EXPERIMENTAL STUDY ON ENGINEERING EFFECT OF HOLLOW-BLOCK MOUND BREAKWATER

Wu Hualin[1] , Zhang Junyong[2], Liu Gaofeng[1]

Abstract: Effects of estuary regulation engineering are related to structure type of its dykes, but it is difficult to study the effect of local complex structure with physical model directly. Taking NⅡC segment of the 2nd phase project of Deep Water Channel at Yangtze Estuary as a case, the paper discussed the method of research on engineering effect of hollow block structure by combining flume experiment with physical model. The method makes it possible to research the effects on current and riverbed induced by complex local structure with large-scale physical model. By comparison of different schemes, it is derived that the scheme without 2600m-long training dike of NIIC segment do harm to the exit channel of North Passage, and there are little influence with the scheme of the height of 2600m-long training dike of NIIC segment debasing 1m or the scheme of adopting hollow-block mound breakwater structure.

Key words: *hollow-block mound breakwater, permeability, engineering effect, flume experiment, physical model*

Waterproof and weakly water-permeable structure types such as caissons, rubble mound are widely used in estuary and coastal engineering. Two sorts of structures are popularly used in building seawall and designed training dike when the groundwork is of silt or soft clay: one is rubble slope mound on reinforced groundwork, including the rubble mound with artificial blocks; another is the pile structure (Xie，1996). The regulation engineering in the project of Deep Water Channel at Yangtze Estuary are mainly formed by three parts: south training dike, north training dike and spur dike groups between them. The south training dike is 48.077 km long, and the north designed training dike is 49.200 km correspondingly. N II C segment, which lies in the upper north training dike with the length of 2.6km, is on the groundwork of in argillaceous soil. The under putty surface elevation of groundwork is approximately -7.6~-8.6m (the Woosung basic plane). On this groundwork, with the failure field test of inserting big prestressed reinforcement concrete cylinder structure, more than 20 application schemes were proposed by many domestic designing departments. Among the 20 schemes including replacement of artificial block body mask in the slope mound or artificial block body mask packed in bags granulated substance core of bank mound breakwater on the sand groundwork; the in-depth cement mixes up (CDM) and in semicircle caisson mix dike the ground; stand erect dike with sunk reinforced concrete big cylinder and stand erect the dike with sunk steel cylinder, etc.. By comparing all the 20 schemes, the new developed hollow block mound breakwater（Xie et al. 2004) was adopted for the advantages of genius design, less weight, convenient construction, reasonable construction cost, well stability, and small risk.

Since this new structure is being used in the domestic river and sea engineering for the first time, some key problems, which may determine whether or not a scheme will be adopted, need to be solved in laboratory in advance. The key questions include: character of water permeability, the influence of different hollow block structure and its place form to the character of water-permeable, whether the effect of regulation project will be influenced by water percolation, the influence of the water

percolation to the basic functions of training dike ----"conducting current, blocking the sand, reducing the silt", etc.. Flume and physical model is a valid way widely used in the research of estuary and coastal engineering problems（Huang, 1995; Yang, 2001; Han et al. 2002). But still few were performed on the water permeability of mound structures. Based on the projects in the 2nd phase project of Deep Water Channel at Yangtze Estuary, a normal model of flume experiment and a big metamorphosis physical model were creatively combined in this paper to research the former problems. It is basic aiming to provide a scientific basis for project decision-making and instruction opinion for further design.
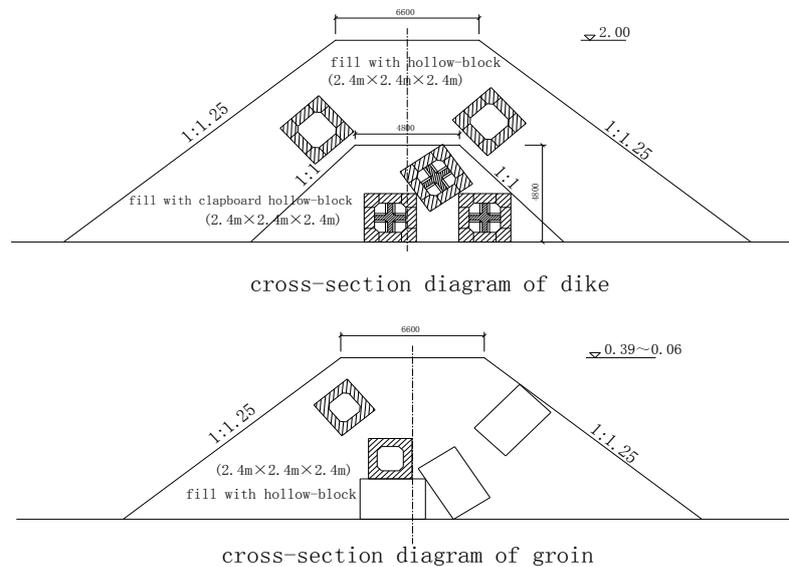
Fig.1 designed training dike and groin structure in NIIC segment

1 Research method

According to the design document, the NIIC designed training dike was constructed with porous hollow blocks of 2.4m×2.4m×2.4m .Inside the dike was also constructed with the same block constitutes with partition board (Fig. 1a). Spur dikes in N II C segment were constructed by hollow block constitutes of 2m×2m×3m (Fig.1b).

