattering ranges are shown in this figure. This figure shows the silica-sand, $(d_{50})_m = 0.15$mm (open circle) sufficiently satisfies the scale-model relationship, however the $(d_{50})_m = 0.09$mm silica-sand is shifted slightly upward from the scale-model relationship. The time dependency of the wave height and period during the storm were considered by separating the storm term into some time intervals which wave height and period wereevaluated, furthermore, three classification methods were employed for comparison purpose, mean significant and maximum, as shown in Figure 4. In the model test the three types of waves were then scaled down to 1/50 by the Froude law and regular waves employed. Therefore, wave height, period, and wave duration time were each taken as a variable in the model. Figure 6 shows that the mean tidal level in Naoetsu during the storm, 11th to 18th, varies from -2cm to 45cm. From this figure, it is clear that the passing of the lower depression generated a significant storm surge. Therefore, it is assumed that this tidal change influenced the Ogata coast as well. If the variation of tidal level is scaled down to 1/50, the range of variation in the model becomes 0. 94cm. Then, water level in the model test, that is the water depth of wave flume was held a constant. The model test conditions which were set by thus modeling technique, were arranged in Table 1.

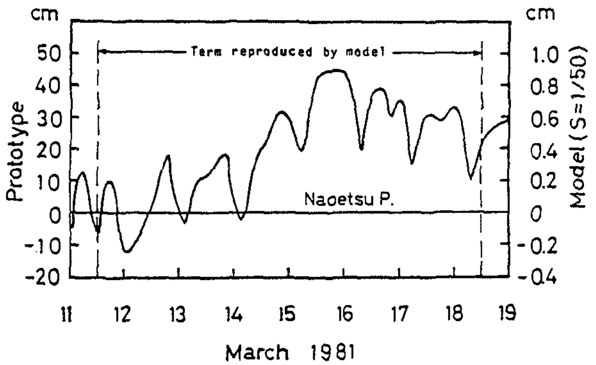


Figure 6 Variation of tidal level and storm surge in Naoestu.

Table 1 Experimental conditions to reproduce beach processes of Ogata coast.

Run No.	Grain size d_{50} mm	Wave character-listics		Step No. ①	② -1	-2	-3	③	④	⑤	⑥
				t=2h33m	3h	6h	9h37m	3h32m	1h16m	2h33m	4h14m
2	0.15	Hmean	H(cm)	1.2	0.8	0.8	0.8	3.5	5.8	3.6	1.6
4	0.09		T (s)	0.71	0.71	0.71	0.71	0.71	1.13	1.13	0.71
			H_0/L_0	0.0211	0.0141	0.0141	0.0141	0.0626	0.0335	0.0222	0.0283
1	0.15	$H_{1/3}$	H(cm)	2.0	0.8	0.8	0.8	5.2	8.8	5.2	2.4
5	0.09		T (S)	1.06	0.92	0.92	0.92	0.92	1.6	1.5	0.92
			H_0/L_0	0.0125	0.0079	0.0079	0.0079	0.0511	0.0234	0.0139	0.0235
3	0.15	Hmax	H(cm)	3.6	0.8	0.8	0.8	7.0	13.6	9.0	3.6
6	0.09		T (s)	1.06	0.92	0.92	0.92	0.92	1.7	1.98	1.13
			H_0/L_0	0.0257	0.0079	0.0079	0.0079	0.068	0.0309	0.0142	0.0222

5. REPRODUCTION BY MODEL TEST

Movable-bed model tests was carried out in a medium-sized wave flume of dimensions 28m long, 0. 5m wide and 1m deep, with a flap-type regular wave generator. An initial model beach profile was formed in the on-offshore direction corresponding to a 900m offshore distance in the prototype. This initial profile corresponds to the location indicated by the survey profile line in Figure 1, taken on the 11th just prior to the storm. Wave properties are varied according to Step Nos. ①～⑦ in Table 1, while the wave duration intervals are specified by the Froude's time scale for the step like functions shown in Figure 4. The changes in beach profile were also measured at the times indicated in Step Nos. ①～⑦ in Table 1. We classified the measured beach profile data into the following three groups, and discussed each from the standpoint of the reproduction of field beach profile.

(1) Beach profile

Figure 7 shows the beach changes in the model due to regular waves. The beach profiles that changed more significantly than those in the step are only shown in this figure. In this figure, the initial beach profile marked by ① (Step No. ①), and final beach profile by ⑦ are shown overlapping their corresponding field beach profile. From this figure, it is found that sand dunes (reflection bars) form on the onshore and offshore sides of the longshore bar when the significant and maximum waves were employed. The influence of the partial standing waves is considered to contribute to bar formation.

