Structural Design of the Waterway Regulation Project of Dongbei Waterway in the Lower Reaches of Yangtze River

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Abstract. In view of the navigation problem of Dongbei Waterway in the lower reaches of the Yangtze River, the evolution of riverbed and the characteristics of the obstacles are analyzed. The engineering layout scheme is determined by various methods such as model test. In the design of engineering structure, the geological conditions of the project area are analyzed through geological exploration. The applicable engineering structure form is determining, the advanced and mature bank protection and beach protection structure is adopted in the regulation of the Yangtze River channel, and the optimized structural design is adopted to strengthen the stability of project and deal with problems such as geology and strong erosion. The environmental design material and the green structure type are adopted in the structural design to meet the ecological benefits of the project, which can provide reference for the engineering design of similar channel improvement project.

Keywords: Dongbei Waterway; Waterway engineering; Structural design; Revetment; Beach protection belt

1. Introduction
Channel improvement is an important engineering measure to improve the navigation capacity of river channels and improve navigation conditions, which is of great significance for the realization of shipping economy. There are mainly two types of waterway improvement engineering measures, one is to renovate the building, and the other is to dredge the river. The implementation of the two engineering methods can improve the water flow structure and improve the navigation capacity of the channel. As a golden waterway that traverses east and west, the Yangtze River trunk line has gradually carried out remediation of the navigation section, continuously improving the navigation conditions and navigation standards. The application of the Three Gorges Reservoir has changed the conditions of incoming and outgoing water from the downstream section. The guardian-type control project has been widely applied to the conditions for the discharge of clear water from the Three Gorges Reservoir. The guardian-type control project protects the key trough from expanding along the two sides by controlling the key movable shoal. At the same time, the low-lying shoal in the trough is in control and not be washed away, so that the clear water scouring only develops vertically, and the navigation depth can be increased. The middle and lower reaches of the Yangtze River belong to alluvial rivers. The riverbed particles are fine particles with strong mobility. The phenomenon of shore bank collapse is very common. Due to the clear water discharge, the water flow scouring ability is enhanced, and the
structural stability of the rectification building is a key factor for the project effect. At the same time, the ecological effect of the project is getting more and more attention in the design of the waterway regulation project.

2. River Navigation Obstruction Characteristics and Engineering Scheme

2.1. Introduction of the Navigation Channel
Dongbei Waterway of the lower reaches of Yangtze River starts from Bali River Estuary and is connected to Zhangjiazhou Waterway. It descends to Xiaogu Mountain and connects with Madang Waterway. The total length is about 34km. The waterway has a narrow curved shape with two ends and a wide width in the middle. The upper section of the waterway from the Bali River to Qianmen is called the Hukou Waterway. The river is straight and there is a point bar called Sizhouwei on the left bank. The thalweg and the main channel are near the right bank. The lower section of the channel is a micro-bend-divided. XiasanHao island divides the river into Dongbei horizontal-channel and Dongbei straight-channel. Dongbei horizontal-channel of the left branch is the main channel, Dongbei straight-channel of the right branch is the branch channel, and Dongbei horizontal-channel has a transitional shoal. The water channel is shown in Figure 1.

![Dongbei Waterway and engineering layout](image)

**Figure 1.** Dongbei Waterway and engineering layout

2.2. Channel Obstruction Characteristics
Since the impoundment of the Three Gorges Project, affected by the sand trapping in the Three Gorges Project and the decrease in the amount of sand coming from the upper reaches of the Yangtze River, the annual average sediment transport in this section has been reduced by 70% to 80% compared with the average annual sediment transport before the impoundment. As the amount of incoming sand decreases, the sediment transport in the river section increases, resulting in changes in the scouring and siltation adjustment of the river channel. Under the new water and sand conditions, the left gully of Sizhouwei point bar is obviously developed. The sulcus outlet flows down the left edge of XiasanHao island. The main current tends to be in the right, and the inflow conditions of the transition section are unstable. The scouring of the left margin of XiasanHao island is intensified, and the scouring development provides a source of sand for the siltation of the lower transitional section. The left margin of XiasanHao island continually scours and recedes, and the water front from left bank of ShangsanHao continent to Xinba section continually collapses, resulting in the retreat of left and right
borders of the transitional riverbed at the same time. The riverbed of the transitional section is widened, the flow velocity is reduced, and the sediment is easy to be silted. The shallow conditions appeared in the unfavorable years result in the navigation conditions not meeting the maintenance standards of 4.5m×200m (water depth× waterway width), which is unfavorable for the stability of navigation conditions and the safety of navigation.

