CHAPTER 211

THREE DIMENSIONAL EFFECTS OF SEAWALL ON THE ADJACENT BEACH

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ABSTRACT

The effects of seawall on the adjacent beach is examined by the three dimensional physical model test. The experiment results are analyzed by means of the volumetric change analysis and the shoreline change analysis. The results show that the groin effects are dominant but they are localized within a region spanning three or four times of seawall length for the cases tested

1.Introduction

Beach erosion is found along many portion of the coast of the world. The cause of the erosion could be sea level rise, reduction in sediment supply, interruption of the littoral drift by structures. There are several conventional engineering solutions to combat such erosion. Those are (1) coastal structure such as groins,seawalls, breakwater and coastal dike, and (2) non structural solutions , such as beach nourishments. Among them , seawalls might be the most efficient and direct method to protect the up-land property provided that they are designed adequately.

Recently, the adverse effects of seawalls on their fronting and adjacent beaches have great attention and raised criticism about the use of seawalls in the coastal area. The most often alleged effects are (1) offshore profile slope steepening, (2) intensified local

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scour, (3) transport of sand to a substantial distance offshore, (4) adverse down drift erosion and (5) delay post-storm recovery(Dean,1986).Although numerous examples can be found from articles in newspaper or popular magazine reporting the adverse effectsof seawall, reliable and scientific based document is actually scarce. Moreover, the conclusion derived from the few technical reports on the adverse effects of seawalls remains controversial.Considering the merits of seawall altogether as means of coastal protection without firmly establishing their effects might be irrational. Therefore, there is a need to examining the effects of seawall carefully and to quantify them if possible. Also, by examining the cause and effects of seawall might lead more rational design in the future. The main objectives of the present study is to attempt to quantify the three dimensional effects on beach changes. In order to gain a fundamental understanding it was decided to conduct three dimensional model tests in the laboratory environment.

2.Possible Mechanisms of Seawall Effects

The effects of seawall are not well understood, but several possible mechanisms can be deduced from our general knowledge in coastal engineering. These are illustrated in Fig .1 and also described below.

(1) flanking effects; Flanking due to wave refraction and diffraction is expected to occur on the corners of the seawall to cause local erosion.

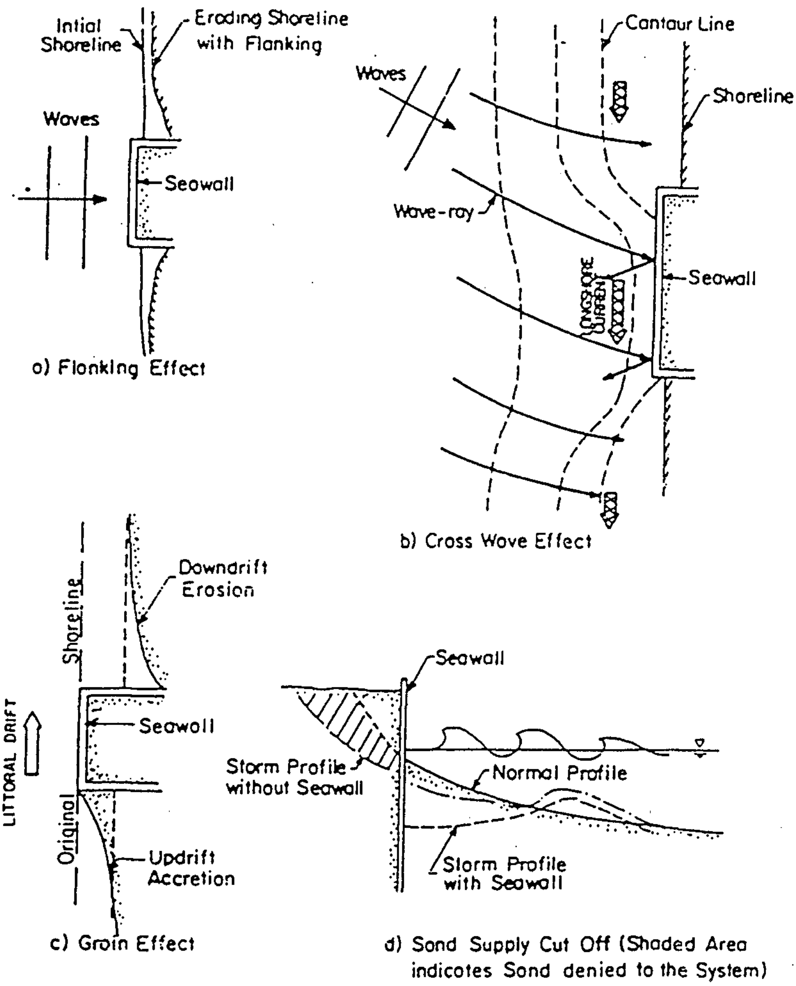
(2)cross wave effects; During storm surge period, the water depth in front of seawall is likely to be larger than that along beach and wave reflection will occur as shown in Fig. 1(b). Consequently, the longshore current together with more reflected wave energy trapped in the trough will remove sand in front of seawall and transport them to down drift location.

