A comparative study of seagoing waterway between Hangzhou Bay and world-class bays

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Abstract. Zhejiang provincial government proposed the construction of Zhejiang Greater Bay Area (GBA) in 2017. River-sea intermodal transport is the core competitiveness of the bay area (BA). Compared with the sea shipping of the world-class BAs, the seagoing waterway of Qiantang River has long been the short board of regional economic development. Based on the core cities of the three BAs in the world, this paper makes a comparative study on the seagoing waterway of the Qiantang River Estuary and Hangzhou Bay, summarizes the history and current situation of the research on the seagoing waterway of the Qiantang River, and gives suggestions on the seagoing waterway of Hangzhou Bay with reference to the development path, strategy and successful experience of the world famous BAs.

1. Introduction

The local government firstly put forward the construction concept of Zhejiang Greater Bay Area, China in 2017. The official report proposed to plan and implement the action plan for the construction of GBA, focusing on the construction of Hangzhou Bay Economic Zone, and strive to build Hangzhou Bay Economic Zone into a world-class Bay Area by 2035. Hangzhou Bay Economic Zone, is located in the coastal zone, the Yangtze River Economic Belt, the Yangtze River Delta City Group and the “the Belt and Road Initiatives” strategic location. Up to now Hangzhou has taken the lead in putting forward the strategy of “Gather around the river to development”, focusing on the construction of Hangzhou Bay Economic Zone, and striving to make Hangzhou as the main platform, main battlefield and main engine for the construction of Zhejiang GBA.

The BA refers to an area composed of one or several connected bays, harbors and adjacent islands, and also a comprehensive city group with a coastal bay [1]. Previous studies have shown that river-sea intermodal transport is the core competitiveness of the BA and this is also the key point of the construction of Zhejiang GBA. From the perspective of space, the Qiantang River has provided necessary conditions for the development of waterway, but from the perspective of time, the Qiantang River has experienced thousands of years of struggle for this. However, the Qiantang River waterway transportation currently presents a scene which is quite different from the world-class BAs. Figure 1 shows the current situation of waterway transport in the core cities of three world-class BAs and the Central Business District (CBD) of Hangzhou. It can be seen from the figure that different from the core cities of the three major BAs, the waterway transport near the CBD in Hangzhou is still
dominated by small fishing boats. The waterway potential of Qiantang River Estuary has not been well
developed, especially the potential of tourism transportation, urban commuter transportation and
freight transportation to sea. This paper compares the seagoing waterway of Qiantang River Estuary
and Hangzhou Bay with that of the three major bay core cities in the world.

![Figure 1](image)

**Figure 1.** Current situations of waterway carriage in the core cities of world-class BAs and the CBD of Hangzhou. (a) Hangzhou; (b) New York; (c) San Francisco; (d) Tokyo.

### 2. The development experiences of three world-class BAs

Nowadays the BA has become an important growth pole that drives global economic development and
a leader in technological change, and thus has derived a unique economic form - the BA economy. As
an important part of the BA space, ports and cities play a role of link and radiation. Therefore, the BA
economy can be said to be a unique economic form formed by the high integration of coastal economy,
port economy, urban economy and network economy. Throughout the world, there are thousands of
well-known bays, but there are only three real mature BA economies, namely, New York BA, San
Francisco BA and Tokyo BA (Figure 2). The construction of Guangdong-Hong Kong-Macao GBA has
risen to the China National Strategy in 2016, becoming an important part of the national regional
coordinated development strategy [2]. The Comparison of economic and social indicators of main bay
areas in the world in 2016 is shown in Table 1.

| Items                           | Z-GBA | GHKM-GBA | NY-BA | SF-BA | T-BA |
|---------------------------------|-------|----------|-------|-------|------|
| Total area (10^4 km^2)          | 4.59  | 5.65     | 2.15  | 1.79  | 3.68 |
| Population (10^4 people)        | 3080  | 6670     | 2340  | 715   | 4347 |
| GDP (trillion USD)              | 0.48  | 1.36     | 1.4   | 0.8   | 1.8  |
| GDP National share (%)          | 4.24  | 12       | 8     | 4.3   | 26.4 |
| GDP per capita (10^4 USD)       | 1.54  | 2.04     | 5.98  | 11.19 | 4.14 |
| Port container (10^5 TEU)       | 2290  | 6520     | 465   | 227   | 766  |
| Airport passenger (million people) | 40    | 175      | 130   | 71    | 112  |
| Proportion of tertiary industry (%) | 51.7  | 62.2     | 89.4  | 82.8  | 82.3 |
| QS top 100 universities in the world | 1     | 4        | 2     | 3     | 2    |
| Number of headquarters of the world's top 500 companies | 3 | 17 | 22 | 28 | 60 |
Abbreviations. Z-CBA: Zhejiang GBA, GHKM-GBA: Guangdong-Hong Kong-Macao GBA, NY-BA: New York BA, SF-BA: San Francisco BA, T-BA: Tokyo BA.

