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EFFECTS OF SPUR DIKES AND BLOCKING OF JIANGYA NORTH CHANNEL ON THE DEEP NAVIGATION CHANNEL IN THE YANGTZE RIVER ESTUARY

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Abstract: This paper presents a study of changes in the percentage of flow and the tide ebb prism in the North Channel of the Yangtze River Estuary. The analysis is based on data measured before and after the first phase of deep channel training project for navigation. The effects of building spur dikes and blocking Jiangya North channel on the tide flow, as well as new measures for improving flow conditions in the North channel, were extensively investigated. The research results are valuable for the Second and Third phases of deep channel training project for navigation.

The first phase of deep channel training project for navigation in the Yangtze River Estuary was conducted from Jan. 1998 to Jan. 2001. As a result, a navigable channel with 8.5 m deep was generated, and significant economic benefits were achieved. The first phase project includes the first phases of channel training, channel dredging, and channel improvement.

In this study, the flow and sediment movements in North Channel of Yangtze River Estuary, as well as the effectiveness of spur dikes and blocking of Jiangya North channel, were investigated by using hydrological data measured before and after the channel training project. The research results are very helpful for the Second and Third phases of the project.

1. CHANGES OF PERCENTAGE OF FLOW IN NORTH AND SOUTH CHANNELS

The percentages of flow on North channel in Yangtze River Estuary are given in Table1, which were measured by Shanghai Design and Survey Institute. There are two survey sections for monitoring the variation of percentage of flow in the North and South channels. The first survey section (Jiangyanansha section) is located at the front edge of the center bar, crossing both the North and South channels. The second survey section (Jiuduanshashangsha section) is located in the downstream of the Jiangya north channel and the Hengsha channel, as shown in Fig.1. In North channel the second survey section is just downstream of spur dikes S1 and N1, while it extends over the South channel with a direction perpendicular to the flow of South channel. The Hengsha channel is a channel entering the North Channel from Beigang. The Jiangya north channel is a channel connecting the North channel to South channel. Under natural conditions, the tide ebb passes Hengsha channel from Beigang to North channel, and then continuously enters the South channel through the Jiangya north channel. There is no any diversion channel in South channel between the first and second survey sections. However, the Jiangya north channel was blocked in the first phase of the channel training project.

It can be seen from Table 1 that the percentage of flow at the first section in North channel was increased from 60.8% in Aug. 1998 to 62.1% in May 1999 after the installation of South dike of diversion intake. Then the percentage of flow in North channel started decreasing while the Jiangya north channel being blocked up, and it further decreased following the spur dikes construction and channel improving. The percentage of flow in North channel finally decreased from 60.8% in Aug.1998 to 47.6% in March 2002 after the completion of the first phase project, with a total of 13.2% deduction. The maximum deduction of percentage of flow in North channel was 14.5%, which occurred between Aug. 1999 and March 2002. The decrease of percentage of flow in North channel was mainly due to spur dikes, as well as blocking of the Jiangya north channel. So, if only spur dikes were used, the decrease of percentage of flow in North channel would be little less.

Table 1 The percentage of flow in North channel (PFN) before and after the First phase project (at first and second survey sections)

Date	PFN at sec. No. 1	PFN at sec. No. 2	Note
Aug. 1998	60.8	53.7	The project started in July 1998.
Mar. 1999	62.0	52.4	The South dike of diversion intake completed in may 1999.
May 1999	62.1	59.8	
Aug. 1999	60.4	61.4	The diversion intake and part of dike completed.
Nov. 1999	57.3	58.1	
Mar. 2000	52.1	57.1	
May 2000	53.9	54.2	The spur dikes completed on may 7, 2000.
Sep. 2000	50.9	54.1	
Nov. 2000	49.8	53.3	The first phase of channel improving project started in Nov. 2000 and finished in Jane 2001.
Feb. 2001	47.9	51.9	
Apr. 2001	48.6	53.4	
Jan. 2001	47.3	51.9	
July 2001	46.5	51.4	
Oct. 2001	47.1	52.4	
Mar. 2002	47.6	49.5	

