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ANALYSIS ON MORPHOLOGY OF RIVER CHANNEL AND VARIATION OF DISCHARGING CAPACITY IN THE ESTUARINE REACH OF THE YELLOW RIVER

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Abstract: According to the measured data of incoming water-sediment and river sections in the estuarine reach below Lijin in the period of Qingshuigou path, the longitudinal and transverse variations of sections, bankful flow and water stage have been analyzed. On this basis, the flood discharging capacity and situation of flood control of the existing estuarine reach have been briefly studied. It is shown from the research results that the longitudinal and transverse variation of sections are related to incoming water-sediment, estuarine deposition and extension, and shifting of river course closely, and the bankful flow is changed with the variation of section morphology. The continuous small runoff and less sediment incoming from 1986 to 1996 and estuarine deposition and extension have made the sections shrink, the bankful flow reduce, the water stage under the same flow raise and the flood discharging capacity lower. The retrogressive erosion in the estuarine reach was once caused by the diversion of river branch of Qing-eight section in 1996. However it has been back-deposited gradually since 1998. At present because the bankful flow in the estuarine reach is comparative small and the harnessing project is not consummate yet, the situation of flood control cannot be optimistic.

Key words: Qingshuigou path, Bankful flow, The estuarine reach, Flood discharging capacity

1. CONDITION OF INCOMING WATER AND SEDIMENT

During 1976-2000 in Qingshuigou path, the mean amounts of incoming water-sediment for years are $221.61\times10^9 m^3$ and $5.790\times10^9 t$ respectively at Lijin station, are 49% and 51% of their mean value for years from 1950 to 1975; are 64.6% and 67.8% of mean amounts of water-sediment for years in the long series of 1950-2000. Since 1986 the amounts of incoming water-sediment in the estuary of the Yellow River have reduced obviously, the average annual amounts of incoming water-sediment are $154.27\times10^9 m^3$ and $3.57\times10^9 t$ respectively in 1990s, are 45% and 41.8% of mean amounts of water-sediment for years in the long series of 1950-2000, the sediment concentration is 23.2kg/ m^3 close to 25 kg/ m^3 of mean sediment concentration for years (1950-2000).

The annual distribution of water-sediment in the estuary of the Yellow River is not uniform. The incoming water and sediment are mainly concentrated on flood season every year, but also on several flood processes. The mean amounts of water-sediment in the flood period for years (1950-2000) account for that of 61% and 85% in the whole year.

The yearly variation of incoming water-sediment in the estuary of the Yellow River is great. The maximum annual runoff measured was $904\times10^9 m^3$ (1964), the maximum annual sediment amounts were $21.08\times10^9 t$ (1958), the minimum annual runoff was $18.6\times10^9 m^3$ (1997), the minimum annual sediment amounts were $0.164\times10^9 t$ (1997). The range of annual water into sea is 48.6 times, the range of annual sediment amounts into sea is 128.5 times. The ratio of maximum discharge to minimum discharge for years is infinitely great because of no flow in spring.

2. VARIATION OF SECTION MORPHOLOGY

2.1 VARIATION OF CHANNEL'S CROSS-SECTION MORPHOLOGY

According to the data of big section measured, the variation of main channel's morphology of typical sections in the estuarine reach since 1976-2001 is shown in Table 1 and Table 2.

Table 1 Statistics of variation in main channel area of several sections in the estuarine reach(m^2)

year	Linjin	Yihaoba	CS6	CS7	Qing 1	Qing 2	Qing 7
1976. 10	2682	1983	2357	2492	2437		
1979. 10	2117	1446	1855	1829	1592	2047	
1985. 10	3146	2210	3449	2109	3475	2263	1632
1996. 5	1345	1190	740	1235	1349	913	939
1996. 9	1596	1640	1343	1802	2544	1167	1388
2001. 10	1194	1436	871	2843	2179	998	1229

