CHAPTER 91

MOVABLE-BED EXPERIMENTS OF SHANTOU HARBOR

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ABSTRACT

The paper, based on the macroscopic analysis of the sediment movement, deals with the movable-bed model experiments of the coast under the combined action of the wave and tidal current. By these experiments we mainly desire to solve the problem of the way how to regulate the outer sandbar, including the rational trend of the guide dike, its length and the expected siltation amount in the navigation channel.

1. INTRODUCTION

Shantou Harbor is an important commercial port in the north-east of Guandong Province and lies at the estuary which is the junction of two rivers, i.e. Rongjiang and Hanjiang.

As the result of the sediments transported from the upstream, i.e. Rongjiang and Hanjiang, the tide and wave actions in the seaboard region as well as the influence of coastal reclamation, the sediment deposits in the harbor basin in the inner navigation channel of Shantou Harbor have grown up. Especially, the development of the sandbar in the outer navigation channel not only affects the navigable depth of the passage of Shantou Harbor, but will obstructs the further expansion of the deep-water berth of the harbor as well.

The navigation channel outside of Shantou Harbor was dredged three times respectively in 1977, 1979 and 1980. However, the dredged channels were still silted up to the original states between six and nine months after dredging them. The obstruction of the further development of Shantou Harbor by the outer sandbar and the severe silting conditions after dredging of the outer navigation channel have attracted much attention of the production and construction departments concerned as well as scientific research institutions.

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2. PROBLEMS ENCOUNTERED IN THE DESICN OF COASTAL MOVABLE-BED MODEL UNDER THE COMBINED ACTION OF WAVE AND TIDE

2.1 About in-shore and off-shore models

French scholar C. Migniot, after summing up the experiences of movable-bed model for the investigation of the French coast, pointed out that with our gradual understanding of sediment transport process, the laws governing these natural phenomena have been found to be more and more complicated and the similarity of all conditions to the prototype can hardly be obtained in the same model for sediment study. Therefore, making selections from reproduction phenomena are required and the model scales specially used for the selected experiment type would be adopted. Portugal scholar Castanho, Canadian scholar J.W. Kamphuis and Chinese scholar Chen Zixia have made some specialized discussions in this respect. Especially Kamphuis explicitly divides a coastal movable-bed model into two kinds, i.e. inshore model and offshore model. Either of these two kinds of model, however, lays respective emphasis on its reproduction. They have different condition of similarity and different sediment transport scale and scale of scouring and silting time.

Basing upon the findings in our experiments as well as our specific purpose of experiment and specific district, we use the movable-bed model for regulation of the outer sandbar ---- the offshore model, and movable-bed model for sand catching effect by sediment retention dike ---- inshore model.

2.2 About rate of distortion of the coastal movable-bed model under combined action of wave and tide

In the experiments on the movable-bed model for sandbar regulation, it is necessary to stimulate the combined action of two dynamic effects by the wave and tide at the same time. A distorted model should also be made, because both the similarity requirements of the sediment under the combined action of the wave and tide and the problems of the experimental equipment and sand material should almost be considered.

According to the few examples that can be found for the time being the rate of distortion of coastal movable-bed models under the combined action of wave and tide is from 3 to 8.

It may be seen from the description above-mentioned that, if the wave diffraction is not selected as the key conjunction in the model reproduction and proper material taken as the model sand to satisfy the starting similarity and the falling similarity of the sediment movement, some model distortion should be allowable.

3. MOVABLE-BED MODEL TESTS FOR THE SANDBAR REGULATION

3.1 Analyses of evolution and grain size of the sediment

The sandbar in the navigation channel outside of Shantou Harbor was dredged four times respectively in September of 1977, July of 1979, October of 1980 and September of 1981. The cross sections of the excavated channel after silting are shown in Fig.1.