Figure 2. Geographical situation of each BA. (a) Zhejiang GBA; (b) New York BA; (c) San Francisco BA; (d) Tokyo BA

2.1. New York BA
New York BA (Figure 2b) is the core area of the U.S. economy, the core center of world finance and the international shipping center, and is regarded as the head of the international BA. New Jersey Port, located on the east coast of northern America, has long been crowned the largest port in the east of the United States. It is the huge throughput function and strong radiation force of the port that promotes the development of New York and New Jersey regional economy and become an important gateway of import and export logistics in the United States and international market. Founded in 1921, the Port Authority of New York and New Jersey plays an important role in promoting the transportation, trade and economy of the New York BA. It is a trans-regional management organization jointly established by the government of New York State and New Jersey State, which provides a new model for the development and public management of the New York BA. It emphasizes the management of the landlord port model and diversified operation [3], recommended by the United Nations to the world in the 1980s.

2.2. San Francisco BA
San Francisco BA (Figure 2c), located in northern California, is one of the most important high-tech R&D centers in the world. San Francisco BA can be divided into North Bay, San Francisco, Peninsula,
East Bay (represented by Oakland) and South Bay (represented by San Jose) according to its geographical attributes [4]. San Francisco is mainly dominated by tourism, service industry and financial industry; San Jose is located in “Silicon Valley”, with developed electronic industry, which concentrates manufacturing industries such as electronic computers, electronic instruments and aerospace equipment; Oakland is mainly dominated by port economy, and its port is one of the earliest ports in the world using container transportation. San Francisco, Oakland and San Jose adopt different development strategies and industrial layout, so that they can coordinate development and reasonable division of labor, so as to maximize the aggregate effect of the bay area economy.

2.3. Tokyo BA

Tokyo Bay (Figure 2d) lies on the Kanto plain of Japan’s granary in the north, surrounded by Boso-Hanto and Miura-Hantou in the East and West, and passes through the Uraga strait to the south out of the Pacific Ocean. The characteristics of the economic development along the coast of Tokyo BA are that the port construction drives the economic development. Along the coast, there are six ports, namely, Tokyo port, Chiba port, Ksarazu port, Yokosuka port, Yokohama port and Kawasaki port, which are closely connected with the horseshoe port group, and the functional division system of each port is distinct. Driven by a large number of ports, the Tokyo BA has gradually formed two industrial zones, namely, Tokyo-Yokohama and Tokyo-Chiba, with developed industries such as steel, petrochemical, modern logistics, equipment manufacturing and high-tech [5]. In addition to the concentration of industries and population, Tokyo BA has become the largest industrial city group and the largest international financial, transportation and trade center in Japan, and is one of the most developed and urbanized city groups in the world.

2.4. Hangzhou Bay Economic Zone

Hangzhou Bay Economic Zone mainly covers six cities: Hangzhou, Ningbo, Shaoxing, Jiaxing, Huzhou and Zhoushan. It has 68% of Zhejiang Province's total economy, 55% of its population, 78% of its invention patent applications, 76% of its high-tech industrial output value, 78% of its domestic listed companies and 75% of China's top 500 private enterprises. However, compared with the main BAs in the world (Table 1), there is a certain gap in terms of economic aggregate, R&D capacity, population agglomeration, industrial structure and other indicators in Hangzhou Bay area at this stage. But it is undeniable that Hangzhou Bay Economic Zone has its own potential advantages in port and shipping. In particular, Ningbo-Zhoushan Port, located at the intersection of “the Belt and Road Initiatives” and the Yangtze river Economic Belt, exceeded 1 billion tons in cargo throughput in 2017, ranking first in the world for nine consecutive years, and third in container cargo throughput in the world.

A port is an important node for the development of the BA economy. The three world-class BAs are located at the main sea port, with a long and narrow coastline and a wide economic hinterland (Figure 2), and form a port city group corresponding to the hub port and the feeder port. The three BAs have completed the transformation from the traditional port economy to the modern urban economy, such as the New York BA represented by finance, the San Francisco BA represented by information technology (IT), and the Tokyo BA is the product of the industrial era. All three BA make full use of the port group, strengthen the economic transactions between domestic and other countries, and in the BA for access to information, strengthen the communication with the international economy, the BA significantly increased degree of external links and internal integration level, the BA has become the hub of regional economic development, including information, capital and technology hub.

