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EVOLUTION FEATURES AND WAY OF THINKING FOR REGIME CONTROL AND REGULATION OF THE YANGTZE ESTUARY

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Abstract: The article summarizes the historic and recent evolution features of the Yangtze estuary. Recently, deposition accelerated and the water diversion ratio decreased gradually in the North Branch, while the water diversion ratio increased and the change in scouring and deposition becomes stronger in the river channel at local sections in the South Branch. Such evolution situation severely constrains the sustainable development of the riparian economy, so control of the river regime is vitally important. The basic principle for regime control is to strengthen the role of control of the nodes and bifurcate mouths to the river regime based on the evolution features of the estuary and the principal aspects of the influence factors to the channel evolution and determine different regime control objectives in the light of the difference of various river sections. The main way of thinking for regime control is to control the direction of primary current at the Xuliujing node and stabilize the Baimao Shoal to create favorable conditions for the river regime of the downstream channel and the North Branch; narrow the middle and lower North Branch, reduce the tidal flow, adjust the power ratio of river flow and tidal current, and alleviate the backflow of water, and sediment to the South Branch; and harness the Three Shoals and stabilize the river regime to provide favorable conditions for the riparian infrastructures and the deep water navigation course of the North Pass of the South Sub-branch.

Key words: Yangtze estuary, Evolution feature, Regime control, Basic principle, Way of thinking

1. INTRODUCTION

The estuary section of the Yangtze, starting from Xuliujing upstream to the No.50 light beacon at the mouth, about 181.8 km long, is the entrance of the Yangtze to the East China Sea. The section, having experienced long-term evolution, bifurcates in the shape of sector, with its width increasing from 5.7km at Xuliujing to 90km at the mouth, gradually forming the present overall setup of 3-step bifurcations and 4 entrances to the sea.

The Yangtze estuary is a medium ocean-continent bi-phase tidal estuary, both releasing the runoff and sediment load from upstream and taking in the tidal current and sediment from outside of the mouth, which is not only big in amount but also in amplitude of variation in a year and over years, with strong power action and significant influence of typhoon tide. In addition, the estuary region, crossing both Jiangsu Province and Shanghai Municipality, is one of the regions most developed in economy, culture and science where human activities are quite frequent in fighting natural disasters and developing and utilizing mud flats and shorelines, water and soil resources, navigation resources, etc. Impacted by various factors, the river courses and mudflat channels are changing in scouring and sedimentation, the main current swings and the regime changes in a complex way at the estuary, resulting in shallower navigable course by sedimentation at the South Sub-branch and the North Sub-branch downstream of the South Branch of the estuary, unstable mud flat and channel of the approaching navigable course of the South Channel and the North Channel to the sea, and continuously contracting navigable course of the New Baoshan, which endangers the normal

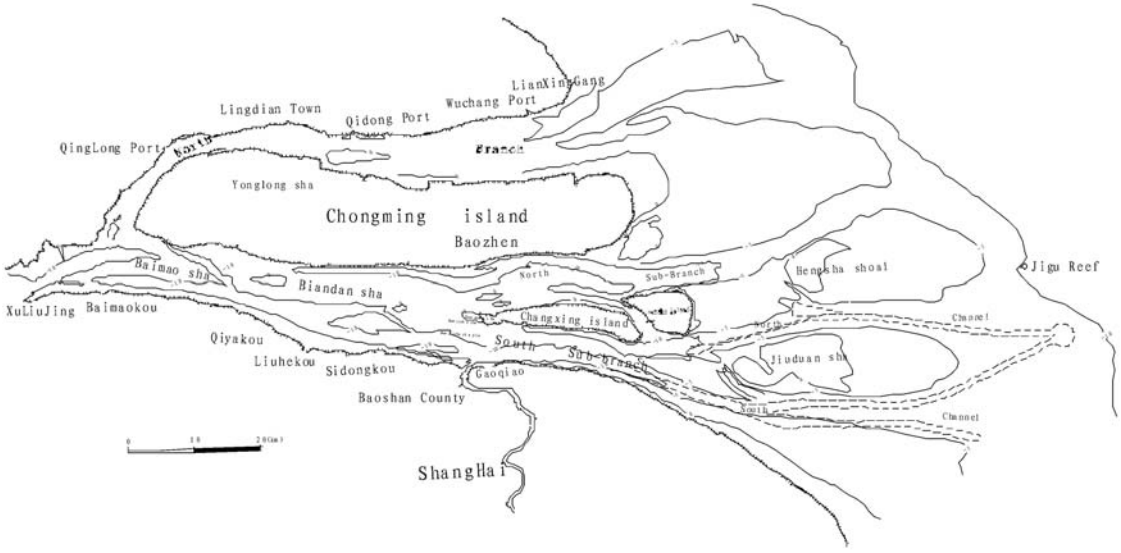
operation of riparian infrastructures including Baoshan Steel Works, Shidongkou Power Plant, riparian harbors and ports and diversion and drainage facilities and even the deepwater navigable course and de-functions the North Branch of the estuary in terms of navigation with salty tide moving upwards and water, sediment and salt backflowing to the South Branch, influencing the regime stability and utilization of freshwater resources of the South Branch. The evolution situation of the estuary severely restrains the regional advantages and the utilization of the potential resources and limits the sustainability of the riparian economy. The integral regulation for the Yangtze estuary is underway on an all-out basis at present and the regime control is one of the major components. The article intends to discuss the way of thinking for the regime control and regulation works at the estuary on the basis of the evolution features of the river course.

