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Ecological technology model and path of seaport reclamation construction

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ABSTRACT

Reclamation plays an important role in alleviating the contradiction between the supply and demand of land. But its environmental negative effect is also obviously. Considerable research has been conducted on the environmental impact assessments of reclamation activities, but few and scattered studies have focused on how to reduce the negative impacts of reclamation projects on coastal ecosystems. Therefore, this paper considered the ecological technology integration study of reclamation construction as the breakthrough point. China, which has the highest reclamation scale worldwide, was also selected as the main research area, and its representative seaports were selected as the subjects of the study. Then, questionnaire survey and literature analysis were conducted. The ecological technology model and path of the seaport reclamation construction were studied by focusing on port site selection, port plane layout, wharf structure and plane form. Construction material selection and ecological restoration construction projects were also investigated. The suggestions regarding scientific demonstration and planning of port site selection, ecological port plane design and structure, application and innovation of recycling economy technology, and active construction of ecological restoration engineering were provided. The purpose of this research is to determine the effective implementation of ecological and environmentally friendly reclamation under a reasonable management scale, thus providing a reference for establishing the ecological technology model of reclamation and promoting the effective protection and sustainable development of marine resources from the perspective of source planning and management.

1. Introduction

Considered as an important way for human beings to develop and utilize coastal zones, reclamation plays a critical role in the coastal areas to utilize sea resources, alleviate the contradiction between land supply and demand, and expand the development space. Reclamation is a common global phenomenon and mainly distributed along the East Asian coast, the Persian Gulf coast, the western coast of Europe, and the coast of North America (Yue et al., 2015). Large-scale reclamation activities have basically ceased in the developed countries in Europe and the United States (Piersma, 2009), whereas they remain active in developing countries and some other developed countries in Asia (Li et al., 2014), particularly in China, Japan, Korea, and Persian Gulf (Martínantón et al., 2016). And the total amount of reclamation projects and the scale of individual reclamation projects in China rank first in the world (Martínantón et al., 2016). The National Sea Area Use Management Bulletin published by the State Oceanic Administration in China reported that, the confirmed and authorized total national sea reclamation accumulative area increased by 106.36 km^2 from 2002 to 2015, with an average increase of approximately 7.6 km^2 every year.

The types of reclamation land include port construction, industrial park construction, urban residential expansion, airport runway construction, agricultural land, and military strategic land. The most prominent type is the reclamation of seaports, especially since most of the seaports worldwide are constructed by occupying sea space (Martínantón et al., 2016). Port has always been an important means of global economic exchange, and China has maintained its status as a major port country in the world for a long time (Zuo et al., 2017). By the end of 2016, China's ports had 30,388 berths for production and 2317 berths at the 10,000-ton level and above, and the throughput of port cargo and container has ranked first globally for 14 consecutive years. The statistics in 2016 and 2017 indicate that the 100-million-ton ports and container ports in the mainland of China accounted for seven of the world's top 10 (Tables 1 and 2). Additionally, China not only has the largest port population but also has the largest number of port reclamation areas worldwide (Martínantón et al., 2016).

Although sea reclamation has solved the land problem and helped in economic development, it results in the change of coastline and destruction of coastal zone ecological environment (Duan et al., 2016). Due to the construction of a large number of coastal projects, including reclamation activities, the total length of coastlines in mainland China has increased continuously from 15612.6 km in 1980 to 18604.4 km in

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Table 1
Top 10 ports in the world for cargo throughput in 2016 (Unit: million tons).

Ranking	Port Name	Country or Territory	Throughput Capacity
1	Ningbo-Zhoushan Port	China	9.2
2	Shanghai Port	China	7.01
3	Singapore Port	Singapore	5.93
4	Suzhou Port	China	5.74
5	Tianjin Port	China	5.50
6	Guangzhou Port	China	5.22
7	Tangshan Port	China	5.16
8	Qingdao Port	China	5.01
9	Hedland Port	Australia	4.84
10	Rotterdam Port	Holland	4.61

Note: Data were collected from the public data of the Ministry of Transport of the People's Republic of China website (http://www.mot.gov.cn), Maritime and Port Authority of Singapore website (https://www.mpa.gov.sg), Port of Rotterdam website (https://www.portofrotterdam.com) and Pilbara ports authority (www.phpa.com.au).

Table 2
Top 10 ports in the world for container throughput in 2017 (Unit: 1×10^4 TEU).

Ranking	Port Name	Country or Territory	Throughput Capacity
1	Shanghai Port	China	4023
2	Singapore Port	Singapore	3367
3	Shenzhen Port	China	2521
4	Ningbo-Zhoushan Port	China	2464
5	Hong Kong Port	China Hong Kong	2076
6	Busan Port	Korea	2046
7	Guangzhou Port	China	2037
8	Qingdao Port	China	1830
9	Dubai Port	The United Arab Emirates	1537
10	Tianjin Port	China	1506

Note: TEU represents twenty-foot equivalent unit. Data were collected from the China Port Network (http://www.chinaports.com).

