Beach and Trough Stability Study of the Xiyang Sea Area of Jiangsu Province

Chen Jun, Zhu Fan
College of Harbour, Coastal and Offshore Engineering, Hohai University, Nanjing, 210098, China
junchen@hhu.edu.cn

Abstract: The dynamic geomorphology of the Xiyang sea area, the largest tidal channel in the northern part of the Radial Sand Ridges in the South Yellow Sea, is complex. This paper studies the tidal flat and tidal channel stability and the evolution of the coast off the Xiyang sea area by combining topographic surveys in different periods with the data from remote sensing satellites. The result shows that the state of west tidal flat of the Xiyang tidal channel has changed from long-term siltation to dynamic balance of erosion and siltation. The Dongsha Sand Ridges on the eastern side of the Xiyang tidal channel has moved eastward and southward. The exchange of water and sand in the seas of Piaoersha and Sanyazi sand ridges was frequent with no significant rules of erosion and siltation.

1. Introduction
The offshore Radial Sand Ridges off Jiangsu coast has a wide area, special genesis, and complex dynamic sediments. Transformed by modern hydrodynamics and human beings, it boasts the hydrological sediment characteristics and coastal evolution law that have attracted research attention. As the largest tidal channel in the northern part of the Radial Sand Ridges, the evolution of the Xiyang sea area directly responds to the water and sand migration law and indirectly serves the development and construction of the port. In the past ten years, with the development of the projects of the tidal flat, the pier, and the deepwater channel regulation, the erosion and siltation dynamics in the Xiyang sea area have become extremely sensitive. Therefore, this paper takes the Xiyang sea area as the research object to discuss its stability so as to reveal the evolution law of the beach and trough and predicts the dynamic evolution of this sea area in the future.

2. Overview of the study area
The Radial Sand Ridges in the South Yellow Sea are distributed in the Yellow Sea inland waters from the south of Sheyang Port to the Haozhi Port with the north-south boundary between 32° 00'-33° 48', the length of about 200 km, the east-west boundary between 120° 40'-122° 10', and the width of 90 km (Figure 1). The Radial Sand Ridges, consist of more than 70 sand ridges and inter-ridge tidal channels which are distributed alternatively, radiates to the sea like a fold fan with Qionggang Port as the apex. The Xiyang tidal channel, the largest tidal channel in the north wing of the Radial Sand Ridges, is located between the Dongsha sand ridges and the muddy tidal flat.

Xiyang sea area has regular half-day tides with an average tidal range of 3.7 m. According to the hydrological observation of 14 fixed vertical lines in the Xiyang tidal channel from November 25 to December 2, 2009, the current velocity during the flood and the ebb is 1.20 m/s ~ 1.78 m/s and 0.82
m/s ~ 1.42 m/s respectively during the period of spring tide; that of moderate tide is 0.90 m/s ~ 1.30 m/s and 0.80 m/s ~ 1.16 m/s respectively; that of small tide is 0.72 m/s ~ 1.09 m/s and 0.63 m/s ~ 1.10 m/s respectively, in which the flow rates of rising tides are larger than those of falling tides and the flow rates in the southwest are greater than the ones in the north.

The suspended sediment concentration is relatively high: the average sediment concentration during the flood and the ebb is 0.100 kg/m$^3$ ~ 0.536 kg/m$^3$ and 0.148 kg/m$^3$ ~ 0.559 kg/m$^3$ respectively. It gradually decreases from south to north, increases from the surface to bottom. The ratios of the measured average sediment concentration of bottom and the surface are 2.19 and 2.21 respectively.

Fig.1 Location map of research area

3. Research data
This paper mainly adopts chart data and data from remote sensing satellite in different years.

The topographic data mainly covers the maritime charts from the Sheyang estuary to the Lusi Port of the Navy Command of the People’s Liberation Army of China in 1979 and 2003, and the maritime chart from the Sheyang estuary to the Lusi Port of Marine Bureau of the People’s Republic of China in 2012. This paper conducts standard digitization processing on the maritime data, extracts isobath data such as chart measurement points and isobath data while setting the elevation reference to the national 85 elevation. The superposition analysis of the isobath data of different years is used to reveal the long-term evolution law of the Xiyang tidal channel and the Xiaoyisha-Piaoers-Sanyazi sand ridges.

The data from remote sensing satellite mainly covers remote sensing data of medium and high resolution optical satellite (including Landsat series, HJ-1 series, GF, ZY-3, etc.) in the Xiyang sea area from 1976 to 2018, focusing on the analysis of five clear images of low-level tides. The image should cover the entire study area and be clear, rich in layer and moderate in contrast. The image cloud is small with good quality, making it easy for geometric correction and water edge information extraction. When processing data, first select the 1:50,000 topographic map as the reference map to register the HJ image on April 26, 2012; then use the 2012 remote sensing map as the reference image, and complete the geometric correction of other remote sensing images with the total error within one pixel by selecting the evenly distributed control points (18-34), the quadratic polynomial correction
model and the bilinear interpolation method. The superposition analysis of the low tide waterside data in different years is used to reveal the evolution law of Xiyang sea area.