For the difficulty in modeling the small-scale structure of hollow block mound breakwater in distorted model, small scale undistorted model of flume experiment was adopted to replace it. With this method, accurate simulation in partial structure was possible in the huge physical model of Yangtze estuary. So the influence of different structure types of mounds to the total effect of regulation engineering can be researched. On the other hand the penetrability character of different structure pattern may be researched by flume experiments as well.

The detail was: use the 1:20 normal flume model to study the permeability of prototype structure,

and then find the similar simplified structure which can be used in the big model of Yangtze estuary, so as to study the influence of project structure to the effect of regulation engineering.

2 Flume experiment

2.1 Model design

The experiments were performed in a flume with changeable slope and wave flow, the flume was 35m long, 0.5m wide, and 0.7m deep, equipped with electromagnetic current meter, the three dimensional ADV current meter, lathe flow-velocity meter, water level meter and so on. Normal model with the ratio of 1:20 was designed based on the physical body of flume. The simulation between the model and the prototype may be guaranteed while the geometry and material was similar. The model was mainly designed according to the law of similitude in flow kinematical conditions. The related scales relations may be calculated by the two-dimensional non-steady flow equation of motion and the equation of continuity.

2.1.1 Normal model with scale relation of 1:20

$$\lambda_L = \lambda_h = 20 \tag{1}$$

$$\lambda_Q = \lambda_L^{5/2} = 1788.85 \tag{2}$$

Here L means length, h means water depth, Q is flow discharge, λ is scale relation. When actual flow discharge is $Q_M(m^3/s)$, then prototype flow discharge of list wide $q_P(m^3/s.m)$) can be calculated as

$$B_P = B_M \cdot \lambda_L \tag{3}$$

$$Q_P = Q_M \cdot \lambda_Q \tag{4}$$

$$q_P = \frac{Q_P}{B_P} = \frac{Q_M \cdot \lambda_Q}{B_M \cdot \lambda_L} = 178.885 Q_M \tag{5}$$

2.1.2 Model with scale relation: vertical 1:125, plane 1:1000

$$\lambda_L = 1000, \lambda_H = 125 \tag{6}$$

$$\lambda_Q = \lambda_L \lambda_h^{3/2} = 1397542.49 \tag{7}$$

When actual flow discharge is $Q_M(m^3/s)$, then prototype flow discharge of list wide $q_P(m^3/s.m)$) can be calculated as

$$B_P = B_M \cdot \lambda_L = 0.5 \times 1000 = 500m \tag{8}$$

$$Q_P = Q_M \cdot \lambda_Q = 1397542.49 Q_M \tag{9}$$

$$q_P = \frac{Q_P}{B_P} = 2795.085 Q_M \tag{10}$$

2.2 Results

The water permeability of training dike and groins with hollow block mound structure was studied by flume experiments. Hollow blocks were made according to the scale relation of 1:20. Training dike and spur dike with the structure of rubble mound were widely used in the first phase project of Deep Water Channel at Yangtze Estuary, and proved to be little permeable by field data.

For the proper appraisal of water permeability of hollow block structure, rubble mound should be modeled as a foundation for compare. Inside the mounds used in the project of Deep Water Channel at Yangtze Estuary was mainly rubble stone weighed 10～100kg ,which should be stones 1.25 ~ 12.5g weight in the experiment based on the ratio rule. But actually we took 0.3～17g crushed stone instead. The porosity gauged in laboratory was 47.2%. The body of r rubble mound was actually constructed with rubble stones 300 ~ 400kg in weight, but corresponding stone calculated in model may be 37.5 ~ 50g in weight, finally we took 40 ~ 50g crushed stone for simulation with the porosity gauged in laboratory was 48.7%.

The mound structural model was placed in the middle of the flume, and flow will penetrate the mound while a water level difference exists. Maintain certain discharge constantly and after a while, a stable water level difference can be gauged. The flume discharge was gauged by the electromagnetic flow meter and verified by lathe flow-velocity meter. Obviously, the bigger the flow discharge through the mound was, the greater difference of water level between the upper stream and downstream was. Relational curve between them reflected the water percolation characteristic of certain structure.