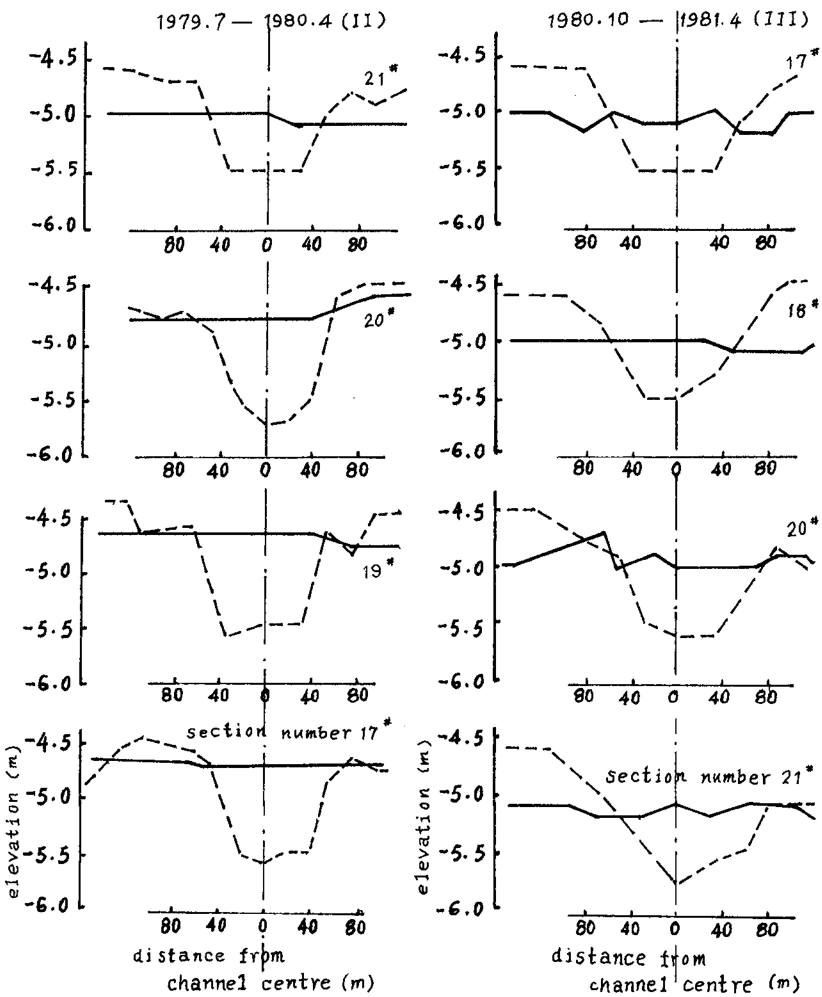

Fig.1 Variations in cross sections of the outer navigation channel after the first and second time's excavating

It can be seen from Fig.1, after the excavating of the first three times, from 1977 to 1981, the excavated channel was silted up respectively within 8, 9 and 6 months, the range of which being 150m wide on east and west side of the channel. There existed no evident navigation channel at all. The mean water depth after silting-up basically restored to be natural water depth of the year before 1977. While silting-up the navigation after dredging, the scouring action on either side of the channel occurred and the scouring range was wider and wider one after another.

In order to make a further inquiry into the condition of the siltation after channel excavating, we made analysis of the grain sizes of four silt samples on the vertical line taking in one year after the second time dredging, in the navigation channel within the sandbar. Its results are shown in Fig.2.

From the figures, we know the deposited silt in the channel basically have the grains of 0.1mm fine sand, amounting about to 75-80% of the total. Besides, 20-25% or so is silty clay of 0.009mm grain diameter. The former coincides with the size grades of the sediments of the beach face nearby (see Fig.2) and the latter is the size grades of suspension load in the river.

It can be seen from above analyses for the evolution and grain sizes, the main cause of the siltation of navigation channel is the restoration of the natural balance for the reason that the sea-bottom sediments of the shoal on the east of the channel, under the eastward wave action, was in the form of transportation on the bed load as well as of semi-suspended load.