2015 (average annual increase of 85.48 km), which then led to the constant shifting of coastline types, from natural to artificial (Xu, 2016). The length of the artificial coastline has increased from 32.3% of the total coastline length in 1980 to 68.5% in 2015 (Xu, 2016). Meanwhile, the coastline of mainland China has encroached the sea in general (Xu, 2016). Except for a small part involving a natural change in deposition, the shifting can be mainly explained by large-scale land reclamation; moreover, sea reclamation for port construction is the most prevalent (Xu et al., 2013). For instance, a main reason for the dramatic change in the coastline of Tianjin in China is the construction of the Tianjin Port. The change in the natural coastline is permanent and irreversible, and such have led to the changes in the original hydrology, landform, sediments, and ecosystem structure of the coastal zone. The transformation of coastlines from natural to artificial can also alter the water flow direction and hydrodynamic force of the ocean (Murray et al., 2014; Jin et al., 2017). The coastline continues to move towards the sea, causing the loss of coastal zone wetlands and mangroves and the destruction of coastal ecosystem stability, biodiversity and services (Tian et al., 2018; Ma et al., 2017). With regard to the reclamation activities, the suspended sediment and the permanent occupation of the sea area will result in great pressures on phytoplankton and benthic organisms in nearby waters (Sun and Liu, 2014). The dredging and mining of dredged materials needed for the formation of reclaimed land and the dumping of dredged materials will also alter the landform and sediments, and eventually influence the carrying capacity of the marine environment (Suo et al., 2015).

Constructing the coastal zone building engineering by ecological and sustainable ways is increasingly emphasized (Firth et al., 2014), and the related researches have been studied worldwide. However, the main focus is on the ecological construction of defensive infrastructures, such as coastal zone banks and dikes. Masria et al. (2015) studied different types of coastal defense systems around the world and determined four types, namely, hard types (seawall, revetments, bulkhead, dikes, and levees), soft types (beach fills, dredging or sand bypassing, and sand dune stabilization), submerged types (submerged breakwaters, perched beaches, and artificial headlands), and innovative types (geotextile structures, beach drainage systems, beach management systems, and pressure equalization modules). They proposed that the innovative and soft coastal zone protection systems can significantly improve the recovery of beaches without affecting the environment and aquatic habitats. Perkins et al. (2016) also found that “soft” engineering is effective in protecting biodiversity, nutrient structure, ecosystem function and service, and the connectivity among habitats. In practical application, Shin et al. (2016) found that the use of stacked geotextile structure in port construction can effectively protect the beach line and improve the safety of coastal zone buildings. Ng et al. (2015) determined that reef biota can be transplanted to the inter-tidal zone of seawall, which can not only improve the biodiversity of coastal zone constructions, but also form biological protection and effectively enhance the ecological value of seawall. Sherrard et al. (2016) found the porous coastal defense structures can contribute to biodiversity conservation, the internal surface of artificial structures has a benign environment that avoids dry pressure and reduces scour from moving sediments. Through the physical model experiment of movable bed, Smith et al. (2017) found that dredged soil has great applicability in inshore and surf areas, and can play a certain role in wave elimination. Healy et al. (2002) identified that disposing the dredged materials of sea channels in the water depth of approximately 5 m in the surf zone can rearrange the section of sub-tidal beach and cause the beach dimension to be in a healthy state.

However, the researches on the specific ecological planning, designs and technologies application for the ecological construction of reclamation projects are limited. With regard to seaport construction in which reclamation activities are the most prevalent, many countries have identified green ports as the target for port development. Regardless whether such ports are in Australia, Japan, US, UK, China, or other countries with rich experiences in green and ecological port construction, the main focus is on environmental protection measures that can be implemented in the construction process during operational management. Pollution control, energy saving, and emission reduction (such as in Sydney Port, Long Beach Port, Liverpool Port, and Valencia Port) have been the typical focus of seaport reclamation projects, but the application of ecological planning concepts and technologies in specific engineering contexts is still insufficient. Moreover, no integrated research has been conducted on how to determine the suitability of different ecological reclamation technologies under different environmental constraints, and considered which ecological technologies should be popularized and innovated.

Reclamation activities in many developed countries have generally ceased. However, reclamation in controllable scales is needed in developing countries. Given these contexts, the aim of this study is not to encourage reclamation activities but to explore how to conduct reclamation in reasonable management scales and one that is more ecological and environmentally friendly than the current practice. According to Odum and Odum (2003), the design of ecological engineering should not end with the construction of reinforced concrete but with the application of ecological technology, and thus, the reclamation can be matched with the ocean and coastal zone system. Accordingly, this paper discusses and summarizes the ecological technology models and paths of seaport reclamation by combining the technology models of seaport site selection, plane layout design, engineering structure, and ecological restoration in the process of seaport reclamation. On the one hand, this research can guide the scientific and reasonable development and construction of seaports from the aspects