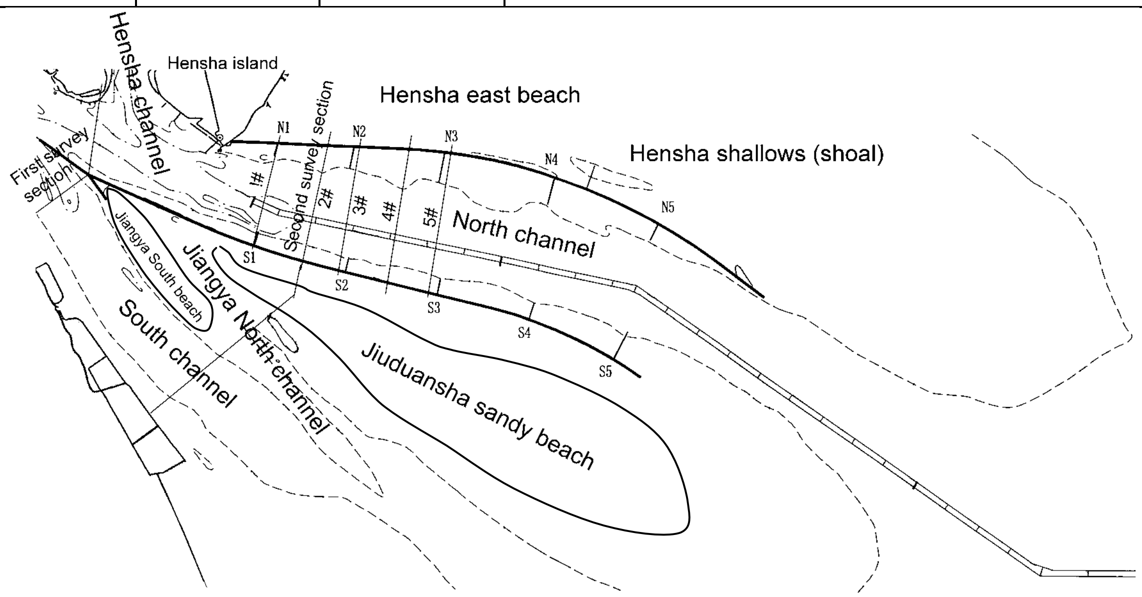

Fig. 1 Plan view of the first phase of deep navigation channel in the Yangtze River Estuary

The percentage of flow in North channel at the second section was 53.7% in Aug.1998. It increased to 61.4% in Aug. 1999 because of block up Jiangya north channel after the first phase project, with a rising of 7.7%. However, at that time the effects of blocking up Jiangya

North channel did not finish and therefore the percentage of flow was still not stable. After Aug.1999, the construction of spur dikes started, and due to their effects the percentage of flow decreased from 61.4% to 49.5% in March 2002. The maximum deduction reached 11.9% during Aug. 1999 to March 2002. The effect of spur dikes should be larger than this value, because percentage of flow in North channel caused by blocking up Jiangya North channel had not reached stable in Aug. 1999.

According to the above analysis, the diversion project and the blocking of Jiangya North channel had positive effects on the increase of percentage of flow in North channel. The blocking of Jiangya North channel was particularly effective for increasing the percentage of flow at the second survey section in North channel. But it caused the percentage of flow decreasing at the first survey section in North channel. However, the spur dikes resulted in increase of percentage of flow at both two survey sections in North channel.

The spur dikes could cause the percentage of flow in North channel to reduce, the reduction was less than 14.5% at the first section and more than 11.9% for the second section. The blocking of Jiangya north channel caused the percentage of flow in North channel to increase more than 7.7% at second section. The diversion intake and underwater surface dikes caused the percentage of flow in North channel to slightly increase at the first survey section, with a value bigger than 1.3%. The spur dikes affected the percentage of flow in North channel at both survey sections, with a higher effect on the second survey section than on the first survey section. This was simply because the spur dikes were closer to the second survey section, and the Hengsha channel and Jiangya north channel were between the first and second survey sections.

2. CHANGES OF TIDAL EBB PRISM BEFORE AND AFTER THE FIRST PHASE PROJECT

This section mainly discusses changes of tide ebb prism in North and South channels. Changes of tide ebb prism in different time periods were estimated based on measurements given in Table 1 and the typical high tide (corresponding to flow discharge of 30,000m^3/s in Yangtze River) provided by River Estuary and Costal Research Center of Ministry of Communications. The total tide ebb prism at the first survey section was 2137.17 million m^3, and 285.34 Million m^3 between the first and second sections (including the tide ebb prism from Hengsha channel). The estimated results are given in Table 2.