(3) groin effects; If the shoreline retreat due to littoral drift, the seawall will eventually protrude seaward and act like a groin. Although this groin effect does not remove sand from the system it inverse downdrift erosion pressure.

(4) sand supply cut off; Seawall prevents sand from being added to the littoral system, which again adds erosional stress downdrift and could result in lower bar profile in front of seawall during the storm surge period.

3. Model Test Apparatus and Test Condition

The model test is carried out in the wave basin of the Coastal and Oceanographic Engineering Department, University of Florida. The dimension of the basin is



a) Flanking Effect

b) Cross Wave Effect

c) Groin Effect

d) Sand Supply Cut Off (Shaded Area indicates Sand denied to the System)

Fig. 1 Possible Mechanisms of Effects of Seawall approximately 28m x 28 m and 1m deep. The beach and seawall system used in the experiments is shown in Fig . 2. The beach is composed of 125 tons of well sorted quarts sand. Both side of the beach are constrained by wooden template cut into a design beach profile shape. This design allows wave induced long-shore current to circulate unimpeded through the backside of beach. The beach profile is shaped in accordance with the concept of equilibrium beach profile(Dean 1977). The length of seawall is 3.0m and with 1.0m return walls on each side to prevent flanking. The height of seawall is 45 cm which is sufficient to prevent wave over topping. The toe of the seawall is located at 45 cm above the basin bottom which corresponds to the mean water level in the present test configurations.

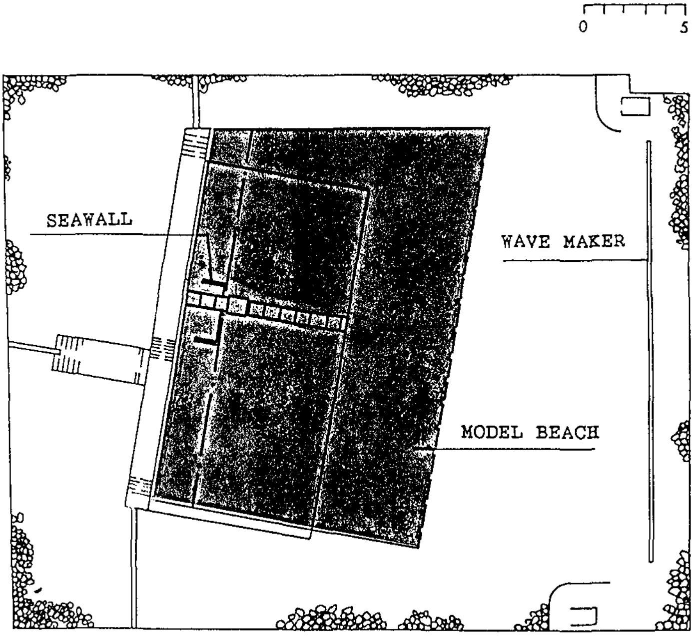


Fig . 2 Model Test Apparatus

The beach was subjected to the test wave condition for a designated duration. During test period, profile measurements were carried out at regular intervals. A total of 21 profiles were surveyed at equal spacing of 75 cm. Surveys were conducted at 0, 1, 2, and 4 hrs. Wave height was 11 cm and wave period was 1.74 s. The test conditions are summarized in Table 1.

