CHAPTER 224

INVESTIGATION ON IMPROVEMENT OF YANGTZE ESTUARY

Yen Kai & Yan Yixin

Abstract

The improvement of the Yangtze Estuary has attracted much attention in China. The fluvial processes of the estuary are rather complicated. The frequent move of sandbanks in the estuarine channels and the bar forming at the mouth give much trouble to navigation.

Investigation on the guiding principles and schemes for the improvement of the Estuary has been carried out since 1958. Comprehensive field survey, laboratory experiments and numerical modeling as well as planning work have been done in the past 30 years with some preliminary achievement. A scale model study with horizontal scale 1:1600 and vertical scale 1:120 was conducted by the Nanjing Hydraulic Research Institute.

Introduction

The Yangtze River is the largest river in China, with a total length of 6300 km and a catchment basin of 1,800,000 km^2. The 145 km stretch from Xuliujing to the sea forms the estuary. As a result of interaction of river flow and tidal current, the estuary is splitted into several channels. It is bifurcated by the Chongming Island into North and South Branches. The former undergoes serious accretion and the latter is now the main passage for runoff and navigation. The South Branch is further divided into North and South Waterways by Changxing and Hengsha Islands. Finally the South Waterway is again bifurcated into the North and South Channels(Fig.1).

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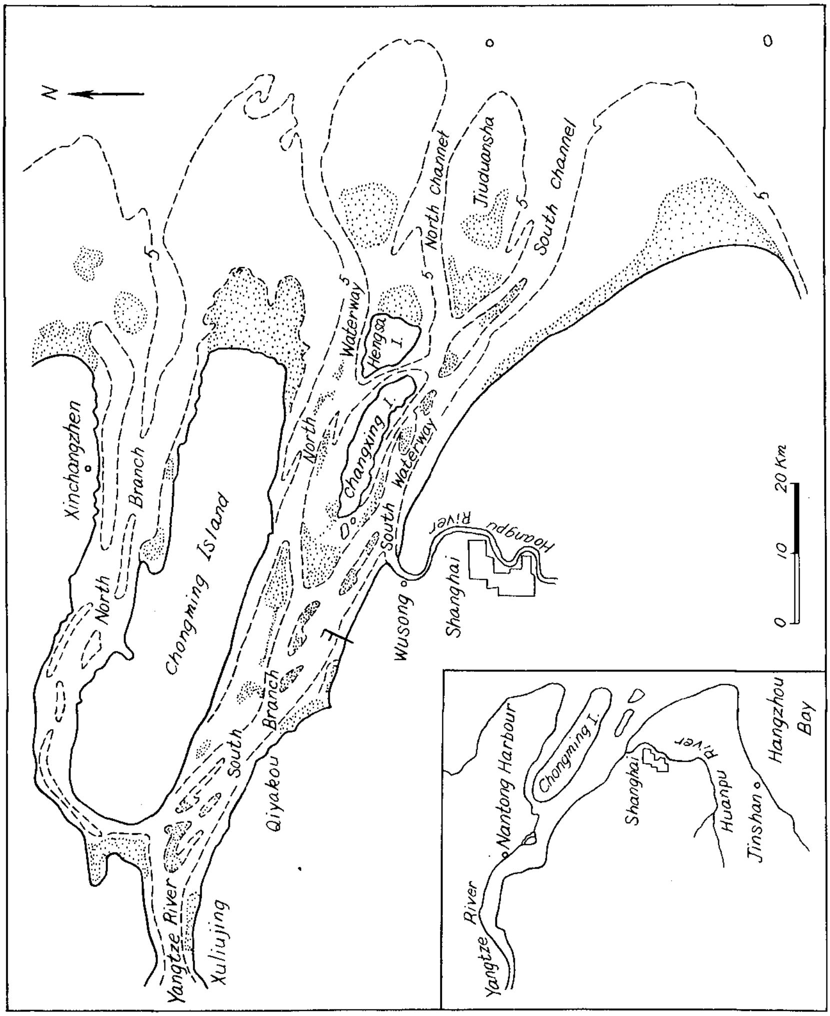

Fig.1 The Yangtze River Estuary

As the Yangtze Estuary, serving as a vital passage for foreign trade and the gateway of the largest port of China, Shanghai, has a great value in the development of China's national economy, its comprehensive improvement has attracted much attention in China.

