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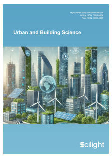

Article

Coupling Mechanism of Ecological Resilience and Flood Control Engineering: A Four-Dimensional Framework for Coastal Park Disaster Reduction—A Case Study of the Dike Improvement Project of Dajiaoshan Coastal Park in Nansha

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Abstract: Aiming at the dual challenges of storm surge safety and landscape conservation in coastal parks, existing studies often separate ecological resilience from flood control engineering, lacking an integrated framework to coordinate the two, thus failing to provide effective technical support. This study proposes their coupling mechanism and constructs a four-dimensional framework centered on engineering, ecological, social and governance resilience. Adhering to the "adapting measures to local conditions and time" strategy, it integrates four technical systems to build a safe, adaptive and sustainable natural-artificial collaborative disaster prevention barrier. Taking Nansha Dajiaoshan Coastal Park's flood control improvement as an empirical case, the model solves traditional pain points such as sea view obstruction and ecological damage, raising the flood control standard from less than 20-year to 200-year return period, and achieving multi-dimensional balance. It fills the research gap, provides a global reference, enriches coastal disaster risk management research, and promotes the integrated development of ecological resilience and engineering technology.

Keywords: ecological resilience; flood control barrier; landscape-integrated levee; hierarchical wave reduction; flood retention and regulation

1. Introduction

1.1. Research Background and Significance

The Pearl River Estuary, as one of the most economically active coastal areas in China, is affected by global climate change with frequent extreme rainstorms, strong typhoons and other disastrous weather events, leading to a significant increase in flood and storm surge risks in coastal areas. As the boundary zone between land and ocean, the coastal zone has special land-sea composite attributes and is vulnerable to the dual disturbances of human activities and climate change [1]. Traditional flood control engineering generally has outstanding problems such as ecological fragmentation and high cost, with the core contradictions concentrated in three aspects: first, the contradiction between flood control safety and landscape continuity, as the traditional high dike design is easy to block the sea view and separate the organic connection between the park and the coastal landscape; second, the contradiction between engineering measures and ecological protection, as the construction of hard engineering structures is easy to damage the original vegetation and topographic texture of the site, affecting the integrity of the ecosystem; third, the contradiction between construction cost and resource utilization, as the new construction requires a huge amount of earthwork and high investment cost, while ignoring the potential utilization value of existing facilities.

In the construction of urban flood control dikes, urban dike projects such as the Lingshan Island Super Dike [2], Qianhai Sea Dike in Shenzhen [3] and Sanzao Bay Sea Dike in Zhuhai [4] mostly focus on the shaping of urban landscape and image. Most of them are rebuilt on the basis of the original dikes, failing to fully take into account the value of the original dikes, and ignoring the ecological and safety value of the original ecology and vegetation along the coastal line. Traditional sea dikes adopt the integrated tide and wave defense design in accordance with the Code for Design of Sea Dike Engineering (GB/T 51015—2014) of China, which has great limitations with the enhancement of tide and wave dynamics and the improvement of urban construction requirements. On this basis, the sea dike design based on “wave-tide separation” puts more emphasis on the diversification of protective measures, focusing on the diversified integration of engineering and ecology.

The resilience of engineering has been gradually strengthened on the hard basis of traditional dike engineering, and engineering resilience has long been regarded as the mainstream view of resilience. With the deepening of the academic understanding of system and environmental characteristics and their interaction mechanisms, the traditional engineering resilience theory has gradually shown the shortcomings of rigidity and singleness [5]. Holling [6] argued that resilience should include the magnitude of disturbance that a system can absorb before changing its own structure. Liao pointed out that ecological resilience emphasizes the ability of a system to survive regardless of whether its state changes [7], while engineering resilience emphasizes the ability to maintain stability, ensuring that the system has as little fluctuation and change as possible. Walker et al. proposed that resilience should not only be regarded as the recovery of a system to its initial state, but also the ability of a complex social-ecological system to change, adapt and transform in response to pressures and constraints [8].

This study focuses on the core demand of “coordination between flood control safety and landscape ecology”, and explores the flood control improvement path of efficient utilization of existing resources and integrated application of ecological technologies. At present, the uncertainty faced by urban development [9] has increased significantly, and the accompanying disaster risks have shown a global, social and multiple transformation. Coordinating the relationship between man and nature, mitigating the impact of external disturbances, and enhancing disaster resistance capacity have become key issues to promote the sustainable development of cities [10]. The delta urbanism theory puts forward the core strategy of ecological water conservancy projects of “co-construction with nature” [11]. Wu Zhiqiang proposed that in the face of disaster shocks, cities need a complete resilient spatial system to minimize damage during disasters and achieve rapid recovery after disasters [12].

Nature-based Solutions (NbS) have received extensive attention in the field of urban flood control [13,14]. SECURE-NBS conceptualizes the outcomes of NbS as a co-produced social-ecological process, in which benefits and trade-offs interact dynamically across spatial and temporal scales [15]. Studies have shown that the combination of green infrastructure and gray infrastructure can significantly improve the comprehensive resilience of the system [16–18].

However, existing studies mostly focus on theoretical discussion or single technology application, lacking systematic empirical research on the multi-dimensional coupling mechanism of “safety-ecology-landscape” in coastal parks in high-density built-up areas. Especially in the context of frequent extreme climate events, how to quantitatively evaluate the wave dissipation efficiency of ecological measures is still a key scientific issue to be solved [19] urgently.

This study focuses on the core demand of “coordination between flood control safety and landscape ecology”, and explores the flood control improvement path of efficient utilization of existing resources and integrated application of ecological technologies. It aims to construct a replicable and popularizable disaster prevention logic system of “natural-artificial system coordination”, and promote the transformation of flood control engineering from simple “engineering safety” to “ecological safety + landscape experience + climate adaptation”.

1.2. Research Objectives

The core objective of this study is to solve the core pain points in the current field of urban flood and storm surge prevention, construct a multi-dimensional integrated natural-artificial collaborative disaster prevention logic system, and maximize the disaster prevention efficiency and achieve multi-benefit synergy and win-win results. Godschalk [20] argued that a resilient city should be a combination of sustainable physical systems and human communities, and the planning of physical systems should play its role through the construction of human communities. This view provides core theoretical support for the construction of disaster prevention logic in this study.

The core of the natural-artificial system collaborative disaster prevention logic is to break the separation between engineering and nature, and between disaster prevention and people's livelihood, adhering to the design strategy of "adapting measures to local conditions and time". At the design strategy level, "adapting measures to local conditions and time" runs through the whole process: "adapting to local conditions" is reflected in adapting to the natural background and historical texture such as site topography, hydrology and vegetation, and formulating differentiated technical schemes; "adapting to time" is manifested in responding to the stochastic characteristics of storm surge disasters and realizing the time elastic transformation of "normal-emergency integration". The research is carried out around four dimensions: flood control safety, landscape ecology, resource utilization and economic optimization:

1. In terms of flood and storm surge prevention safety, the flood control standard is increased to 200-year return period, breaking through the limitation of single engineering measures to resist the superimposed risk of extreme storm surge and rainstorm; through zoning guidance, restricting spatial development, or relying on blue-green infrastructure to reduce the impact of floods.
2. In terms of landscape ecology, realize the organic integration of dikes and park landscape, ensure the permeability of sea view, and improve the ecosystem service function of the site [21].
3. In terms of resource utilization, maximize the activation of existing resources such as original vegetation, old dikes, squares and landscape lakes in the park, and reduce the disturbance of engineering construction to the site.
4. In terms of economic optimization, precisely control the scale of engineering investment and reduce later operation and maintenance costs.