2. EVOLUTION FEATURES AT THE ESTUARY

The historic evolution of the Yangtze estuary has experienced significant changes in location and shape since historic records. To date back to 6000-7000 years ago, the estuary moved downwards continuously around Yangzhou and Zhenjiang. In 7th century, sands came out of water to form an island at Chongming to bifurcate the Yangtze into the South Branch and the North Branch at the estuary. The main current of the Yangtze went through the North Branch during 13-17th centuries and changed to the South Branch in early 18th century while the North Branch started to shrink. From the mid 19th century to the mid 20th century, the setup of the South Sub-branch and the North Sub-branch and the South Channel and the North Channel formed in succession. In general, the historic evolution at the estuary is characterized by main current moving southwards, sand bars integrating into the banks, river channels contracting, and river mouth extending outwards.

The recent evolution features at the estuary are as the follows: The flow diversion ratio of the North Branch decreases gradually and the action of the rising tidal current becomes stronger; The flow velocity and passage of rising and falling tides varies significantly in most sections and the submerged sands and central bars in the river channel are prone to developing and silting with unbalanced scouring and sedimentation; The tide confluence of the South Branch and the North Branch moves upwards. Sedimentation is severe in the river courses near the confluence zone of the upper section of the North Branch and the scouring increases slightly in the middle and lower North Branch in recent years but the channel tends to shrink slowly in general. The flow diversion ratio of the South Branch increases and the scouring and sedimentation changes strongly; The old and new shoales of the Baimao Sands at the upper South Branch are scoured and silted alternately and the south and north courses of the Baimao Sands are scoured deeper, while the so called 3 Sands, say, Biandan Sands, Liuhe Sands and the Central Sands at the lower section of the South Branch are not stable in movement and scouring and sedimentation; The diversion mouth of the South Sub-branch and the North Sub-branch moves upwards and downwards by a big margin and the diversion ratio changes alternately by about 50%; The flow diversion ratio of the South Channel and the North Channel of the South Sub-branch developed alternately before 1984 and was slightly adjusted after 1984. In the decade after 1992, the north course of the Baimao Sands at the upper South Branch tends to silt, while the south course develops slightly; The right edge of the Biandan Sands is in a state of scouring in general, with scouring above and sedimentation below the Nanmen port; The Liuhe Sands, through repeated combination and separation, becomes the New Liuhe Sands and the Sandpile, between which a gully is formed and develops and becomes the main passage to the South Sub-branch; The central sand head moves slightly downwards and the south sand head passage shrank continuously during 1992-2001 and was again scoured during 2001-2002; The Xinqiao passage to the North Sub-branch, after rapid development during 1992-1998, was relatively stable from 1998 to 2001 and

slightly shrank after 2001. The diversion point of the South Sub-branch and the North Sub-branch moves continuously downwards. The regulation works for the deepwater navigation course to the sea was implemented for the North Channel of the South Sub-branch in 1998, where the phase I works had implemented the south and north guide dykes, totally 57.9km long, 10 groins, 4.81km diversion mouth works, 42.5km dredging works (8.5m water depth), which was completed in June 2001. The phase II navigation course regulation works is now under progress.



