The Development of Offshore Artificial Island Construction and Application of Key Hydrodynamic Technologies in China ——Take Haihua Island Project as an Example

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Abstract: In recent years, with the development of China's coastal waters and coastal urban space expansion needs, the construction of artificial islands on the sea has achieved rapid development. In order to allow it to further promote the development of Marine economy in our country, relieve the contradictions of land and environmental pressure and maintain the Marine ownership plays an important role in our country, research from the review summarizes the development of China offshore artificial island and the technical characteristics of typical artificial island has been built and under construction engineering examples, the paper introduces the construction and offshore artificial island development present situation, and sums up the construction of artificial islands facing the core issues. At the same time, based on the analysis on the status at present domestic offshore artificial island, points out the key technology of the construction of the island, and in the sea flower island project carried out by the series water power project as an example, a detailed discussion on wave flow elements, the seabed sediment, as well as the influence on surrounding channel water exchange, and the three dimensional seepage flow, etc. The research achievements of the project. The research points out that the future construction of artificial islands should return to rationality and science and pay more attention to the integration of natural ecology and environment.

1. Introduction

With the rapid development of global economy and the gradual decline of traditional land-based resources, coastal countries and regions have been soberly aware that the ocean is a new space for survival and development, and ocean development has become an important strategy, which is related to the sustainable development in the future. Since the eleventh Five-Year Plan, China has entered the period of the fastest growth in the area of land reclamation, with an average annual reclamation area of
In 2009, the area of land reclaimed from the sea nationwide was confirmed to be nearly 18,000 hectares, making it the largest year in history. According to data published in the Management Bulletin on the Use of Sea Areas by the State Oceanic Administration (SOA), China's annual land reclamation in recent years has been a massive 10,000 hectares. In 2015, China reclaimed 11,055.29 hectares of land from the sea, up 13.19 percent year on year. With the increasingly prominent contradiction of land use and the continuous appreciation of land value, the construction of artificial islands at sea has become a way to develop and utilize Marine resources and expand the space of urban development in China's coastal areas. Related works independent approval to start construction fast unprecedented, since first development construction project started, offshore artificial island has been in the development of Marine economy in our country, relieve the contradictions of land and environmental pressure and maintain Marine ownership has played an important role in our country, the artificial island built technology also get rapid development in the practice and exploration.

China has a large number of offshore artificial island projects, rapid construction, rapid accumulation of practical experience, and rapid development of related technologies. With the implementation of many engineering projects, this has promoted the rapid progress of design, scientific research and construction technologies. Objectively speaking, the large-scale reclamation of islands brought about economic and technological development, but also must face up to the related problems. Now, more attention is paid to the ocean and ecological environment during the development. At present, as the national Marine inspector, has on the protection of Marine ecological environment, the science GuanHai use sea, fully enhance the level of Marine ecological civilization construction in our country, developed the most stringent wai reclamation controls, advocate the priority protection, intensive use of concept with the sea, the sea the development and utilization of sustainable development have been attached great importance and implemented. Against this background, this paper analyzes and summarizes relevant core issues and key technologies according to the current situation of artificial island construction, so as to explore the direction of returning to science and sustainable development.

2. General situation of the development of Artificial islands

2.1 Current situation and characteristics of artificial island development and construction

Artificial islands are islands built by man rather than by nature. They are a form of land reclamation. Most of them are small islands formed by independent reclamation to support buildings or structures that have realized corresponding functions. As early as the Jiajing Period of the Ming Dynasty (AD 1522-1567), there is a written record of the construction of artificial islands in China. However, the construction of modern artificial islands on the sea started relatively late, with the main functions of oil and gas development and real estate tourism, and most of them are offshore fixed artificial islands [1]. Due to the lack of management and practical experience, the development of artificial islands on the sea has once caused damage to the Marine ecological environment and resources, and also affected the performance of Marine functions. With the introduction of a series of strict reclamation and control measures in 2013, this trend has been effectively reversed, and the construction of artificial islands is also developing towards a scientific and environmental trend.