Hydrological Features of the Estuary

Both the river runoff and the tidal flow play important role in moulding the estuary. The yearly mean total runoff amounts to 925 x $10^9 m^3$ with an average discharge of 29,300 m^3/s. The max. discharge is 92,600 m^3/s and the min. is 4620 m^3/s. The tide in the estuary is semidiurnal tide, with a mean tidal range at the mouth of 2.66 m, a max. of 4.62 m and a min. of 0.17 m. The intensity of tidal current varies with seasons, generally it is high in the flood season. For example, in the flood season, at the mouth of South Channel the average current velocities during flood and ebb tide are respectively 0.91 m/s and 1.13 m/s, the respective max. values are 1.64 m/s and 1.88 m/s. The tidal current could reach as far as 300 km from the mouth and the effect of tidal action could be felt at the Datung Station, some 640 km from the mouth in the low water season with strong tide.

The total silt load is on the average 486 x 10^6 t per year, with a mean silt concentration of 0.54 kg/m^3, being high in the flood season, attaining 1.00 kg/m^3, and low in dry season, amounting to 0.10 kg/m^3.

The salinity at the mouth of the estuary is on the average 16‰ . It varies with seasons, reaching 20% in dry season and 10‰ in flood season. The estuary belongs to the partly mixing type, but during the flood season with high river runoff it may be changed into a weak mixing type and in dry season into well mixed type.

Morphological Characteristics of the Estuary

The mouth of the Yangtze Estuary was located about 200 km inland of its present position some 3000 years ago and the land of Shanghai and Chongming Island were formed by the alluvial deposition during the last thousand years. Under the action of Coriolis force the ebb current is deflected to the right bank of the channel and the flood current to left. This gives rise to a divergence of ebb and flood currents in the channel, causing deposition of sediment in the slack water zone between the two currents paths. As the process of deposition goes on shoals are formed which in the course of time may be developed into islands, such as the Chongming Island and the Hengsha Island. Take the Chongming Island for example, it divides the estuary into two branches.

More or less influenced by the Coriolis force the main ebb current enters the South Branch and in the North Branch the flood current predominates. The flood current in the North Branch, being close to the north bank, causes bank erosion with consequent accretion at the south bank, i.e. the north waterfront of the Chongming Island. As to the South Branch, the erosion of the south bank has been long since checked by the construction of bank protection works, thus aggravated the erosion of the north bank, i.e. the south waterfront of the Chongming Island. There is, therefore, a tendency of gradual shifting of islands or sandbanks to the north in the Yangtze Estuary, which may eventually result in their attachment to the north bank.

As the South Branch is now the main passage for runoff and navigation, it has called much of our attention. One important featuer of the South Branch is the periodic shifting of the bifurcation point of the North and South Waterways, the range of shifting may attain 20 km or more. Such shifting has in turn influence on the fluvial processes of the two Waterways, causing frequent move of sandbanks in the channels. The cause of shifting is rather complicated. One important point is that, when the main current takes one of the Waterways, say the North Waterway, then more sediment, particularly the bed load, is also carried into this Waterway, causing accretion, reduction of channel capacity and increase in flow resistance. The main current is thereby obstructed and gradually turned into the South Waterway. In the meantime, due to the encroachment of the bifurcation point, it shifts gradually downstream, twisting the channel leading to the North Waterway, thus further increases its flow resistance and reduces its discharge capacity. When the flow in the South Waterway is increased to such an extent that its channel capacity is not sufficient to take over the increased ebb flow, a new channel leading to the North Waterway will eventually be cut through the sandbanks upstream of the bifurcation point, and a new bifurcation point is thus formed. The old bifurcation point is then gradually abandoned. A similar cycle of such change will occur when the main ebb flow turns from the South Waterway to the North Waterway. Nevertheless, a relative stable condition could occur when the ebb flow is approximately equally divided into the two Waterways.

