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MODEL STUDIES ON LOCAL SOCUR IN THE REGULATION PROJECT OF THE DEEP CHANNEL IN THE CHANGJIANG ESTUARY

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Abstract: The local scour of the 1st-phase regulation project of the deep channel in the Changjiang Estuary were experimentally studied. The local-scour pits around head of the groins and the north jetty were simulated in a wide flume. Comparing the result of model tests with the prototype measurements indicates that the depths of local-scour on head around the north jetty in a fine agreement. In the tests, the local scour depths in steady flow and tidal current were studied, and the natural sand and lightweight model sediment used in model were compared too.

Key words: Local scour, Groins and jetty, Model test, Changjiang Estuary

1. INTRODUCTION

The regulation projects of deep navigation channel in the Changjiang Estuary consist of the diversion work, north and south jetties, and groins. The groins are constructed every certain distance along north and south jetties to regulate current and maintain channels. The first-phase regulation project constructed 3 groins along north jetty and 3 groins along south jetty (Fig.1). Scour of riverbed in general occur near the groins and local scour holes appeared. Local scour on the head of groins affects the stability of the groins and is disadvantageous to the water depth of navigation waterway. North jetty spread east forward from Hengsha Island. Tidal currents of the shoal region intercepted by the jetty forms currents along North jetty and intensified current round the head of North jetty. The scours appear along both sides of the jetty and the front of jetties heads, the security of structures can’t be assured. Therefore, the test studies, on local scours in the fronts of the groins and north jetty, is very needed to determine reasonable ranges of river bed protection.

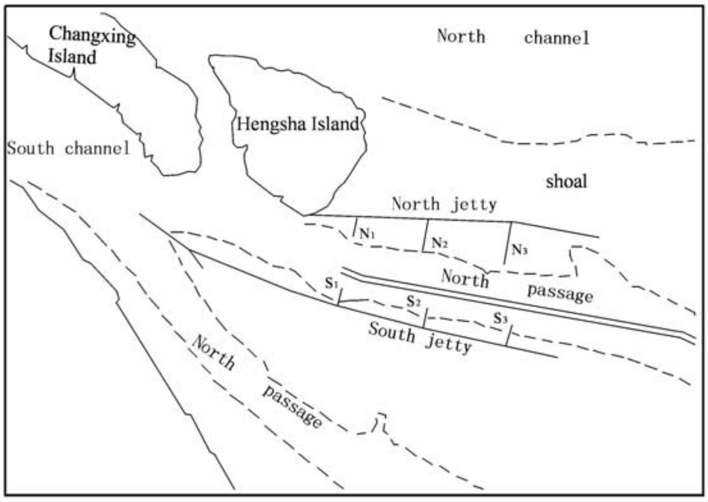

Fig. 1 Sketch map of 1st phase project of deep channel in Changjiang Estuary

METHODS OF TEST STUDY

Local scour near structure is a 3-D problem. In general only normal model is used for studying the depth of local scour. Model sand's selection is difficult in the movable-bed model, the verification is difficult too because lack of local scour depth data in most conditions. So it's difficult to take one scale model to forecast local scour depth accurately. To solve the problem, series model is taken, that is, by use of several models different in scale and applying the model test results to prototype, a more reliable result than that of one scale model can be obtained. For limit equilibrium scour problem, series model is taken widely in determining scour depth and had much experience. Series model is taken widely in scour and protection in piers of bridge, caissons, and cofferdam. In earlier time, only bed materials in prototype are used in the model. Series model test results are extended to prototype, which is simple and can obtain satisfied result easily. With the application of series model test, the sand used in model is developed to lightweight sand.