With the establishment of the Hangzhou Bay Economic Zone and the construction of the Zhejiang GBA, an economic, financial, information, import and export, manufacturing, high-tech, tourism and shipping center with Hangzhou as the core, it is urgent to dredging a thousand-ton sea channel of the Qiantang River, realize the qualitative leap of waterway transport development, and accelerate the development of the Qiantang river shipping.
3. The history and current situation of the Qiantang River seagoing waterway research

Qiantang River estuary is the only channel connecting the river and sea in Hangzhou (Figure 3a). From the Qiantang River Estuary to the north, it can reach Shanghai port, the international shipping center; to the east, it can reach Ningbo-Zhoushan port, the key point where the North-South coastal route meets the “golden waterway” of the Yangtze River, and it can also be combined with Yangshan Port, and integrate into China’s river and sea shipping network. However, the development of Qiantang River's waterway transportation has been restricted by three factors: the plane swing of Qiantang River Estuary's deep channel line, the longitudinal huge shallow water area of sand bar (Figure 3b) and the tidal bore. After a long period of reclamation, the river mouth section is narrowed, the plane swing of the deep channel line is controlled from 4 ~ 11 km to 2 ~ 3.5 km, and the amplitude and frequency of the swing are greatly reduced. However, the tidal bore and elevation of sand bar and still have little change. Restricted by these two factors, the Qiantang river channel to the sea has not been improved so far. With the gradual implementation of the reclamation planning, a relatively stable deep channel appeared on the south bank of the Jianshan section. Hangzhou had actively carried out the preliminary research work of port and dock construction.

3.1. The first stage

In 2003, the outline of “Golden Waterway” development plan of Hangzhou (2003 ~ 2020) compiled by Hangzhou Development and Reform Commission and Hangzhou Transportation Bureau put forward the channel layout of “Connecting to the East”, which means that ships in Qiantang River can go to sea to communicate with ports along the coast of China.

In August 2003, Xiaoshan district government organized and completed the “Preliminary Analysis of the Waterway Conditions of Xiaoshan Qiantang River Seagoing Dock”. The report points out that the closed harbor is a measure to enhance the advantages and avoid the disadvantages of the Qiantang River Estuary. After the project, the guarantee rate of 3000t class ships can reach 70%, and 5000t class ships can reach 30 ~ 40%. However, the problems such as the flow pattern, sediment deposition and tidal bore impact of the waterway need to be further studied.

3.2. The second stage

In March 2005, Hangzhou Development and Reform Commission organized the “Pre-feasibility Study on the Construction Scheme of the Qiantang River Waterway”, and proposed to move the outlet of the Qiantang River down to the Xiaoshan east coast section, according to the characteristics of the main channel of the Jianshan section lying stably after the reclamation of the north bank in 1997. The report
points out: “the port built on the east Xiaoshan route has the advantage of short tidal route and deep water depth, basically has the waterway conditions of 1000 ~ 3000 t class seagoing ship; in view of the open wharf front tide flow is rapid, the flow pattern is complex, the loading and unloading condition is bad and so on, using closed type of port construction scheme, in order to avoid the tidal bore, fast flow and low hydrodynamic influence on ship loading and unloading, and better solution to the restrictions of tidal bore and sand bar on waterway may become a new seagoing waterway of Hangzhou”.

In March 2006, Hangzhou Transportation Bureau organized and carried out the research on “Analysis of Waterway Conditions of Qiantang River Dock in Hangzhou Port”. According to the report, the construction of the port on the east line of Xiaoshan has the following advantages: (1) the main stream of the south branch has existed in location of the project, and the deep channel is close to the bank, and the bottom elevation of the deep channel changes from - 3.0 ~ - 9.0m; (2) the construction of the port on the south bank of Jianshan section avoids the waterway block on the top of the sand bank of Qiantang River, the channel to the deep water area by tide is short, the bottom elevation of the channel is low, and the ship can sail by tide. The following problems still exist in the construction of Xiaoshan east line port:

(a) The water depth guarantee rate of wharf apron is low. The average guarantee rate of 3.0m water depth (500t) at low tide level is 75%, and that of 5.0m water depth (1000t) at low tide level is only 31%; in case of more than once-in-10-year flood, the ship docking operation will be difficult to guarantee for a long time.

(b) The hydrodynamic force is strong, and the east line of Xiaoshan has one of the largest tidal bore in Qiantang River Estuary. The measured maximum tidal bore height is 2.5 ~ 3.0m, and the measured flow velocity after the tidal bore exceeds 5.0 m/s, so there is a risk in the loading and unloading operation of the ship docking at the wharf.

(c) In Jianshan section, the main channel swings frequently, and the waterway guarantee rate of channel is relatively low. In the middle tide level, the waterway assurance rate of 500t level can reach 100%, but that of 1000t level is only 72%, and that of 3000t level is only 43%.

(d) There is no suitable anchorage nearby.