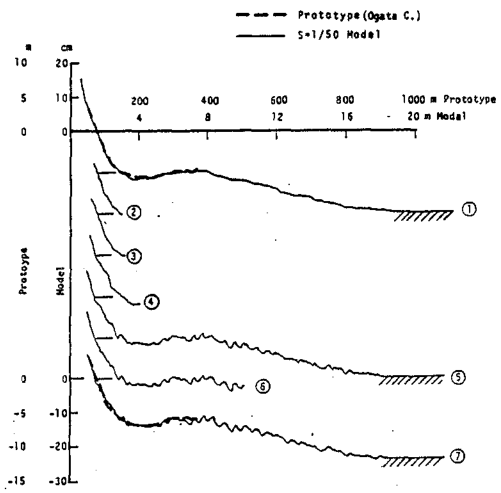
The initial and final Ogata coast beach profiles, 11th and 18th, were used to examine and compare the reproductive capability of the based on variations in sediment grain-size and wave height classification, where the solid and dash-dotted lines represent grain-sizes of 0. 09mm and 0. 15mm, respectively as shown in Figure 8. From this figure, it is shown that the reproduction of the beach profile is best when using regular waves which correspond to the mean waves of the observation records, that the reproduction capability significantly decays as the order of the wave exceeds the significant. However, the sediment grain-size was found to produce little effect on model reproduction as compare to wave scaling.

(2) Shoreline change

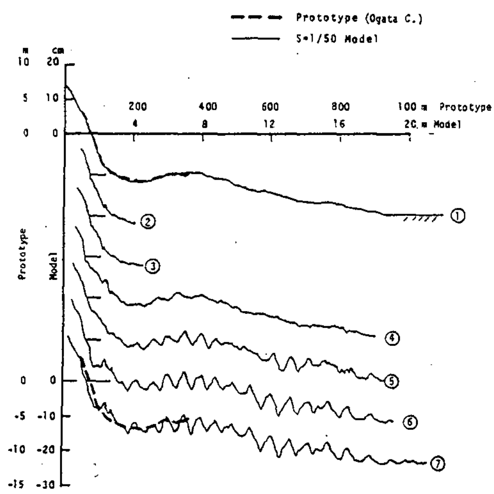
The temporal changes in the shoreline of the model tests from the initial state on the 11th by the mean, significant and maximum waves are arranged in Figure 9, such that the profiles corresponding to the two of sediment grain-sizes are distinguishable. In this figure, the results are shown only for Step No. ⑦ (final experimental data), along with the corresponding range of experimental error. Also, a field shoreline measurement taken on the 18th is shown along with the tidal variation corresponding to that day. From the comparison of the shoreline change by the model tests with the field, it is found that, when mean waves are used in the experiment, the reproduction is much better than profile reproduction using the significant and maximum waves.

(3) Sand volume change

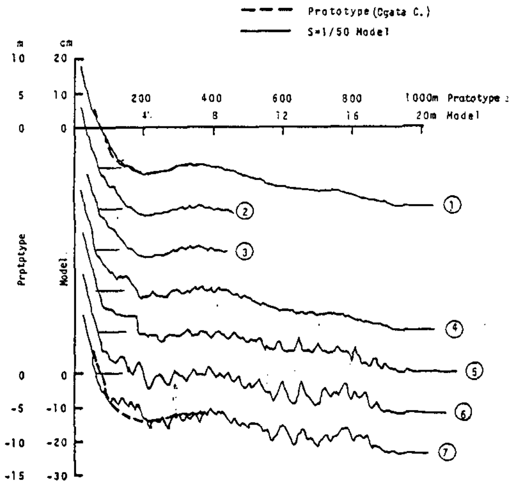
We examine the reproduction in term of the sand volume change which can be calculate from the beach profile change. The sand volume change per 1m width in the field was calculated over a 260m



7 (a) mean wave height, H_{mean}, Run No. 2



7 (b) significant wave height, $H_{1/3}$, Run No. 1



7 (c) maximum wave height, H_{max}, Run No. 3

Figure 7 Reproduction of beach change processes in the model dye to the regular waves.