Seen from fig.2, the water percolation degree of designed training dike structure was obviously more serious than that of designed spur dike. When the water level difference was 60cm, the flow discharge of list wide went through the rubble mound was only 1.2 m^2/s and the corresponding discharge through the designed spur dike was 2.9 m^2/s. Compare with rubble mound the water percolation degree in designed training dike and the designed spur dike were much bigger. When the water level difference was 60cm, the flow discharge of list wide went through the rubble mound was only 1.2 m^2/s. The structure of designed training dike had a list wide discharge 3.5 times to that of rubble mound, and the design spur dike structure was 2.4 times to that. In addition, influence of different construction methods of hollow block to water percolation was also studied(Wu, 2005).

On this foundation, according to the request of Yangtze estuary model, we studied the simplified structures of hollow block training dike and spur dike by flume experiments. By changing water percolation in the simplified training dike and spur dike with a vertical scale of 1:125 and plane scale of 1:1000, we acquired proper water percolation relation which coincided the curve of water level difference ~ water percolation discharge between prototype and model. The comparison can be seen in Fig. 3 and Fig. 4. In a whole, the similarity proved to be fine. The experimental achievement may be supplied in the Yangtze estuary model in studying the influence of different water percolation structure to the effect of regulation engineering.
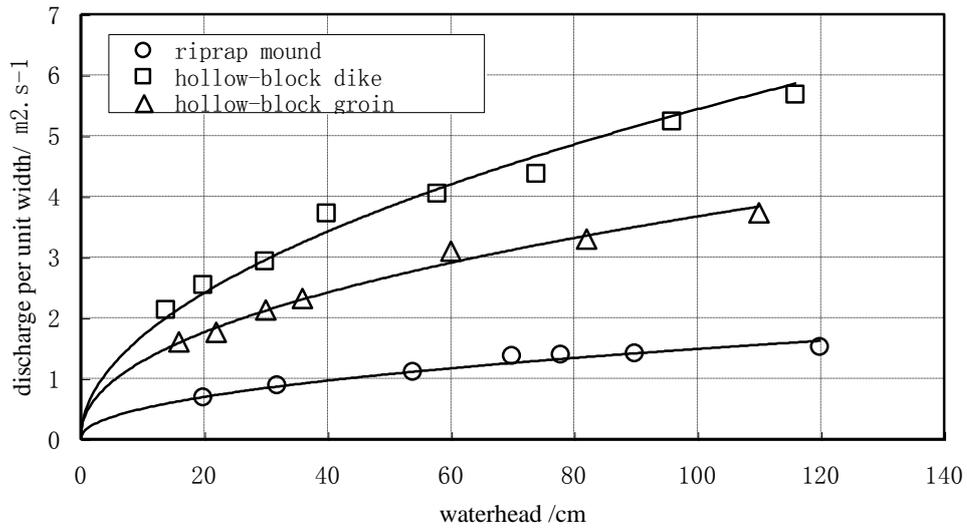
Fig.2 Permeability curves of the designed training dike and groin structure of NIIC segment
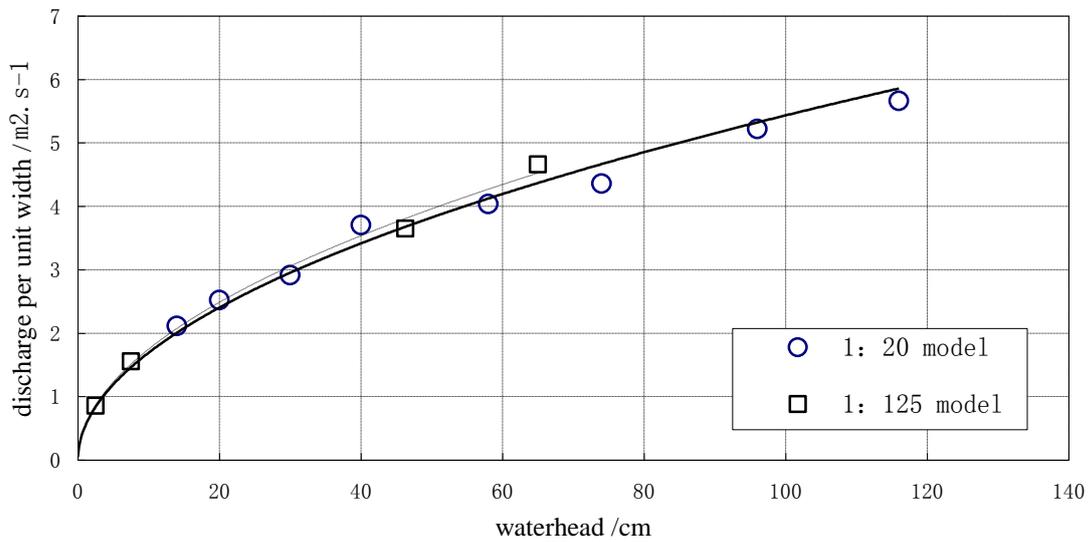
Fig.3 Permeability curves of the different scale designed training dike
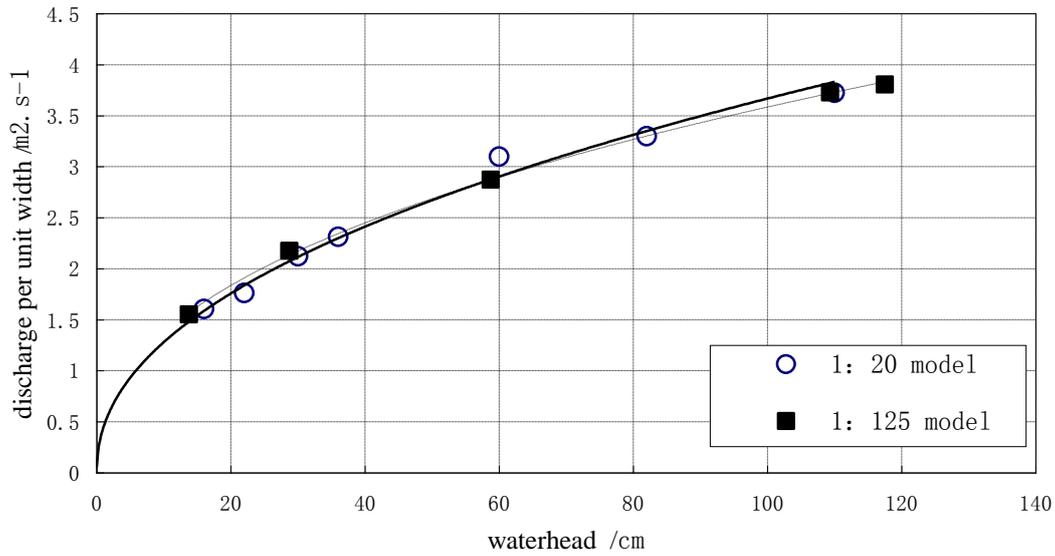
Fig.4   Permeability curves of the different scale designed groin