Table 2 Statistics of $\sqrt{B}$/H variation of several sections in the estuarine reach

year	Linjin	Yihaoba	CS6	CS7	Qing 1	Qing 2	Qing 7
1976. 10	4.98	7.29	10.88	8.56	18.84		
1979. 10	6.28	9.98	14.36	15.13	12.30	10.73	
1985. 10	4.30	6.69	7.99	6.17	8.82	11.81	11.56
1996. 5	10.9	12.3	5.19	12.52	15.06	9.56	14.04
1996. 9	8.46	7.25	4.72	8.17	8.30	6.99	9.43
2001. 10	6.70	8.13	5.52	16.90	11.59	8.18	16.10

It is seen from table 1 that the variation of main channel area in various periods is different, affected by incoming water- sediment and change of course (braid) mainly. During 1976-1979, the area of main channel below the bank in the reach decreased, it was because of good condition of incoming water-sediment in the estuary in 1976, while the path was changed with retrogressive erosion, leading to the area of main channel between Lijin and Xi- hekou be larger, then between 1977 and 1978 the water was less with much amounted sediment, the flood was smaller, the mean sediment concentration in the flood period was higher (above $50kg/m^3$), **(**Wang Kairong, Ru Yuying et al. 2001's Annual Consultant Report in the Estuary of the Yellow River. Yellow River Institute of Hydraulic Research, April, 2002) the deposition of main channel between Lijin and Xihekou occurred, its section area reduced, the $\sqrt{B}$/H enlarged (shown in Table 2), the main channel was wide and shallow; that was the stage of deposited plain into the channel below the point of course changed in Xihekou, up to 1979, the wide-shallow channel with 0.54m of the mean height difference of plain-channel was deposited on the original delta land surface. During 1979-1985, because of favorable condition of water and sediment, and a single channel was formed below the point of course changed, the whole reach below Lijin was scoured, the area of main channel increased by a wide margin, the $\sqrt{B}$/H decreased, the section morphology become narrow and deep. Before the flood period from 1985 to 1996, because of sustainable low flow and less sediment, the main channel was deposited and contracted seriously, the area of main channel reduced 42%-79% of margin, the $\sqrt{B}$/H of majority of sections enlarged, the section become relative wide and shallow. The braid changed in Qing-eight in June, 1996 met major flood in August precisely, the main channel was deepened by scouring, its area enlarged, the $\sqrt{B}$/H reduced, the section become relative narrow and deep. From then on, because of unfavorable condition of low flow and less sediment, the deposition and contraction occurred in the main channel again, the area reduced, the morphology was developed to be wide and shallow. The area of majority of sections and sectional morphology in Oct., 2001 was close to that before 1996's flood.

2.2 VARIATION OF LONGITUDINAL SECTION OF RIVER BED

The variation of erosion and deposition in the channel causes the corresponding regulation of longitudinal section certainly. The variation of longitudinal section is reflected on the slope variation. The common deposition along the distance and retrogressive erosion can make the slope of river bed become steep. Adversely, the deposition along the distance and retrogressive erosion can make the slope of river bed become gentle. Because of different width of main channel in each section of the lower Yellow River, the longitudinal section of river bed becomes into step shape, i.e. it is steep from the wide section to narrow one, it is gentle from the narrow section to wide one, it is seen from the long interval that the longitudinal slope of river bed in the estuarine reach also has a certain changeable law.

After the change of course of Qingshuigou path in May, 1976, the slope of river bed between Linjin and Xihekou was relative gentle, only $0.79^{0}/_{000}$ after the flood period of this year, then with the retrogressive erosion developed to the upper reaches step by step, the slope become steep gradually, but the range was not big (shown in Table 3). After the braid changed in Qing-eight in 1996, the slope between Linjin and Xihekou enlarged $1.09^{0}/_{000}$ on one occasion, up to 2001, the slope was regulated to $0.97^{0}/_{000}$, but it was bigger than $0.79^{0}/_{000}$ in initial period of change of course.