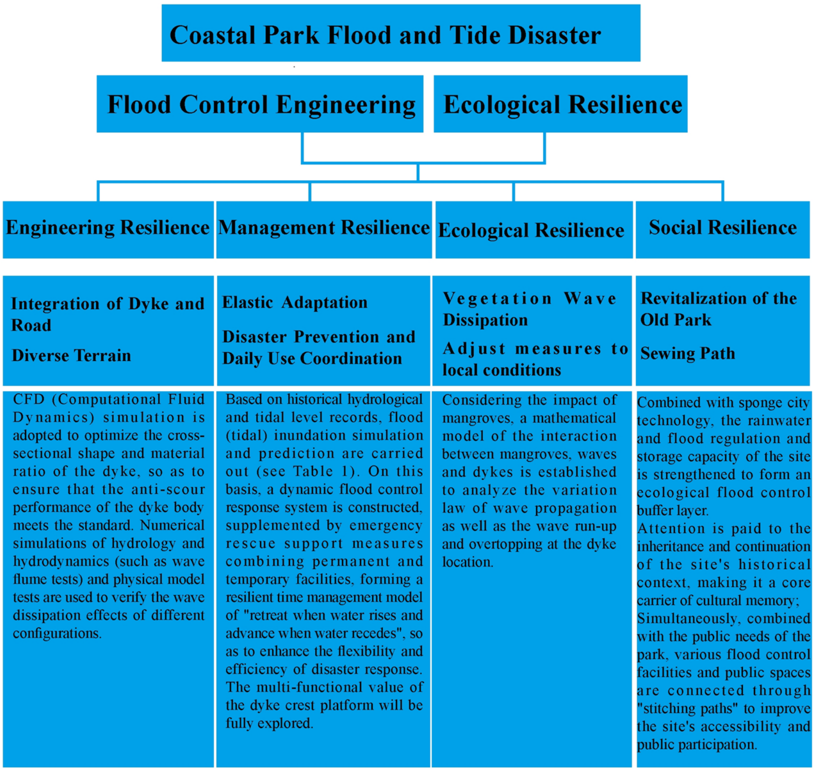
In summary, this study clearly targets the core problems of "insufficient efficiency of single engineering defense, separation between engineering and nature as well as people's livelihood, and inefficient utilization of site resources" in current urban flood and storm surge prevention. It deeply integrates the resilient city theory with flood control engineering practice, and finally proposes the construction path of composite space under the design concept of "natural-artificial system collaborative disaster prevention logic". Taking the flood control improvement project of Dajiaoshan Coastal Park in Nansha as the empirical carrier, it verifies the feasibility and comprehensive benefits of the ecological flood control technology system. It can provide a reference practical path for urban flood and storm surge prevention under the coupling mechanism, enrich the theoretical system of natural-artificial system collaborative disaster prevention in the field of urban research, provide new ideas and methods for the application of ecological flood control technology in architectural science, and help improve the level of urban resilience construction.

2. Research Methods and Technical System

2.1. Coupling Mechanism between Ecological Resilience Theory and Flood Control Engineering

The Resilient Cities Network defines a "resilient city" as a city system that has anti-interference ability and resilience capacity at both software and hardware levels when facing risk shocks, can reduce risks and losses, quickly recover to the original state, or achieve a better new state through adaptation [22]. Jha, Miner and Stanton-Geddes argued that urban resilience has four main components, namely infrastructural resilience, institutional resilience, economic resilience and social resilience [23]. Recent studies have further emphasized the application of the "adaptive cycle" in flood control engineering. For example, Zhang et al. (2023) pointed out that flood control strategies for coastal cities should shift from static defense to dynamic adaptation [24], fully considering the uncertainty of sea level rise; model simulations confirmed that the combination of mangroves and offshore submerged dikes can reduce wave overtopping by 40–60% under extreme storm surges [25]. In addition, studies targeting the Guangdong-Hong Kong-Macao Greater Bay Area have shown that the composite ecological sea dike can reduce the whole life cycle cost by about 30% [26] compared with the traditional sea dike while improving biodiversity. These latest achievements provide solid theoretical support for the construction of the "rigid-flexible composite" technical system in this study.

Taking the dike improvement project of Dajiaoshan Coastal Park in Nansha as an example, this study couples ecological resilience with urban flood control engineering. Through systematic investigation and follow-up research of the park project, combined with the whole construction process and implementation effect of the project, it constructs a resilience improvement system with both scientificity and practicability. In the dimension of resilience objectives, this study constructs a four-dimensional collaborative improvement system with engineering resilience, ecological resilience, social resilience and governance resilience as the core goal orientation: (see Figure 1)



Engineering Resilience	Management Resilience	Ecological Resilience	Social Resilience
Integration of Dyke and Road Diverse Terrain	Elastic Adaptation Disaster Prevention and Daily Use Coordination	Vegetation Wave Dissipation Adjust measures to local conditions	Revitalization of the Old Park Sewing Path
CFD (Computational Fluid Dynamics) simulation is adopted to optimize the cross-sectional shape and material ratio of the dyke, so as to ensure that the anti-scour performance of the dyke body meets the standard. Numerical simulations of hydrology and hydrodynamics (such as wave flume tests) and physical model tests are used to verify the wave dissipation effects of different configurations.	Based on historical hydrological and tidal level records, flood (tidal) inundation simulation and prediction are carried out (see Table 1). On this basis, a dynamic flood control response system is constructed, supplemented by emergency rescue support measures combining permanent and temporary facilities, forming a resilient time management model of "retreat when water rises and advance when water recedes", so as to enhance the flexibility and efficiency of disaster response. The multi-functional value of the dyke crest platform will be fully explored.	Considering the impact of mangroves, a mathematical model of the interaction between mangroves, waves and dykes is established to analyze the variation law of wave propagation as well as the wave run-up and overtopping at the dyke location.	Combined with sponge city technology, the rainwater and flood regulation and storage capacity of the site is strengthened to form an ecological flood control buffer layer. Attention is paid to the inheritance and continuation of the site's historical context, making it a core carrier of cultural memory; Simultaneously, combined with the public needs of the park, various flood control facilities and public spaces are connected through "stitching paths" to improve the site's accessibility and public participation.

Figure 1. Technical Architecture Diagram.

- Engineering resilience focuses on the stability and adaptability of the core flood control structure, and builds the foundation of disaster resistance through structural optimization and technological innovation;
- Ecological resilience relies on the self-organization capacity of the original and reconstructed ecosystems to realize ecological disaster mitigation functions such as wave reduction and soil and water conservation;
- Social resilience takes the improvement of public participation and cultural inheritance as the core, and enhances public recognition and enthusiasm for disaster prevention through space sharing and functional compounding;
- Governance resilience focuses on dynamic response and emergency dispatch, and improves the efficiency and flexibility of disaster response through elastic design.

At the technical system level, the “numerical simulation–physical model–engineering practice” integrates four core technologies: diversified engineering disaster mitigation, ecological barrier disaster mitigation, renewal of existing parks, and normal-emergency integration, forming a systematic disaster prevention barrier with complementary functions and synergistic efficiency, and providing practical reference for the coupling construction of similar urban flood control engineering and ecological resilience.

2.2. Project Overview and Study Area

The ecological dike project area is located in Dajiaoshan Coastal Park in the south of Jiaodong Joint Embankment, Nansha New District, Guangzhou. The dike of the park is generally east-west oriented. The west end of the dike line is connected with the Huigu Super Dike, and the east end is closed by the mountain near the north gate of the park, forming a closed protection circle with a total length of about 1.43 km. According to the planning, the flood control standard of Dajiaoshan Coastal Park is 200-year return period.

