

POSSIBLE SILTATION BELOW THE TIDAL BARRAGE AT THE MOUTH OF CAO-E RIVER

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Abstract: The Cao-e River is the second longest branch river of the Qiantang Estuary, the total length of its main river is 197 km and the catchment area is 6080 km². The tidal barrage will be built in order to prevent the intrusion of tide and saline water, store and supply freshwater, improve the condition of navigation and make good use of the land resources on both banks of the Cao-e River.

1. INTRODUCTION

If a tidal barrage is built in the main river belonging to tidal estuary with high sediment concentration, possible siltation will occur, causing for the tidal discharge decreasing, tidal wave deformation and runoff decreasing, even more, the serious siltation may have impact on flood control and draining of waterlogging. So it is necessary to explore the siltation topography before the tidal barrage being built. But the Cao-e River is a branch river of the Qiantang River; the construction of tide barrage at the mouth of the Cao-e River is different essentially from that at the Qiantang Estuary.

According to the observed topographical data, the paper analyses the characteristic of the fluvial process of the Jianshan reach of the Qiantang River, which is out of the mouth of the Cao-e River, the factors effecting the changes of flat and main channel, predicts the siltation topography after the implementation of planning line of the Qiantang River.

2. MAJOR FACTOR IN CHANGES OF THE FLAT AND THE MAIN CHANNEL AT THE MOUTH OF CAO-E RIVER

According to the observed hydrographic and topographic data, the following are the factor having much to with the changes of the flat and the main channel out of Cao-e River.

The yearly changes of hydrographic. The yearly and monthly changes of runoff upstream have direct effect on the main flow direction in Jianshan river reach, it is northload or southload of the main stream that has greatly effect on the width of flat out of the mouth of Cao-e River. Because the main channel of the Qiantang River is straight in the condition of high water and curved in the condition of low water, generally the main channel goes north in high flow year or in serial high flow years, then the large area of high flat is silted out of the mouth of Cao-e River, the main flow curves south in low flow year or serial low flow years, then high flat is silted in the northern bank and flat face is low and narrow.

The changes of boundary condition. According to the regulatory principle named whole-line constriction and the planning line of Jianshan river reach, the reclamation of the southern bank has reached planning line since 1970s, the distance between the embankments at the mouth of Cao-e River decreased about 12.5km, but the average width of the flat out of the mouth of Cao-e River was 7.7km. The reclamation of northern bank of the Qiantang River was begun in 1997, the distance between the embankments decreased 2.5km again, the main

stream of Qiantang River has been pushed 3km southward, and the average width of flat out of mouth has been changed to 2.4km.

3. THE CHARACTERISTIC OF FLUVIAL PROCESS IN JIANSHAN RIVER REACH

The main stream in Jianshan river reach plane-swings frequently with strong range of swing. The river width is 15–20km downstream Shibao, the bed material is fine silty sand, which is easy to scour and silt, in addition to the effect of the stream bifurcation of flood tide and ebb tide and the action of bore, plane range of swing reaches 5–15km. Generally the main stream curves south in low flow year or serial low flow years. On the contrary, the main channel straightens north in high flow water year or during the flood period. It is the swing rule of the main channel in Jianshan river reach. The main channel swinging and going in different direction lead to the instability of rising and collapsing of the flat and the main channel. When the main channel goes south in low flow year, the siltation of high flat happens in northern bank and the main channel is near to the mouth of Cao-e River; in high flow year the main channel goes north so that the siltation of high flat happens in southern bank. It shows that the variation of the flat depends on the position of the main channel of Qiantang River.

In Jianshan river reach, the plane-expanding rate of river width is very high and the lifting rate of riverbed is high too, the river channel is both wide and shallow, and expands suddenly downstream 86Qiu of Xiaoshan, the stream flow of flood tide and ebb tide bifurcates, so the eyot often forms here.