3.Physical model experiments

3.1 Introduce of model

In order to solve the many technical problems in construction of deep water channel in Yangtze estuary, the Ministry of Communications investigated to construct the Yangtze estuary integrity physical model in Shanghai in 1998.The model is huge with the plane scale relation was 1,000 and vertical scale relation was 125, changing rate was 8. The peak of tidal current in Yangtze estuary is nearby Jiangyin, Jiangsu Province. The model terrain is upper to Ligang, 10km upstream Jiangyin gauging station. Considering the interaction of branches downstream Xuliujing, the north boundary of the model was in Subeizui, and the south boundary was in Nanhuizui. Open sea boundary was approximate 40m isobaths outside the mouth of northern Branch, 35m isobaths outside North Channel, 30m isobaths outside North Passage and 25m isobaths outside South Passage. Upstream the boundary is located in Datong, 400km apart from Jiangyin in Anhui Province. For the similar of tidal wave, Datong and Ligang was connected with a distorted channel. The layout of model can be seen in Fig. 5.
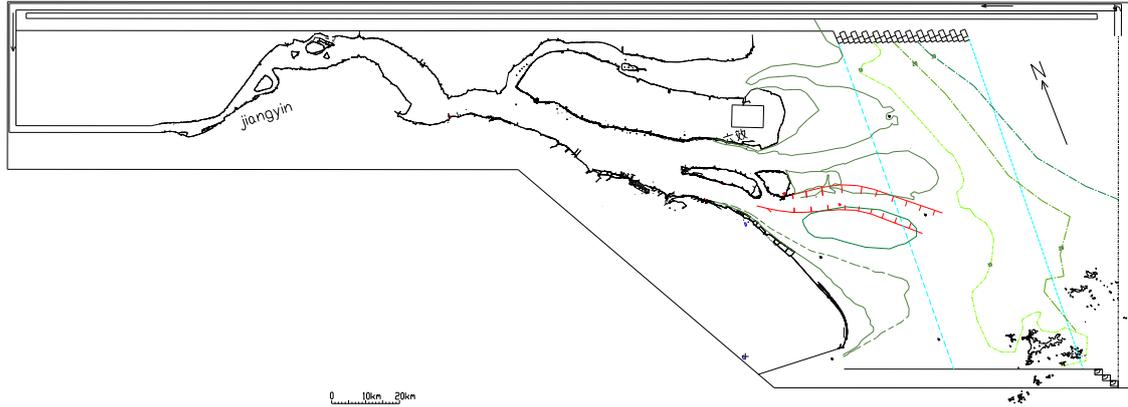
Fig.5 Sketch of Changjiang estuary model

The model was designed according to the laws of geometry similar, gravity similar, resistance similar, tidal current inertia similar, silt starts, bed load discharge similar, erosion and deposition time similar, settlement similar and so on. By compare, special handled model sediment was adopted to be the model sand to simulate bed load movement in the North Channel in Changjiang Estuary. The median diameter of model sediment was 0.15mm with the bulk specific gravity is 1.12 t/m³; the dried bulk specific gravity was 0.6 t/m³. Scale relations in the model were in Table 1.

