CHAPTER 214

EXPERIMENTAL STUDIES ON THE EFFECT OF THE DREDGING ON CHANG-HWA RECLAMATION AREA, TAIWAN

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ABSTRACT

The effects of offshore dredging at Chang-Hwa reclamation area, Taiwan, are investigated by using movable bed model tests. A practical scale relation for the design of movable bed model is presented. It takes the advantage to give more flexibility for the selection of model sediment. The scale relations of wave conditions in the model test are obtained based on the similitude of two parameters: wave steepness and mobility number. Time scale of sea bottom changes is determined by longshore sediment transport rate. Experimental results show that the proposed scale relations are able to reproduce beach changes in nature. Topographical changes before and after dredging are predicted in model tests. Special attention was made to study the location of erosion and accretion of sea bed configuration owing to offshore dredging.

INTRODUCTION

In recent years the utilization of coastal zone has been increased for human activities due to the growth of economics and population and the limited land. The land reclamation project was steadily executed at Chang-Hwa Coast, located on the west coast of central Taiwan (see Fig. 1), to obtain an industrial area. The method of dredging from offshore sea bed is considered as one of the sources of sand supply for

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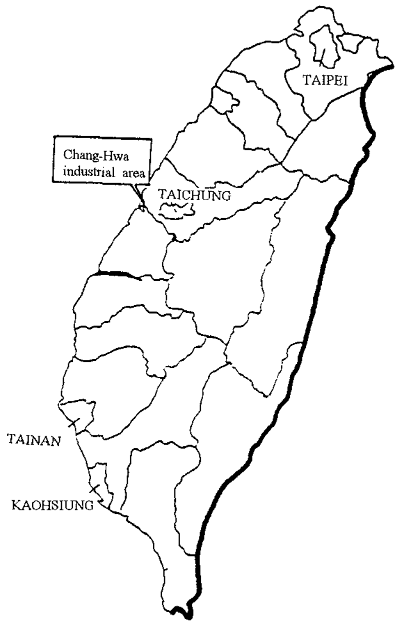

Figure 1 Geographical location of Chang–Hwa industrial area in Taiwan

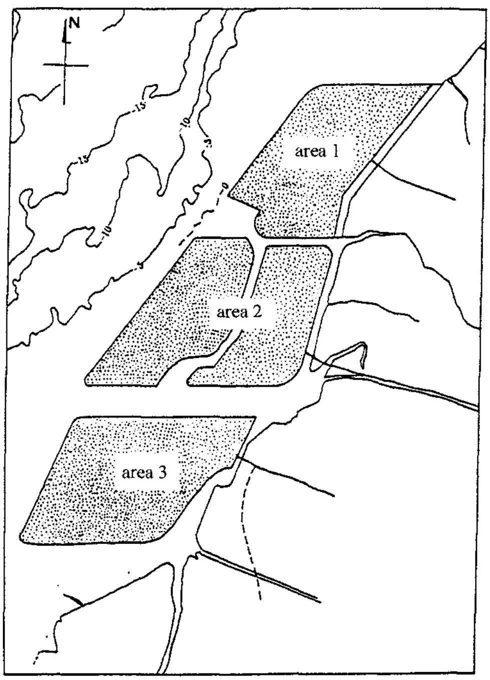

Figure 2 Schematic diagram of Chang–Hwa reclamation area

reclamation. The reclamation regions at Chang-Hwa Coast shown in Fig. 2 covers a length of 12 kilometers from north to south and extends 3.5 to 4.5 kilometers offshore. The planed layout is divided into three districts (Fig. 2) with a total area of 3643 hectares to accommodate heavy industries such as machinery, steel, power and petrochemistry. Generally the topographical changes in the coastal region tend to reach a dynamic equilibrium for a long term period without significant interference. However, a new sea bottom formed after dredging may lead to changes of coastal process and result in beach erosion. An assessment of coastal environment impact for this project becomes important in engineering practice.

It is recognized that field survey, physical hydraulic model and numerical modeling are three dominant methods to solve coastal problems. Among them, the physical hydraulic model is an alternate means of replacing governing equation with complicated initial and boundary conditions and permit examination in controlled conditions of coastal processes and effects due to gravity waves and other environmental forces.