This area is located in the estuary area of the Pearl River Delta. The Pearl River Estuary is a weak tide estuary, the tide is irregular semidiurnal tide, and the diurnal tide inequality is significant. The tidal type in the sea area is irregular semidiurnal tide, with an average tidal range of 1.32 m (urban construction datum) and a maximum tidal range of 3.7 m (urban construction datum) [27] over the years. It is mainly affected by typhoon storm surges from the open sea. The tide gauge stations near the project area are Nansha Station and Dahu Station. The original vegetation outside the old dike is mainly coastal mangroves and *Casuarina equisetifolia* forest belts, mainly concentrated in the coastal area on the west side of the site, and the inner side of the old dike is mainly *Ficus microcarpa* community. The total area of the project is 800,000 m^2, with a coastal line of about 1.5 km.

The original flood control facilities of the park were built around 2000, with a flood (storm surge) prevention capacity of less than 20-year return period. The main park road, Binhai Avenue, runs through the park from east to west, with a total length of 1.5 km. The original dike crest elevation was 6.3–8.6 m (urban construction datum), and the wave-facing surface was protected by masonry with mortar. There were problems such as insufficient dike crest elevation, aging of the facing structure, and weak wave dissipation capacity. The dike was seriously damaged after long-term wind and wave erosion (see Figure 2), and the risk of wave overtopping under extreme weather was prominent.

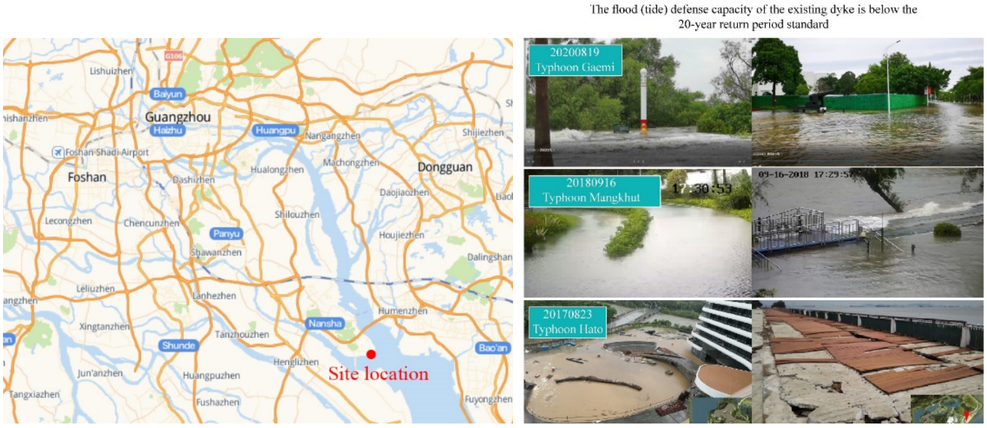


Figure 2. The disaster report of the base.

2.3. Data Collection and Processing

- For hydrometeorological data, the hourly tide level data from 1963 to 2018 of Nansha Station, from 1984 to 2018 of Dahu Station, historical typhoon tracks and storm surge water increase data were collected. According to the analysis results of the Special Study on Flood Control Elevation Demonstration of Outer River Dikes in Nansha District: Review of Design Tide Level and Water Surface Line Results in Nansha District (China Water Resources Pearl River Planning Survey and Design Co., Ltd., March 2020, Guangzhou, China), the design tide level of Nansha Station is adopted for the project location.
- For topographic and geomorphic data, UAV tilt photogrammetry technology was used to obtain a Digital Elevation Model (DEM) with an accuracy of 0.05 m, combined with underwater multi-beam sounding data, to construct a complete integrated land-water topographic model.
- For vegetation and ecological data, field quadrat surveys were conducted to record the species, diameter at breast height, crown width, root distribution and density of the original vegetation, and a vegetation parameter database was established.

2.4. Combination of Numerical and Physical Models

This study adopts the relevant technical methods of the Pearl River Hydraulic Research Institute to carry out numerical simulation research on the rationality of the dike reconstruction and improvement of Dajiaoshan Coastal Park. To fully consider the influence of mangroves on the hydrological and hydrodynamic characteristics of the dike, the numerical control equation was first modified, and a mathematical model of mangrove-wave-dike interaction was established. The study focuses on analyzing the law of wave propagation, wave run-up and overtopping characteristics at the dike position, clarifying the wave run-up on the dike body and wave overtopping at the dike crest after the construction of Dajiaoshan ecological dike, and providing theoretical support for the dike reconstruction and improvement.

Based on the Navier-Stokes equation, this study uses the CFD open source program OpenFOAM to develop a three-dimensional numerical simulation model for hydrological and hydrodynamic simulation of wave run-up on the ecological dike of Dajiaoshan. Considering the momentum damping effect of mangrove vegetation, the Navier-Stokes momentum equation is modified by introducing vegetation drag force and inertia force terms. The modified momentum equation is as follows:

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\frac{2}{3}\mu\frac{\partial u_k}{\partial x_k}\delta_{ij}\right]+\rho g_i-F_{d,i}-F_{i,i}$$

where: ρ is the water density (kg/m^3); u_i, u_j, u_k are the velocity components in x, y, z directions (m/s); t is time (s); p is pressure (Pa); μ is the dynamic viscosity coefficient of water (Pa·s); δ_{ij} is the Kronecker symbol; g_i is the component of gravitational acceleration (m/s^2); $F_{d,i}$ is the component of vegetation drag force (N/m^3); $F_{i,i}$ is the component of vegetation inertia force (N/m^3).

The vegetation drag force and inertia force are calculated by the following formulas:

$$F_{d,i} = \frac{1}{2}\rho C_d a u|u|u_i$$

$$F_{i,i} = \rho C_M a \frac{\partial u_i}{\partial t}$$

where: C_d is the vegetation drag coefficient; a is the projected area density of vegetation (m^2/m^3); $|u|$ is the velocity modulus (m/s); C_M is the vegetation inertia force coefficient. In OpenFOAM, the drag coefficient (C_d) is set to 1.52, the inertia force coefficient $C_M = C_m + 1$ is set to 2 (Sumer and Fredsoe, 2006), and the plant density is set to 1 plant/m^2. To accurately simulate the blocking difference of different parts of the plant on the water body, a hierarchical coefficient assignment method is adopted to generalize the blocking effect of plant roots, stems and leaves.

The total numerical simulation period is set to 800~1000 s, and the time step (Δt) adopts adaptive mode; the modified k-ε turbulence model is used to simulate the turbulence vortex characteristics near the vegetation area, and its control equations are as follows:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho u_j k)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right) + G_k - \rho\varepsilon - Y_k$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho u_j \varepsilon)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right) + C_{1\varepsilon}\frac{\varepsilon}{k}G_k - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} - Y_\varepsilon$$

where: k is the turbulent kinetic energy (m^2/s^2); ε is the dissipation rate of turbulent kinetic energy (m^2/s^3); μ_t is the turbulent viscosity coefficient (Pa·s); σ_k and σ_ε are the turbulent Prandtl numbers of k and ε respectively; G_k is the generation term of turbulent kinetic energy; Y_k and Y_ε are the correction terms of turbulent kinetic energy and dissipation rate under the action of vegetation; $C_{1\varepsilon}$ and $C_{2\varepsilon}$ are empirical constants. The improved Volume of Fluid (VOF) transport function is used to accurately capture the motion interface between air and water, and the VOF equation is as follows:

$$\frac{\partial \alpha}{\partial t} + u_j\frac{\partial \alpha}{\partial x_j} = 0$$

where: α is the volume fraction of water, $\alpha = 1$ represents the pure water area, $\alpha = 0$ represents the pure air area, and $0 < \alpha < 1$ represents the gas-liquid interface area.