Table 1 Model scale relations

category	Name of ratio	symbol	Calculated value	Used value
geometry similarity	Plane length	λ_L	1000	1000
	Vertical height	λ_H	125	125
flow similarity	velocity of flow	λ_u	11.18	11.18
	Flow time	λ_t	89.44	89.44
	Flow flux	λ_q	1397500	1397500
	Chezy coefficient	λ_c	2.83	2.83
	Maning's coefficient	λ_n	0.79	0.79
bed load transport similarity	specific gravity	$\lambda_{\gamma s}$	2.366	2.366
	diameter of particles	λ_d	0.27	0.27
	threshold velocity	λ_{U_c}	11.18	10.48~12.9
	Falling velocity	λ_ω	1.4	0.97
	Dry volume-weight	λ_{γ_0}	2.0	2.0
	Rate of sediment transporting per width	$\lambda_{q_{sb}}$	346.5	356
	Erosion and deposition time	λ_{t1}	721.5	702

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3.2 Model confirmation

Model tide level was confirmed by flood tide process in 1998. As shown in Fig.5, the stations include Niupitan, Middle of North Channel, Hengsha, Changxing,Waigaoqiao, Wu Songkou, Baozhen, Nanmen port, Xuliujin and Jiangyin. Reciprocation flow inside the mouth was confirmed by field data of actual flood tide at the same time. In total sixteen points were distributed to measure flow velocity both in South Gang, North Gang, South Channel and North Channel. Because of Coriolis force, the fluid state in lower and mouth of North Channel presents the characteristic of revolves flows. For lack of field data, the field data of cross-section 5# in 1997 and in DS1and DS2 in 2000 were adopted on the confirmation. The experimental data indicated that the model tide level process line and flow distribution coincide with the prototype well. Reproduction of riverbed change in Yangtze estuary deep water route caused by the first phase project in 1999.2~2002.2 was carried out in a changeable riverbed model. Compare with the prototype, the model had a rough similar terrain both in area of erosion and deposition and the quantity in erosion and deposition(Wu, et al. 2003; Wu, et al. 2005) .

3.3 Experimental schemes

3.3.1 Consult experiment of the construction length of N II C segment in designed training dike

Case 0, the background case, the determined planes scheme of arrangement in 2nd phase project of Deep Water Channel at Yangtze Estuary. NIIC section was 2600m long, the elevation of designed training dike is +2.0m (the Woosung basic plane, similarly hereinafter), with water-proof structure.

Case 1, N II C segment designed training dike does not construct, means the 2600m long designed training dike does not exist;

Case2, Half of the N II C segment was constructed ,means the 1300m long designed training dike does not construct.

3.3.2 Consult experiments of the elevation of N II C segment designed training dike

Case 3, the elevation of N II C segment designed training dike was -2.0m;

Case 4, the elevation of N II C segment designed training dike was ±0m;

Case 5, the elevation of N II C segment designed training dike was +1.0m.

3.3.3 Experiments on N II C segment with water percolation structure

Case6, N II C segment was 2600m long and +2.0m in elevation, constructed with 2.4×2.4×2.4m hollow blocks. 2×2×3m hollow block structure was adopted in the 100m spur dike in segment N6, 950m long spur dike in segment N8, and 800m long spur dike in segment N10 .

The water percolation designed training dike and spur dike were simulated by the equivalent simplified structures studied by flume experiments in preceding text.

3.4 Results analysis

Flow velocity, flow direction and the terrain near the project were gauged in experiments. The layout of cross section of flow velocity gauging can be seen in Figure 6.
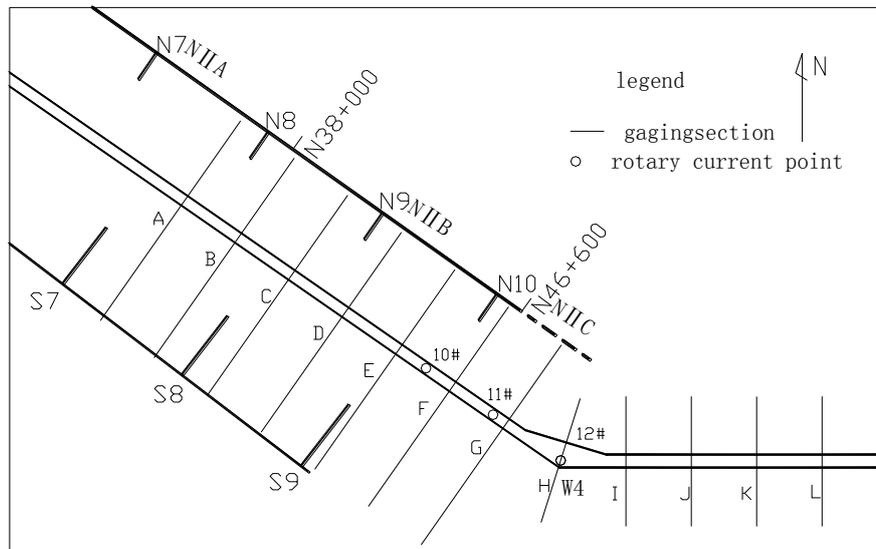
Fig.6 Flow velocity survey points in model