Satisfactory reproduction of sandy shore and nearshore regions in a movable bed model can provide a valuable tool to the coastal engineering. Design and operation of moving bed models are a difficult task involving complex considerations of hydraulics and sedimentation. The aim of this paper is to investigate the effects of offshore dredging on reclamation area by movable bed tests. A practical scale relation for the design of movable bed model is presented. Predictions of topographical changes after dredging and countermeasures against beach erosion are discussed.

MODEL SIMULATION

1. Scale Relationships

A practical scale relationship for the design of movable bed test is proposed to reproduce physical features of sediment transports in prototype. Two parameters of wave steepness and mobility number were selected as the important factors of beach changes:

$$\left(\frac{H_0}{L_0}\right)_m = \left(\frac{H_0}{L_0}\right)_p \tag{1}$$

$$\left(\frac{U_*^2}{\gamma' g D_{50}}\right)_m = \left(\frac{U_*^2}{\gamma' g D_{50}}\right)_p \tag{2}$$

where H_0 and L_0 are the wave height and wave number in deep water, respectively. U_* is the bottom friction velocity, γ' the submerged specific gravity of sediment, g the gravitational acceleration, and D_{50} the median diameter of sand grain. The subscript m and p represent physical quantities of model type and prototype, respectively.

According to the former scale laws [3,4,6,7], the sediment in the model can not be chosen freely that makes the scale laws inapplicable in most of cases. The present scale give more flexibility for the selection of model sediment.

Based on the similitude of Eqs. (1) and (2), the scale relations for wave height and wave period are found as follows

$$N_{H_0} = \left(N_{\gamma'}^{1/2} N_{D_{50}}^{1/2} N_f^{-1/2} N_v^{2/3}\right)^{6/7} \tag{3}$$

$$N_T = \left(N_{\gamma'}^{1/2} N_{D_{50}}^{1/2} N_f^{-1/2} N_v^{2/3}\right)^{3/7} \tag{4}$$

where N denotes the ratio of parameter of model to prototype, N_v is the vertical scale, f the friction factor. N_f=10.4 was adopted in the present study. The conversion of wave height and wave period between the model and nature was obtained on the basis of Eqs. (3) and (4).

Tidal variation should be considered in model test because it causes sediment movement significantly in Chang-Hwa area. This area has a maximum tidal change of 4.5m and its temporal variation has been modeled. The similitude of Froude number was applied for simulating tidal variations:

$$N_{F_r} = \frac{N_u}{\sqrt{gN_v}} = 1 \tag{5}$$

in which u indicates tidal velocity. From Eq. (5) the tidal period scale ratio is obtained

$$N_{td} = N_h^{1/2} \tag{6}$$

The equation of sediment conservation is

$$\frac{\partial h}{\partial t} = \frac{1}{1-\lambda}\frac{\partial q_y}{\partial y} \tag{7}$$

where h is the water depth, t the time, λ the sediment porosity, q_y the littoral transport per unit width. It is assumed that both model and prototype have the same value of λ, then Eq. (7) is reduced to

$$N_t = N_v N_h N_{q_y}^{-1} \tag{8}$$

in which N_h is the horizontal length scale and N_{q_y} is the littoral transport scale. The time scale for sediment transport is obtained from Eq. (8) based on littoral sediment transport formula proposed by Le Mehaute[6]:

$$N_t = N_h^2 N_v^{-1} N_{\gamma'}^{1/2} N_{D_{50}}^{-1/2} \tag{9}$$

Its inappropriate for apply Eq. (9) for the case of a topographical changes induced by typhoon waves. Hughes [3] suggests an empirical relation of time scale

$$N_t = N_v^{1/2} \tag{10}$$

2. Preliminary tests of the distorted ratio

The distorted ratio was determined by the preliminary tests performed in a 60m × 1m × 1.2 wave flume. Three selected beach slopes $\tan\beta$=1/30, 1/40, and 1/50 were placed with fine sand of 0.12mm median diameter under the action of monsoon and typhoon wave conditions. The vertical scale is calculated on the basis of the distorted ratio and horizontal scale. These geometric scales were chosen in order to let model be similar to the prototype in sea bed changes.