Based on sea island needs and technological development situation in our country, there are common characteristics of the following aspects, including: (1) the purpose of the island has become increasingly diverse, from the initial offshore oil and gas exploration and development, to the sightseeing tourism, high-end residential, to cruise home port, sea-crossing passage node and offshore airports, experienced a evolution from single function to meet the demand of compound;(2) The site selection of the project is mostly near the shallow sea. In this way, it is convenient to use local materials, reduce the construction cost and difficulty, and strengthen the connection with the land by means of cross-sea Bridges, tunnels, Bridges and ships;(3) The construction form of island body is becoming more and more novel. From the beginning, the island body is mainly fixed, but in recent
years, floating type has been tried. In addition, the plane layout form has broken the original single regular rectangle or square, and the shape is diversified and more integrated with local culture and modern needs.(4) The main body of project investment has gradually diversified. In the past, it was mainly state-owned enterprises and local governments. In recent years, it has attracted more private and private enterprises and other investors, and even foreign capital has become the main body.

2.2 Overview of typical artificial island projects

Although The construction of artificial islands off the sea started late in China, it develops fast and has many practical projects. In addition to the ongoing construction of artificial islands in the South China Sea in recent years, many typical projects have been completed or under construction. Several representative projects are listed as follows:

(1) The East and West Artificial Islands project of The Hong Kong-Zhuhai-Macao Bridge, a maritime traffic hub

The world-renowned Hong Kong-Zhuhai-Macao Bridge was officially opened to traffic at 9 am on Oct 24, 2018. Among them, the east and west artificial islands, as bridgeheads, are the crucial link connecting the Hong Kong-Zhuhai-Macao Bridge, and are praised as the miracle in the history of artificial islands construction in the world, as shown in Figure 1-A. The distance between the nearest edge of the two artificial islands is about 5,250m, and the design shape is oyster shell. According to the calculation of the outer edge line of the wave barrier wall of the artificial islands, the length of The East Island is about 625m, the widest part of the transverse is about 215m, and the total construction area is about 100,000 square meters. The West Island is 625m long, 190m wide at its widest point and 98,000 square metres in area. In order to ensure the progress of the whole project, this project did not use the traditional sand-filling method to build the island, but adopted the steel cylinder, which sank into the sea and was inserted into the mud surface to a depth of 21m. Then, sand was injected into the cylinder, and the sunken tube of the embedded tunnel was closed and backfilled. The island wall was protected by wave elimination measures and protection engineering.

(2) The first ecological artificial island -- China Merchants Plaza Beas Island

It is the first commercial sea project approved by the State Council of China, and has attracted much attention at home and abroad since the formal construction started in February 2010. Beas Island, with an investment of about 3.5 billion YUAN, is located in Zhangzhou Economic and Technological Development Zone, Fujian Province. It is the first commercial sea project approved by the State Council. The reclamation has formed a land area of 182.30 hectares with a radius of 840 meters, in the shape of double dolphins, as shown in Figure 1-B. With 11.7 km of coastline, the island-building project has been completed by means of encircling and then filling. The design of this project adopts the standard of "double hundred", that is, the flood control standard takes the design high water level once in 100 years and the wave element once in 100 years.

(3) The southernmost cruise home port -- Sanya Phoenix Island

Phoenix Island is a landmark building in Sanya. Since the end of 1990s, it has gone through the first phase of the project and the current second phase of the project. The first-phase project of Sanya Phoenix Island, with a total investment of 3.5 billion yuan, is located on the coastal cay of Sanya Bay in Sanya City and is an artificial island for dredge-filling, as shown in Figure 1-C. The island is 1,250 meters long and 350 meters wide. It covers an area of 547.5 mu (365,000 square meters) and has a planned gross floor area of 480,000 square meters. The second phase of the island reclamation project has been officially started on April 10, 2014. Because the island is located in Sanya Bay and adjacent to the mouth of Sanya River, the planning and design of the island has been controversial from construction to construction. Most of the issues focus on the impact on the beach and ecological revetment environment of Sanya Bay, and relevant demonstration and research have been ongoing.
2.3 The core issue of artificial island construction

Through the investigation of more than ten artificial islands at home and abroad, extensive research has been conducted from the aspects of Economics, Engineering, Environment and safety, etc. According to its corresponding English initials, it can be summarized as "3E+S". The basic conclusions are as follows:

(1) From the perspective of economy, functional selection has a significant impact on the profitability of the operation of artificial islands in the later stage. For example, artificial islands with clear application functions, such as airports and ports, have relatively ideal operation conditions. However, the operation of artificial islands for commercial and tourism purposes is closely related to the local economic and social development, and the first-mover advantage will be relatively obvious.