2.3. Project Plan Layout
According to the characteristics of current river channel changes in Dongbei Waterway and the problems existing in the navigation channel, it is determined through research that the management idea of Dongbei Waterway improvement project is to curb the trend of pattern changing in an unfavorable direction, maintain the current channel conditions, and avoid the development in an unfavorable direction.

The construction objective of this project is: scale of the navigation channel reaches 4.5m×200m×1050m (water depth × waterway width × bending radius), the guarantee rate is 98%, and fleets weighed 20,000-4,000 tons in total consisting of 2,000- ton or 5,000-ton barge shall be open to navigation in this channel, 5,000-ton sea-going vessels shall be able to sail in this channel taking advantage of the natural water depth.

According to the construction goal of Dongbei Waterway channel regulation project, and the impact of the project construction on the external environment such as river regime and flood control, the engineering plane of the project is studied and proposed through the research methods of physical model and mathematical model (Figure 1). (1) Two protective belts are arranged in the upper middle part of the shoal of Sizhouwei point bar, with lengths of 740m and 719m respectively and widths of 150m. (2) Three protective belts are arranged on the left margin beach of Xiasanhai island, with a length of 393m, (including the bend-end 50m), 371m (including the bend-end 50m), 331m, a width of 120m. (3) The length of the left revetment of Xiasanhai island is 2615 m. (4) The length of the revetment of Shangsanhai continent tail is 1884m. (5) The already built revetment in the area of Xinba on the left bank of Dongbei horizontal-channel is reinforced, and the length is 1490m.

3. Engineering Structure Design

3.1. Principles of Structural Design
According to the characteristics of this project, the main principles of the structural design of the revetment building are: (1) The selected structure can resist the erosion of the water flow, adapt to the deformation of the riverbed, the structure is stable and safe, durable, and firmly connected with the beach. (2) The topography, engineering geological conditions and water flow conditions should be fully considered in the design. (3) Easy for construction and maintenance. (4) Materials and components should be properly selected and cost-effective.

The main principles of the revetment engineering structure design are as follows: (1) It should conform to the principle of adapting to local conditions, taking advantage of the slope, and taking local materials. (2) It should be able to adapt to riverbed deformation, maintain a stable structure, easy for maintenance and has a reasonable cost. (3) Eco-friendly revetment should be used as much as possible and coordinated with the buildings and environment in the neighboring districts.

3.2. Design Parameters
(1) Designed lowest water level
According to the Inland River Shipping Engineering Hydrological Code (JTS 145-1-2011), the designed lowest water level should take the value of the lowest navigable water level, and the design of the lowest water level of the project site is calculated by the water level ratio. In this project, the designed lowest water level of protective shoal of Sizhouwei point bar is 3.9m, and the designed lowest water level of the left margin protective belt of Xiasanhai island is 3.7m (1985 national elevation reference plane).
(2) Construction water level
According to the construction intensity and construction capacity, combined with the hydrological data of the engineering river section over the years, the construction water level is determined to be 3m above the designed lowest water level through comprehensive consideration. For example, the construction water level of the protective belt of Sizhouwei point bar is 6.9m.

(3) Designed velocity
Considering the research results and measured data of the model, the measured surface velocity of the river section of the project is generally less than 2m/s and the maximum is less than 2.5m/s. From the safety point of view, the designed velocity of the river section is taken as 3.0m/s in this project.