Table 3 Statistics of the longitudinal slope of channel in typical years in the estuarine reach ($^{0}/_{000}$)

year / section	1976	1979	1985	1988	1992	1996	2001
Lijin-Xihekou	0.79	0.81	0.84	0.88	0.89	1.09	0.97
Balow Xihekou	1.33	1.23	1.2	1	1.15	1.14	1.12

The regulation variation of riverbed slope in the tail reach below the point of course changed was relatively complicated and severe. The riverbed slope of course below Xihekou in initial period of course changed was bigger, $1.33^{0}/_{000}$, through the scouring by major flood of 5 years from 1981 to 1985, an amount of sediment was carried into the estuary, resulted in deposition and extension in the tail reach of estuary, the path into sea longer and the retrogressive deposition more serious, making the slope of reach below Xihekou become gentle gradually, after the flood period up to 1988 the slope was regulated to $1^{0}/_{000}$. Then with the sustainable low flow and unfavorable condition of incoming water-sediment, the deposition along the reach occurred, the riverbed slope become steep, again adding the effect of the braid changed in Qing-eight in 1996 and project enforcement of river dredging for dike strengthening in 1998, up to 2001, the riverbed slope was regulated to $1.12^{0}/_{000}$.

2.3 VARIATION OF TRANSVERSE SLOPE ON OVERFLOW LAND SURFACE

The variation of transverse slope on overflow land surface from 1976 to 2001 between lijin and Xihekou reaches was not big. The tail reach below the point of course changed from 1976 to 1979 was the stage of channel by deposition, the transverse slope on overflow land surface in Qing-one enlarged, but the deposition ratio on transverse in Qing-two and Qing-three sections was uniform, the variation of slope was not great. Through scoured by major flood from 1980 to 1985, the main channel was deepened by scouring and widened, the variation of transverse slope on overflow land surface was not big, the amounts of incoming water-sediment from 1986 to 2001 were little, the flood was not up to overflow land, the variation of slope on overflow land surface was not obvious. Up to 2001 the right bank of Qing-one and Qing-two section was near the project, the transverse slope of the left bank was about $4.0^{0}/_{000}$

and $2.0^0/_{000}$; the slope in the left bank of Qing-three section was gentle, but the slope in the right bank was steep, about $1.9^0/_{000}$ and $9.0^0/_{000}$; the slope of the left-right banks of Qing-four section was basically same, about $3.5^0/_{000}$; the transverse slope in the left bank of Qing-six and Qing-seven sections was steeper than that in the right bank, respectively the slope in the left bank was $4.5^0/_{000}$ and $9.0^0/_{000}$, the slope in the right bank was $3.0^0/_{000}$ and $7.0^0/_{000}$.

3. VARIATION OF BANK HIGH FLOW

The compound cross section was much assumed in the estuarine reach of the Yellow River, the main channel in the flood period was a main passage of discharging flood, therefore the variation of bank high flow affected the variation of flood carrying capacity in the river course to a relative extent, shown in Table 4.

Table 4 Statistics of bank high flow in typical years in the estuarine reach (m^3/s)

year / section	1976	1979	1983	1985	1988	1992	1996	2000	2001
Lijin	6800	4400	5000	6800	4200	3200	3500	3400	3400
Shibagongli		2800	4000	5000	3500	3000	3200	3000	3000

Remarks: The Shibagongli section is changed as Xihekou section after 1992.

It can be seen obviously from the above Table that the variation of bank high flow was identical with one of the main channel's area, the channel constricted from 1976 to 1979, the area of main channel reduced, the bank high flow also reduced; after scoured by major flood from 1980 to 1985, the channel was scoured deeply and widely, the area of main channel enlarged, the flood carrying capacity also enlarged; before the flood period from 1986 to 1996, the bank high flow decreased continuously, it increased in the flood period of 1996 slightly, afterwards it decreased. The flood carrying capacity of main channel in 2001 reduced timely in comparison with 1985.

4. STAGE FLUCTUATION

It can be seen from Fig. 1 and Table 4 that the stage fluctuation with $3000m^3/s$ was identical with one of bank high flow, during the interval of main channel's scouring, the bank high flow enlarged, the stage lowered, otherwise, it was reverse. The stage in Lijin, Yihaoba and Xihekou in 2001 raised 1.14m, 0.78m and 1.26m respectively in comparison with 1976.