Fig. 3 shows the time history of standard deviation of beach profile changes for different beach slopes and wave steepnesses H_0/L_0. It is seen that the minimum standard deviations are occurred $\tan\beta$=1/50 for all H_0/L_0 on the exception of H_0/L_0=0.047. Since the averaged beach slope in the prototype is 1/300, this implies that the proper distorted ratio is 6.

Based on scale ratios mentioned above, all physical quantities are calculated and listed in Table 1. Table 2 gives the time scale of topographical changes during monsoon and typhoon .

MODEL TESTS

Planar movable bed model tests were conducted in a wave basin of 50m × 16m × 0.8m. Four wavemakers wave been installed in the basin to generate regular waves from deep water. The board of each wavemaker is 4m in length and is motivated by a 20HP motor. A total number of wave conditions have been tested for sea bottom changes under the conditions of (1) the present condition; (2) dredging at -15m water depth; (3) countermeasures for shore protection after dredging. These test cases are presented in Table 3.

Coal ash was used as bed material which has a median diameter of 0.12mm, with a submerged specific gravity of 1.02. The field sand has a median diameter of 0.24mm with a submerged specific gravity of 1.65. All relative physical quantities in model and prototype are given in Table 1.

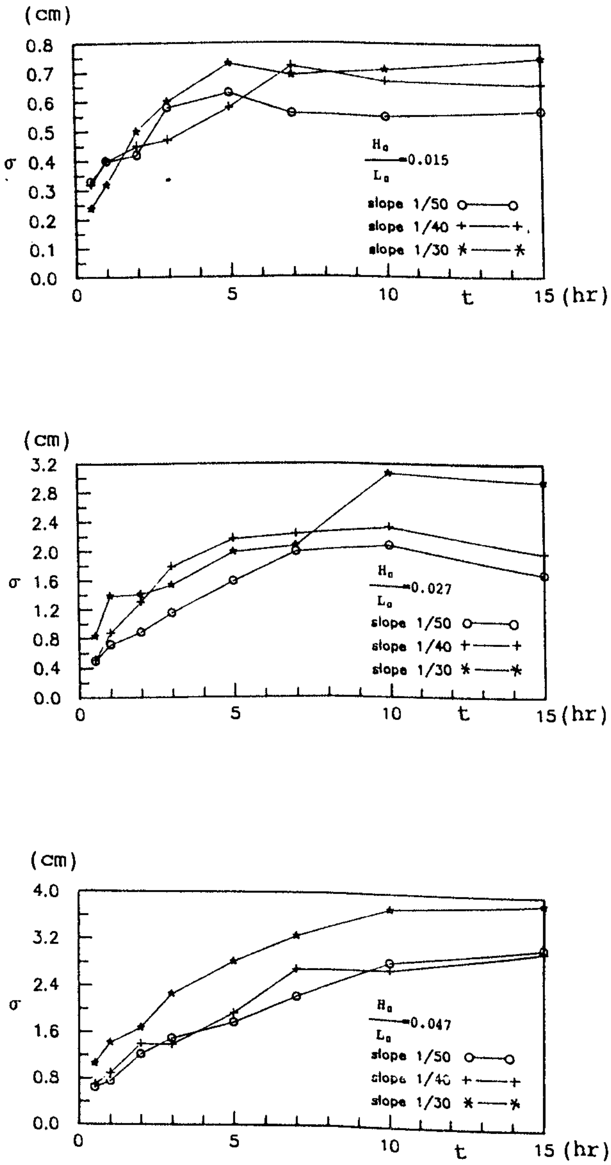

Figure 3 Time history of beach profile changes

Table 1. Physical quantities in model and prototype

physical quantity	scale	prototype		model
horizontal length	1/600	24.0km		40m
vertical length	$\frac{1}{100}$	water depth	+3m～-2.0m	+3cm～-2.0cm
		tidal level	+2.38m - -2.13m	+2.86cm～-2.56cm
wave height	$\frac{1}{74.3}$	monsoon wave	2.60m	3.35cm
		typhoon wave	4.50m	6.90cm
wave period	$\frac{1}{8.62}$	monsoon wave	7.76sec	0.90sec
		typhoon wave	11.20sec	1.38sec
Tidal period	$\frac{1}{10}$	12.42hr		1.242hr
submerged specific gravity	$\frac{1}{1.62}$	1.65		1.02
median diameter	$\frac{1}{2}$	0.24mm		0.12mm