Table 1 Test Condition

Case	wave height (cm)	wave period (sec)	water depth (cm)	wave angle (°)	seawall	elapsed time (hour)
Case1	11.0	1.74	45.0	0	no	4.0
Case2	11.0	1.74	45.0	0	yes	4.0
Case3	11.0	1.74	45.0	5	no	4.0
Case4	11.0	1.74	45.0	5	yes	4.0
Case5	11.0	1.74	45.0	10	no	12.0
Case6	11.0	1.74	45.0	10	yes	5.0

4. Volume Change Analysis

The codinate system in this study is shown in Fig. 3.

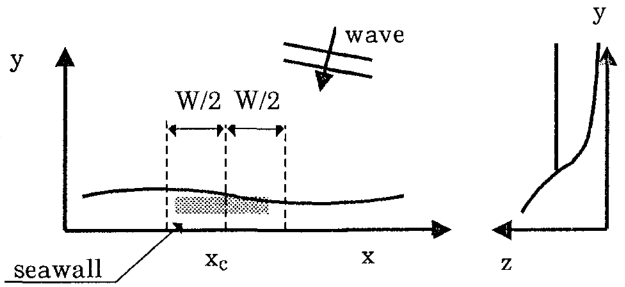


Fig. 3 Cordinate System

Based on the cordinate system, the rate of volumetric change in a local control area centered around the seawall, $v_l(t)$ is defined as

$$v_l(t) = \int_{x_c - W/2}^{x_c + W/2} \int_0^{y_0} \frac{\partial z}{\partial t} \, dy dx, \qquad (1)$$

where z =profile elevation, x=shore-parallel axis, y=shore-perpendicular axis, x_c is the location of the center of seawall ,y_0 = measurement length, W is the width of control area and t is time. .

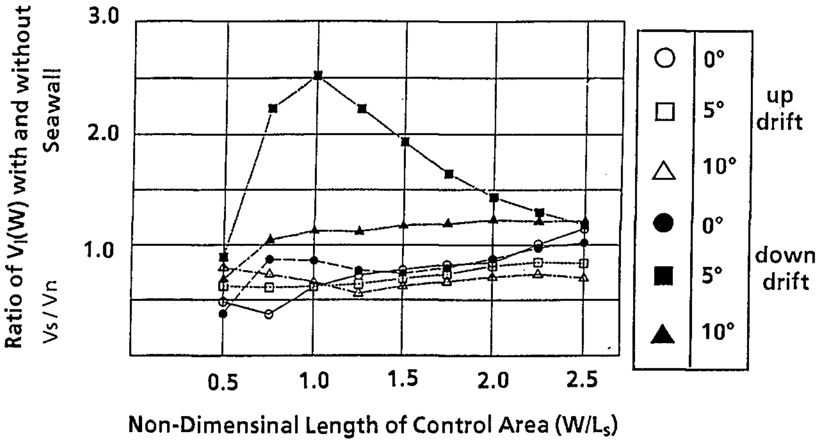
The ratio of the volumetric change , with(v_s) and without(v_n) is plotted against the non - dimensional control width(W/L_s) where L_s is the length of seawall in Fig. 4. If the ratio is lager than 1.0, the rate of erosion is lager with seawall than without seawall and vice versa.

In Fig.4(a), the ratio of v_s and v_n is plotted for the updrift and down drift region separately. In the updrift region, v_s/v_n is always less than 1 irrespective the width of the control region and the wave angles. Thus, in the case of normal incident wave, this value less than one because more sand is retained by the seawall in the backshore than the additional material being eroded in front of seawall, when compared with the natural beach case. For cases with oblique waves on the other hands, sand is retained in the updrift due to groin effect. They also make this ratio less than unity. On the down drift side, the situation is different, As expected, under normal incident waves v_s/v_n is less than 1.0 much the same as the updrift side. Under oblique waves, v_s/v_n is less than 1 when W/L_s =0.5, or when the control region coincides with seawall length much the same as the two dimensional model test case by Barnett (1988). Apparently, even under oblique wave, the material retained from the scouring trough in front of seawall. However, when W/L_s become larger than 0.5,v_s/v_n also become larger than 1.0. The presence of seawall now interrupt the normal longshore transport and cause down drift erosion to be greater than the natural beach condition.