According to similarity principle, model design must keep to similarity law and similarity scale relationships to obtain correct test result. Series models consist of several models of different scale, expanded test results of models to similarity model to remove errors and to realize the similarity model and prototype. Defined normal model geometric scale λ_{H0}, when the model meets entirely similarity condition of normal model, $\lambda_{hs} = \lambda_H = \lambda_{H0}$ （λ_{hs} is scale of scour depths， λ_H is model geometric scale）. When model deflects from similarity condition, it follows that $\lambda_{hs} \neq \lambda_H \neq \lambda_{H0}$. The deflection of λ_H from λ_{H0} results in the deflection of λ_{hs} from λ_H, can be formulated as follow that

$$\frac{\lambda_h}{\lambda_H} = \left(\frac{\lambda_{H0}}{\lambda_H}\right)^{\alpha} \tag{1}$$

Selected model scour depth h_s as ordinate and model scale λ_H as abscissa, drew test results on log-log paper can get one straight line. When model scale $\lambda_H = \lambda_{H0}$, corresponding scour depth h_s is scour depth of prototype. If we select λ_H and h_s from two scale models among series models, the slope (α) of the straight line be gotten

$$\alpha = [(\lg(h_{sm2}\lambda_{H2}) - \lg(h_{sm1}\lambda_{H1})]/(\lg\lambda_{H2} - \lg\lambda_{H1}) \tag{2}$$

Then we can come out prototype scour depth from formula (1) directly.

λ_{H0}=1 means extending to prototype when series model used prototype sand. When non-prototype sand is used, $\lambda_{H0} \neq 1$, it equals to a scale value solved according to sediment movement similarity condition of normal model.

2. SIMILARITY CONDITION OF SERIES MODEL

To simulate local scour near construction, model flow should meet the Froude scale law, that is, $\lambda_v = \lambda_H^{1/2}$. In practical the range of scour and adjacent bed protection of structure is paid more attention. So, the distribution of model velocities should be similar to natural flow field.

For local scour, the velocity of model should be exceeded incipient velocity of model sand. that is, $V_m > (V_C)_m$. In order to avoid the difficulty of scour in model sand and abnormal scour, in general model velocity should be greater than1.2 $(V_c)_m$ and be less than 3.0 $(V_c)_m$ in practice.

To remove the effect of model water surface tension, model minimum depth h_m must be greater than 1.5cm. Model current must be turbulence, Reynolds number of model must be greater than 2000.

The geometric shape of scour hole should be similar and underwater repose angle of model sand must be equal to that of prototype sand, the latter condition is met if model sand is prototype sand.

If velocity of prototype is low, prototype sand used in the model can't meet incipient condition usually, lightweight sand may be selected. To judge the reasonableness of the result of series model test when lightweight sediment is used, the test result of lightweight sediment must compared with that of prototype sand.

The scour depth on the head of groin is relative to current, bed load, and the groin form. Simulating entire groin's length in normal model is very difficult as the ratio of groin length to water depth (b/H) is great in estuary. Based on the local scour data of natural groins, Zhanghaiyan points out that if b/H is greater than 25, scour depth is related with Froude number and water depth. In series model design of groin scour, $b/H \geq 25$ should be met.

3. LOCAL SCOUR TEST OF THE HEAD OF THE HEAD OF GROINS

3.1 TEST CONDITIONS

The location of designed groin head is near –5m contour in north passage, bed-load near groin head is silt, medium diameter D_{50}=0.16mm. The floodwater and spring tide are used as hydrographic test condition. The local scour of groin N_1, N_3, S_1 and S_3 are studied according to different current speed. From the view of current condition near groin's head, ebb strength velocity is 2.5−3.0m/s, flood strength velocity is 1.10−1.45m/s, ebb duration as 1.5−2.0 times as flood duration. Maximum ebb velocity occurs on lower tidal level, Maximum flood velocity occurs above middle level, so ebb currents are the main power of scour on groin's head. Based on comparison of scour depth in steady flow with that in tidal current, ebb velocity and corresponding tidal level are selected to make scour test under steady flow in flumes in size of 30m×6m×0.6m and 50m×15m×0.6m respectively. The flow field and tidal level are provided by physical model of Changjiang Estuary.

3.2 SCOUR ON HEAD OF GROIN IN STEADY FLOW AND TIDAL FLOW

Taking 250m length of groin N_1 for test, model scale λ_H=100. The velocity is 2.5m/s and water depth is 6m in steady flow test. The maximum flood velocity is 1.2m/s, maximum ebb velocity is 2.5 m/s, and water depth varies from 5m to 8m in tidal current test. The lightweight asphaltic sediment is used, had a density of 1.18t/m^3, and a median grain size of 0.35mm. The velocity in model is greater than incipient velocity of sediment.