3.4.1 Influence to flow velocity in sea-route

Flow velocity data in channel can be seen in Table 2 and Table 3.

Table 2　Ebb velocities in the channel　（m/s）

Section number	Background velocity	Decrease 2600m velocity	ΔV	Decrease 1300m velocity	ΔV	Dike elevation -2m velocity	ΔV	Dike elevation 0m velocity	ΔV	Dike elevation 1m velocity	ΔV	Permeable dike velocity	ΔV
A	2.05	1.98	-0.06	2.03	-0.02	2.00	-0.04	2.07	0.02	2.09	0.04	2.07	0.02
B	2.07	2.10	0.03	2.05	-0.02	2.01	-0.06	2.10	0.02	2.07	-0.01	2.07	-0.01
C	2.09	2.04	-0.05	2.04	-0.05	2.11	0.02	2.09	0.00	2.08	-0.01	2.08	-0.02
D	2.07	2.05	-0.02	2.06	-0.02	2.03	-0.05	2.03	-0.04	2.06	-0.01	2.04	-0.04
E	2.00	1.93	-0.07	1.99	-0.01	1.95	-0.04	1.93	-0.06	2.01	0.01	2.01	0.01
F	1.89	1.81	-0.08	1.90	0.01	1.83	-0.06	1.84	-0.04	1.89	0.00	1.88	-0.01
G	1.77	1.69	-0.08	1.70	-0.07	1.70	-0.07	1.71	-0.06	1.75	-0.02	1.73	-0.04
H	1.58	1.51	-0.08	1.54	-0.04	1.53	-0.05	1.50	-0.09	1.57	-0.01	1.57	-0.01
I	1.43	1.35	-0.09	1.39	-0.04	1.36	-0.08	1.36	-0.07	1.42	-0.01	1.41	-0.02
J	1.29	1.16	-0.12	1.18	-0.10	1.20	-0.09	1.23	-0.06	1.26	-0.03	1.27	-0.02
K	1.25	1.15	-0.10	1.15	-0.10	1.18	-0.07	1.19	-0.06	1.23	-0.02	1.24	-0.01
L	1.15	1.02	-0.13	1.05	-0.10	1.07	-0.07	1.09	-0.05	1.12	-0.02	1.15	0.00
average			-0.07		-0.05		-0.06		-0.04		-0.01		-0.01

Table 3   Flood velocities in the channel （m/s）

Section number	Background velocity	Decrease 2600m velocity	ΔV	Decrease 1300m velocity	ΔV	Dike elevation -2m velocity	ΔV	Dike elevation 0m velocity	ΔV	Dike elevation 1m velocity	ΔV	Permeable dike velocity	ΔV
A	1.21	1.18	-0.03	1.16	-0.06	1.13	-0.09	1.14	-0.07	1.15	-0.06	1.18	-0.03
B	1.20	1.23	0.03	1.15	-0.04	1.20	0.00	1.15	-0.05	1.18	-0.02	1.18	-0.02
C	1.18	1.10	-0.08	1.13	-0.06	1.22	0.04	1.12	-0.06	1.17	-0.01	1.13	-0.05
D	1.32	1.28	-0.04	1.40	0.08	1.31	-0.01	1.27	-0.05	1.26	-0.06	1.27	-0.05
E	1.12	1.23	0.11	1.17	0.05	1.18	0.06	1.12	0.00	1.16	0.04	1.07	-0.05
F	1.59	1.36	-0.23	1.42	-0.17	1.44	-0.15	1.36	-0.23	1.40	-0.19	1.55	-0.04
G	1.57	1.16	-0.41	1.29	-0.28	1.40	-0.17	1.46	-0.11	1.46	-0.11	1.51	-0.06
H	1.32	1.16	-0.16	1.20	-0.12	1.22	-0.10	1.25	-0.07	1.29	-0.03	1.24	-0.08
I	1.14	1.15	0.01	1.13	0.00	1.13	-0.01	1.14	0.00	1.16	0.02	1.16	0.02
J	1.05	1.04	-0.01	1.06	0.01	0.99	-0.06	1.02	-0.03	1.05	0.00	1.04	-0.01
K	1.00	0.97	-0.03	0.99	-0.01	0.99	-0.01	1.00	0.00	1.00	0.00	0.96	-0.04
L	0.94	0.89	-0.05	0.87	-0.07	0.91	-0.03	0.89	-0.05	0.94	0.00	0.88	-0.06
average			-0.08		-0.06		-0.04		-0.06		-0.04		-0.04