4. Main result

4.1 Geomorphological features of Xiyang sea area

The Xiyang sea area can be roughly divided into three parts, namely, the Xiyang tidal channel, the west coast, and the Dongsha sand ridges.

The Xiyang tidal channel is adjacent to the coast in the west, the Pingtuyang sea area in the north, the Dongsha sand ridges in the east, and the Tiaozi sandbank, the core sand bank of the Radial Sand Ridges in the south. Starting from Doulong Port in the north, it reaches to the Liangdu estuary in the south. It runs northwest-southeast for about 80 km and is roughly parallel to the shoreline with straight channels. Its east-west width is about 12 to 25 km with Xiaoynsha and Piaoersha as the boundary for division. The west trough is the main trough, with a water depth of about 11 to 25 m; the east trough is slightly shallower, about 12 to 17 m. The two troughs merge into one waterway near Sanyazi sand ridge, and extend southward into the Tiaozhi sand bank.

The west side of the Xiyang tidal channel is a 2 km wide silty plain coast with straight shorelines and a gentle slope. The shore beach sections are divided into two types. The first one is in the shape of a convex with the average slope of about 0.8‰. Due to limited tidal flat width, its outer edge is controlled by the deep groove of Xiyang Sea, leading to steep underwater bank slope. The second one is in the shape of a double convex with an average slope of about 0.4‰-0.5‰ and the tidal flat width of more than 4 km. Maintaining in a stagnant state, it mainly distributes in the nature reserve and the coast near the Liangdu estuary in the southern part of the Xiyang tidal channel.[7]

In the east side of the Xiyang tidal channel lies Dongsha sand ridges, the largest sand ridges in the north wing of the Radial Sand Ridges. It takes Dongsha-Gaoni as the main body and covers Xiaoynisha, Piaoersha, Sanyazi, Liangyuesha, and Niluohang, among other sandbars. Dongsha sand ridge is about 20 km wide and 70 km long. Its main part runs roughly from north to south, with an area of nearly 700 km². Its straight bank lines in the west are mainly controlled by strong reciprocating flow while its twisted bank lines in the east are mainly controlled by the outer waves and currents.[8] Gaoni is a sandbar separated from the eastern part of Tiaozini sandbank in recent years and merged with Dongsha, and now it is an important part of Dongsha.

4.2 Dynamic evolution of the west coast

In the past 40 years, the tidal flat along the western side of the Xiyang tidal channel has been steadily expanding towards the sea. The artificial coastline is significantly closer to the sea, and the supra tidal zone has been basically surrounded (except for the area adjacent to the nature reserve). The average width of the tidal flat was reduced from 20 km to about 2 km. At present, it is controlled by the boundary conditions of the artificial coast and the west trough, and is basically in a dynamic equilibrium state of erosion and siltation.

From the analysis of reclamation projects from 1978 to 2018 by taking the Doulong Port of Yancheng National Nature Reserve in Jiangsu to Liangdu estuary in the north of Tiaozini sand bank, it can be seen that the artificial shoreline of this section advances to the sea by an average of 11-20 km with a reclamation area of 745 km² (Table 1). The two periods with the highest reclamation intensity were 1978-1986 and 1996-2006, accounting for 81% of the total area in the past 40 years. Dafeng Port has the shoreline with the largest advancement towards the sea, which has now reached inside the Xiyang tidal channel in the form of port trestle.

The Xiyang sea area is similar to a semi-enclosed bay with the north connected to the outer sea, the west restricted by the coast, and the east and the south surrounded by Dongsha and Tiaozini sand bank. The Pingtuyang Sea in the north is relatively open with the water depth gradually increasing from north to south and the trend scouring trough runs from north to south. Recent decades have seen more large-scale land reclamation and other projects on the west side of the beach in order to meet the
needs of economic and social development in coastal areas, which have changed the land boundary conditions of the Xiyang sea area. As the shoreline continues to move towards the sea, and the tidal prism decreases drastically, which directly leads to the concentration of the fluctuations in the waterway, thus the adjustment of scouring and silting in the seabed.