Table 2 Estimated results of tide ebb prism in different time periods （10^6 m^3）

Date	Tide ebb prism in South channel (1)	Tide ebb prism in South channel (2)	Tide ebb prism in North channel (1)	Tide ebb prism in North channel (2)	Tide ebb prism difference between (1) and (2) in North channel
AUG.1998	837.77	1121.62	1299.40	1300.89	1.49
May,1999	809.99	973.85	1327.18	1448.66	121.48
Aug.1999	846.32	935.09	1290.85	1487.42	196.57
Nov.2000	1072.86	1131.31	1064.31	1291.20	226.89
Mar.2002	1119.88	1223.37	1017.29	1199.14	181.85

Under natural conditions in Aug. 1998, the tide ebb prism at the first survey section plus the tide ebb prism between the first and second survey sections should be equal to the tide ebb prism at the second survey section. However, It can be seen from Table 2 that the tide ebb prism between the first and second survey sections had only 1.49 million m^3, which was equal to the sum of the tide ebb prism entering North channel from Hengsha channel and the tide ebb prism between the first and second survey sections, minus the tide ebb prism from North channel pass thought Jiangya north channel flowing to South channel. The tide ebb prism between the first and second survey section was getting larger when Jiangya North channel was blocked.

It can be seen that the percentage of flow in North channel at the first survey section was reduced from 60.8% in Aug. 1998 to 47.6% in March 2002, with a deduction of 21,7% after the first phase project. The percentage of flow in North channel at the second survey section was reduced 4.2% from Aug. 1998 to Mar. 2002, and the tide ebb prism was reduced 7.82%. The blocking of Jiangya channel caused the increase of percentage of flow in North channel below the intake of Jiangya channel and the decrease of tide flood current. It also resulted in the decrease of percentage of flow in South channel below the exit of Jiangya channel and the increase of tide flood current. The blocking of Jiangya channel may eliminate part of the negative effect of spur dikes on the percentage of flow in North channel. As a result, better conditions for navigation developed after the first phase project.

3. EFFECTS OF SPUR DIKES AND BLOCKING OF JIANGYA NORTH CHANNEL ON CHANNEL SCOURING

After the first phase project, the spur dikes and blocking of Jangya North channel resulted in scouring in North channel. Locations of cross sections N_1-S_1 and N_2-S_2 between the North and South spur dikes are shown in Fig. 2. The data of scouring and deposition in North channel are given in Table 3.