Table 2. Time scale of topographical changes

wave \ quantities	scale	prototype	model
monsoon wave	1/5267.4	0.6 year	1.0 hr
typhoon wave	1/10	10 hr	1.0 hr

Sea bottom topography was measured at 30 minutes time interval by five point gauges set up on a moving vehicle. Ten traps were buried at the middle position of the model to measure littoral transport across surf zone. Fig. 4 depicts the distribution of littoral transport from laboratory observations. The summation of all traps gives the total longshore sediment transport. Fig. 5 presents temporal variations of longshore sediment transport. We notice that longshore sediment transport tends to become a constant value after 3 hours.

RESULTS AND DISCUSSION

1. Sea bed changes under present conditions

Using the time scale obtained in the previous section, the monsoon and typhoon waves were respectively generated for 10 hours in the model for the equivalent of 6 years and 10 hours in the nature. The topographical changes under the action of monsoon and typhoon waves in NNE direction are shown in Fig. 6 and Fig. 7. In both cases, the region of the existence of longshore current caused sea bed changes owing to limited sand supply from upstream. Erosion of the sea bottom occurs around seawall of each reclamation area. A remarkable recession of the shoreline appears at area 1 .

2. Sea bed changes after dreading

The industrial area shown in Fig. 8 and Fig. 9 was reclamated by sand materials. The method of dredging from offshore sea bottom at -15m water depth is considered as one of the sources of sandy supply for reclamation. It extends to 1.5km offshore and the water depth becomes -16m at the dreading area. All sides of industrial area were protested by seawalls to prevent beach erosion from wave attack.

From Fig. 8, we can see that severe erosion takes place along new seawalls. The wave conditions are the same with those without dredging. The figures show the wave energy is not attenuated due to a deeper bathmetry. The interaction between incoming waves and reflected waves forms a very complicated distribution of longshore sediment transport. In Fig. 9, it is evident that on-offshore sediment is dominated for topographical changes. Most of sands were carried offshore and deposit at deep water.

Table 3. Cases of planar movable bed tests

Case No.	wave condition NNE	Case No.	Wave condition SW	construction	sand supply
R1	H_0=3.35 cm T=0.90 sec t=10 hr	R9	H_0=3.35 cm T=0.90 sec t=10 hr	present seawall	longshore sediments
R2	H_0=3.35 cm T=0.90 sec t=10 hr	R10	H_0=3.35 cm T=0.94 sec t=10 hr	present seawall	longshore sediments
R3	H_0=3.35 cm T=0.94 sec t=10 hr	R11	H_0=3.35 cm T=0.94 sec t=10 hr	new seawall	longshore sediments
R4	H_0=6.90 cm T=1.38 sec t=10 hr	R12	H_0=3.35 cm T=0.94 sec t=10 hr	new seawall	longshore sediments
R5	H_0=3.35 cm T=1.38 sec t=10 hr	R13	H_0=3.35 cm T=1,38 sec t=10 hr	new seawall groins	longshore sediments
R6	H_0=6.90 cm T=1.38 sec t=10 hr	R14	H_0=6.90 cm T=1.38 sec t=10 hr	new seawall groins	longshore sediments
R7	H_0=3.35 cm T=0.90 sec t=10 hr			new seawall	longshore sedimenets river
R8	H_0=3.35 cm T=0.90 sec t=10 hr			new seawall groins	longshore sediments river