3.3. Structure Design of Protective Belts

3.3.1. Engineering Geology. The geological survey shows that the riverbed strata in the protective belt of Sizhouwei marginal bank and the left margin of Xiasanhao island are mainly the Quaternary Holocene alluvial (Q₄) ① layer and ③₁, ③₂ layer of fine sands. The thickness is more than 20m, the superficial layer is loose, and gradually becoming slightly dense and medium dense. Among them, the surface layer ① is loose fine sand, the allowable bearing capacity is f =100 kPa, and the foundation strength can meet the upper load requirement. The shallow silty sand structure is loose; the anti-scouring ability is poor.

3.3.2. Structure selection. Combined with the geological conditions of the protective shoal area, concrete soft mattress (D type soft body mattress) is selected for the underwater bottom protection of the protective shoal of waterway engineering. The soft block body is good in integrity and can adapt to the deformation of the river bed, which can meet the design expectations. The cast-in-place unit mattress is adopted in the onshore protective shoal, the cast-in-place unit mattress has better integrity, better anti-aging effect, and easy for construction, thus showing a better beach protection effect. To deal with the erosion of the edge of the protective shoal, the tetrahedron-like penetrating frame or riprap is used to reduce the velocity of the water flow, promote sedimentation, and prevent the displacement of the edge of the shoal strip due to local erosion.

3.3.3. Structural design of the protective belt of Sizhouwei marginal bank. The protective revetment of Sizhouwei marginal bank is divided into two parts, in which the D-type soft body mattress is used in bottom protection below the construction water level (height 6.9m), and the horizontal overlap between mattress is 6m~12.4m. The cast-in-place unit mattress is used above the construction water level, which is connected with Sizhouwei marginal bank, and the cast-in-place unit mattress is connected with the D-type soft body mattress for 10m. Among them, the D-type soft body mattress of riprap ballast is 1m, the mattress is 30m wide and the riprap is thickened by 1.2m, and the edge of the mattress body is thrown into the water-permeable frame for anti-shock treatment. The root of the beach protection belt is connected to the bank of the left bank of the river to ensure the stability of the root of the beach. The slope type revetment is used for shore connection, and its structure consists of three parts: dry water platform, onshore slope protection and underwater bottom protection. The main role of the riprap thickening in the axial zone of the shoal zone is to strengthen the beach protection function and enhance the structural stability. According to the ecological study, the maximum riprap in the axis area is 1.2m to ensure that the large-scale aquatic life such as the finless porpoise can pass with ease.
3.3.4. Structural design of Xiasanhaoo island protective belts. The bottom protection structure of Xiasanhaoo island protection belts are bounded by the construction water level. The D-type soft body mattress is used below the construction water level. The cast-in-place unit mattress is used above the construction water level, and the mattress and mattress are overlapped. The 1#, 2# protection belts with a longitudinal axis of 30m wide is 2m thick. Due to the large flow velocity in the beach protection area, the ballast riprap strength is greater than that of Sizhouwei point bar belt project. In order to prevent the erosion of the edge of the shoal belt, the head of the belt zone and the edge of the upstream and downstream is reinforced, in which the head of the beach belt is reinforced with riprap within 30m. Because the head is close to the channel, the permeable frame is large and sharp, it is reinforced by riprap to ensure the safety of the sailing ship. A permeable frame is adopted on the upstream and downstream of the protective belt, with an upstream width of 20 m and a downstream width of 25 m.

3.4. Revetment Engineering Structure Design

3.4.1. Engineering Geology. The bank slope of the revetment project of Shangsanhaoo continent is a III type multi-layer structure. The composition of bank slope is cohesive soil and sand alternately layered or sandwiched, and the muddy soil is partially trapped. The sand layer in the lower part of the bank
slope is easily eroded by the water flow, and the groundwater may seep through the sand layer in the upper part of the bank slope. Therefore, the bank slope has poor erosion resistance and poor stability.