(2) From the engineering point of view, the foundation settlement, earthquake liquefaction, hydrogeology and so on the determination of design elements, structure, and storm surge protection ocean disaster protection problems in need to consider the development of the artificial islands, such as through some engineering measures to avoid, but need to develop more efficient and economic technology solutions.

(3) From the perspective of environment, the construction of artificial islands, no matter what type, will bring irreversible impact on the surrounding ecological environment. How to take certain measures to reduce the impact of ecological environment or compensate for the ecological environment will be an inevitable problem for the construction of artificial islands in the future. Among them, floating artificial islands have obvious advantages over traditional stationary ones in terms of environmental impact.

(4) From the perspective of safety, risks mainly come from Marine disasters, investment returns and later operation and maintenance, which should be fully demonstrated and evaluated in the initial planning stage.

3. Research status

3.1 Theoretical research

In terms of hydrodynamic and plane layout of artificial islands, Academician Xie Shilin [2] theoretically discussed and analyzed the shape and overall layout of artificial islands, the influence on the deformation of nearby coasts, wave propagation and diffraction, and surrounding erosion and silting.

Artificial island base structure and construction technology research, chang [3] landfill for dalian airport industrial park project, analyses the artificial island construction function and the size, design standard, the location of the island, the key basic data acquisition, plane form and general layout, land formation and foundation treatment, new bank protection structure, construction organization, key technology such as ecological and environmental protection, monitoring and control. Beam girder [4] for the zhuhai-macau port island in engineering area of natural environmental conditions and than choose the overall layout and planning, hydraulic revetment structure, land form and methods of ground treatment scheme and construction organization and several key technology into island, the
local ecological and environmental protection measures, is deduced from a set of relatively complete, the reasonable method for construction of offshore artificial island. Jinhui [5] in the key technology of engineering design Pisces island in the early stage of the reclaiming land from the sea to design how to consider and the cohesion between the late cover planning, and according to the position of the engineering geology is relatively complicated, the characteristics of the silt layer thickness is larger, the artificial island layout, revetment structure scheme, foundation treatment, land reclamation, special function construction and other key technology research. Dong Zhiliang [6] showed in the research and application of key technologies of large area sea reclamation cofferdam project that the formation of cofferdams, as the basic link of the whole sea reclamation project, directly affects the safe and smooth progress of subsequent land area formation and soft foundation treatment construction. Presents around the sea land building in our country development present situation and the structure of cofferdam filling and the construction technology, and combining the hong kong-zhuhai-macao bridge the zhuhai-macau port island reclamation engineering project, the paper mainly discusses the ripped-rock cofferdam, the sandbag cofferdam, compound sandbag cofferdam, plug-in steel cofferdam construction and water, and key construction techniques of intelligent control system.

Island bay water exchange capacity research, accepted at [7] in haikou artificial island engineering, for example, such as using MIKE21 hydrodynamic and HD module based conservative material convection - diffusion mathematical model, simulation of the control gate controlled by artificial island lake water flow and water exchange, by adjusting the number of control gate, location and the local lake drainage boundary to optimize design scheme.Han Weidong et al. [8], aiming at the weak exchange capacity of water body in the encircline type port pool, took the two port areas of Lianyungang port as an example, established the model of tidal current and convective diffusion, and studied the effect of water exchange channel in the encircline type port area on the improvement of water quality.