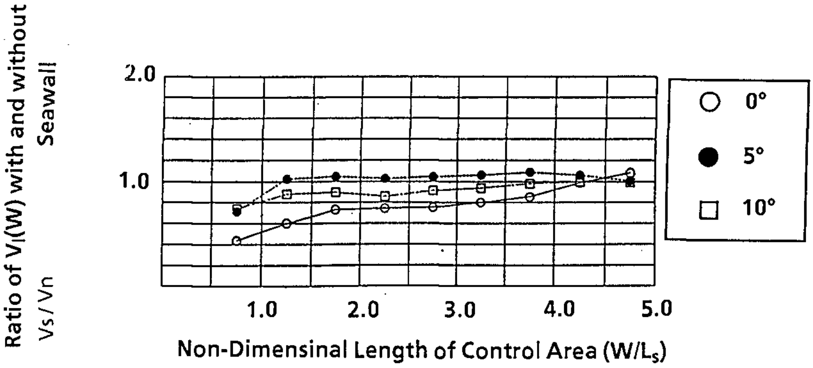
Finally, in Fig. 4(b) the ratio of total volumetric change including both updrift and down drift region are given. It can be seen that when $W/L_s<1.25$,$v_s/v_n<1.0$. When $W/L_s>1.25$, the ratio of v_s/v_n become constant and approaches 1 as it should do when W/L_s becomes large. Therefore, the effects of seawall appears to be quite localized ,certainly within 3 to 4 times of seawall length for the cases tested.

5.SHORELINE CHANGES

Fig. 5 shows general view of bathymetric change of four hours elapsed time for all cases tested. It can be seen that for the natural beach under normal incident waves the shoreline almost uniformly recessed. As wave angle is larger , the recession of the shoreline becomes



a) Ratio of Volumetric Change with and without Seawall Up-Drift ,Down Drift Separatlely



b) Ratio of Volumetric Change with and without Seawall

Fig. 4 Volumetric Change in Local Control Area larger. For the seawall backed beach under normal incident waves, the shoreline also uniformly recessed, but under oblique waves ,the recession of the shorelines of down-drift side is larger than that of natural beach , and that of up-drift side are smaller. The scour hole can be seen in front of seawall and the contour lines in front of seawall protrude shore ward there.

Shoreline changes are examined by means of Empirical Eigenfunction (EEF)analysis . For a multi variate function such as the three dimensional contour line represented by h(x,y,t) there are several possible combinations of eigenfunction representation such as