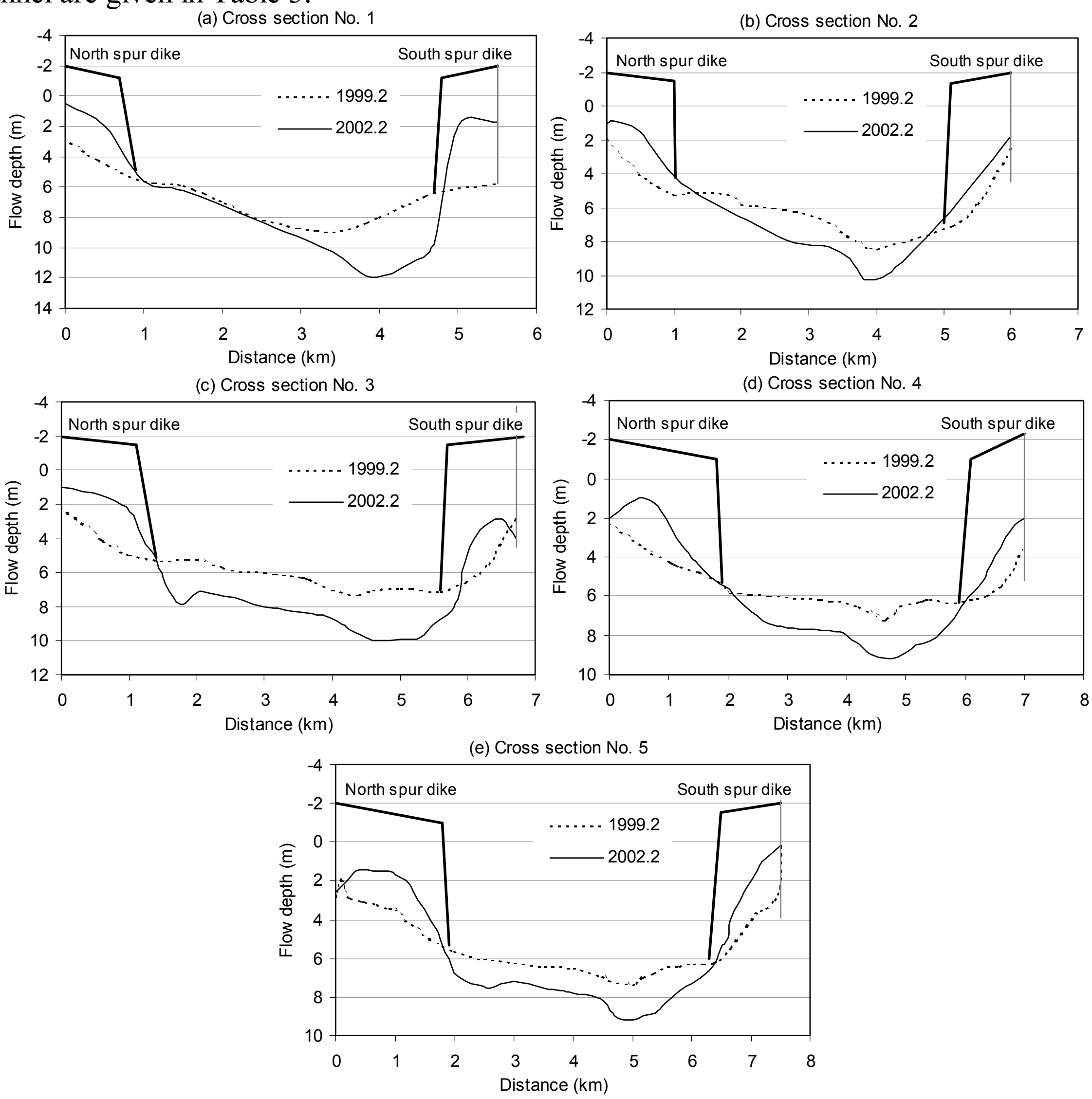

Fig. 2 Cross sections measured at different times

Table 3 Scouring and deposition in North channel after the first phase project (area under 2m)

Cross section	Area in 2/1999 (10^6m^2)	Area of spur dikes (10^6m^2)	Ratio of area of spur dikes %	Area between spur dikes (10^6m^2)	Area between spur dikes in 2/2002 (10^6m^2)	Area of scour (10^6m^2)
1#(N1-S1)	483.92	86.94	17.97	396.98	449.38	52.40
2#	485.49	485.49	---	---	502.74	17.25
3#(N2-S2)	505.52	112.01	22.16	393.51	477.42	83.19
4#	527.51	---	---	---	553.51	26.00
5#(N3-S3)	546.54	113.21	20.71	433.33	488.75	55.42

The percentage of flow at the first survey section in North channel decreased 4.2% and the tide ebb prism decreased 7.82% after the completion of the first phase project. It can be seen from Table 3 that the cross sectional area of North channel decreased 20.28% due to the construction of spur dikes. After a period of time, the cross sectional areas at N_1-S_1, N_2-S_2 and N_3-S_3 became 7.18%, 5.55% and 10.58% smaller than their original areas, respectively. On average, the cross sectional area was 7.77% smaller than the original sectional area. This means that the average velocities at these sections between the spur dikes were roughly the same as in natural conditions. Because there existed local scour holes and return flow zones around the spur dikes, the real average velocity should be larger than under natural conditions if excluding the inactive flow areas.

Under natural conditions, the velocity in North channel was not big enough for carrying all the sediment load, and minor deposition was expected. After the spur dikes were constructed, the cross-sectional area decreased. However, the percentage of reduction of tide ebb prism in North channel was smaller than the percentage of reduction in sectional area. This brought an increase in velocity around the head of spur dikes, resulting in scouring in the North channel. Now the reach with spur dikes has basically reached its equilibrium in term of scouring and deposition. In the second phase project, if the velocity can be kept the same as or little larger than the current value in North channel, an equilibrium channel shall be maintained.

The channel scouring may be analyzed by using the sediment carrying capacity formula given by $S = K(V^3/ghw)^n$. The depth h of navigation channel in the second phase project is required to increase to 10-10.5m from 8.5m in the first phase project. The flow depth increase of 17.6%-23.5% requires the velocity to increase 5.6%-7.3%. If the slope and roughness can be kept constant, then the velocity can be easily increased. Usually the roughness can keep constant, but slope may have some change because of the effect of spur dikes. Therefore, it is very important to avoid any additional increase of roughness induced by spur dikes.

4. EFFECTS OF SPUR DIKES ON SCOURING IN NORTH CHANNEL IF JIANGYA NORTH CHANNEL NOT BLOCKED

The above analysis has shown that the North channel can keep a navigable channel with 8.5m deep by using spur dikes and blocking of Jiangya north channel. This section discusses the possibility to keep an 8.5m deep navigable channel if Jiangya north channel was not blocked. For this analysis, the following assumptions are assumed:

(1) The percentage of flow and the tide ebb prism in North channel at the first and second survey sections in Aug. 1998 are equal to real data. The percentage of flow and the tide ebb prism in North channel at the first survey section in May 1999 is also equal to real data.