3.2 Key technologies of artificial island construction

By combining the water environmental dynamic conditions of the construction of artificial islands in the sea and the research on the structure of the island, the key technologies for the construction of artificial islands in China at present mainly include the following aspects:(1) the site selection and layout of the project should conform to the natural environmental conditions of the sea as far as possible;(2) Plane layout and shape design, more consideration is given to the needs of Marine ecology and landscape, the outline is mostly irregular shape, and the length of coastline is extended with the help of curve or folding coastline layout, so as to improve the value of land development;(3) The future development trend is to adopt upright/sloping traditional bank revetment to reduce risks, and to further develop flexible Marine structures that can effectively reduce wave and current energy functions;(4) Island filling scheme: select backfill materials, first surround and then fill, foundation treatment by using Marine resources, and select appropriate island filling scheme according to local topographic and geomorphic conditions, engineering geological conditions, planning function positioning, development mode and building structure requirements.(5) Construction technical scheme: "surround first, fill later" is adopted to prevent the loss of island-building materials and protect the Marine ecological environment;(6) Land island means of transport, which are commonly used by barges and ferries, undersea tunnels or sea-crossing Bridges, depending on the investment cost and use value;(7) The impact of Marine ecological environment. With the increasing attention paid to environmental issues, the erosion of surrounding seabed, the pollution of water bodies and the living environment of benthic organisms need to be paid attention to at the initial stage of planning and demonstration.
4. Take Haihua Island engineering research as an example

4.1 Project summary
As the government of Hainan province during the period of "twelfth five-year" in western Hainan tourism which is a project of sea island, located in the Hainan Danzhou Qinlan Bay waters, Pu between port and Qinlan port, North Qinlan economic development zone, South Pu Town, North to Bai Majing town, the coast is more than 600 m, about 6.8 km, total span project planning is about 7.53 km², with the sea location situation as shown in figure 2. The project is located in Danzhou Bay, Hainan, with an investment of more than RMB 160 billion. It is more than 600 m from the coast and has a total span of about 6.8 km. The island is composed of three independent offshore islands, with a planned reclamation area of about 8 square kilometers. The planned plane shape is three flowers blooming in the sea, so it is named "Haihua Island". At present, the reclamation has been completed and the construction of supporting facilities on the ground is under way.

![Fig.2 Haihua Island layout situation map](image)

4.2 Research work

4.2.1 Special studies
The construction of structures such as the offshore artificial island project will break the dynamic balance of water and sand in the original sea area, so that the wave propagation, flow field characteristics, seabed scouring and silting trend of the proposed project water area will change, and cause a certain degree of impact on the offshore water exchange and biological environment. In this context, the project carried out a series of related research work, in order to provide a scientific basis for the feasibility of the project construction and the further improvement of the scheme.

(1) Research on design wave elements of human engineering island, mainly through the establishment of sea area wave mathematical model, analysis and calculation of the wave field in the area where the project is located, and based on this, further analysis and calculation of wave elements at the front edge of island body embankment under various working conditions, to provide basic parameters for the design.

(2) Research on the impact of seabed erosion and deposition and the construction of structures such as artificial island projects in the intertidal area will break the original balance and change the flow field and seabed erosion and deposition in the project area. Based on the numerical simulation technology of waves, currents and sediment, this study calculated and evaluated the changes of the
hydrodynamics of the sea area around the artificial island and the changes of the seabed erosion and deposition after the construction of the artificial island, providing a basis for the demonstration and comparison of the scheme.

(3) bank revetment wave profile test and research, in view of the island of revetment design scheme selection of typical section, through the two-dimensional cross section wave physical model test (as shown in figure 3 - a), measured under the condition of different design standards, the typical bank protection period of armor block stability of the proposed construction project, wave after the wave and the wave point pressure acting on the revetment roof parapet walls. In order to determine the elements of the proposed revetment, such as the section size, the height of the wave wall and the stability of the revetment block, the foundation is provided for the design, implementation and safe use of revetment.

(4) Experimental study on the integral wave physical model; establish a three-dimensional integral wave physical model including the sea area around the artificial island (as shown in FIG. 3-B); carry out relevant studies on wave propagation law and influence, including: wave height distribution at the position of the seawall, which provides a basis for structural design; the effect of wave deformation between petals of sea flower was simulated, and the influence of wave deformation, superposition and climbing on the determination of sea embankment top elevation was analyzed. Under different combinations of conditions, the stability, climbing and water upwelling of the protective block in different sections of the artificial island provide the basis for verifying the stability of the protective block in three-dimensional conditions and determining the top elevation of the breakwater wall in different sections.

(5) Physical model test of sediment erosion and deposition in engineering. Through the physical model test of sediment moving bed under the interaction of wave and current, the strength and amount of sediment erosion and deposition before and after the project are tested and studied, and the influence degree and scope of sediment erosion and deposition on the surrounding shoal are predicted and analyzed for experimental study.