$$h(x,y,t)=\sum_{m} w_m c_m(t) e_m(x) f_m(y)\,, \tag{2}$$

$$h(x,y,t)=\sum_{m} w_m c_m(t) e_m(x,y)\,, \tag{3}$$

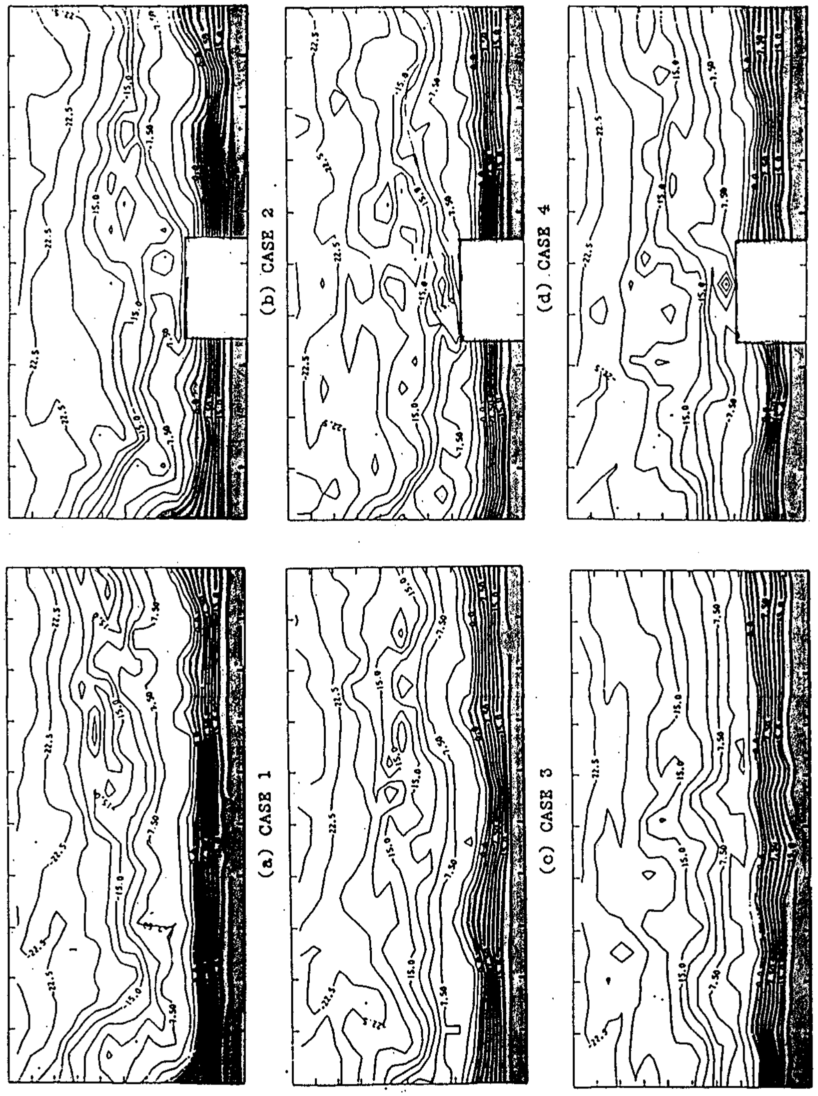
$$h(x,y,t)=\sum_{m} w_m c_m(x,t_o) e_m(y,t_o)\,, \tag{4}$$

where w_m is the weighting function, c_m, e_m, f_m are eigen vectors and m is the mode. These combination are, however,not independent of each other. The hope is to have the right choice such that most of the variance in the data set will be accounted for in fewest terms. Unfortunately, at present, there is no criterion for making such a choice and one has to rely on intuition and trial and error. After a number of preliminary tests, it is decided to use the distance from a baseline to shoreline ,d(x,t) , as the dependent variable. Thus, we assume that this distance can be represented by the linear sum of spatial eigenfunction, $S_m(x)$,and temporal eigenfunction $T_m(t)$, of the following form:

$$D(x,t)=d(x,t)-d(x,t_o)$$

$$=\sum_{m=1}^{\infty} w_m S_m(x,t_o) T_m(t)\,, \tag{5}$$

where D(x,t) is the difference between the distance of the shoreline at time t and that of the initial shoreline , and t_o is the initial time.



(a) CASE 1

(b) CASE 2

(c) CASE 3

(d) CASE 4

(e) CASE 5

(f) CASE 6

Fig .5 Contour Maps for Four Hours Elapsed Time

In applying the procedure outlined here to the present experiment data set, a number of problems are identified that require special attention:

(1)Owing to the existence of offshore shoals and bars , d(x,t) has , at times, multi - values. Care must be exercised to select the depth contour that is physically meaningful.(2) In EEF analysis, the contour lines near it are clearly not continuous. In such case, the contour lines are divided into segmented continuous lines and EEF analysis is performed to each line individually.

Fig.6 shows the results of EEF analysis for all cases. In all the cases tested, the first eigen vector appears to account for more than 90% of the variance. Therefore , there is no surprising that the real shoreline changes is similar to the first spatial eigen vector. For cases of erosional waves with normal incident angle, ideally the shoreline would recede uniformly as there should be no longshore component of sediment transport. By examining Fig. 6 for the case of no seawall, the first spatial eigen vector is almost a parallel line with the exception near the edge where the three dimensional effects come into play. For the case with seawall , the first spatial eigen vector is almost a parallel line. The flanking effects, if any, is not visible. The temporal vectors are almost identical for both cases.

Under oblique waves, for the case of no seawall, the first spatial eigen vector exhibits a rhythmic features in addition to a uniform recession. The first temporal vectors appear to be similar to the case of normal incident waves. With presence of seawall, the rhythmic features on the updrift sides becomes more pronounced. Again, the temporal vectors possess similar characteristics as the previous cases. Now, as the wave angle increases(to 10 degree), this rhythmic features diminishes in amplitude. The groin effects becomes more evident that results in severe down - drift erosion immediately in the shadow of the seawall.