5. ANALYSIS ON FLOOD CARRYING CAPACITY IN EXISTENT COURSE

The flood carrying capacity of river course shows the size of discharge under some stage, which directly affected the relationship between stage and discharge. This relationship can both affect the flood carrying capacity of section and be taken as the basis of predicting the situation of flood control. The inlet's hydrological station in the estuarine reach is Lijin Station, where a series of observed data is long, with four gauging stations of Yihaoba, Xihekou, Shibagongli and Dingzilukou successively, the observation time in Yihaoba and Xihekou started after 1958 and 1976 respectively, without stopping up to now. But in Shibagongli and Dingzilukou stations there is no observed data recently. In recent years there is no major flood occurred in the estuarine reach, in view of above conditions, the stage-discharge relationship in Lijin section before the flood period of 2002 has been analyzed deeply with hydraulic factor method, major flood analytical method in history and rising difference method respectively. For both Yihaoba and Xihekou sections, limited by the data, the stage-discharge relationship is analyzed and calculated by the stage relative method mainly, shown in Table 5.

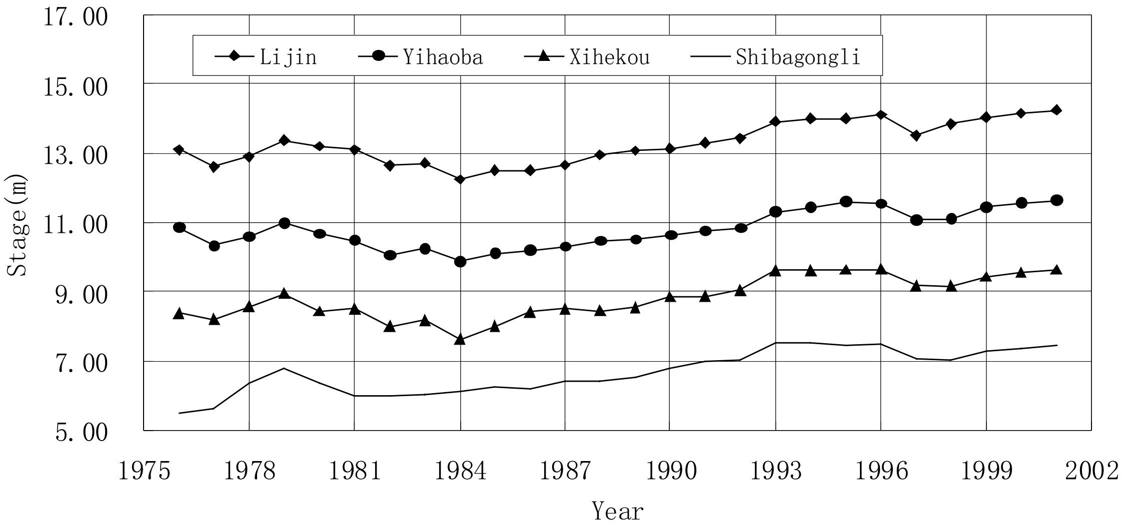

Fig. 1 Stage fluctuation with 3000 m^3/s

Table 5 Stage-discharge relationship in the estuarine reach in 2002 (calculated)

Discharge (m^3/s)	Stage in Lijin (m)	Stage in Yihaoba (m)	Stage in Xihekou (m)		
			Stage relative method	Slope borrowed method	Slope corrected method
3000	14.28	11.70	9.80	9.58	9.74
5000	15.18	12.41	10.36	10.14	10.30
7000	15.91	12.99	10.82	10.60	10.76
10000	16.91	13.79	11.45	11.23	11.39
11000	17.22	14.03	11.64	11.42	11.58