The finite volume method is adopted for the discretization of the control equations. Its core idea is to integrate the mass conservation equation and momentum conservation equation in the grid cell to realize the discretization of the control equations. The integral form is as follows:

$$\int_V \frac{\partial(\rho\varphi)}{\partial t}dV + \oint_A (\rho\varphi u_j)\cdot dA = \oint_A \Gamma_\varphi \frac{\partial\varphi}{\partial x_j}\cdot dA + \int_V S_\varphi dV$$

where: φ is the general variable (which can represent velocity, k, ε, α, etc.); Γ_φ is the diffusion coefficient of the general variable; S_φ is the source term; V is the volume of the grid cell (m^3); A is the surface area of the grid cell (m^2). The calculation area is divided into several regular or irregular micro grid cells, and the balance calculation of mass conservation and momentum conservation is carried out for each grid cell respectively; the PIMPLE algorithm (combining the advantages of SIMPLE algorithm and PISO algorithm) is used to discretize and solve the control equations, and finally the pressure field and velocity field satisfying mass conservation are obtained.

Wave generation adopts the numerical boundary wave making method. By setting the analytical or numerical solution of the wave on the fixed boundary, the velocity of water particles is determined to realize the accurate generation of the target wave; wave absorption adopts active wave absorption technology, which can effectively suppress the reflection of waves at the boundary by adding the method of correcting the velocity boundary, so as to ensure the accuracy of simulation results.

2.5. Four-Dimensional Technical Framework System

The construction of the flood and storm surge prevention engineering system is based on the natural and humanistic background of the site, comprehensively considering the core elements such as topography, hydrological regime, vegetation distribution and historical texture. Through refined field surveying and mapping and ecosystem assessment, coupled with historical hydrological data and climate prediction results, a flood control system with both safety and adaptability is constructed, and sufficient spatial elasticity is reserved to cope with the uncertainty of the future environment and disasters. At the technical level, through systematic analysis of key data such as site elevation, soil bearing capacity and vegetation distribution, it provides quantitative support for the formulation of differentiated design strategies.

Aiming at the occasionality and irregularity of storm surge disasters, an elastic engineering system is constructed with “rigid-flexible composite” as the core: at the rigid level, the stability of the core flood control structure is strengthened; at the flexible level, the adaptive capacity of the system is improved through ecological design; at the same time, a multi-objective optimization engineering structure framework is established to realize the collaborative balance of multiple objectives such as flood control safety, ecological protection and space utilization.

(1) Engineering Resilience Disaster Mitigation System

The integrated design strategy of “dike-road integration” is adopted, and a graded hierarchical disaster mitigation system is constructed combined with cascade layered layout, so as to realize the intensive utilization of land resources while improving flood control efficiency. Through the road lifting technology, the original park road is integrally lifted above the flood control design water level, and the road structure itself is used as the main body of the dike, which greatly reduces the area of new hardened ground and the disturbance to the ecological environment of the site.

Based on the topographic characteristics of the site, the area is divided into three functional levels: preliminary wave dissipation zone, main flood control dike zone and rear buffer zone. A multi-level wave energy dissipation system is formed through the classification of terrain elevation difference. Among them, the preliminary wave dissipation zone adopts shoal wetland and cascade section design, which can effectively dissipate and break the incident wave energy, reduce the scouring erosion of ground cover plants during the backwater period, and has the functions of rainwater collection and soil and water conservation at the same time; the main flood control dike body adopts the composite structure form of dense concrete or eco-bags filled with block stones, which takes into account the ecological connectivity inside and outside the dike body on the basis of ensuring the structural strength and flood control stability; the rear buffer zone is planted with a large area of native ground cover plants under the premise of meeting the wave overtopping specifications, to create an ecological environment suitable for the natural growth of local vegetation, and further improve the ecological resilience of the system.

For the construction waste generated by the dike reinforcement project, a resource recycling strategy is adopted. The demolished concrete fragments, bricks and stones are crushed and used as the basic filler for terrain shaping, which not only reduces the project construction cost, but also reduces the discharge of solid waste, practicing the concept of ecological cycle. Relying on recycled materials to stack and shape abstract terrain, combined with lighting system and vegetation embellishment, a “disaster prevention narrative landscape” carrying the connotation of disaster prevention and control is constructed, realizing the organic integration of disaster mitigation function and cultural communication.

In the dike shape design, streamlined or stepped section shape is adopted, which not only conforms to the law of hydrodynamics to reduce the local flow velocity and weaken the flow scouring force, but also forms the visual focus of the site and improves the landscape aesthetic value. To realize the balance between function and aesthetics, the dike section shape and material ratio are optimized through Computational Fluid Dynamics (CFD) simulation to ensure that the anti-scouring performance of the dike body meets the standard; for large-scale terrain reconstruction design, hydrological and hydrodynamic numerical simulation such as wave flume and physical model tests are used to verify the wave dissipation effect of different forms, so as to accurately control the unity of artistic design and disaster mitigation function.

(2) Ecological Resilience Barrier Disaster Mitigation System

Focusing on the ecological integration goal of ecological dike construction, a comprehensive technical path is adopted based on the protection of original ecology, with multi-level vegetation wave dissipation as the core and intensive engineering structure as the support. In the planning stage, priority is given to the protection of existing plant forest belts, and the bypass dike layout strategy is adopted to take the original forest belt as the first ecological barrier.

The vegetation configuration is dominated by salt-tolerant species with developed root systems, priority is given to local salt-tolerant and wind-resistant tree species such as *Casuarina equisetifolia* and *Pittosporum tobira*, matched with mangroves, *Phragmites australis*, shrubs and ground cover to form a multi-level wave dissipation forest belt. Its planting density and wave dissipation efficiency are accurately determined through hydrological and hydrodynamic physical model tests and numerical simulation. For example, mangroves can achieve 30–50% wave height reduction [28].

The dike body structure adopts concealed treatment, and the form with less land occupation such as wave wall is optimized to compress the land use width. Combined with fine terrain adjustment, the dike is embedded into the forest land or green space to avoid the rigid engineering interface and maintain the natural texture of the site. Finally, the coordinated development of flood control safety and ecological protection is realized.

(3) Social Resilience Disaster Mitigation System

Adhering to the concept of “renewal of the existing park”, a trinity functional composite space system of “history-ecology-disaster prevention” is constructed to realize the organic integration of dike engineering and the renewal of the existing park. In the implementation of the project, for the areas with high original elevation of the site, the sections with solid foundation are directly retained or locally reinforced, and incorporated into the main structure of the dike, which greatly reduces the amount of demolition and reconstruction works and improves the engineering economy.

Combined with Sponge City technology, rain gardens are planned and constructed in the low-lying areas of the existing park to strengthen the rainwater and flood regulation and storage capacity of the site. At the same time, the internal water surface is integrated into the dike flood control barrier system to form an ecological flood control buffer layer. Attention is paid to the inheritance and continuation of the historical context of the site, and the historical traces such as the old dike body and the original path texture are retained to make them the core carrier of cultural memory.

Synchronously, combined with the public demand of the park, new functions such as viewing platforms and ecological education nodes are implanted, and various flood control facilities and public spaces are connected through “connective paths”, so as to improve the accessibility of the site and public participation, and finally meet the functional demand of elastic land use.

(4) Governance Resilience Disaster Mitigation System

Aiming at the stochastic characteristics of storm surge disasters, a flexible time elastic system is constructed with “elastic adaptation and normal-emergency coordination” as the core, to realize the dynamic balance between flood control safety and space utilization. In the technical path, flood (storm surge) inundation simulation and prediction are carried out through historical hydrological tide level records (see Table 1), and a dynamic flood control response system is built on this basis.