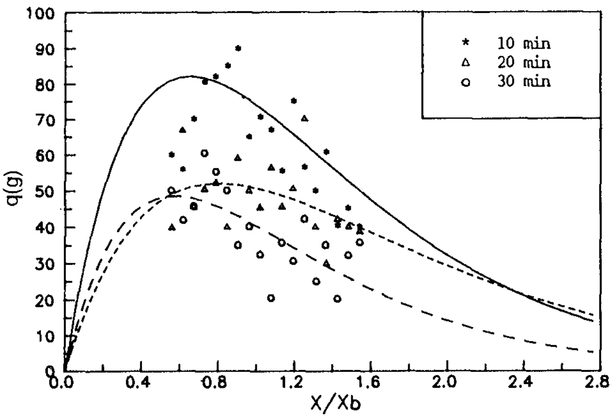

Figure 4 Distribution of longshore sediment transport

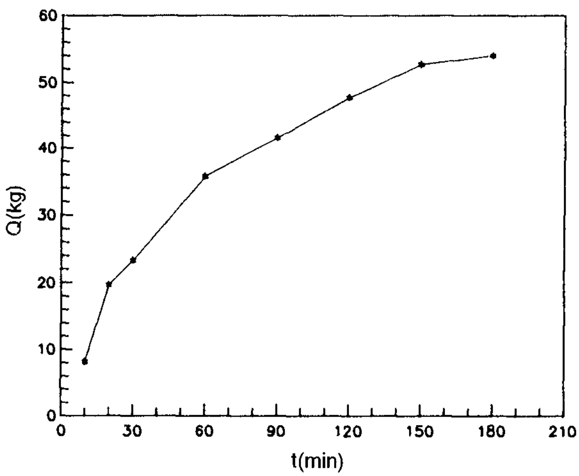

Figure 5 Temporal variation of total longshore sediment transport

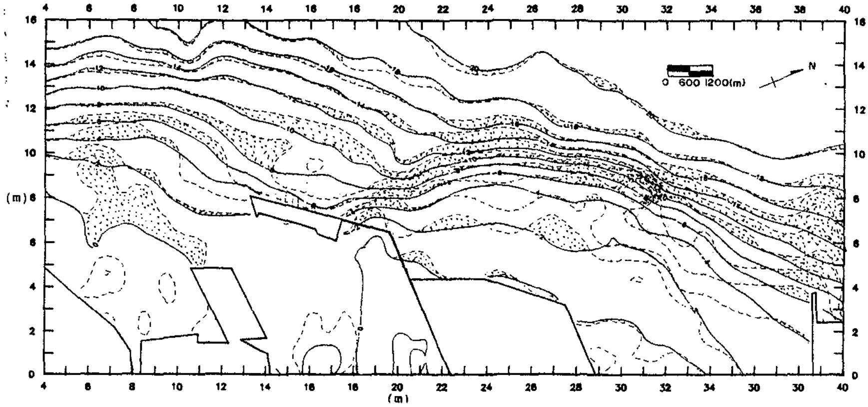

Figure 6 Sea bed changes due to monsoon wave action
(the present condition)

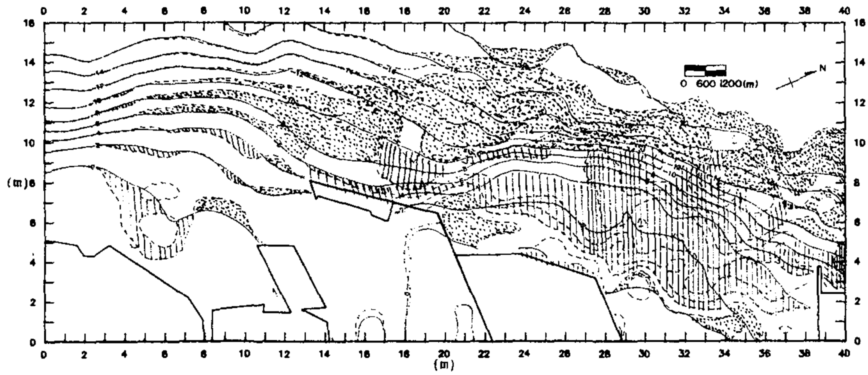

Figure 7 Sea bed changes due to storm wave action
(the present condition)