6 Correlation between Shoreline Changes and Volumetric Change

The correlation between shoreline changes and volumetric changes are examined here. The one-line theory for shoreline change is based on the following continuity equation of sediment flux:

$$\frac{1}{h}\frac{\partial S}{\partial x}+\frac{\partial d_s}{\partial t}+p=0\,, \tag{6}$$

where d_s denotes shoreline change, S is the longshore sediment transport, h is the water depth at a closure point, p is the sink/source of sediment. Eq.(8) can be written in this finite difference form neglecting the term, p,

$$\Delta d_s = -\frac{1}{h}\frac{\Delta t}{\Delta x}\Delta S = -\frac{1}{h}\,\Delta V, \qquad (7)$$

where ΔV is the volumetric change per unit length along shore.

The value of h is usually treated as a constant. Therefore, according to one-line model the shoreline changes, Δd, has a linear relation to the cross-sectional volumetric changes. Fig . 7 shows the comparison of the calculated shoreline changes based on Eq (7) to the measured shoreline changes. As can be seen, agreement are good for beach with no seawall. The agreement actually becomes better as the test duration increases. This is because the profile gradually reaches the new equilibrium configurations. For beaches with seawall the agreement is poor at the initial stage but improved progressively as the duration of test becomes longer. Obviously, during the early stage of profile adjustment, the main mode of sediment transport is in the cross-shore direction. The one-line model which assumes no profile adjustment between time steps cannot be applied. As time elapses the profile becomes stabilized and longshore transport takes over as the main mode of sediment transport. The presence of seawall will create profile disturbance in both up-wave and down wave directions away from the seawall as can be seen in Fig 7 .However , as time progress, the disturbance, instead of spreading further, actually, tends to diminish and the beach will revert back to the natural state of no seawall with the exception of the very localized effects just adjacent to the seawall.

7.Concluding remarks

To examine the effects of seawall , volumetric change analysis and shoreline changes analysis were employed. In volumetric change analysis, it was found that under normal incident wave, the rate of volumetric erosion as well as the total eroded volume in front of seawall was smaller than that of natural beach. For oblique waves, due to groin effects the erosion of down drift side is severe, but the effects were found to be localized within a region spanning 3 to 4 times of seawall length of fronting beach centered around seawall.