(2) The total tide ebb prisms in South and North channels at the first and second survey sections are constant.

(3) The percentage of flow in North channel at the first survey section would decrease 10% after spur dikes was installed.

The reasons for these three assumptions are as follows:

(1) In Aug. 1998, before the project starting to construct, the percentage of flow and the tide ebb prism should represent the values under natural conditions. The blocking of Jiangya north channel had no affect on the percentage of flow and the tide ebb prism at the first survey section. But it did has affect on the percentage of flow and the tide ebb prism at the second survey section before May 1999.

(2) The percentage of flow and the tide ebb prism in North and South channels changed considerably after the spur dikes were constructed. However, the sum of tide ebb prisms in South and North channels at the first and second survey sections keeps constant.

(3) The real data at the first survey section indicated the percentage of flow in North channel has decreased14.5% after the first phase project. This includes the effects of both spur dikes and blocking of Jiangya north channel. Therefore, the 14.5% decrease is larger than the deduction by only spur dikes. Real data indicates that the percentage of flow in North channel at the second survey section decreased 4.2% after the first phase project, which including the effect of both spur dikes and blocking of Jiangya north channel. These two measures had effects being contradictory to each other. The spur dikes made the percentage of flow in North channel to decrease and the blocking of Jiangya north channel made it to increase. At first, the percentage of flow in North channel increased 7.7% due to blocking of Jiangya north channel, then it decreased 11.9%. The percentage of flow in North channel should had a decrease smaller than 11.9% if the Jiangya north channel was not blocked. Therefore, we assume that the blocking of Jiangya north channel can decrease the percentage of flow in North channel at the first survey section by 10%.

According to the above assumptions, the tide ebb prisms and the percentage of flow in North channel at different cross sections and different times are calculated, the result are given in Tables 4 and 5.

Table 4 The tide ebb prisms at the first and second survey sections (10^6 m^3)

Date	South Channel (1)	South Channel (2)	North Channel (1)	North Channel (2)
Aug. 1898	837.77	1121.62	1299.40	1300.89
May. 1999	809.99	1093.76	1327.18	1328.75
Mar. 2002	1023.70	1307.55	1113.47	1114.96

Table 5 percentage of flow in North channel (if Jiangya North channel not blocked)

Date	Percentage of flow (1)	Percentage of flow (2)
Aug.1898	60.8	53.7
May.1999	62.1	54.85
Mar.2002	52.1	46.02

According to the above calculations, the tide ebb prism in North channel at the second survey section in March 2002 was 14.3% less than in Aug. 1998. The percentage of flow in North channel at the second survey section in March 2002 was 7.68% less than in Aug. 1998.

The cross sectional areas of N_1-S_1, N_2-S_2, and N_3-S_3 decreased 20.28% on average due to the construction of spur dikes. The scoured area would be about 5.98% of the cross sectional area after the spur dikes were constructed if the flow velocity was kept the same as that under natural conditions in North channel. The scouring area would be less than 12.51%, which is the actual value under present conditions. We can see that the blocking of Jiangya north channel is very important.

The construction of a lot of spur dikes causes the percentage of flow in North channel to decrease. This is not good for long-term stable operation of North channel. The blocking of Jiangya north channel can cause the percentage of flow in North channel to increase, which is good for long-term stable operation of North Channel.

5. FLOW PATTERN NEAR CHANNEL TRAINING STRUCTURES AND EFFECTS OF ENLARGED SUBMERGED DYKE ON PERCENTAGE OF FLOW

The velocity distribution near the intake of diversion work indicated that the water of tide ebb prism flows from North channel to South Channel over submerged dyke and intersects with submerged dyke with an angle of 15 degree and a velocity of1.33-1.45m/s. The flow ratio will increase if submerged dyke o be prolonged and heightened.

As an alternative measure, we suggest the submerged dykes be prolonged and heightened, which can make the percentage of flow in North channel to increase.

The above analyses indicate that first phase project has reached its goal of developing a navigable channel with 8.5m depth. Two kinds of measures were used, one was the spur dikes and the other the blocking of Jiangya north channel. Among them, the blocking of Jiangya north channel partially compensated the decreasing tendency induced by spur dikes, and increased the percentage of flow and the tide ebb prism in North channel. Although the calculated results in Table 4 are rough estimations, they are correct qualitatively. We can see that the tide ebb prism is increasing, and the velocity of tide ebb and the scouring volume are also increasing. But we should keep in mind that the percentage of flow and the tide ebb prism in South channel downstream of the exit of Jiangya north channel decreased after blocking of Jiangya north channel.

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