Schematic map of the river regime at the Yangtze estuary

3. REGIME CONTROL GUIDELINE AND ENGINEERING PRINCIPLE

The guideline of regime control at the estuary is based on the new way of thinking of water control and the strategic requirements of the sustainable and concerted social, economic and environmental development, fully taking into account of the latest development needs of the social and economic sectors and in close conjunction with the stability of navigation course, development and utilization of water and soil resources, and requirements for flood (tide) control, riparian economic facility operation, ecological construction and environmental protection. It aims to control the river regime at key locations of the Yangtze estuary to provide solid foundation for the formation of advantageous regime and functioning of the integral regulation at the estuary. The principle of "guiding actions according to circumstances, overall planning, all-round consideration, long-term and near-term combination, and controlling both the principal and the secondary" is implemented and the concerted development of population, resources, environment and social economy carried out for the regime control.

Based on the above guideline and basic principle for river regime control and in the light of the evolution features at the estuary, the estuary regime control works should focus on the following:

a. The objectives of regime control differ for the South Branch and the North Branch. At present, the power of rising tide prevails in the North Branch, where the rising tide is big in amount with much sediment carried from outside of the mouth which is easy to silt and backflows the South Branch. The south side of the North Branch (north edge of Chongming Island) silts rapidly, so it is preferably for the North Branch mainly to control and adjust the distribution relation between the taken-in tide and the runoff, reduce the amount of coming sediment and sedimentation, improve the situation of backflow of water, sediment and salt to the South Branch and satisfy the development and utilization of water and soil resources. For

the wide South Branch where there are numerous submerged sands and the scouring and sedimentation of sands and mud flat changes frequently, it is preferably to control the swinging of the main channel, the movement of submerged sands, and the diversion ratio of bifurcations and satisfy the infrastructure construction such as navigation course, harbors and ports.

b. The regime control works at the estuary should base itself on the historic evolution rule of "main current moving southwards, sand bars integrating into the banks, river channel contracting, and river mouth extending outwards" at the estuary and should be implemented phase by phase at proper time in conjunction with the recent evolution features and comprehensively taking into account of various needs. It is not desirable to over-accelerate or retard the natural evolution process of the estuary. At present, the Yangtze estuary has bifurcations of three steps. The bifurcate channels south of Chongming Island have strong power of runoff and tidal current, with big space of evolution and development, while the rising tidal current prevails at present in the North Branch north of the Island, in a state of shrinkage with a diversion ratio less than 3%. It is seen from the situation at the front edge of the submerged delta of the estuary that there is a submerged valley for years outside of the estuary, extending NW-SE to the estuary. The top end of the valley extends till the outside side of the east beach of Chongming Island, directing to the Lianxing port and the North Branch; while from the tide current system of the ocean in vicinity of the estuary, the shore-side current of the Chinese Yellow Sea prevails downwards in the SE direction along the Northern Jiangsu shoreline in the north outside of the Yangtze mouth and the strong Taiwan warm current and its diffusion dominates upwards in the SE along the submerged valley, which directs to the North Branch, therefore, it is seen from the present situation that the entrance of the North Branch to the sea still has quite strong power of tidal current and fairly favorable boundary conditions, so the natural declination of the North Branch would be a long process. In addition, in view of the requirements for the ecology, navigation and the local river systems, the Yangtze estuary should still be remained in the general setup of four entrances to the sea for a long period of time recently.

c. The regime control works at the estuary should base itself on the principal aspects of the influence factors to the river channel evolution. The control role of the nodal points and bifurcation mouths to the river regime should be enhanced to form an integral regime control. The Yangtze has bifurcations of three steps, say, the South Branch and the North Branch, the South Sub-branch and the North Sub-branch and the South Channel and the North Channel. At present, the South Branch and the North Branch and the South Sub-branch and the North Sub-branch are still in a natural state except the South Channel and the North Channel where the diversion control works had been implemented at the entrances to the sea in the phase I works of the deepwater navigation course regulation. This natural state exists numerous unstable factors of river regime, therefore, the regime control at the mouths of these bifurcations will become the issue of attention.

4. WAY OF THINKING FOR REGIME CONTROL

The way of thinking for regime control is concluded based on the recent evolution of river channel and the above regulation principles as the following:

a. Stabilize the regime of the Chengdong section upstream, control the guiding direction of main current at the Xuliujing node and stabilize the Baimao shoal to facilitate the even diversion of the river channels south and north of Baimao Sands so as to create favorable conditions for the river regime of the downstream and the North Branch.

The change of regime in the Chengdong section influences the direction of the Yangtze main current entering the estuary section and the role of diversion of the Xuliujing node, therefore, stabilization of its regime is the foundation of the estuary regulation works.