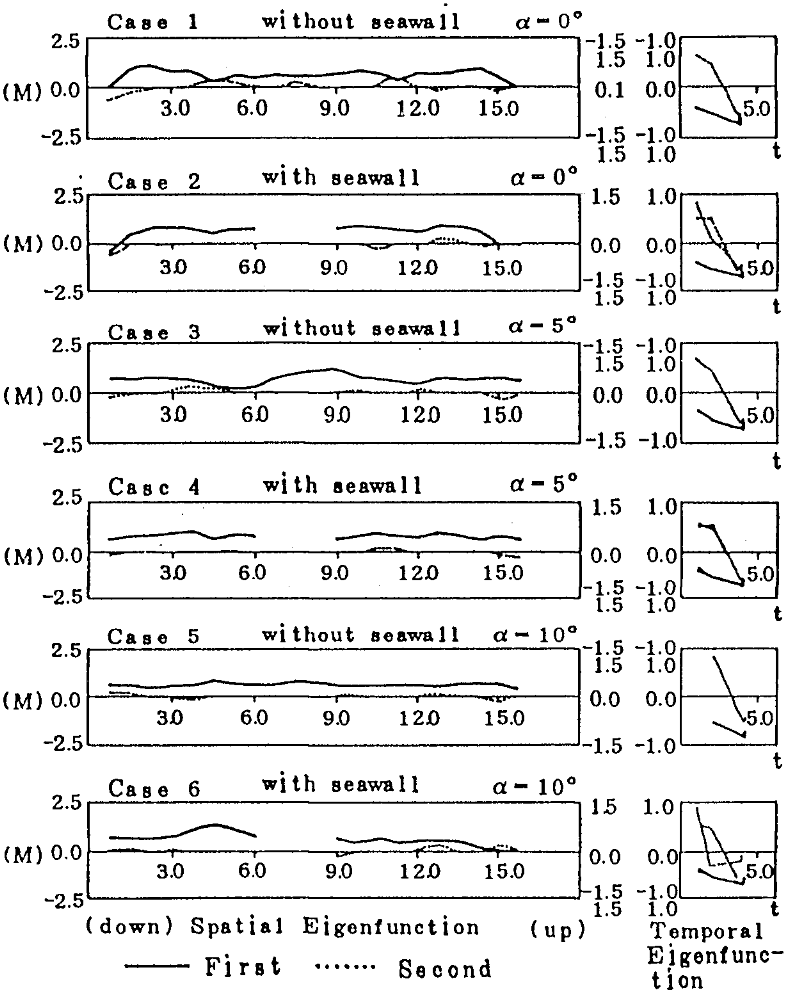
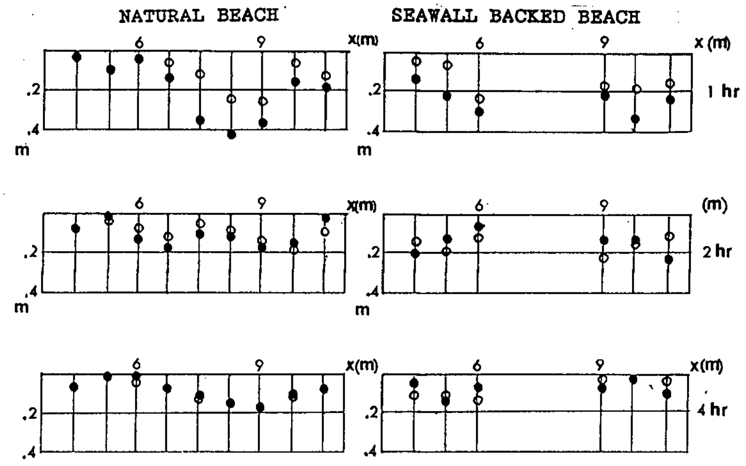
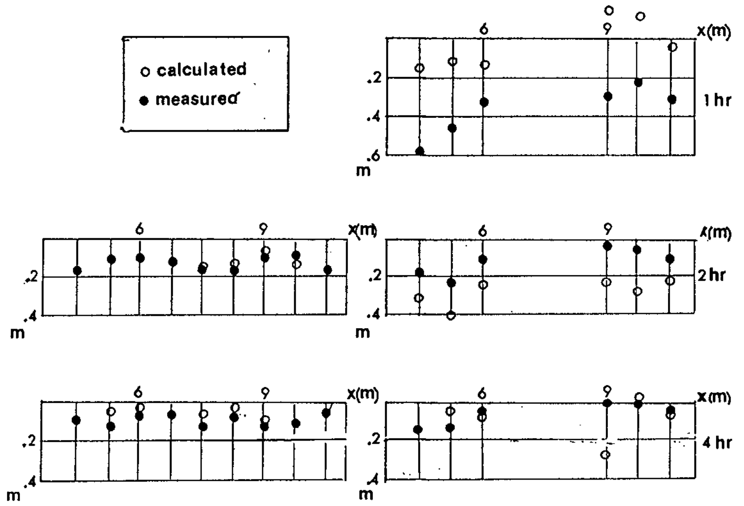


Fig. 6 Spatial and Temporal Eigenfunction



a) Case 3 5° b) Case 4 5°



c) Case 5 10° d) Case 6 10°

Fig. 7 Comparison of Shoreline Changes Calculated and Measured

In shoreline change analysis, empirical eigen function were utilized. EEF was applied to the shoreline changes. The first spatial eigen function accounted for 90 % of the variance of shoreline data. Under normal incident wave, the spatial eigenfunction manifested a uniform recession and was very similar for a natural beach and seawall backed beach. Under oblique wave, the local effects of increased down drift erosion and decreased updrift erosion were evident.

The validity of one-line model for seawall backed beach was examined. Comparison between the measured shoreline and calculated shoreline supported the validity of one-line model for natural beach , but for seawalled beach especially at the initial stage of profile evolution while shoreline changes were dominated by on/off shore transport, one-line model was not valid well.

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