The characteristic of scour and siltation in Jianshan river reach is that siltation happens in flood current and scour happens in tidal current, while its upriver goes the other way; scour happens in the winter and siltation happens in the summer in Huangzhou Bay, and Jianshan river reach goes the reverse direction, that is to say the close exchange of sediment exists between Jianshan river reach and its upriver—Hangzhou Bay.

4. THE CHANGES OF THE FLAT AND THE MAIN CHANNEL IN JIANSHAN RIVER REACH SINCE THE REGULATION AND RECLAMATION.

The distance between embankments in cross-section at the mouth of Cao-e River was 26.5km in 1970. The embankment line was pushed 12.5km northward for the reclamation of southern bank, and the distance of cross-section at the mouth of Cao-e River has decreased to 14km in 1995. After 1997 the reclamation of northern bank was begun, the embankment line was pushed 2.5km toward the river, so that the distance between embankments decreased to be 11.5km, and the cross-section at the mouth of Cao-e River has been constricted by 57 percent.

The low flat line in the southern bank or the distance that the main channel is away from southern bank can be regarded as the criteria of measuring the width of flat face below the tidal barrage. Table 1 shows the changes of the flat and the main channel before the reclamation and after the reclamation.

Table 1 The changes of the flat and the main channel before the reclamation and after the reclamation in Jianshan river reach unit: km

Term	Time	The distance that—1.8m contour line of low flat is away from southern bank	The distance that the main channel is away from southern bank	The distance between embankments at the mouth of Cao-e River
Before the reclamation	July 1970(bias north)	18.00	19.5	26.50
During the time of reclamation	1995	7.75	9.6	14.0
Recently	2002	2.35	2.6	11.5

5. THE PREDICTION OF CHANGES OF THE FLAT AND THE MAIN CHANNEL AFTER PLANNING LINE BEING CARRIED OUT

5.1 THE ANALOGICAL ANALYSIS OF RIVER SHAPE IN JIANSHAN RIVER REACH IN LOW FLOW YEAR

After the planning line being implemented, the plan-shape of curve river channel is similar to the one in 1983(low flow year) when high flat silted in the northern bank. The former radius of curvature in the centerline of curve river channel was 8.9km and the later one was 8.8km in 1983.

It is the position of main channel in Jianshan river reach that determines the width of flat face above low flat line out of the mouth of Cao-e River. The thalweg index— K is regarded as the position of the main channel. Suppose K is the ratio of the distance which main channel is away from northern bank to river width, the value of K is the relative position of the main channel. When K is equal to 0.5, it means that the main channel is near to the centerline of river, when K is less than 0.5, the main channel is in the north of river; when K is more than 0.5, the main channel is in the south of river. The larger the value of K is, the nearer the main channel is to the southern of bank. The river shape from 1982 to 1985 represents going south, the river shape from 1992 to 1995 represents going north and the river shape from 1998 to 2001 means the result after reclamation of northern bank. The average thalweg index of each cross-section in different term along the river is calculated and the points are in Fig 1. See Fig.1 shows before the reclamation of northern bank, the thalweg index is less than 0.4, the main channel is in the northern half-side of river. After the low flow year the thalweg index is more than 0.7, the main channel is in the southern half-side of river. But the thalweg index is more than 0.7 that is similar to the one in the low flow year since the reclamation in the northern bank. It means the main channel is in the southern half-side of river since the time when the reclamation in the northern bank led to the form of curving river potential.

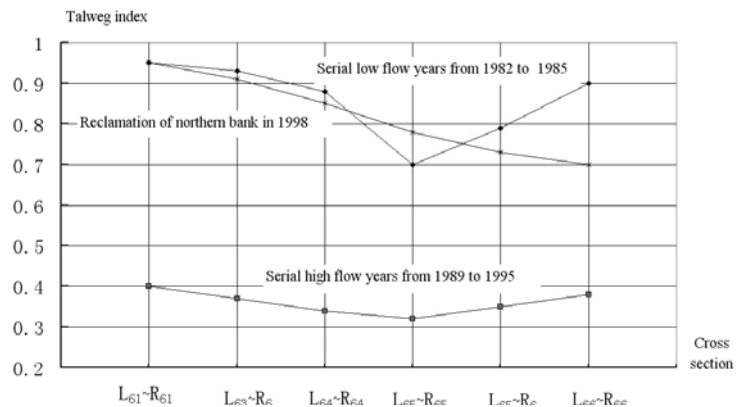


Fig. 1 The changes of thalweg index in each cross-section of Jianshan river reach.