The Xuliujing node section is an artificially contracted section above the mouths of the South Branch and the North Branch of the Yangtze estuary. The river was 13km wide at this section before 1950s and was narrowed to 5.7m because of the successive enclosing reclamation of sand bars during 1958-1972, forming an artificial node. The formation of the node mitigated the influence of the upstream regime change to the downstream sections on one hand and impelled the continued deterioration of inflow conditions and decreasing of the runoff of the North Branch on the other hand. The diversion ratio decreased from 7.6% in 1958 to below 5% in recent decade. So the North Branch presents a tendency of shrinkage by sedimentation. In view of the dynamic condition of flow of this section and the present evolution situation and the overall regulation goal of the North Branch, the contracted section at Xuliujing is preferable to basically keep unchanged in the present state of shoreline rather than to further contract the shoreline, and, if necessary, it is preferable to take proper control and guiding works based on the change condition of the water course of the Langshan Sands upstream and the regulation goals of the water courses of the Baimao Sands and the North Branch.

The lower end of the Xuliujing contracted section is close to the bifurcate section of the Baimao Sands in the upper South Branch and its north course is closely connected with the inlet of the North Branch. Influenced by the difference of Yangtze flow and tide current, the swinging at the tail of Xuliujing deep channel, the change at the mouth of the North Branch and the flow features of its own bifurcate sections, the south course of Baimao Sands has been dominating in most years in recent four decades, while the north course experienced the evolution process of shrinkage, development and slow shrinkage and the scouring and sedimentation of the shoal of the Baimao Sands changed over years with the head moving downwards due to scouring. The change of the river regime of this section plays a key role in the regime change at the lower South Branch downstream, at the diversion mouth of the South Sub-branch and the North Sub-branch and even in the whole mouth section of the South Branch, which caused the movement and change of scouring and sedimentation of various submerged sands in the South Branch on one hand and resulted in movement of the diversion mouth of the South Sub-branch and the North Sub-branch upwards and downwards, frequent change of bars and mud flats and un-stability of navigation course on the other hand. After 1990s, the power of the south course of the Baimao Sands became slightly stronger and the main current increased inclining northward after getting out of the Qiyakou, while the New Baoshan passage of the lower South Branch to the South Sub-branch shrank gradually, unfavorable for the stability of navigation course and utilization of shoreline and directly endangering the safety of riparian economic facilities. Therefore, the regulation that will stabilize the shoal of the Baimao Sands and the rational diversion ratio of the south and north courses should be urgently implemented in combination with the regulation requirements for the North Branch so as to form the river regime that is favorable to the South Branch and stabilizes the navigation course and, at the same time, it is preferable to meet the regulation requirements for the North Branch as much as possible.

b. Narrow the middle and lower North Branch, reduce the taken-in tide, adjust the power ratio of river flow and tidal current, and alleviate the backflow of water, sand and salt to the South Branch.

After the main current of the Yangtze changed to the South Branch at the estuary in early 18th century, the discharging capacity of the North Branch decreased gradually and sand bars were silted and rose rapidly and gradually accreted as islands which, under the action of artificial measures, were gradually integrated into the bank. The diversion ratio of the North Branch was about 25% of the total amount of the Yangtze in 1915, so it still has the function of diversion to a certain extent. Afterwards, influenced by the swinging of the main current of the lower Chengtong section upstream, the main current of estuary, after getting out of

Xuliujing, inclined to the south bank, remaining the inflow conditions of the North Branch deteriorating gradually, the cross-section of riverbed reducing, the deep channel silting and rising and the discharging capacity decreasing. The diversion ratio of the North Branch was reduced to 7.6% by 1958. In nearly 50 years after 1958, the river channel shrank from 13km to 5.7km near Xuliujing due to large-area enclosing reclamation at Tonghai Sands and near Jiangxin Sands upstream of Xuliujing, which gradually became a narrow artificial node, thus mitigating the influence of the change of the main current upstream to the inlet section of the South Branch and the North Branch. In 1970, the north course of Jiangxin Sands at the Xuliujing node on the north bank was blocked, causing inferior inflow to the North Branch, as a result, the diversion ratio was kept below 5% after 1975, the action of the rising tidal current became stronger, the backflow of water, sand and salt of the North Branch to the South Branch was conspicuous, and the sedimentation was severe, particularly in the upper North Branch. The sand bars and sands caused by separation of flow routes of rising and falling tides developed and, with influence by various factors including human activities, the Yujiao Sands, Yongnong Sands and Xingnong Sands in the North Branch were accreted and integrated into the bank in succession. During the accretion, the upper and middle North Branch silted rapidly and the river channel was contracted to a certain extent, while the lower section was rather slow and the rate of shrinkage of the channel increased to a certain extent from upstream to downstream and the channel presented a tendency of slow shrinkage.