Tab. 1 Reclamation area between Doulong estuary and Liangduo estuary from 1978 to 2018

| Statistical Time (year) | reclamation area (km²) | average velocity (km²/a) |
|------------------------|------------------------|--------------------------|
| 1978-1986              | 260                    | 32.5                     |
| 1986-1996              | 40                     | 4                        |
| 1996-2006              | 340                    | 34                       |
| 2006-2018              | 105                    | 8.75                     |
| 1978-2018              | 745                    | 18.625                   |

4.3 Dynamic evolution of the Dongsha sand ridge group

The evolution characteristics in the past forty years are as follows:

1) Characteristics of erosion and deposition of the main sandbank of Dongsha

The overall geomorphologic pattern of Dongsha remained basically unchanged, while the scouring and silting was adjusted to erosion in north and siltation in south. Comparing the 1978-2018 satellite images, it can be seen that under the influence of various factors such as wind waves, currents, and the 745 km² tidal flat on the west coast of the Xiyang tidal channel, the northwestern edge of Dongsha eroded about 3-4.5 km to the southeast; the west edge, about 1.5 km away to the east; after merging several sandbanks, the south of Dongsha silted up to the southeast (18 km to the south), and the main sandbank area increased from 580 km² in 1978 to 700 km² in 2018. At present, the southern part of Dongsha has been merged with the eastern part of Tiaoziisha and the northern part of Zhugensha.

2) Dynamic evolution of Xiaoyinsha, Piaoersha and Sanyazi

The Xiyang tidal channel was widened from 10 km to over 20 km from the north of Chuandong Port, in the middle of which lied Xiaoyinsha, Piaoersha, and Sanyazi. Because of their relatively low elevation, the change process of small exposed beach area even if at low tide level is difficult to accurately detect using remote sensing images. Therefore, the analysis of erosion and silting is mainly based on the chart data.

According to the 2012 chart, the south side of Xiaoyinsha was connected with Piaoersha and Sanyazi. The -10m isobath enveloped three small sandbars with a total area of about 238.17 km², of which the area above the 0 m isobath was 32.49 km², that between the -5 m~0 m isobath was 73.95 km², and that between the -10 m~5 m isobath was 131.73km². By comparing the 1979 and 2012 sandbar scouring and silting statistics (Table 2), it can be seen that the area above the -10m isobath decreased from 260.12 km² in 1979 to 238.17 km² in 2012. Specifically, the area of sandbar above 0 m increased by 14.51 km², mainly in Piaoersha and Sanyazi; that between 0~5m reduced by 26.6 km², mainly in Xiaoyinsha and Sanyazi; that between the -5~10 m isobath decreased slightly by 8.26 km².

Although the overall performance was reflected as scouring, the performance of each sandbar varies: Xiaoyinsha and Piaoersha experienced obviously scouring, while Sanyazi, silting.

Tab. 2 Erosion and siltation of the Xiaoyinsha, Piaoersha and Sanyazi from 1979 to 2012 (km²)

|     | >0m  | 0<~5m | -5<~10m |
|-----|------|-------|---------|
| Year| 1979 | 2012  | 1979    | 2012 |
| Xiaoyinsha | 1.60 | 1.42  | 30.05   | 18.60 |
|     | 1979 | 2012  | 57.22   | 43.04 |
| Piaoersha | 0   | 8.11  | 24.87   | 24.25 |
|     | 0   | 8.11  | 24.87   | 24.25 |
| Sanyazi | 17.98 | 22.96 | 45.63   | 31.10 |
|     | 13.06 | 47.84 | 13.06   | 47.84 |
| Total | 19.58 | 32.49 | 100.55  | 73.95 |
|     | 139.99 | 131.73 | 139.99  | 131.73 |

5. Conclusion

The Xiyang sea area runs from northwest to southeast. Starting from Doulong Port in the north and reaching the Liangshui estuary in the south. It is divided into the west and troughs by Xiaoyinsha and
Piaoersha. The west trough is the main trough. The two troughs merge into one waterway near the Sanyazi, and extend southward into the Tiaozini sandbank.

The west artificial coastline of the Xiyang tidal channel advanced towards the sea for an average of 11-20 km from 1978 to 2018; the surrounding area reached 745 km²; the average width of the tidal flat was reduced from 20 km to 2 km. At present, controlled by the boundary conditions of the artificial coast and the west trough, the tidal flat is basically in a dynamic equilibrium state of erosion and siltation.

The offshore Dongsha sand ridges experienced the three stages of formation, erosion adjustment and southward expansion, and has become the largest sandbank in the Radial Sand Ridges.

Xiaoyinsha is an important boundary separating the west and east troughs. In the east-west direction, its position was stable at 10 km away from Wanggang Por The area where Piaoersha and Sanyazi are located is the juncture not only between the main sand bodies of Xiaoshasha and Dongsha, but also between the west trough and the east troughs and the main waterway in the southern part of the Xiyang sea area. It has strong tidal current and high sediment concentration with frequent exchanges of water and sand, which can easily cause the adjustment of the seabed erosion and siltation.

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