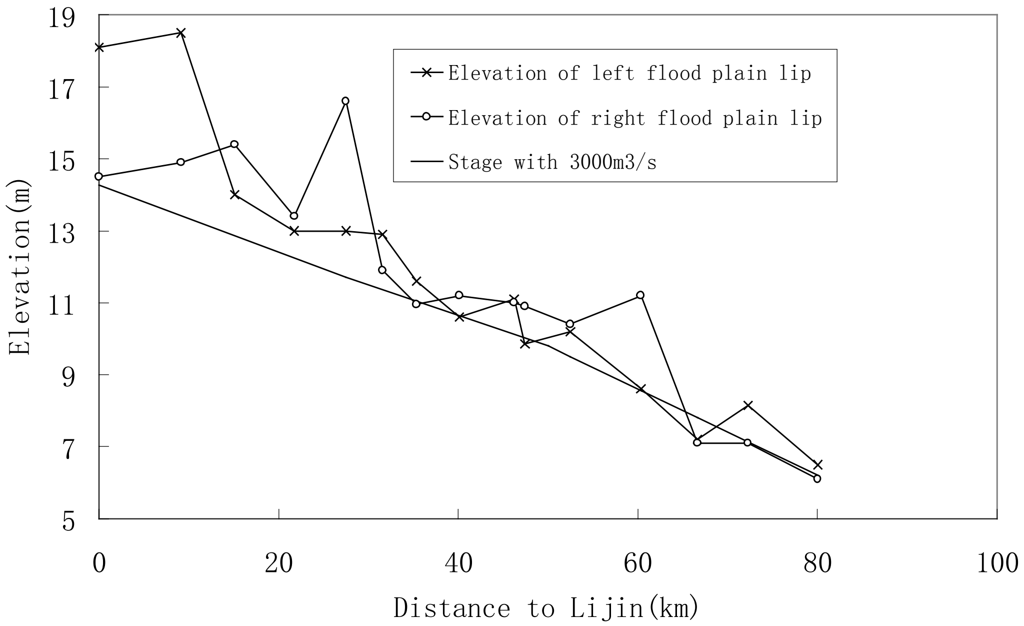

Fig. 2 Variation along the distance between flood plain elevation and stage with 3000m^3/s

6. BRIEF ANALYSIS ON FLOOD CONTROL SITUSTION

The variation along the distance between stage with 3000m^3/s and elevation of flood plain lip in each section (big section in Oct., 2001) can be seen from Fig. 2. The bank high flow between Lijin and Zhujiawuzi was above 3000 m^3/s, about 3200-3400 m^3/s, the bank high flow below Zhujiawuzi was about 3000 m^3/s, it was smaller in Qing-three section, about 2700

m^3/s estimated. The difficult point of flood control not only lies in the elevation of dike and bam but also their problems appear on a weak link of project, such as breach and leakage etc, the existent problems(FENG Zihuan, ZHANG Tongde et al, 2001) of flood control in the estuarine region at present; the transverse slope of flood plain is large, with danger in flooding of training dike and scouring dike directly by flood; the size of elevation and section in dike works is not enough; the length of vulnerable spot engineering is not enough, if the flood was overflowed, the flow regime should be difficult to control, leading to the flooding of training dike easily; the quantity of training works are few, the length of single works is not enough; the elevation of a part of buttresses is lower, the capacity of flow regime controlled is poor; the slope of root stone is steep with poor stability. Therefore the situation of flood control in the estuarine reach must never be off guard.

7. CONCLUDING REMARKS

Through the analysis mentioned above, several recognitions have been obtained as follows:

The variation of section morphology is mainly affected on the condition of incoming water-sediment and change of course (braid).

Since 1985, the deposition of main channel is seriously contracted, up to 2001 the reduced range of main channel's area is 35%−75% (above Qing-three).

The transverse slope of flood plain's surface in the tail reach below the point of course changed is larger.

The reach's bank high flow decreases, the stage with same discharge increases, the bank high flow at present is about 3000 m^3/s. We cannot be optimistic about the situation of flood control in the estuarine reach.

REFERENCES

FENG Zihuan, ZHANG Tongde et al. View on the Planning of Flood Control at River Mouth of the Yellow River. Journal of Yellow River, No. 10, 2001