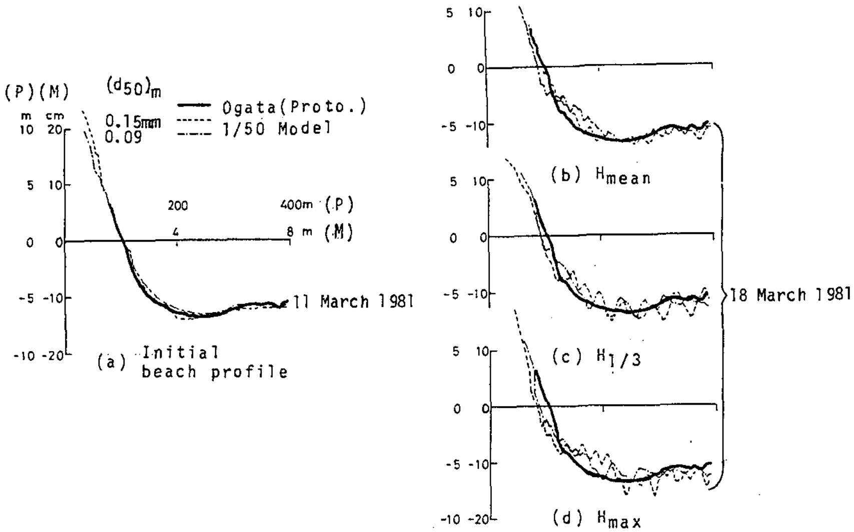


Figure 8 Comparison between the Ogata coast beach profile on the 11th and initial beach profiles, and between the Ogata coast on the 18th and model beach profiles reproduced by three kinds of waves.

range included the shoreline, for the period between the 11th and the 18th. By calculating the sand volume change of the model in the same manner and taking the scale into consideration, a comparison is made between the model and the field as shown in Figure 10. In this figure the differences in both sediment grain-sizes and wave properties are distinguished. As is seen in the comparison, the model test results which were used the mean and the significant waves reproduce the field very well, however, field reproduction is very poor for both sediment grain-sizes when employing the maximum waves.

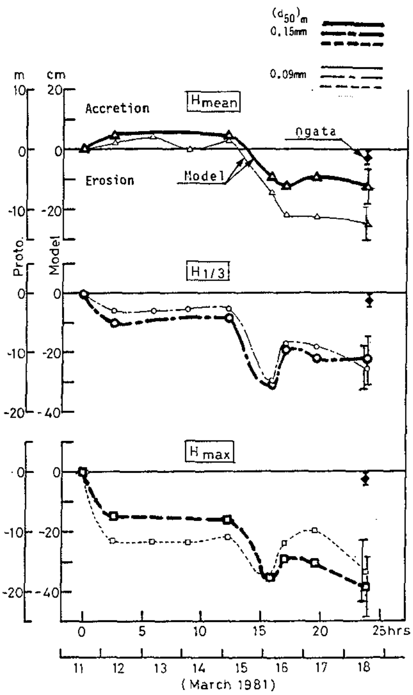


Figure 9 Reproduction of shore-line change.

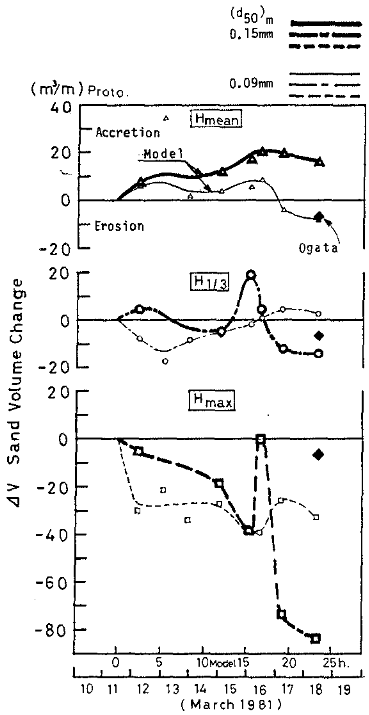


Figure 10 Reproduction of sand volume change.

6. DISCUSSION

Some scale-model relationships of beach change processes have reported till now, as reviewed by Hallermeier (1985). This model test study was performed applying the author's scale-model relationship which was described in the sections 3. (1)~3. (5). Therefore, quoting the scale-model relationship which is possible to compare to the author's one, we discuss about the relation between them. Especially, the fall time perameter which is introduced from the criterion separating on-offshore transport by Dean (1973) is frequently quoted in the study on the similitude of beach change, so that we examine the correspondence between the authors' and Dean's scale-model relationship.

Dean (1973) studied experimentally the onshore or offshore direction of sediment motion, and reported that the normal and storm beach profiles can be classified by:

$$\frac{H_0}{L_0} \gtrless 1.7 \frac{\pi w}{g T} \qquad \begin{array}{l} \text{offshore (storm profile)} \\ \text{onshore (normal profile)} \end{array} \tag{4. a}$$

or

$$\frac{H_0}{w T} = c \tag{4. b}$$

where H_0 is the wave height in deep water, L_0 the wave length in deep water, g the gravity acceleration, w the settling velocity of sediment, T the wave period, and c the constant. Eq. (4. b) is described as tha fall time parameter. Letting the notation $\lambda_{Parameter}$ represent the ratio of the model to the prototype and using Froude similitude between the wave period and the length, the scale-model relationship of Eq. (4. b) is finally written as follows:

$$\lambda_w = \lambda_l^{1/2} \tag{5}$$

Because the experimental scale of the model tests is $\lambda_l = 1/50$, the required settling velocity rate of model and prototype sediments by Eq. (5) becomes

$$\frac{(w)_m}{(w)_P} = \frac{1}{7.1} \tag{6}$$

As mentioned above, the sea-bed sediment grain-size at Ogata coast varies from $(d_{50})_P$=0. 2mm to 1. 5mm in on-offshore direction and its typical grain-size is $(d_{50})_P$=0. 4mm. By using the relationship between the sediment grain-size and the settling velocity, that is, Eq. (6), the sediment grain-size to be used in model becomes $(d_{50})_m$=0. 06~0. 14mm and the typical size is $(d_{50})_m$=0. 086mm. Thus when $(d_{50})_P$=0. 4mm, the grain-size scale by Dean's parameter becomes $\lambda_d = (d)_m/(d)_P \cong 1/4.7$, while author's similitude is $\lambda_d = 1/3.7$. The comparison between authors' similitude (dotted dash line) and Dean's grain-size scale is shown by the cross symbol "+" in Figure 5. From this comparison, it is interesting to note Dean's grain-size scale is slightly shifted from the authors, that is, the grain-size of the model obtained by Dean's grain-size scale relationship becomes slightly finer than the authors.

Therefore, one of the two kinds of sediments which were used in this model test approximately agrees with the grain-size scale by the authors and Dean.

Table 2 Synthetic evaluation of the model reproduced processes of Ogata coast.

Run No.	Wave characterlistics		Beach profile	Shoreline change	Sand volume
2 4	Mean wave	H_{mean}	○	○	△
1 5	Significant wave	$H_{1/3}$	△	△	○
3 6	Maximum wave	H_{max}	◆	◆	◆

○ : "very good" reproduction △ : "good" reproduction ◆ : "bad" reproduction

7. SUMMARY AND CONCLUSION

In this model study the Ogata coast beach profile changes were modeled according to the methods described in sections 3. (1), 3. (3), and 3. (4) for the initial beach profile, wave characteristics, sediment material, and its grain-size, respectively. The model eaves were varied according to the measured Ogata coast storm wave intensity, and the wave duration time of regular waves in the model test were scaled down using Eq. (3). Wave characteristics were determined by the method described by 3. (2). Beach change processes due to time-dependent storm waves were found to be reproduce by using model waves corresponding to a one hour mean wave representation of field observations.

The two different sediment grain-sizes used in model test did not have a clear effect upon the reproduction.

The degree of reproduction due to regular waves corresponding to H_{mean}, $H_{1/3}$ and H_{max} with regard to the beach profile, the shoreline change, and the sand volume change are summarized in Table 2. From this table, it is found that, when the beach profile was reproduced very well, the reproduction of shoreline change and sand volume change were also.

It is concluded that reproduction in the model tests is "very good" when the regular waves corresponded to the mean wave in the field was used; "good", when using significant waves; and "bad" when using maximum waves.

The sediment grain-size of model which was determined by the authors' scale-model relationship was nearly equal to the value derived by Dean's relationship where the typical sediment grain-size in the Ogata coast was $(d)_p=0.4$mm. It should be noted that sediment grain-size of model, determined by Deans' scale-model relationship, changes depending on the settling velocity of sediment of field (prototype).

8. REFERENCES

1) DEAN, R. G. (1973) Heuristic models of sand transport in the surf zone, Proc. Eng. Dyn. in Surfzone, Institution of Engineers, Australia, pp. 208-214.

2) HUGHES, S. A. (1983) Movable-bed modeling law for coastal dune erosion, Jour. Water Port Coast. and Ocean Eng., ASCE. pp. 164-179.

3) HALLERMEIER, R. J. (1985) Unified modeling guidance based on a sedimentation parameter for beach changes, Coastal Engineering, Vol. 1, No. 1, pp. 27-70.

4) ITO, M. and TSUCHIYA, Y. (1984) Scale-model relationship of beach profile, Proc., 19th ICCE, ASCE, pp. 1386-1402.

5) ITO, M. and TSUCHIYA, Y. (1986) Time scale for modeling beach change, Proc., 20th ICCE, ASCE, pp. 1196-1209.

6) TSUCHIYA, Y., KAWATA, Y. and SILVESTER, R. (1985) Beach processes of Sirarahama and its preservation (2), Disaster Prevention Research Institute Annuals, Kyoto Univ., Vol. 28, B-2, pp. 565-590 (in Japanese).

7) VELLINGA, P. (1982) Beach and dune erosion during storm surges, Coastal Engineering, Vol. 6, No. 4, pp. 361-387.