5.2 THE ANALOGICAL ANALYSIS OF THE POSITION OF MAIN CHANNEL BEFORE AND AFTER THE RECLAMATION IN ZHESHAN BAY

Zheshan Bay is upstream Jianshan river reach. There are some similarities between the plane-shape of Zheshan bay and that of Jianshan bay, see Fig.2. Both of them are on the right of bank, the discrepancy of expanding rate of river width is little, the sediment concentration

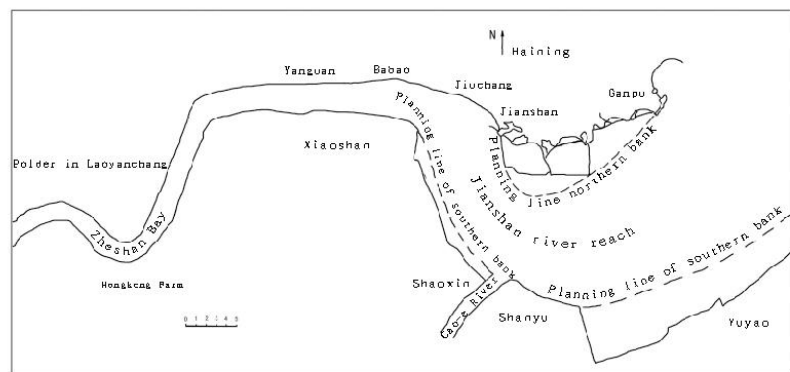


Fig. 2 The plan position of Zheshan bay and Jianshan river reach

is high and flood current goes south, ebb current goes south with a transition section between flood current and ebb current.

The reclamation in northern bank was begun in 1971, with jutting 1.95km to south. The main channel swung to south with a 1.47km average and the distance away from southern bank decreased about 1.5km after reclamation. The reclamation made the northern bank jut another 1km southward in 1977. That is to say it extended 2.9–3.0km more southward after the reclamation. Since then, the main channel around the bayhead is always near to the southern bank despite of the low flow year or the high flow year. (Table 2)

Table 2 The distance which the main channel is away from the northern bank in Zheshan bay unit: km

Time	River width	The average distance which the main channel is away from the northern bank				The average distance which the main channel is away from the southern bank			
		L23J-iuzhogkong	L23-R22	L25-R23	L25-R25	Jiuzhongkong	R22	R23	R25
1966-1970	4.74-.85	2.2	2.4	3	3.2	2.6	2.5	1.9	1.6
1971-1977	2.75-3.7	3.8	4.1	4.5	4.5	0.8	0.7	0.4	0.5
1978-1997	1.85-1.9	3.9	4.2	4.3	4.3	0.84	0.65	0.6	0.51