Compares with the background, various cases may decrease the flood velocities and ebb velocities in channel nearby the NIIC project. Among them, the construction of 2600m designed training dike will influence the effect most obviously, mean flow velocity reduced 7~8 cm/s. The construction of +1m designed training dike and the water percolation designed training dike will bring less effect with the mean velocity reduces 1~4 cm/s.

3.4.2 Influence to flow direction in sea-route

Various cases cause no much change in flow direction both in flood velocities and ebb velocities, the range of change is always limited in 5°. Various plans D ~ F cross section rises the jet stream to the south, the angle of deflection lengthens along with the designed training dike and advances but reduces (Fig.7). The change in flow direction caused by construction of +1m designed training dike and the water percolation designed training dike was small.
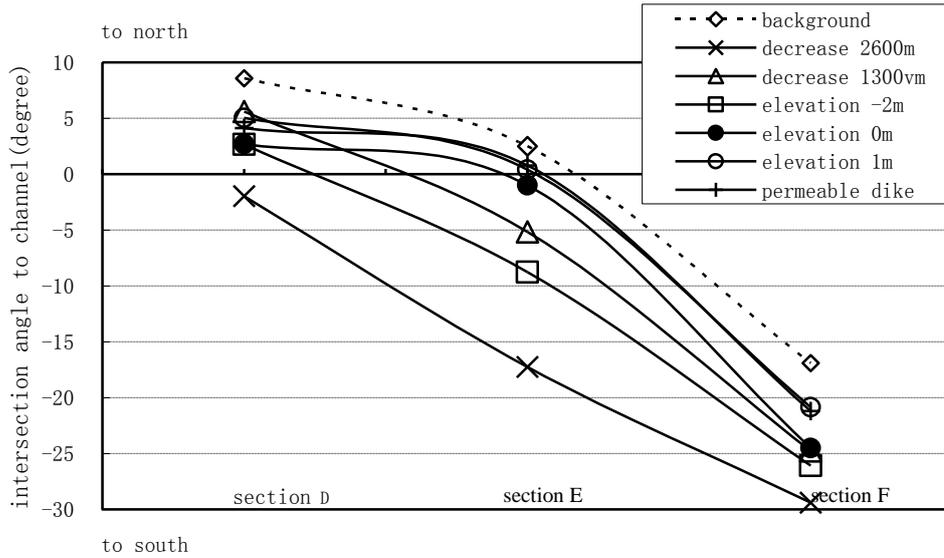
Fig.7   Angle between flood flow and the channel

3.4.3 Influence to flow structure

In experimental schemes, the influenced circumrotating flood current structure in channel was mainly near the cross-section from 10 # to 12 #. The direction of flood flow slightly turned south, the angle turned decreased with the extend or advance of the training dike. Even more, the river mouth nearby revolves flows also has the change in ellipticity, the length axis ratio of revolves flows can be seen in Fig. 8 and Fig.9. Actually, The circumrotate flood current ellipse to change flatly by the circle, and the slightest change happened in the +1m designed training dike plan, following with the water percolation structure, this coincide with the effect of project.
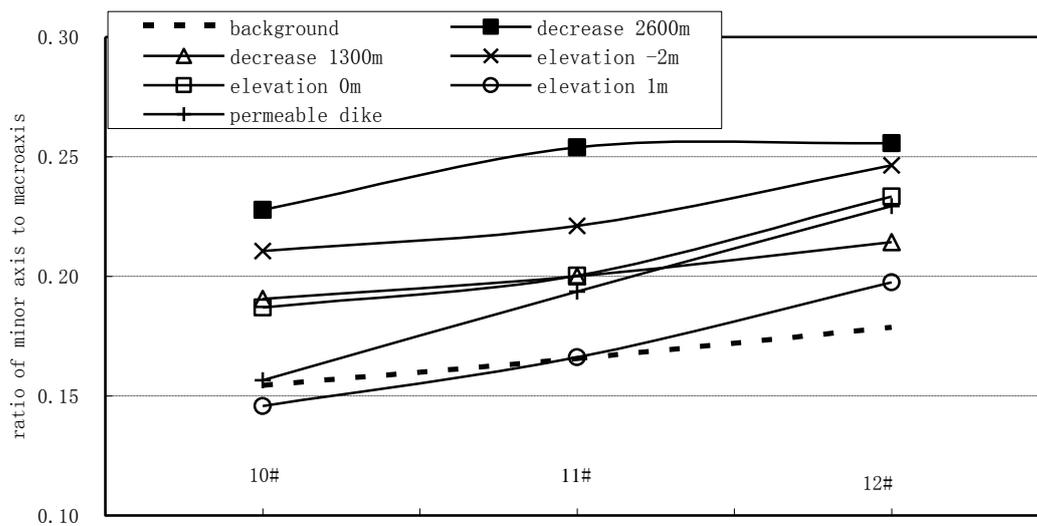
Fig.8   Ratio of minor axis to macro axis of circumrotate ebb current ellipse