Compared with the result of steady flow test, scour equilibrium duration is 3−4 times and maximum scour depth is 0.85 times of that in tidal current. The scour point is not same during flood and ebb, the scour hole shapes are different under two conditions, there is an apparent gulch with 3−4m in depth along groin towards the side of flood tide. Protection of groin head should pay more attention to the side of flood current. The scour holes shape in N_1 groin's head in different flow conditions are shown in Fig. 2.

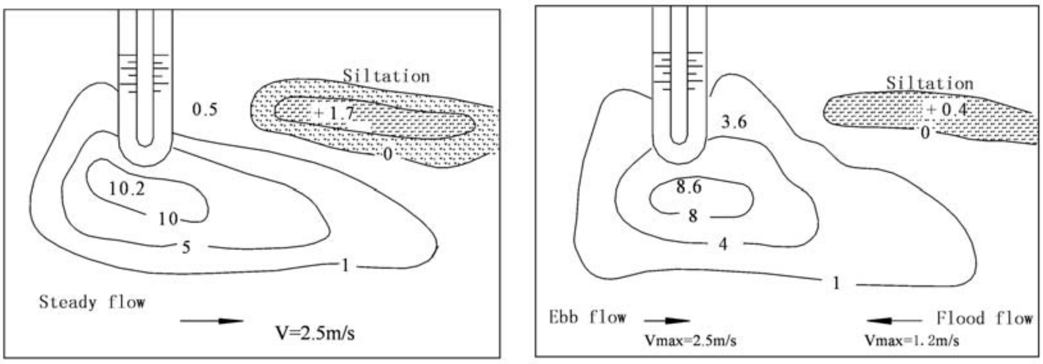

Fig. 2 Local scour holes ahead of groin in steady flow and tidal current

3.3 TEST OF SCOUR ON HEAD OF GROINS

Local scour test in the head of groins selected two model sands, prototype sediment in the North Passage and lightweight asphaltic sediment.

When prototype sediment used in model test, and model scales λ_H are 45, 55 and 75. When lightweight sand used in model and the scale λ_{H0} of similar model is to be defined. According to sediment movement similar condition, the similarity scale λ_{H0} can be calculated. Calculated incipient velocity of sediment by Douguoren formula and the result of experiment [5], and model scale λ_{H0}=20 is obtained. The underwater repose angle of sediment is 32°in prototype, which is 30°−32° in model, met geometric shape similar of scour hole.

According to series model similar condition, series model scales λ_H are 100,150,200. when model sediment is asphaltic sand and the test result is compared with that of series model used prototype sand.

Scour depth can be calculated by follow formula

$$h_{sp} = \lambda_H h_{sm} \left(\frac{\lambda_{H_o}}{\lambda_H} \right)^{\alpha} \qquad (3)$$

where λ_{H0}=1 for prototype sediment extended test, and λ_{H0}=20 for asphaltic extended test. The test results are shown in Fig.1.

Table 1 Results of series model test

Groins		N_1	N_3	S_1	S_3
Velocity in groin head（m/s）		2.5	3.0	2.75	2.95
Prototype sediment	α	-0.073	-0.081	-0.074	-0.072
	Max. scour depth(m)	8.7	12.6	9.5	11.3
Asphaltic sediment	α	0.13	/	0.11	/
	Max. scour depth (m)	10.1	/	10.5	/

Series model test adopted prototype sediment, maximum scour depths on groin head are 8.7−12.6m, main scour range is about 100m ahead of groin, 200m along flow direction. After the riverbed adjacent the front groin head is protected, the flow in groin head can not scour bed directly, it forms scour in outside of bed protection and scour depth and range is small, maximum scour depth is 3−5m. According to designed bed protection range (100m×80m), it can protect groin head from scour and destroy.

The results of the N_1, S_1 groin scour test showed maximum scour depth is 10.1m and 10.5m when the asphaltic sediment used in model. Compared with that of prototype sediment, the maximum scour depth is increase 10%−15% and the extend scour range is increase about 10% in asphaltic sediment series model.