At the facility construction level, adjustable ecological dike design is adopted, matched with permanent-temporary combined emergency rescue guarantee measures, forming an elastic time management mode of “land retreat with water advance and land reclamation with water recession”, and improving the flexibility and efficiency of disaster response. At the same time, the multi-functional value of the dike crest platform is fully explored. On the basis of meeting emergency traffic and rescue dispatch, daily service functions such as viewing and popular science education are added, and the attribute of emergency shelter is superimposed. Through the elastic transformation of functions, “normal-emergency integration” is realized, and the comprehensive utilization benefit of the site is maximized.

Table 1. Statistical Table of Guarantee Rate and Inundation Frequency of Different Water Levels.

Tide Level (m, Urban Construction Datum)	Cumulative Frequency (%)	Guarantee Rate (%)	Average Monthly Inundation Frequency (Times)
5.68	23.9	76.1	28
5.88	15.8	84.2	18
6.00	11.5	88.5	14
6.20	5.9	94.1	7

3. Engineering Practice and Effect Evaluation

3.1. Engineering Practice

The flood control standard of the sea dike in this project is designed according to the 200-year return period. Due to the high landscape requirements of this section of dike, if the traditional “high dike hard barrier” design mode of flood control engineering is adopted, although the flood control capacity can be improved, the tall and hard dike body will seriously separate the park from the coastal landscape, damage the landscape continuity and recreational experience; it is also easy to cause topographic damage and vegetation degradation, which violates the concept of ecological protection. Therefore, this design tries to reduce the dike crest elevation as much as possible to meet the landscape requirements.

The dike is connected from the Dajiaoshan Sluice, arranged northeastward through the banyan forest, intersects with Binhai Avenue about 200 m southwest of Xinghai Conference Center, then arranged along Binhai Avenue until a reserved land northeast of the sea viewing platform. The newly built dike is arranged along the northwest side of the reserved land, and then continues to be arranged northeastward until the north gate of the Coastal Park. According to the site survey and measurement results, the current elevation of this place is higher than the 200-year return period tide level, about 0.5 m (urban construction datum) lower than the designed dike crest elevation, and it is within the protection scope of the Dajiaoshan Fort cultural relics. Therefore, when the 200-year return period tide level is reached, the dike section from the north gate of the Coastal Park to the foot of Dajiaoshan Mountain forms a closed dike through temporary flood control measures such as stacking sandbags to achieve the purpose of flood and storm surge prevention

The dike adopts a three-level ecological dike layout. The first-level dike is the main dike arranged offshore, reaching the design elevation at the first-level dike. According to the numerical simulation calculation and analysis results (see Figure 3), the dike crest elevation is as follows: the dike elevation from Dajiaoshan Sluice to Binhai Avenue about 200 m southwest of Xinghai Conference Center is 8.96 m (urban construction datum); the dike elevation from Binhai Avenue about 200 m southwest of Xinghai Conference Center to a reserved land northeast of the sea viewing platform (originally planned beach land) is 9.26 m (urban construction datum); the dike crest elevation from the newly built dike along the reserved land to the north gate of the Coastal Park is 8.96 m (urban construction datum). (see Figure 4).

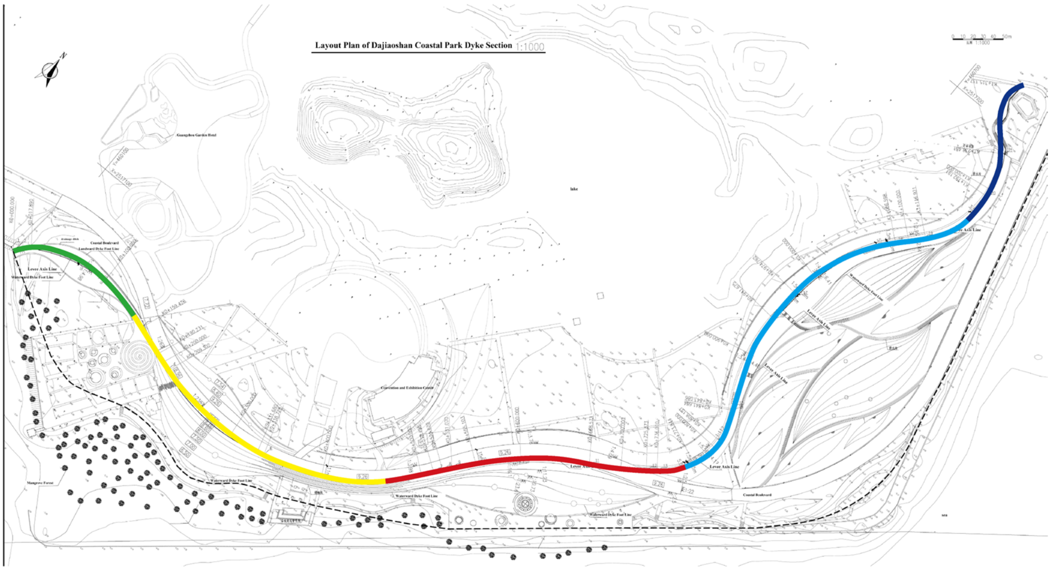
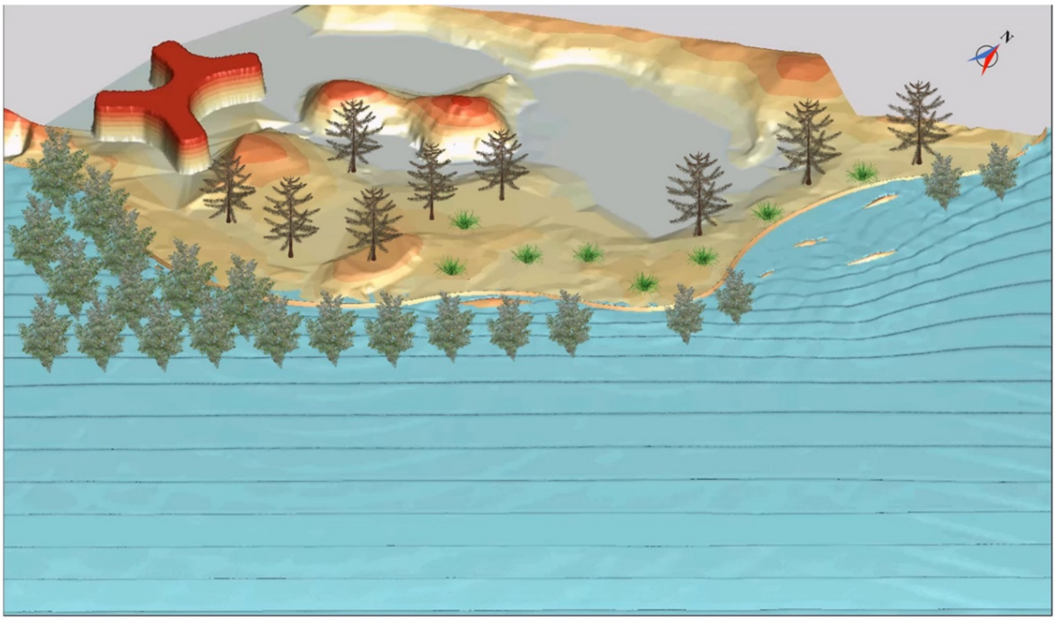
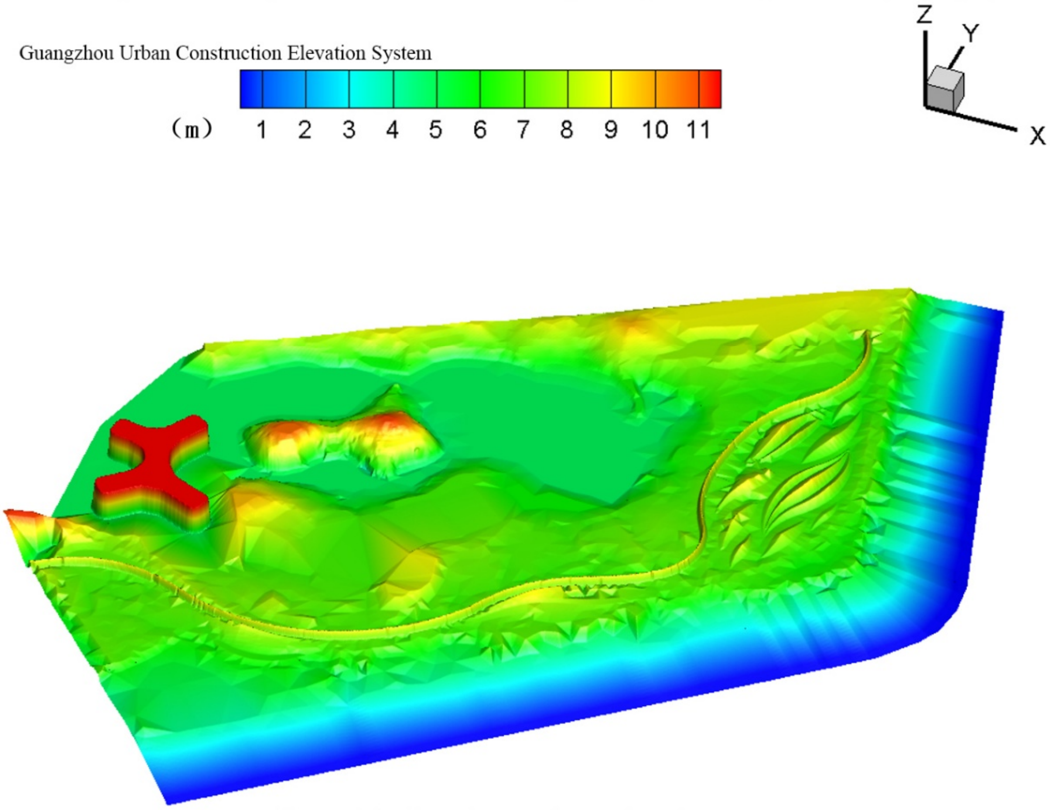