The material composition of Xiasanhaof island is in double-layer structure or multi-layer structure. The upper part is mainly composed of cohesive soil or cohesive soil layered with sand layer, the lower part is sand layer, and the top part of sand layer is above the river water level, and the anti-scour ability is extremely poor. It is easy to be washed away by the water flow, forming a temporary free face, causing the upper cohesive soil to be unstable and collapsed, resulting in the collapse of the bank slope.

3.4.2. Structure selection. The revetment structure can be divided into three types: the vertical structure, the slope type, the combined structure of slope type and the vertical type. The vertical revetment has higher requirements on the bearing capacity of the riverbed foundation. The structure can barely resists the uneven settlement of the foundation soil, resulting in local collapse. Especially in the jacking point of water flow, it is difficult for construction and hard to maintain stability. Slope-type revetment is mainly used for the bank slope with wide river surface and relatively loose land resources. It is the most commonly used revetment structure type in the middle and lower reaches of the Yangtze River. Its main advantage is that it protects the bank by conforming to the form of the river bank. The overall structure is stable and reliable, easy for construction and maintenance, and the interference to the water flow is small.

According to the geological conditions of the revetment project area, the slope type is adopted for Shangsanhaof continent revetment project and Xiasanhaof island revetment project.

3.4.3. Revetment engineering structure design. The structures of the two revetment projects are basically the same. This paper focuses on the revetment project of Shangsanhaof continent. The revetment structure mainly includes the dry water platform, the onshore slope protection, the underwater bottom protection, and the like. The connection sections between the upper and lower ends of the revetment project are connected with the natural bank slope. The dry water platform in the revetment structure is located at the same elevation as the construction water level. Above the dry water platform is the onshore revetment, below it is the underwater bottom protection. The typical section structure of the revetment project of Shangsanhaof continent is shown in Figure 4.

1) Onshore slope protection: mainly includes intercepting ditch, bank slope excavation, bank slope backfilling, drainage blind ditch, onshore anti-filter layer, drainage open ditch and protective surface.

Intercepting ditch: A 1.95m wide intercepting ditch is provided at the top of the slope protection to intercept surface runoff on the continent.

Bank slope excavation and backfilling: For slope steeper than 1:3, the slope can be cut according to the slope ratio of 1:3; for slopes slower than 1:3, the slope can be cut according to the natural slope ratio. The partial slope protection needs backfilling, and the backfill is required to be layered and compacted to achieve the density of undisturbed soil.

Drainage blind ditch: Set the Y-type drainage blind ditch from the top of the slope to the dry platform every 10m on the slope. The blind groove has a rectangular cross section, and the inner layer is covered with a non-woven fabric, and then the small stone is filled.

Onshore anti-filter layer: In view of the fact that there is muddy silty clay in the revetment project of Shangsanhaof continent, the sand layer is permeable to water during construction, which is prone to cause problems such as runoff pipe. For this reason, a new type of filtration structure with good drainage effect, strong filtration, high strength and good durability, drainage pad is selected and horizontal drainage pipe is used for seepage area to solve the impact of seepage on the construction and overall stability of the project.

Protective Surface: 23cm thick gabion is adopted. The structure is a regular rectangular steel wire cage filled with stones. It has flexibility, integrity and ecology. It has good self-adjustment for uneven subsidence, and the structure is porous. The gap is conducive to animal habitation and plant growth.

Drainage open channel: A drainage ditch is arranged on the slope surface every 100m. The bottom
width is 140cm, the height is 90cm, and the three sides are all 45cm thick block stone with a groove depth of 45cm. The top of the gutter is connected to the intercepting ditch, and the bottom end is flush with the dry platform.

(2) Dry water platform: The dry water platform is a paving structure with a width of 3m and a thickness of 1m. The slope drainage mat and the underwater bottom protection stack overlap under the dry water platform.