4. LOCAL SCOUR AROUND HEAD OF THE NORTH JETTY

4.1 TEST CONDITIONS

When the north jetty of the first phase project are completed, the tidal velocity around the head of jetty is very large, the maximum flood velocity and maximum ebb velocity are greater than 2m/s in spring tide, flood currents and ebb currents contributed to the form of scour hole. Entire model and local model are combined to study the scour. Entire model of Changjiang Estuary provides local model with currents boundary condition, local model adopts series model extended method to study local scour. The precondition of local model test is similarity verification of tidal velocity and flow pattern near the head of north jetty.

According to series model similar condition, selected series model scales λ_H are 100 and 150, simulated length of north jetty is 1000m near the head. The local models are built successively in a 50m×15m flume which can simulated to-and-fro flow.

4.2 SCOUR DEPTH AROUND HEAD OF THE NORTH JETTY

According to the Fruode scale law and similar condition of sediment incipient velocity, that is, $\lambda_{Vc} = \lambda_V = \lambda_H^{1/2}$, similar normal model scale λ_{H0}=30 is calculated.

The bed protection widths in front of head of north jetty are 80m,120m and 160m, results of test show that maximum scour depth of north of protection is 8.4−8.8m., scour depth along jetty is 4−6m in north of jetty, in edge of the protection occur a little collapse and don't affect jetty stability. Considering the 10%−15% amplification of scour depth by use of asphaltic sediment, maximum scour depth is 7.5−8.3m near the head of north jetty in practical, the average value is about 8.0m. scour depth along jetty is 3.6−5.8m.

North jetty are constructed to the head of the first phase project on Sep. 1999. Field observation data on Nov.1999 show that maximum water depth point in north of jetty achieved -8.6m from -1.4m and net scour depth is 7.2m, which is very closer to forecasted scour depth 8.0m by model test. Mean scour depth along jetty in prototype is about 4.5m and is close to forecast depth by model test. Fig.3 is scour depth near the head of north jetty in prototype and model.

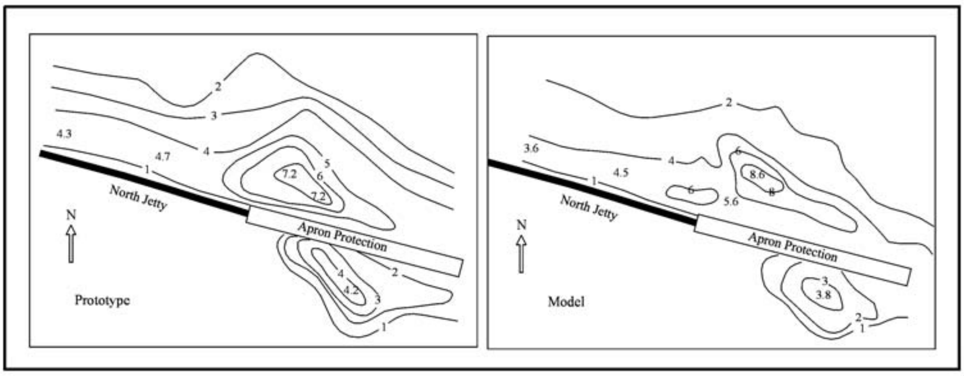

Fig. 3 Local scour around head of North jetty in Prototype and in model

5. CONCLUSIONS

Series model extended method is effective for forecast local scour near construction. It's a key step to select model sediment reasonably according to series model similar condition. For lightweight sediments using in model, in general the result should be compared with test result by prototype sand to obtain reliable result. The scour depth and shape in the head of groins in steady flow and tidal flow are different. If steady flow velocity equal maximum velocity of tidal current, the scour depth in steady flow is 15−20 percent larger than that in tidal flow condition. Riverbed protection in groin's head can restrain local scour effectively. A maximum scour depth range of 8.7m to 12.6m if no protection on head of groins of 1st regulation project, and scour depth and range reduce remarkably when protection was set. Scour depth in outside of the riverbed protection is 3m to 5m, the stability of groin isn't affected. If flood velocity is close to ebb velocity, local scour test around structure must simulate tidal flow in model. Series model should verify flow field to assure similarity of scour hole shape and location of scour depth. By use of test method above mentioned, local scour test results about North jetty in Changjiang Estuary are verified well with surveyed data in field.

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