Figure 3. Levee Layout Plan.



200-year return period effective wave superimposed on planned topography



Overall Model Elevation Schematic Diagram

Figure 4. Three-dimensional (3D) numerical model.

The second-level dike is the existing park road Binhai Avenue. Except for the local reconstruction of the intersection with the first-level dike, the rest basically maintains the current elevation of Binhai Avenue of 6.53~6.91 m (urban construction datum).

The third-level dike is the original old dike, which is a space composed of mangroves, ecological riprap and hydrophilic trails. To ensure the function of the trail and good hydrophilic experience of tourists, the third-level dike should not be frequently inundated, and its elevation is set at 6.2 m (urban construction datum) (see Figure 5).

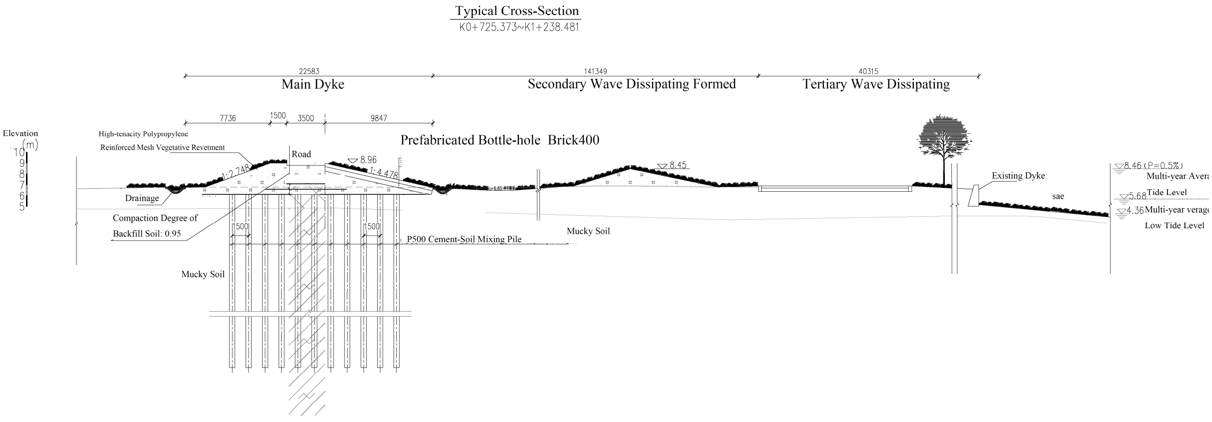


Figure 5. Typical Levee Cross-Section.

The mangrove restoration area is located on the south side of Dajiaoshan Coastal Park in Nansha District, Guangzhou, with a total planting area of 40,183 m^2. The most important prerequisite for mangrove restoration is to create suitable forest land. The distribution and growth of mangroves are affected by many factors, such as temperature, ocean current, wave, bank slope, salinity, tide and sediment quality. Among them, wave shelter conditions and tidal inundation degree are the most important factors affecting their distribution. The former controls the coastal distribution area of mangroves and is a necessary environmental condition for the growth of mangroves. The latter controls the horizontal distribution of mangroves on the tidal flat, that is, mangroves can only occupy the tidal flat surface between the mean sea level (or slightly above) and the high tide level of spring tides. The elevation range of the mangrove edge is 4.5~5.5 m (urban construction datum) (see Figure 6).

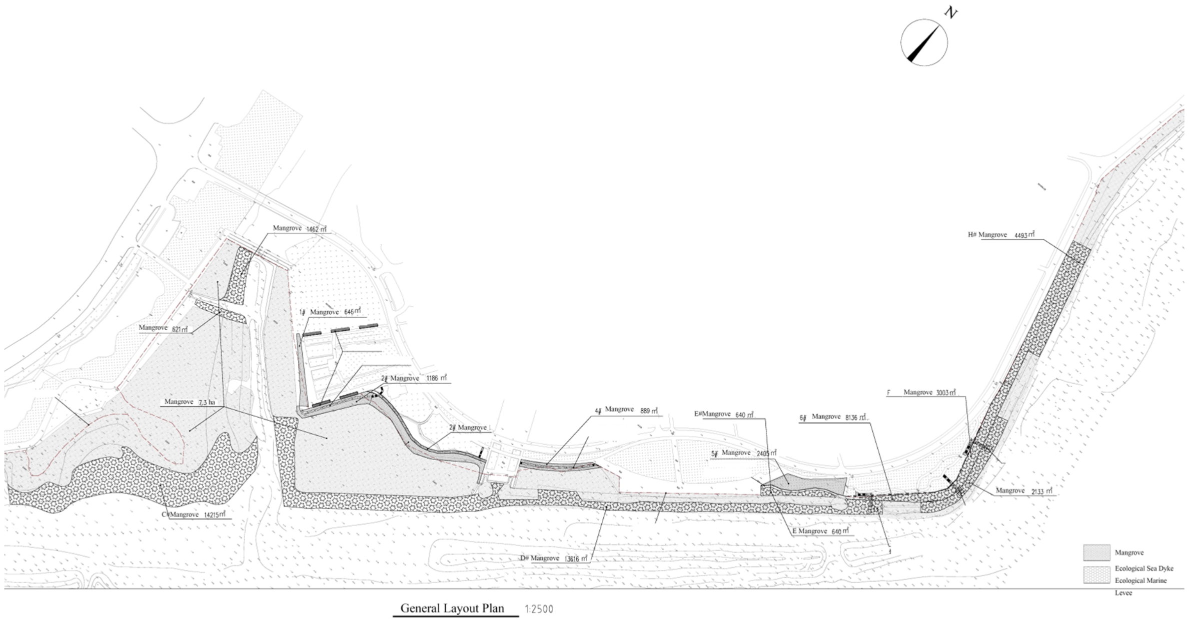


Figure 6. mangrove layout scheme.