3.2 Design of the movable-bed model

Similarity of the bottom load movement contains the starting similarity, the similarity of scouring and silting, sediment transport similarity, the time similarity of scouring and silting and location similarity of silting. For starting similarity, we have

$$\lambda_v = \lambda_{u_o} = \lambda_{v_k} \tag{1}$$

The starting similarity under the current action may use Dou Guoren's formula written in the form

$$\lambda_{v_k} = \lambda_\phi \, \lambda_{\gamma_{s-\gamma}}^{1/2} \, \lambda_d^{1/2} \tag{2}$$

in which

$$\lambda_\phi = \frac{\left[\ln 11 \frac{H}{\Delta} \left(1 + 0.19 \frac{\gamma}{\gamma_s - \gamma} \frac{\epsilon_\kappa + gh\delta}{gd^2}\right)^{1/2}\right]_p}{\left[\ln 11 \frac{H}{\Delta} \left(1 + 0.19 \frac{\gamma}{\gamma_s - \gamma} \frac{\epsilon_\kappa + gh\delta}{gd^2}\right)^{1/2}\right]_m} \tag{3}$$

For computing the bottom sediment discharge under tidal current action, Dou Guoren's formula may be used:

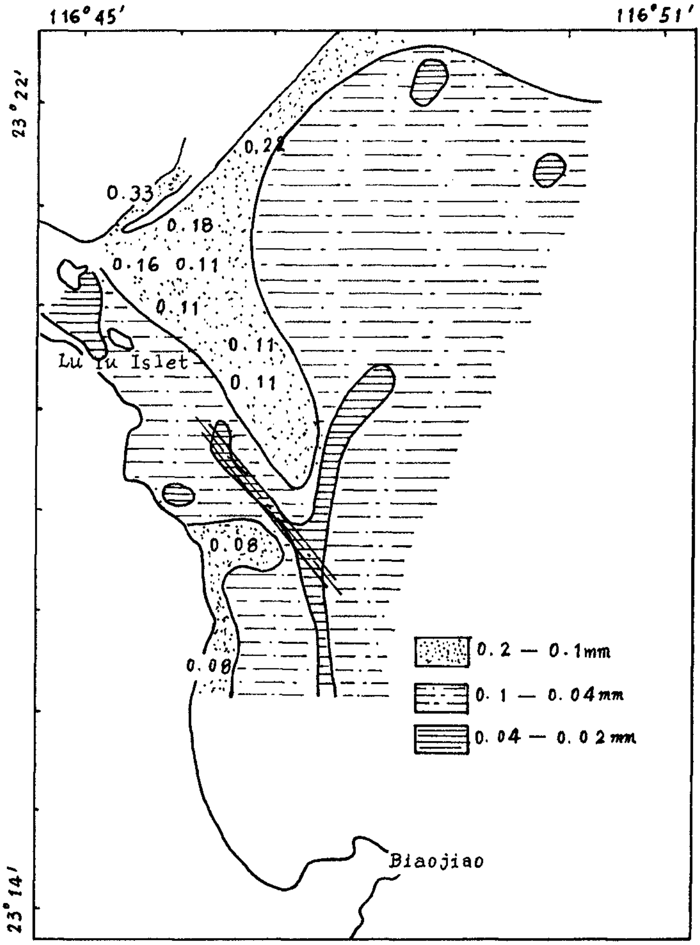

Fig.2 Distribution of bottom sediment at outer sandbar

$$q_{sb} = \frac{K_o}{C_o^2} \frac{\gamma_s \gamma}{\gamma_s - \gamma} (v - v_k) \frac{v^3}{g\omega} \tag{4}$$

While the bottom sediment discharge under the action of wave, Lua Zhaosen's formula may be used:

$$q_{sb} = \frac{2.4 K_2 \gamma \gamma_s}{C_o^2 (\gamma_s - \gamma)} (u - u_k) \frac{u^4}{g\omega} \frac{T}{L} \tag{5}$$

in which u is the mean orbital vibration velocity of particle in oscillating wave.

At present, a satisfactory research result on the bed load transport under the combined action of wave and tide has not been achieved. We have made some model verification and comparison tests for many formulas of bed load transportation and realized that Dou Guoren's and Luo Zhaosen's formulas are consistant with the measured results.

From equations (4) and (5) we get sediment transport scale:

$$\lambda_{qsb} = \frac{\lambda_{\gamma_s}}{\lambda_{\gamma_s} - \gamma} \frac{\lambda_v^4}{\lambda_{Co}^2 \lambda_\omega} \tag{6}$$

the time scale of scouring and silting: $\lambda_t = \dfrac{\lambda_{\gamma o} \lambda_H \lambda_L}{\lambda_{qsb}}$ (7)

and the settling velocity scale: $\lambda_\omega = \dfrac{\lambda_v \lambda_H}{\lambda_L}$ (8)

The determined values of various scales are shown in Table 1.