As a partly mixing type, the Yangtze Estuary shows its typical salinity distribution as shown in Fig.2. It can be seen that there is a longitudinal salinity gradient which affects the ebb and flood currents and sediment movement. In the course of a tidal period

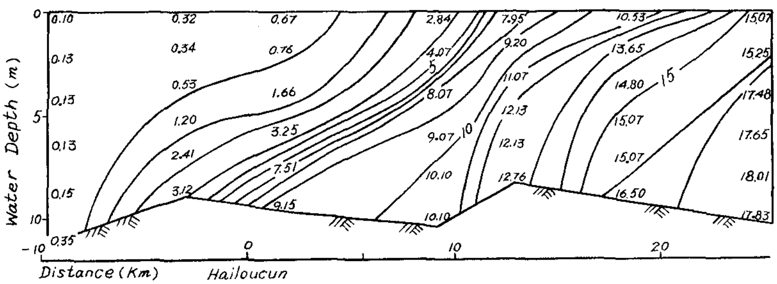

Fig.2 Salinity Distribution in South Channel
Dec. 23-24, 1963 Tidal Range 2.77 m
Discharge 15000 m³/s Salinity in ‰

when the ebb flow turns into the flood flow, we can find a stagnation point somewhere near the river bottom where the net velocity is zero. Around stagnation point there is a stagnation zone where deposition of sediment most likely to take place. The settling of suspended sediment here is further facilitated by the flocculation process caused by the mixing of river runoff with sea water. As a result bars are formed at the mouths of the North Waterway, the North Channel and the South Channel, which extend for a distance of 10 to 20 km or more.

As a rule, deposition on the bars takes place during the flood season and in the dry season the bars are subjected to erosion.

Guilding Principles and Schemes for the Improvement of the Estuary

The improvement of the Yangtze Estuary is chiefly aimed at navigation, with due consideration of the benefits of land reclamation, irrigation and drainage of the adjacent land, water supply, flood protection, tourism industry and environment protection. The South Branch, being the main waterway connecting the inland and ocean navigation, in its natural state is insufficient to answer the growing demand of water transportation. The length of the stretch of the South Branch from Xuliujing to Wusongkou, the confluence of Huangpu River to the Yangtze Estuary, is 69 km. As we know, most of the quays of the port of Shanghai are situated along the banks of the Huangpu River. The upper reach of this 69 km river stretch, from Xuliujing to Qiyakou, for a distance of 35 km is called Baimousa stretch, and lies between the two "nodal points". We take Xuliujing and Qiyakou as "nodal point" or sub-nodal point", because the channel here is relatively stable and is contracted to only about 5 km and 9 km in width respectively. The Baimousa stretch is splitted by the Baimou Sandbank into a north channel and a south channel, the latter is now the main navigation waterway having a water depth of 10 m except at the upper end, where auxiliary dredging is needed to increase the depth required for navigation.

The lower reach of the 69 km river stretch from Qiyakou to Wusongkou is 34 km long and is called Three-Bank stretch, because there are three sandbanks, viz. the Central Sandbank, the Biandan Sandbank and the Liuhe Sandbank in the estuary, which are very unstable. The width of Three-Bank stretch increases from 9 km at Qiyakou to 17 km at Wusongkou, which leads to the formation of shoals here and there in the estuary, among which the three sandbanks are the most prominent ones. The bifurcation point of North and South Waterway lies in this stretch, shifting up and downstream for a distance of ca. 20 km in a period of some 30 years, as mentioned before. The unstable channel condition and the shoals in the channel give much trouble to navigation, although a water depth of 10 m can be maintained for the most part of this river stretch.

Based on the results of investigation, the guiding principles and schemes for the improvement of the Yangtze Estuary may be summarized as follows:

1. Regulation of Upper Reach of South Branch

For the regulation of the upper reach of the South Branch, i.e. the Baimousa river stretch, it is important to protect the two "nodal points" at Xuliujing and Qiyakou. The Xuliujing "nodal point" has the function of stabilizing the direction of main current and refraining shoals upstream from moving downstream into this river stretch. The Qiyakou "sub-nodal point" exercises similar function to the lower reach of the South Branch, which is important for the creation of stable channels.

The existing north and south channels of the Baimousa river stretch will be maintained, but the direction of flow and the river discharges into these two channels have to be readjusted by the construction of regulation work in combination with land reclamation as shown in Fig.3.