According to the numerical simulation calculation and analysis results, the dike crest elevation is determined as follows: the dike elevation from Dajiaoshan Sluice to Binhai Avenue about 200 m southwest of Xinghai Conference Center is 8.96 m (urban construction datum); the dike elevation from Binhai Avenue about 200 m southwest of Xinghai Conference Center to a reserved land northeast of the sea viewing platform (originally planned beach land) is 9.26 m (urban construction datum); the dike crest elevation from the newly built dike along the reserved land to the north gate of the Coastal Park is 8.96 m (urban construction datum).

3.2. Implementation Effect Evaluation

This study found that the "rigid-flexible composite" structure shows better resilience than the single hard structure under extreme working conditions. Compared with the traditional "high dike hard barrier", the graded wave attenuation system of this project greatly reduces the structural load of the main dike through vegetation friction and terrain breaking. This result is consistent with the field investigation results of Feng et al. (2025) on the wave dissipation effect of mangroves, but this study further proves that more efficient energy dissipation can be realized through the coupling of artificial terrain reshaping and natural vegetation in a limited space.

3.2.1. Significant Improvement of Flood Control Standard

After the implementation of the project, the flood control capacity of Dajiaoshan Coastal Park in Nansha has achieved a qualitative leap, with the flood control standard increased from the original 20-year return period to 200-year return period. The synergistic effect of the plant forest belt and the graded wave attenuation system supports the reduction of the dike crest elevation by 0.8–1.2 m (urban construction datum). The wave overtopping discharge is calculated by numerical simulation, and three typical sections of K0 + 100.000, K0 + 400.000 and K0 + 974.762 are selected for calculation. The wave overtopping discharge is 0 $m^3/s\cdot m$ for K0 + 100.000 and K0 + 974.762, and 0.02 $m^3/s\cdot m$ for K0 + 400.000, which meets the specification requirements (see Table 2).

The wave reduction effect is outstanding. Relying on the synergistic effect of the composite forest belt and graded wave attenuation system constructed above, the wave reduction effect of different dike sections meets the standard accurately: the wave height at the dike of section K0 + 190.231K0 + 725.373 (about 535 m long) is reduced to 0.3 m, and the wave height at the dike of section K0 + 000.000K0 + 190.231 and K0 + 725.373~K1 + 238.481 (about 665 m in total) is reduced to 0 m, with a reduction rate of 100%, which greatly reduces the impact load and erosion risk of waves on the dike body. According to the Code for Design of Sea Dikes (SL435-2008), for a sea dike with protected dike crest and well-grown grassland on the back sea side, the allowable wave overtopping discharge is not more than 0.02 $m^3/s\cdot m$, which meets the specification requirements.

Table 2. Statistical Table of Wave Overtopping Discharge of Typical Sections.

Dike Station Number	Wave Overtopping Discharge ($m^3/s\cdot m$)
K0 + 100.000	0
K0 + 400.000	0.02
K0 + 974.762	0

After one year of continuous operation verification, the dike body structure has excellent stability, and the settlement and horizontal displacement are controlled within the allowable range of the specification; the structural safety coefficient meets the standard, among which the anti-sliding safety coefficient reaches 1.30, and the anti-overturning safety coefficient reaches 1.5, which fully meets the stability requirements of the 200-year return period flood control standard, and provides a solid guarantee for the flood control safety of the site. Under the test of Typhoon Tapah, the 16th typhoon in 2025, facing the extreme working conditions of maximum wind speed of 28 m/s, highest water level of 2.8 m (Zhuji datum) and maximum wave of 1.4 m (urban construction datum), the project did not have any hidden dangers such as leakage and dike break, achieving zero record of leakage and dike break, and effectively protecting the safety of people's lives and property. (see Figures 7–10).

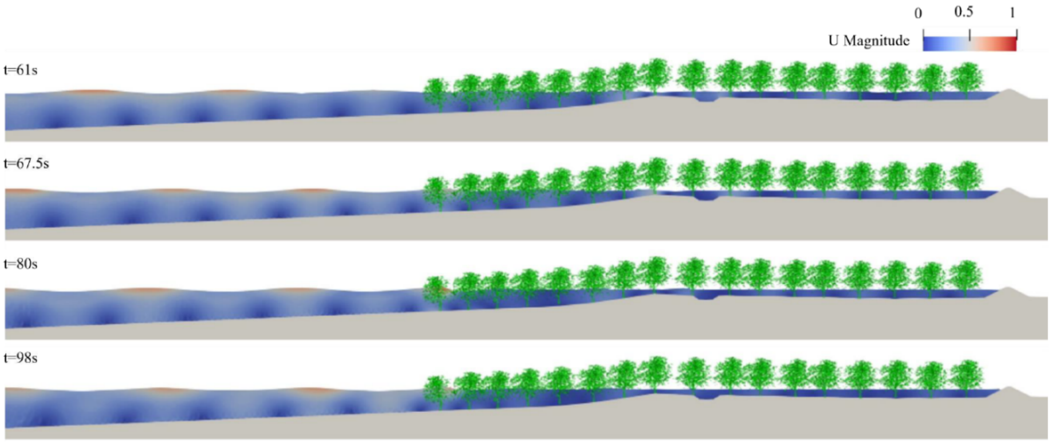


Figure 7. Wave propagation variation at Section 1.

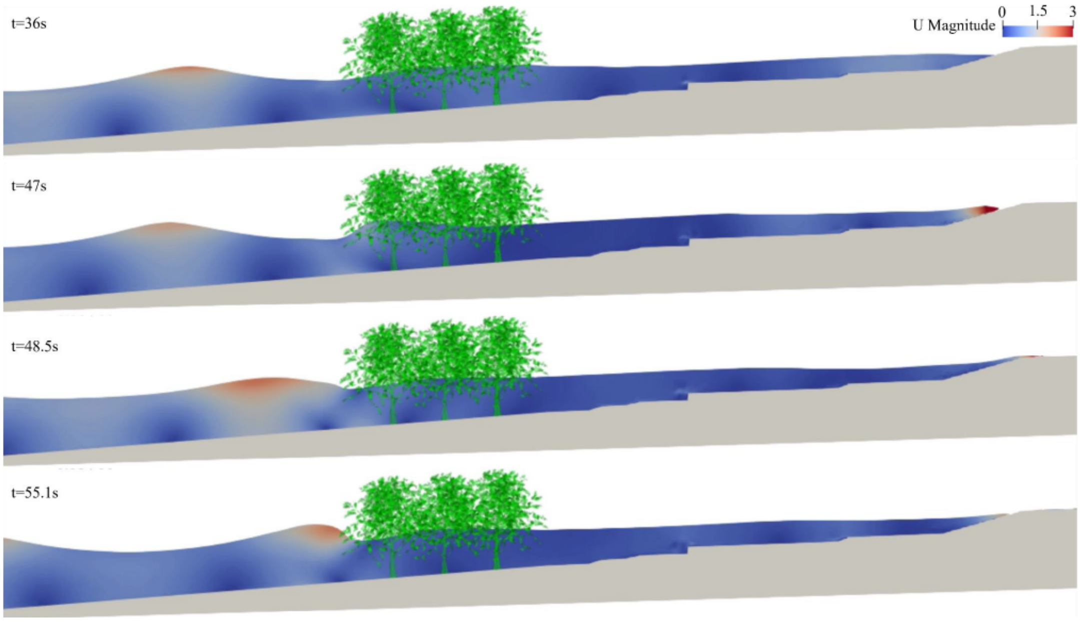


Figure 8. Wave propagation variation at Section 2.