3.3 Selection of the model material

We have made some preparative tests under the actions of wave and tidal current in the end, the saw-dust medium-size of grain diameter D_{50} = 0.4 mm, was selected as the model material in the test.

The evolution analysis and the movement limit of bed load under wave action indicated that the sediment movement in the sandbar area was rather active, being in a state of surface layer movement and complete movement, while in the area beyond -8m, its water depths and topography were basically in stable condition, its sediment movement being in a state of surface layer movement and more and more weaker as it moves offshore. As stated above, if the wave height and wave period are regulated to a proper value, it would be easy to realize the similarity of the sediment movement regime in the above-mentioned area.

Table 1 : Scale for movable-bed model

Name of scale	Symbol	Computed value	Adopted value
Horizontal scale	λ_l		500
Vertical scale	λ_h		80
Current velocity scale	λ_v	8.944	8.944
Wave height scale	λ_H	80	80
Wave length scale	λ_L	80	80
Wave period scale	λ_T	8.944	8.944
Bottom orbit velocity scale	λ_{u_o}	8.944	8.944
Mass-transport scale	λ_v	8.944	8.944
Starting velocity scale	λ_{v_k}	8.944	8.944
Chezy coefficient scale	λ_c	2.50	2.10
Settling velocity scale	λ_ω	1.43	1.01
Grain diameter scale	λ_d		0.275
Dry density scale	λ_{γ_o}		2.55
Sediment discharge scale	λ_{qsb}	150	87
Scouring and silting time scale	λ_t	667	1168

Basing on the relation between the navigation channel water depth after dredging and the silting speed, it indicates that the mean water depth in the dredged channel less than 5 months after dredging could restore to its original water level. Three hours after the beginning of the experiment the longitudinal profile of the excavated channel in the model has a better coincidance in silting regime with that of the prototype. Thus obtaining the actual model scale of scouring and silting time $\lambda_{t2} = 1168$.

3.4 The experiments of regulation schemes

Though the comparison and selection of various options, the movable-bed model experiments finally gives the proper trend and length of the guide dike and the expected siltation in the dredged channel. Its results are shown in Fig.3 and Table 2.

The test results indicate: The option of constructing a 5.2km sediment retention dike attaching 2.75km submerged dike is rather adaptable.