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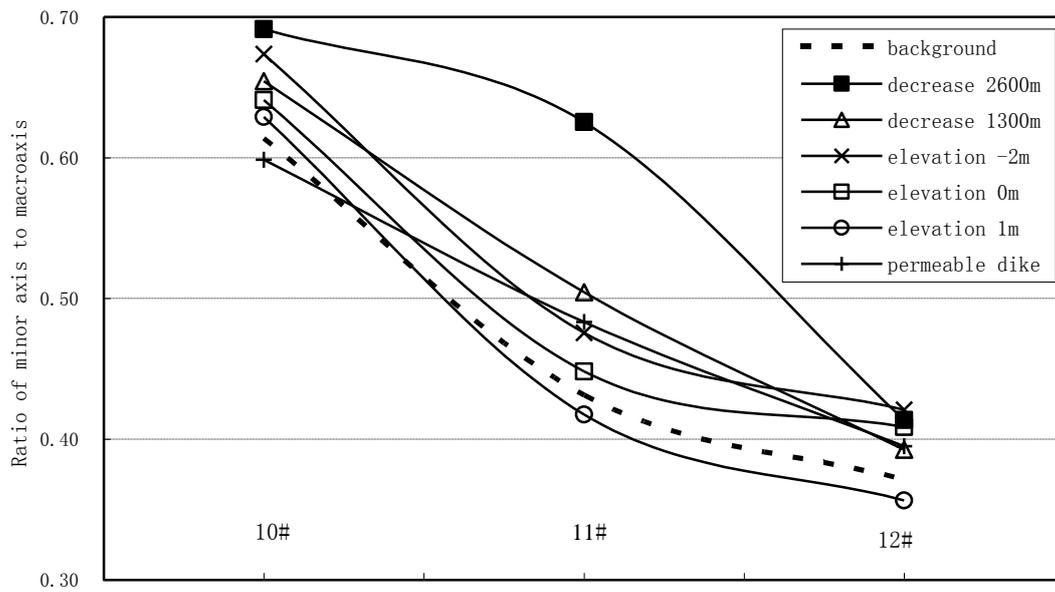
Fig.9 Ratio of minor axis to macroaxis of circumrotate flood current ellipse

3.4.4 Influence to channel terrain

By compare with the balanced terrain of different schemes, the channel influenced by NIIC segment was mainly limited in nearby the mouth of the northern trough. Different terrain characters caused by different schemes can be seen in table 4.

Table 4   comparisons of terrain characters

Item (isobathic)	Background	Decrease 2600m	Decrease 1300m	Dike elevation -2m	Dike elevation 0m	Dike elevation 1m	Permeable dike
8m	Run through	Run through	Run through	Run through	Run through	Run through	Run through
8.5m	Run through	Interrupt 3km	Interrupt 2km	Interrupt 3km	Interrupt 2km	Run through	Interrupt 0.5km
9m	Interrupt 5km	Interrupt 8km	Interrupt 6km	Interrupt 7km	Interrupt 6km	Interrupt 6km	Interrupt 6km

Based on table 4, taken the background scheme as reference, the scheme with no 2600m designed training dike had the worst topographical condition. The topographical condition in scheme with +1m designed training dike and the water percolation designed training dike were quite close to the background.

In conclusion, from the compare between flow velocities, flows direction, the flow structure and, terrain character and so on, the influence of construction of 2600m designed training dike in NIIC segment to the effect of regulation engineering was obvious. Whether a designed training dike with the reduced elevation to +1m or the hollow block sloping faced breakwater water percolation structure was adopted seemed to be no much change to the effect of regulation engineering.

4. Conclusion

In this paper we realized the partial structure simulation in river models. Taking NⅡC segment of the 2nd phase project of Deep Water Channel at Yangtze Estuary as a case, the paper discussed the method of research on engineering effect of hollow block structure by combining flume experiment with physical model. It was concluded that the influence of construction of 2600m designed training dike in NIIC segment to the effect of regulation engineering was obvious. In the NIIC segment , whether a designed training dike with the reduced elevation to +1m or the hollow block sloping faced breakwater water percolation structure was adopted seemed to be no much change to the effect of regulation engineering.

Acknowledgements

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