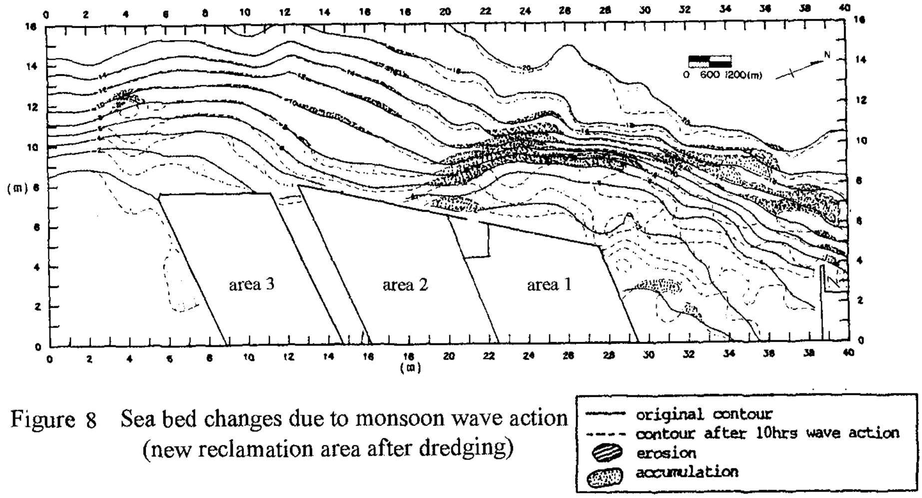

Figure 8 Sea bed changes due to monsoon wave action (new reclamation area after dredging)

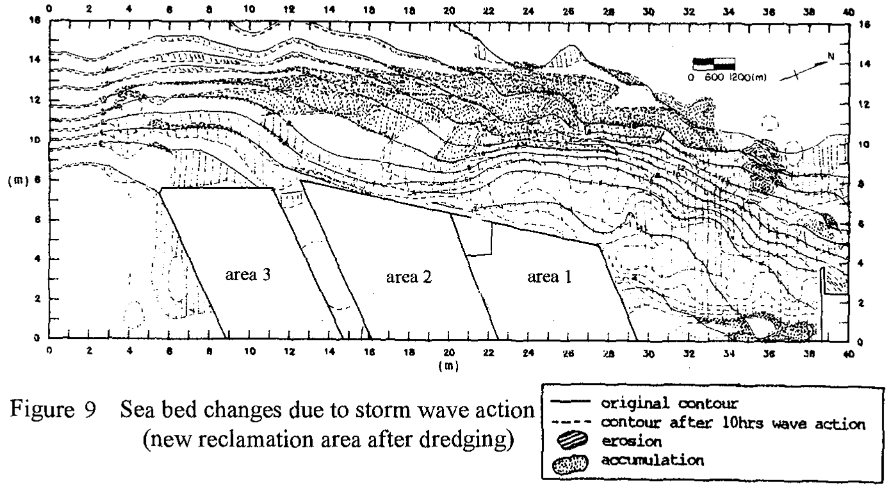

Figure 9 Sea bed changes due to storm wave action (new reclamation area after dredging)

3. New reclamation area protected by groins

Model tests reveal that erosion occurs along the segment of coast from area 1 to area 2. Accretion takes places in the north of Koshui river (area 3). The most important effect due to dreading can be found as shoreline recession and beach erosion in the vicinity of seawalls. To decrease the influence of dredging, the erosion of reclamation area was designed to be protected by groins. The groins in the model were made of small armour units as shown in Fig. 10 and Fig. 11.

The topographical changes for the case of monsoon and typhoon wave attack are illustrated in Fig. 10 and Fig. 11. The wave conditions in these cases are the same as the previous cases. It is noted that the system of groins almost protected the shore from erosion and accordingly the accretion around the shoreline where erosion occurred was stopped.

CONCLUSIONS

The effects of dredging on Chang-Hwa reclamation area have been studied by movable bed model tests. The scale relations of wave conditions in the model design are obtained based on the similitude of wave steepness and mobility number. Time scale of topographical changes is determined by longshore sediment transport rate. The present scale law provides an useful tool in practical applications. It takes the advantage to give more flexibility for selection of model sediment.

Several test cases have been carried out including (1) tests for determination of time scale; (2) tests for sea bottom changes under present conditions; (3) tests for sea bottom changes after dredging at -15m water depth; and (4) tests of countermeasures for shore protection after dredging. The most important influence on the position of erosion has been found. The method of construction of groins was considered to decrease beach erosion. It is shown that the proposed groins protect the shore from erosion quite well.