2. Regulation of Lower Reach of South Branch

In order to maintain a stable deep channel in this river stretch it is necessary to contract the channel,stabilize the bifurcation point of the North and

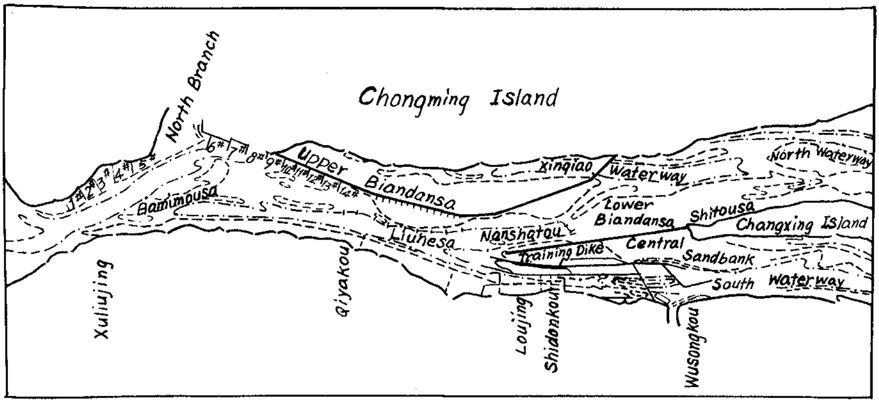

Fig.3 The South Branch of Yangtze Estuary

South Waterways and adjust the discharges into the two Waterways. After analysing the morphological changes in the past it is found that in 1971 when the bifurcation point was situated at a location about 10 km upstream of the Shitousa on the Central Sandbank the channel was relatively stable as shown in Fig.4. So this point may be taken as the project bifurcation point. At present the bifurcation point is several km upstream of the project point and is shifting downstream at a rate of 1 km per year. It is therefore advisable to stabilize the bifurcation point in time to avoid the difficulties incurred when it moves too far downstream.

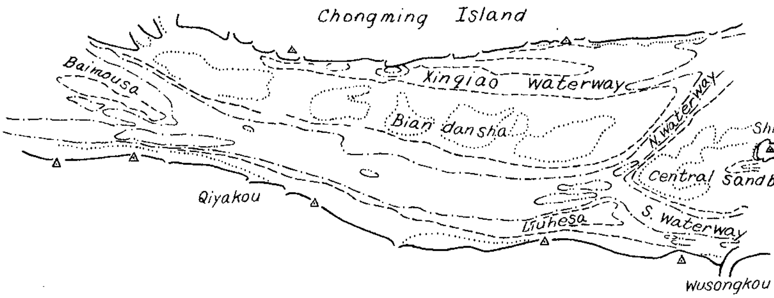

Fig.4 South Branch in 1971

Once the bifurcation point is stabilized, it is still necessary to take measure to control the flow condition so as to approximately equally divide the ebb discharge into the North and South Waterways. Such a discharge distribution is favorable to the maintenance of stable channel condition for both Waterways, each of which is important to navigation. Because the South Waterway is at present the main waterway for seagoing vessels and quite a few important enterprises are situated on its south bank, while the North Waterway is indispensable for the navigation of the Chongming Island and is also a prospective deep outlet channel to the sea.

The waterway channels should be contracted. Studies have been made for the layout and orientation of the channel regulation lines, beyond these lines land reclamation and construction works are prohibited. Some of the branch channel cutting through the sandbanks should be dammed up to reduce the random flow over them.

The stabilization of the Biandan Sandbank is of particular importance to the regulation of the lower reach. The regulation of the upper reach and the stabilization of the bifurcation point of the North and South Waterways are favourable to the stabilization of this sandbank. But due to the existence of the Xinqiao Waterway on the north side of the sandbank there is still random discharge over the latter, affecting its stability. Therefore training work has to be constructed on the south side of the sandbank to cut off the random discharge and to stabilze its south boundary.

The regulation work will be carried out in stages. As the first stage, the work for the stabilization of the bifurcation point should be built in the coming few years. Several schemes have been investigated, and the one comprising a training dike connecting Nanshatou to the Shitousa on the Central Sandbank has been selected (Fig.3). Besides stabilizing the bifurcation point at the project location, it has also the function of refraining the shoals upstream from moving into the river stretch Luojing-Shidonkou and confining the ebb flow into this river stretch, both are favorable to the maintenance of a stable and deep water channel. This is important because the Baoshan Iron and Steel Work, a key enterprise, as well as the prospective deep water berths of the Port of Shanghai are located on south bank of this river stretch. Moreover, the dike will check the flow over the sandbank and prevent the formation of new cut off channel, which would endanger the stabilization of the bifurcation point.