(6) For the influence of the channel in The Yangpu Port area and the surrounding sea areas, a mathematical model is used to simulate and calculate the hydrodynamic conditions, nearby coastal sediment transport and shoreline changes in the adjacent Yangpu channel area before and after the
island construction. The velocity and transverse current of Yangpu Harbor before and after the construction of Haihua Island are calculated statistically, the influence of local flow conditions is analyzed and the influence of the construction of Haihua Island on the surrounding channel is demonstrated.

(7) The experimental study on the mathematical model of water exchange in the bay shows that the weak tidal current dynamics in the semi-closed waters between island groups will directly affect the weakened self-purification capacity of water body and possibly cause water pollution. Based on the flow field numerical model, the tracer method was used to simulate the water exchange capacity in the bay, and the change of the average concentration of the tracer reflected the degree of the water exchange capacity, so as to evaluate the water exchange effect.

(8) In the inland sea and three-dimensional dam seepage, seepage mathematical model research, the FEFLOW flow and material migration model based on finite element method (fem), flower island sea engineering, for example, to its HaiDiBa and flower island sea dike is no seepage and seepage control measures of seepage flow, seepage scope and internally to calculate and analyze the influence of sea level change, provide certain reference for engineering design.

4.2.2 Follow-up research work
Construction of the island body has been completed, and supporting buildings and facilities in the land area are being carried out. At the same time, a more important measure is also being stepped up, that is, to carry out the sea area restoration project, with a view to improving the environmental impact of the sea area caused by reclamation to the greatest extent and improving the water quality and landscape around the artificial island project, which includes:

1. Coral transplantation and coral restoration shall be carried out in an area of not less than 5 hectares;
2. Artificial propagation and release of Marine living resources such as white butterfly shellfish and fish.

5. Summary and Prospect
Although offshore artificial island development and construction of project cases in China, but due to a late start, with the rapid economic development of local demand, once led to get rich quick, lack of long-term comprehensive scientific planning, while special blank of the legal system and the unsound management mechanism lead to the deterioration of the Marine ecological environment, thus to some extent, restricted the coastal areas of economic and social sustainable development.

Looking into the future, China's artificial island construction will return to rationality and science, from industry priority to ecological return, and pay more attention to the integration with the natural environment to minimize man-made damage. At the same time, the need to consider the sea power, sea channel and the ecological environment factors, such as improving the traditional simple and straightforward way of reclamation and engineering layout, avoid adopting sectional bending straightening, reef connection way, maximum limit the primitiveness and diversity of the protection of the original coast, carry out scientific planning and construction of reclamation projects.

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Reference
[1] ZHANG WEI. Research on the Effective Management of Artifical Islands in China. Qingdao: Ocean University of China, 2013.
[2] XIE Shileng. The Progress of Artificial Island Design. Coastal Engineering, 1995(01):1-7.
[3] ZHANG Zhi-ming, LIU Lian-sheng, QIAN Li-ming, CAI Yan-jun. On Key Design Technology for
Large Offshore Man-made Island. Port & Engineering, 2011(S1):1-7.

[4] LIANG Heng. Study on Key Technology for Zhuhai-Macao Port Artificial Island Formation. Tianjin: Tianjin University, 2014.

[5] ZHANG Wei, CHEN Zhen, LIU Ran, CAO Hao. Researches on Water Exchange for Encircled Basin—Take Xuwei Harbor in Lianyungang As An Example. China Harbour Engineering, 2014(03):1-8.

[6] JIN Hui, KE Xue. Key Design Technology of Shuangyu Artificial Island. Port & Engineering, 2013(10):1-6.

[7] DONG Zhi-liang, LIU Jia, ZHU Xing-ke, ZHANG BO-yun, GAO Ming-xin. Key Technology Research and Application of Cofferdam Construction in Large-area Reclamation Project. Port & Engineering, 2013(05):168-175.

[8] JIANG Chang-bo, LI Yuan, GUAN Zhi-xin, DENG Bin. Numerical Simulation of Water Exchange Capability Before and After Port Construction in Tieshan Bay. Journal of Tropical Oceanography, 2013, 32(01): 81-86.