REFERENCE

1. Kuo, C.T., Lai, C.J., and Hsieh, C.H., 1983. Report of Chang-Hwa Project (2): The evaluation of the breakwater to the sand drafts obstruction, Bulletin No.4, Hydr. and Ocean Engrg., Tainan, Taiwan.(in Chinese)
2. Tainan Hydraulics Laboratory, 1992. Field investigation and model test for the reclamation of Chang-Hwa industrial area, Bulletin No.128, Vol.1, Tainan, Taiwan.(in Chinese)
3. Hughes, S.A., 1983. Movable-bed modeling law for coastal dune erosion, J. Waterway, Port, Coastal and Ocean Engrg., 109(2), 164-179..
4. Ito, M. and Tsuchiya, Y., 1984. Scale-model relationship of beach profile, Proc. 19th International Conf. on Coastal Engrg., Housten, 1386-1402.

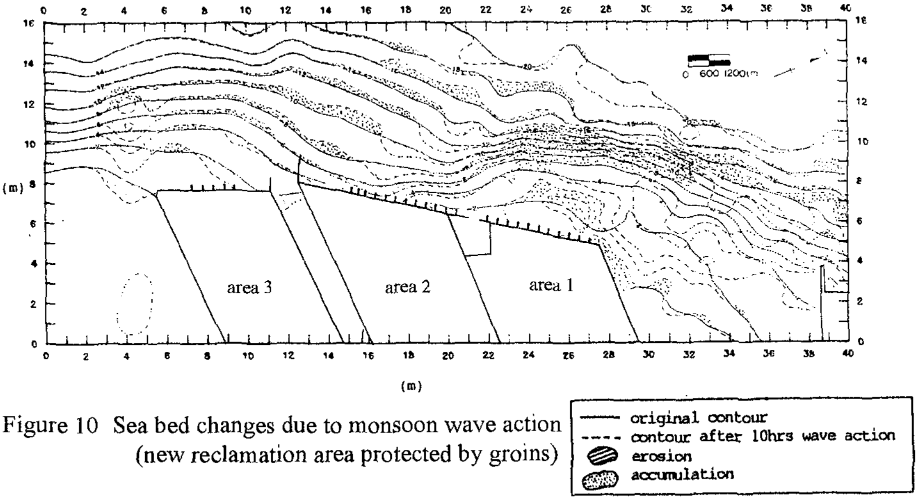

Figure 10 Sea bed changes due to monsoon wave action (new reclamation area protected by groins)

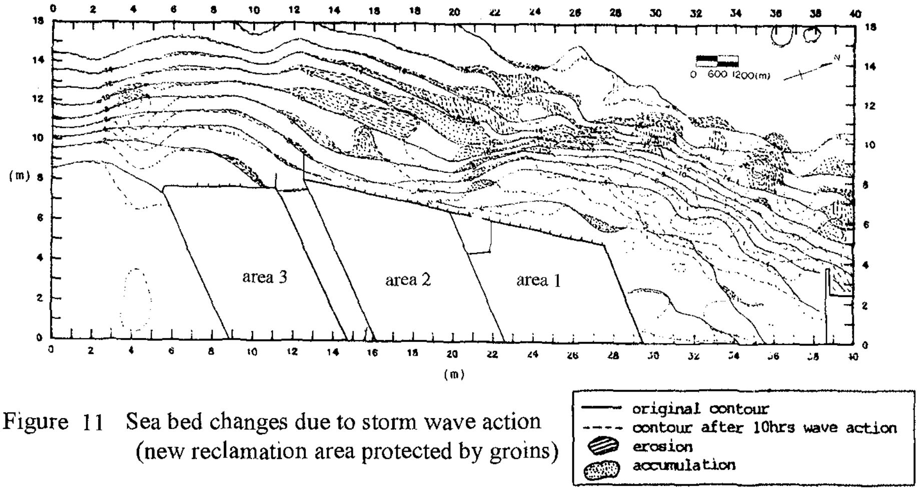

Figure 11 Sea bed changes due to storm wave action (new reclamation area protected by groins)

5. Kuo, C.T. and Lai C.C., 1981. Report on the experimental studies on the topographical changes caused by Chang-Hwa reclamation area, Technical report of Dept. of Hydraulics and Ocean Engrg., National Cheng Kung Univ.(in Chinese)
6. LeMehaute, B., 1970. A comparison of fluvial and coastal similitude, Proc. 12th Coastal Engrg. Conf., 1077-1096.
7. Noda, E.K., 1970. Coastal movable bed model relationship, Report No. Tc-191, Tetra Tech. Inc., Passerine, California.