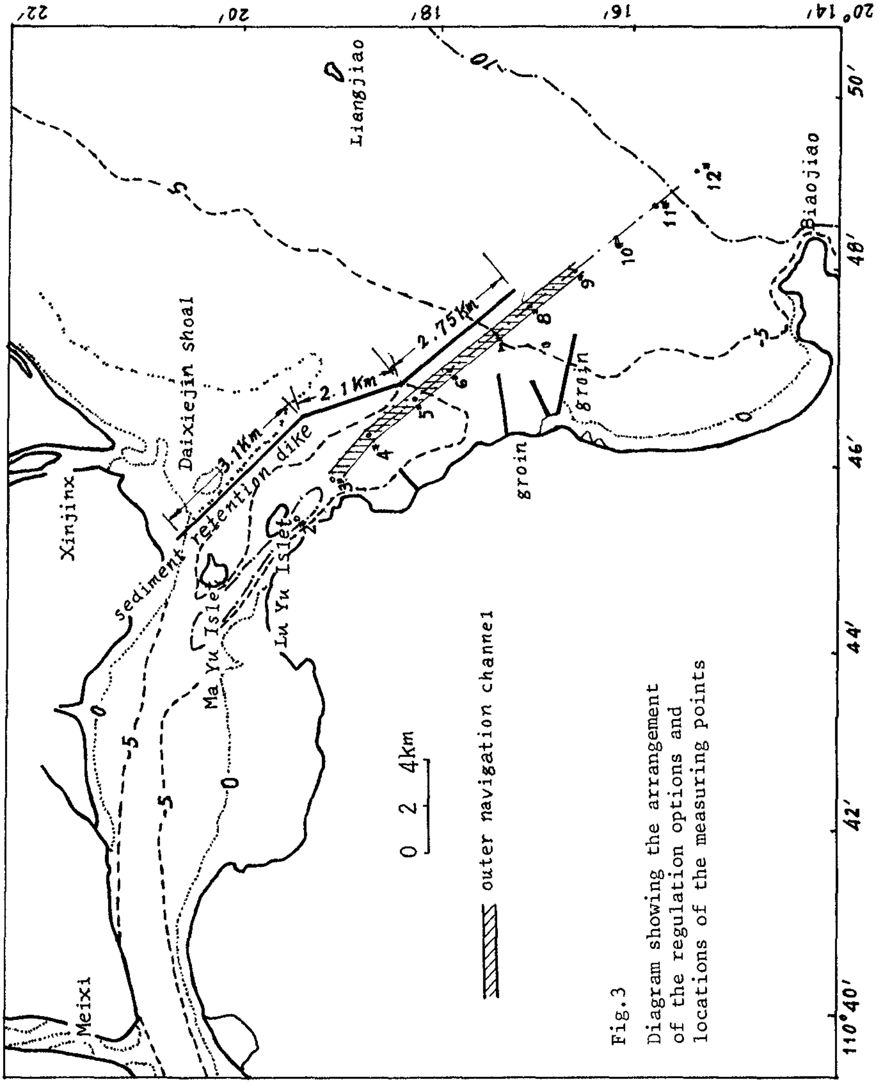

Fig.3

Diagram showing the arrangement of the regulation options and locations of the measuring points

Table 2 : Comparison of the options

Options	Silting quantity in the channel at initial stage ($\times 10^4 m^3$/year)	Silting trend in the channel in further	Resistance to typhoon's silting	Scouring at the dike head
1. To excavate the navigation channel	160	a little reduction	not possessing	
2. To excavate the navigation channel +5.2km sediment retention dike	70	a little reduction	not possessing	greater transverse current and scouring
3. To excavate the navigation channel +5.2km sediment retention dike+2.75km submerged dike	50 - 55	decreased year by year	possessing	basically has no dike head transverse current and scouring
4 To excavate the navigation channel +5.2km sediment retention dike+2.75km submerged dike + two southwest groins	50	decreased year by year	possessing	basically has no dike head transverse current and scouring
5. To excavate the navigation channel +5.2km sediment retention dike+2.75km overflow dike	35 - 40	decreased year by year	possessing	basically has no dike head transverse current and scouring

4. CONCLUSIONS

1. The paper discusses the theory and practice of the coastal movable-bed model tests under the combined action of the tide and wave for the regulation of the outer sandbar at Shantou Harbor on the test results. Our research shows that two kinds of the coastal movable-bed model should be devided according to the experimental purposes and the practice. That is off-shore model and in-shore model; the movable-bed model for the regulation of the outer sandbar at Shantou Harbor belongs to the off-shore model.
2. Our research also indicates that, if we do not select the diffraction phenomenon as the key conjunction in the model reproduction and select fit material as the model sand, which meet the falling similarity of the sediment movement, some model distortion would be allowable.
3. The key point of the determination of the scale of scouring and silting time in the coastal movable-bed model experiment lies in the selection of a better sediment transport formula and sediment transport scale.
4. The macroscopic analysis of the sediment movement in the current of outside and inside of Shantou Harbor indicates Shantou Bay is a type of estuary with the tide action as a dominant factor. The sediment deposit of the outer sandbar mainly comes from Xinjinxi and Wai Sha river and transported from northeast to southwest under the action of the tide and wave. Generally speaking, there is small quantity of sediment deposit in the whole seas and fundamentally in the state of dynamic equilibrium. The main reason of the siltation in the navigation channel is the bed load in the sea bottom transport on the spot and in semi-suspension condition to cause the restoration of natural balance of the sediment and then the siltation of the excavated navigation channel.
5. By way of the fixed-bed model tests under tidal current action as well as the movable-bed model tests under the combined action of the tide and wave, we have made some comparison tests for different option for the outer sandbar regulation. The test results indicate:
A 5.2km sediment retention dike attaching a 2.75km submerged dike is rather adaptable, possessing the effects of restricting the water way to scour the sand as well as the retention of the sediment.

5. REFERENCES

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