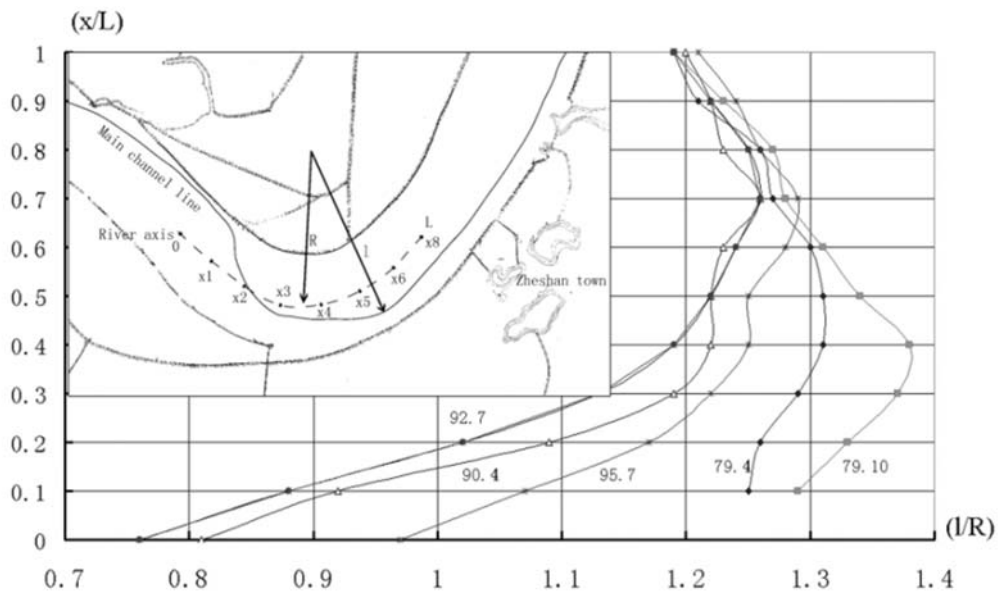


Fig. 3 $x/L \sim I/R$ of the main channel in Zheshan bay

Suppose the length of bend centerline is supposed to L , the start point of bend is 0, the distances which other points are away from the bend centerline are $x_1, x_2, x_3, \dots, x_i=L$, x_i/L is the relative position of each point in the bend. The radius of curvature is supposed to R , the distance which the curvature center of the bend is I , I/R is the relative position of the main channel. When I/R is equal to 1, it means that the main channel is in the mid-bend; when I/R is less than 1.0, it means that the main channel juts to the convex bank; when I/R is more than 1.0, it means that the main channel bulge to the concave bank; the larger I/R is, the nearer the main stream is to concave bank. Constructing the relation between X/R and I/R , both of which are dimensionless parameters, the relative position of the main channel can be defined in different places of the bend. In the low flow year or high flow year, the relation between the relative position of main channel and the relative position of each point in bend after regulation is shown in Fig.3. It tells that the main channel of bend, which is around the

bayhead is always in the south of bend centerline despite of the dry year or the high flow year. That is to say I/R is more than 1.0.

6. THE PREDICTION OF SILTATION BELOW THE TIDAL BARRAGE

6.1 THE PREDICTION OF SILTATION BELOW THE TIDAL BARRAGE IN NORMAL HYDROLOGIC YEAR

Serial high flow years or catastrophic flood hasn't happened since 1998 when the northern bank was reclaimed. The statistic length of beach face above the low flat line of 1998 is regarded as the siltation below the tidal barrage (Table 3).

Table 3 The length of flat face out of the mouth of Cao-e River since the reclamation of northern bank in Jianshan Unit:km

year	1998			1999			2000			2001			2002		
month	4	7	11	4	7	11	4	7	11	4	7	11	4	7	11
distance	2.8	2.7	3.0	1.5	1.8	2.6	2.3	2.5	2.5	2.0	1.5	1.5	1.5	1.7	1.6

The northern bank having been extrapolated 2.5km, the average distance which the low flat line was away from the shore was 7.75 in 1990s and now decreases to 1.5–3.0km. Once the northern bank has been further reclaimed (2.5km southward) to reach the planning line, it is possible for the distance which the low flat line is away from the southern shore to decrease 1.0–2.0km. So the length of silting flat is 1.0–2.0km in normal hydrologic year.