For preliminary study a scale model has been constructed in the Nanjing Hydraulic Research Institute.

Owing to the immense extent of the estuary, a highly distorted model was built with a horizontal scale 1:1600 and a vertical scale 1:120. The model has an overall length of 120 m and a maximum width of 32.6 m. The upper end of the model was connected to an arbitrary meandering channel stretch, 200 m long, representing the waterway upstream of the estuary. Two different tide generating devices, consisting of a tidal chamber and a tail water gate, are installed at the lower end (Fig.5). From the test results it can be seen that, with the construction

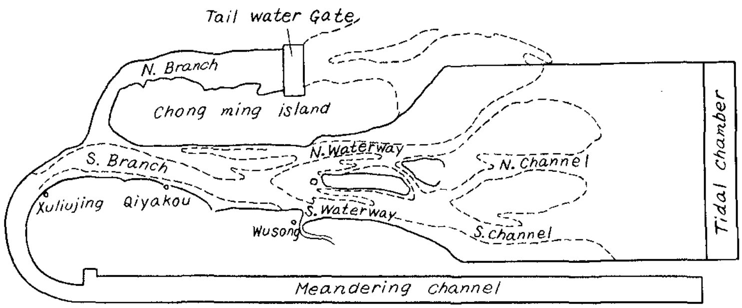

Fig.5 Model Layout of Yangtze Estuary

of the training dike,the ebb velocity flanking the south bank of the south channel is increased, which is favorable to the maintenance of deep water in front of the Baoshan Iron and Steel Work and the project new berths of Shanghai Port, while the current velocities at Qiyakou, Wusongkou and other places in the North and South Waterway are practically unchanged, showing the regulation work will not exercise notable influence on the flow regime upstream and downstream. This means that the training dike as the first stage of the work of regulation can well coordinate with the successive stages of regulation to be followed. The model was essentially a fixed bed model, but some tests were conducted with partly movable bed to observe the fluvial processes of the lower reach of the South Branch. Only fresh water tests were performed, the facilities and techniques for conducting experiments with salt water are now in preparation.

3. Improvement of Outlet Channels to the Sea

As mentioned before, bars are formed at the mouth of the North Waterway, the North Channel and the South Channel, the water depth over the bars is generally 6.0 - 6.5 m. After dredging a water depth of 7 m is now maintained over the bar of the North Channel. Vessels with draft of 9.5 m could enter the estuary by saving the tide.

In the near future it has been proposed to increase the depth to 7.5 m. In prospect, a deep outlet channel of 9.5 m is considered appropriate. Of the three possible outlets, the bar of the North Waterway is shortest and that of the South Channel is longest. To acquire a deep outlet channel dredging alone is impracticable. At present, the yearly maintenance dredging for a 7 m outlet channel is as high as $14 \times 10^6 m^3$, that of a 9.5 m channel would evidently many-fold of this. Training work has to be carried out, supplemented by dredging and land reclamation. Other possible solutions have been proposed, such as the creation of a by-pass outlet channel beyond the influence of bar-forming.

4. Improvement of the North Branch

The North Branch is now under the process of gradual accretion. The sea water intrusion caused by flood tide carries part of the sediment and salt water upstream along the channel and turns them into the South Branch, which is unfavourable to the improvement of the latter as well as to the North Branch itself. In order to reduce the sea water intrusion and to maintain a relatively stable channel in the North Branch, regulation work is also necessary. One way is to confine the North Branch by contraction work or in combination with land reclamation. An alternative is to dam up or partly enclose the North Branch. Feasibility study has to be made to make the final decision.

Conclusions

The improvement of the Ynagtze Estuary is a rather complicated problem. Although comprehensive field investigation, laboratory experiment and numerical modeling, as well as planning work have been carried out in the past 30 years, yet still much remains to be done. The compilation of basic data, particularly at the mouth, should attract much of our attention. The study of fluvial processes should be continued with the aim to find out the optimal scheme and layout of the works of regulation. For this, movable bed model tests with salt water installation should be conducted.

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