On May 24, 2006, Hangzhou Transportation Bureau organized more than 30 experts from various departments and industries such as transportation, water conservancy, ocean engineering, port and shipping, maritime affairs, ship and navigation to review the research results. Experts believed that it was very meaningful and necessary to carry out the research. For the construction of open port in the east line of Xiaoshan, due to the low water depth guarantee rate, large flow velocity, short loading and unloading operation time, no suitable anchorage nearby and other objective reasons, which are of great risk and economically infeasible. The closed port has certain research value, so it is necessary to speed up the preliminary research and the port area planning of the closed port, and conduct in-depth research on many key technical problems of the closed port.

3.3. The third stage

On August 24, 2007, Hangzhou Transportation Bureau hosted the review meeting of three reports, namely, “Special Study on Waterway Conditions, Siltation Changes, Siltation Reduction Measures and Approach Channel of the Closed Port”, “Special Study on Construction Scheme of the Qiantang River Port” and “Special Study on Operation Ship Type of the Qiantang River Port”. After the relevant reports, the expert group composed of eight experts including two Chinese Academicians believed that:

(a) It is necessary to carry out preliminary research on the Qiantang River Port project, and the main conclusions can be used as the basis for the next decision of the project.

(b) Under the special hydrological conditions of Qiantang River, the guarantee rate of 1000t general-purpose ship type for tidal waterway is low, the sediment deposition intensity in the approach channel and entrance area is large, and the cost of daily operation and maintenance is high. At the same time, the high tide level for entering and leaving the port, the ship waterway has a greater safety risk, which is not feasible in safety and economy.
(c) Under the existing conditions, the implementation of the project should be very careful. It is suggested that the relevant departments suspend the implementation of the project in the near future, and continue to strengthen the research and data accumulation of basic work such as hydrology and sediment of Qiantang River, and explore and study other forms of port construction.

(d) In order to solve the problem of waterway transportation of raw materials and products for enterprises in Linjiang industrial development zone, it should give priority to the construction of Jiangdong waterway network by taking advantage of the opportunity of the opening of Hang-Ningbo canal.

In 2010, Shangyu started construction of the Shangyu New Port. In 2013, the 3000t special wharf of Shangyu New Port entered the trial operation stage. The wharf is the only seaport in Shaoxing city, with a designed tonnage of 3000t. However, at the beginning of 2017, the water area at the front of Shangyu New Port was silted up by about 5 ~ 6 m, the deep channel disappeared, and the riverbed reached the highest elevation after 2010. The water depth has been a slight improvement in the last three years.

4. Discussion and conclusions

The river width of Qiantang River estuary is from 1km to 100km, and the navigable water area is open. The depth in the deep channel on the north bank below Ganpu is 12 ~ 15m, and the depth in the deep channel on the coast above Shanyu on the south bank is 6 ~ 10m. The waterway of Qiantang River Estuary has the natural conditions for ships of 5000 ~ 50000 t by tide. At present, there are ports and wharves built on the north bank of Qiantang River by using the deep-water coastline resources of Jinshan, Pinghu, Zhapu, Jiaxing and other places. It is urgent to build ports in Xiaoshan, Shangyu, Cixi and other places on the south bank. Due to the influence of the Qiantang River tidal bore and the variable swing of the main channel with wide and shallow river bed, the channel resources above Ganpu have not been developed so far. Referring to the development path, strategy and successful experience of the world-class BAs, Hangzhou bay seagoing waterway can seek breakthroughs from the following aspects:

- Establish trans-administrative organization to coordinate the waterway development. As the development of Qiantang River waterway channel involves a wide range, complex technology, large workload and large cost, we can refer to the experience of the Port Authority of New York and New Jersey to determine a comprehensive department to take the lead, mainly to coordinate and make decisions on major issues in the waterway development work, and to coordinate the administrative and management affairs of the seagoing waterway in Zhejiang GBA.

- Actively promote the construction of Linjiang dock in Jianshan section. At present, after some necessary reclamation of Qiantang River, the guarantee rate of 3000 t vessels can reach more than 50%. In the east line of Xiaoshan, the project of external convex closed comprehensive wharf is adopted near the coastline bordering Shaoxing. Through the transfer of the dock operation area to realize the communication with the inland waterway network, it is expected to realize the idea of river-sea combined transportation.

- Study on the regulation of sand bar in Qiantang River Estuary. The sand bar of Qiantang River estuary is the product of the trumpet shape. The power of tidal current is far greater than that of runoff, which is the dynamic condition for the formation of the sand bar. The material basis for the formation of the sand bar is the abundant sand sources outside the mouth. Under the current situation of the Qiantang River Estuary moving down and the sand coming from the open sea decreasing, carrying out the regulation of the sand bar in the Qiantang River Estuary, establishing the waterway of the Qiantang River channel to the sea and developing the ship type with shallow draft and large tonnage can significantly increase the shipping capacity of the Qiantang River, so as to meet the needs of the development of the Hangzhou Bay Economic Zone.

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