6.2 THE PREDICTION OF SILTATION BELOW THE TIDAL BARRAGE IN UNFAVORABLE HYDROLOGIC YEAR

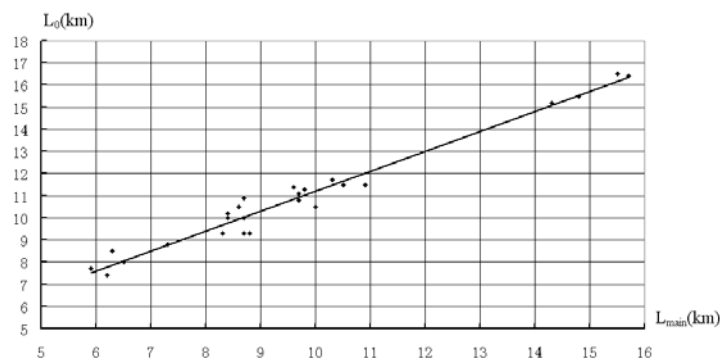


Fig. 4 Relation between L_0 and L_{main}

During serial high water years or catastrophic flood happening, there also exists some range of swing because the river width reaches 9km after the planning line being carried out. For example, when the flood of $14,000\text{m}^3/\text{s}$ happened in 1995 (It was the biggest flood in the 40 year after the Xi-an River Reservoir was built), the main channel swung 3.5km northward. Upon analyzing there is good relation between the distance that the low flat line in the southern bank is away from the northern bank and the one that the main channel is away from the northern bank, see Fig. 4. Based on the relationship, it can be calculated that the low flat line swung 3km northward. In the same hydrologic condition it is impossible for the range of

swing to be so large in the future, because the river channel is curved and the radius of curvature decreases.

The river shape of Jianshan river reach going south 、 north and the main channel swinging have to do with the hydrologic year or the low water、 the high water of the run off, based on topography in July, the relation of distance which main channel is away from northern bank and average discharge \bar{Q}_7 before July is constructed. The distance which main channel is away from shore is quite different before the reclamation and after

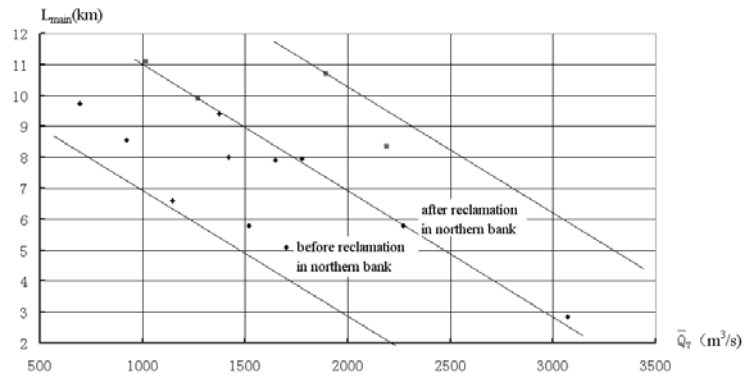


Fig. 5 Relation between Q_7 and L_{main}

the reclamation, so two regions was divided by using two envelope lines, see Fig.5. When \bar{Q}_7 is the same one, the range of swing of main channel is 3.8km before reclamation and 3.1km after reclamation. The average distance which main channel is away from northern bank is 6.7km and 9.6km after reclamation. From Fig.4, the range of swing of the low flat can be calculated to be 2.5km, width of flat face below the tidal barrage increasing.

In addition, according to Fig.3, the range of swing of the main channel in Jianshan river reach can be predicted after the planning line being carried out. The value of x/l at the mouth of Cao-e River is about 0.4 in the Jianshan river reach, then the range of swing of main channel is $\left(\frac{l_L - l_H}{R}\right) \times R$, where l_L/R is the relative position of which the main channel goes south after planning line being carried out. l_H/R is the relative position of the main channel after flood. $\left(\frac{l_L - l_H}{R}\right)$ can be gotten from Fig.3, and the radius of curvature after the planning being carried out in Jianshan river reach is known, so the rang of swing can be calculated to be 2.9km. The range of swing of low beach line is 2.5km from Fig.4.

Based on the two different ways mentioned above, it is predicted that in the unfavorable condition of high water year or catastrophic flood, the low flat out of mouth of Cao-e river will swing 2.5km northward after planning line being adjusted. So the length of beach face below the tidal barrage will extend from 1.0–2.km in normal hydrologic year to 3.5–4.5m.