The above evolution features demonstrate that the power of rising tide, relatively speaking, increased recently in the North Branch and the river course transformed to rising tide channel. The channel of the North Branch presented a tendency of accretion and shrinkage, but the action of tidal current from outside of the exit was still quite strong, i.e., the main power factor of evolution was still quite strong, therefore, the declination of the North Branch would still be a long process and the blockage of the North Branch might get half the results with twice the effort. According to the guideline and basic principle of current regulation works and the features of evolution, the regulation of the North Branch should preferably start with the two ends, that is, entrance and exit, and emphasis should be put on the exit section, which is decided by the present features of power and evolution of the North Branch. To be specific, measures should be taken to contract the entrance section of the tidal current at the middle and lower North Branch to reduce the tide current entering the North Branch so as to fundamentally decrease the tidal power in the North Branch and measures taken at the runoff entrance section of the North Branch (the bifurcate mouth of the North Branch) to increase the runoff and adjust the ratio of runoff and tidal power of the channel, thus gradually mitigating and resolving the backflow issue of the North Branch to the South Branch. At the same time, the needs of beach development and utilization should be properly taken into account.

c. Harness the Three Sands, stabilize the river regime, increase and stabilize the diversion of the South Sub-branch so as to provide favorable conditions for the riparian infrastructures and the deepwater navigation course north of the South Sub-branch.

The river channel becomes wider gradually, the flow diffuses and the submerged sands are numerous from below Qiyakou to the lower South Branch at Wusongkou, where distributed mainly the Biandan Sands, Liuhe Sands and Central Sands (called Three Sands). These sands, influenced by the main current swinging caused by the change of current power upstream, the difference of tidal current downstream of the mouth, and the change of resistance of the river channel geography, have a big change of scouring and sedimentation and the regime is in a state of turbulence in the lower South Branch. For the scouring and sedimentation and movement of these sands, the mouth of the South Sub-branch was blocked in 1950s, which increased the diversion of the North Sub-branch and for some time caused the change of location of the diversion mouth of the North Sub-branch and the contraction and effective operation of the south navigation course. In recent decade, the passage to the North Sub-

branch is the Xinqiao course north of the Central Sands which has been relatively stable since 1998. The Nanshatou course between the southeast side of the Central Sands and the New Liuhe Sands has been continuously shrinking in the recent decade, while the passage between the New Liuhe Sands and the Sandpile has been developing continuously and become the main passage to the South Sub-branch.

The above evolution features demonstrate that the lower section of the South Branch has been relatively stable in general in the recent decade. However, the scouring and sedimentation and movement of local riverside mud flats and submerged sands are still strenuous and frequent and the disorder and unstable elements of the river regime still exist, which is not only related to the regime change of the Baimao Sands section upstream but also closely related to its own channel geography, boundary conditions and the fine bottom sand which is easy to scour. Therefore, for control of regime of the lower South Branch in terms of the channel proper, it is preferable to stabilize the submerged sands, particularly the Three Sands, to form the boundary that will constrain the flow to a certain extent so as to allow the flow going through the channel, and, at the same time, stabilize the flow tendency of the main current entering the lower South Branch and the main channel of the lower South Branch in conjunction with the regulation of the Baimao Sands upstream and basically stabilize the passage locations of the South Sub-branch and the North Sub-branch. In addition, in view of the lower South Branch and the north course of the South Sub-branch which are the key sections connecting the Yangtze shipping and the ocean shipping as well as the numerous key state-owned enterprises on the south bank and the needs for stability of the ocean-going deepwater navigation course north of the South Sub-branch, it is preferable to increase the diversion ratio of the South Sub-branch, which depends on the self resistance of the channel of the South Sub-branch on one hand and is related with the diversion control action of the diversion mouth on the other hand, therefore, in the harnessing of the Three Sands, the regulation for the Biandan Sands emphasizes the diversion, while for the Central Sands and Liuhe Sands emphasis is put on facilitating the flow division of the South Sub-branch. Only integration of the two can come out good results.

5. CONCLUSIONS

The regime control of the Yangtze estuary is a complex, huge and systematic dynamic works, involving various issues and being influenced by numerous factors as well. During the regime control, we should base ourselves on the evolution features of the river channel at the estuary and persist in the concerted development of population, resources, environment and social economy. The river regime control works will play an active role of promotion in the integral regulation of the Yangtze estuary on the basis of strengthening observation, research and scientific management.

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