(3) Underwater bottom protection: D-type soft body mattress is placed from the bank side of the dry platform to the river center. The projection width of the D-type soft body mattress is 80-105m, and the horizontal overlap width of the mattress body is 6m. Outside the dry water platform, the area is steeper than 1:2.5 is filled with ripraps. Ripraps in the mattress edge width of 10m and the outer side width of 15m are thickened to 1.5m. The rest of the mattress has a riprap thickness of 1.0m.

(4) Convergence section: the revetment connection section is the interface between the revetment project and the natural bank slope section. This part is generally prone to damage. In order to prevent the erosion of the joint section, the structure of the connection section is designed as: The slope above the elevation of the platform is cut according to the ratio of 1:3, then covered with the non-woven fabric and paving stone of 0.6m thick; when the water below the platform is steeper than 1:2.5, the slope is adjusted according to the slope ratio of 1:2.5, and then a riprap of 110 to 50.8 m wide and 1 m thick is provided.

Figure 4. Typical section structure of the revetment project on Shangsanhao continent

3.4.4. Reinforcement of Xinba revetment. The revetment of Xinba was constructed by the water conservancy department years ago. At present, the bank slope has collapsed locally. Since the project has implemented a series of projects on the right side of the river, in order to avoid the adverse effect on Xinba revetment caused by the local water flow changes, the dam reinforcement is applied to Xinba revetment to enhance the strength and stability of the revetment and reduce the impact of the project on the flood levee.

4. Preliminary Results of the Project
The construction of the main body of this project was completed in October 2017. It can be seen from the latest mapping that the river course of the river section is stable and the pattern of the beach trough is stable. The project initially inhibited the further development of the left gutter and curbed the widening of the transition section. The navigation conditions in the shallow area were improved and the navigation scale of the river section met the construction objectives. After the 2017 flood season, the buildings in each project area are generally stable, and the partial erosion of the buildings is within the expected range, and the structure itself has good stability. The ecological effect of the ecological revetment structure gradually emerges. After the flood, the sediments on the gabion offer the plants a suitable environment to grow, which can beautify the environment and at the same time take into account the functions of maintaining various biologically suitable habitats and ecological landscape integrity.
5. Conclusion
(1) Influenced by the conditions such as water and sand, the pattern of the beach trough in the river section has a tendency to change in an unfavorable direction. Among them, the shoal of Sizhouwei marginal bank is scoured and the bank at the end of Shangsanhao continents collapses, the left margin of Xiasanbao island scoured and retreated, resulting in two-way widening and siltation of the transitional section. The navigation conditions developed in an unfavorable direction. In order to stabilize the shoal pattern of the river section, improve the navigation conditions, the waterway regulation project is carried out.

(2) According to the management ideas, through the research methods of physical model and mathematical model, the engineering layout of the project is proposed, and the key shoal and shoreline in the river channel are controlled through engineering measures, and the weak links of the existing construction projects are strengthened. The basic shoal pattern has been stabilized to avoid the development of unfavorable changes and maintain the current shoal shape and navigation conditions.

(3) Structural design focuses on analyzing the geological conditions of each project area, reasonably determining the applicable structural forms, and optimizing the structure of the beach protection and revetment projects based on unfavorable geological conditions, refining the treatment of the joints, and strengthening the stability of engineering structure.

(4) Full consideration of environmental protection requirements in structural design, under the premise of realizing the effect of engineering remediation, reasonably determine the thickness of the riprap in the shoal of Sizhouwei, leaving a river channel for the water creatures such as the finless porpoise. The revetment is designed in ecological structure to beautify the environment, while at the same time taking into account the functions of maintaining various biologically suitable habitats and ecological landscape integrity.

(5) In the engineering design, new structures and new processes are innovated for the geological and flow velocity characteristics of the project. For example, according to the characteristics of poor soil quality and poor drainage, horizontal drainage pipes, increased blind ditch and other measures are adopted to improve the stability of revetment, enrich the technology of the channel regulation engineering design, and provide reference for similar engineering design projects.

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