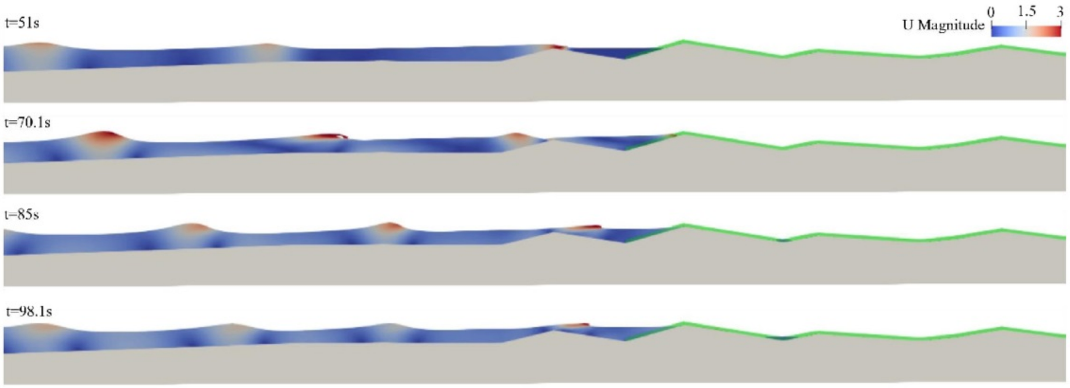


Figure 9. Wave propagation variation at Section 3.

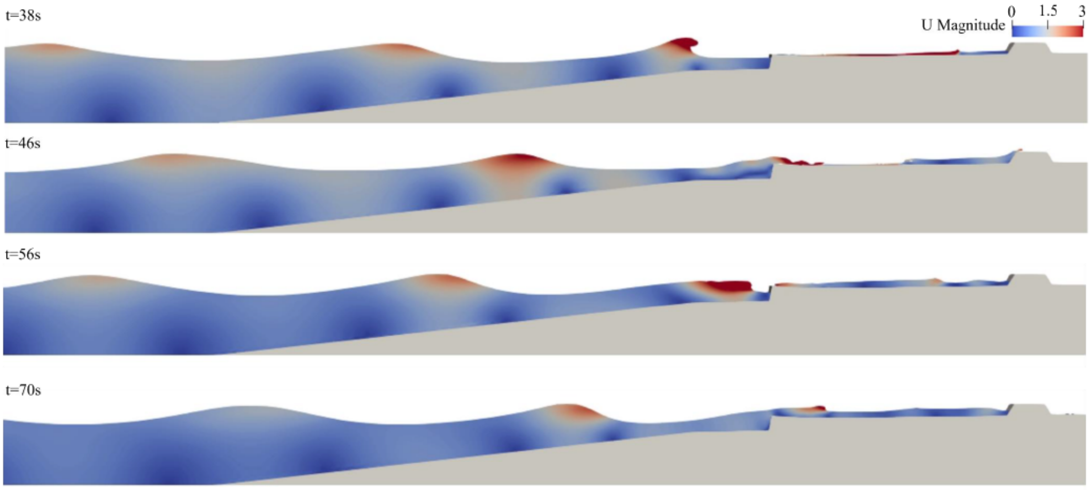


Figure 10. Wave propagation variation at Section 3.

3.2.2. Landscape and Ecological Benefits

After the implementation of the project, it not only meets the 200-year return period flood control standard, but also ensures the sight line connection between the park and the coastal landscape; the landscape continuity and ecological environment quality of the site have been significantly improved, realizing the collaborative optimization of landscape aesthetics and ecological functions.

In terms of landscape continuity improvement, the systematic flood and storm surge prevention design is fully integrated with the forest belt and terrain, which completely eliminates the visual occlusion caused by the traditional high dike, and realizes the sight line connection between the park interior and the coastal landscape. According to the on-site elevation and sight line analysis, tourists can directly view the coastal scenery in 80% of the park area, which greatly improves the leisure and tourism experience of the park.

In terms of ecological environment optimization, the project adheres to the principle of ecological priority, retains more than 90% of the original vegetation, and adds an area of ecological revetment and mangroves of 40,183 m^2. 4485 trees are protected in situ, with an in-situ protection rate of 80.10%; a total of 799 trees are transplanted, with a relocation rate of 14.27%, and the relocation and transplantation utilization rate is 100%.

The carbon sequestration capacity of the ecosystem is significantly enhanced. Referring to the relevant research results on carbon sink accounting of mangrove ecosystems in South China, the annual carbon sequestration of the newly added mangroves is calculated in this study. The calculation formula of the total annual carbon sequestration of the mangrove ecosystem is: $C_{total} = A \times \left(R_{veg} + R_{soil}\right)$, where A is the mangrove area (m^2), R_{veg} is the annual carbon sequestration rate of vegetation, taken as 1000 g C·m^{-2}·a^{-1}, and R_{soil} is the annual carbon burial rate of soil, taken as 200 g C·m^{-2}·a^{-1}. The newly added mangroves can achieve a carbon sink of about 176.68 t CO$_2$-e per year. Referring to the Fudan Carbon Price Index (CPIF) in February 2026, the expected buying price of China Emission Allowance (CEA) in China is 72.47 yuan/ton, the selling price is 83.69 yuan/ton, and the middle price is 78.09 yuan/ton [29], which can generate 13796.68 yuan per year. The carbon sequestration capacity of the ecosystem is significantly enhanced, with obvious carbon sink benefits.

The efficient utilization of existing resources such as old dikes and lakes reduces the proportion of hard measures by 80%. The application of terrain reshaping and landscape-integrated dike technology transforms the dike from a “visual barrier” to a “landscape carrier”. The vegetation coverage rate increases from 65% to 85%, the biodiversity increases significantly, and the ecological value and public service value of the park are improved simultaneously.

In addition, through species restoration and ecosystem restoration, the vegetation conservation and biodiversity maintenance functions of the site have been strengthened, and the ecosystem service functions have been comprehensively improved, providing important support for the construction of regional ecological civilization.

3.2.3. Social and Public Benefits

Through the landscape-integrated dike design and function optimization and upgrading, the public service quality of the park has been significantly improved, achieving multiple social benefits of improved tourist experience, reduced maintenance costs and driven regional economic development.

In terms of the expansion of public recreation functions and regional economic driving, the project has added 3 landscape platforms and hydrophilic platforms, improved about 3.6 km of footpath system, matched with rest seats, new popular science signs, etc., which greatly improved the service carrying capacity of the park. The upgraded park can undertake diversified activities such as ecological popular science, cultural festivals and outdoor sports. In the first month of opening in 2024, the number of tourists reached 240,000; during the first Greater Bay Area Lantern Festival in 2025, it received a total of 710,000 visitors. Based on the per capita ticket of 120 yuan, the direct annual related income is about 85.2 million yuan, and the overall media exposure of the event is close to 4 billion person-times [30], which has significantly driven the development of surrounding catering, accommodation and other related industries, and injected vitality into the regional economy.

In terms of ecological civilization education and social consensus cultivation, the park has added 1 ecological popular science corridor and 3 wetland observation points, and carries out ecological popular science activities for primary and secondary schools and the public all year round, systematically popularizing ecological protection knowledge and disaster prevention and mitigation skills, effectively improving the public’s ecological and environmental protection awareness, and promoting the formation of social consensus on ecological civilization construction.

In terms of operation and maintenance cost control, relying on the ecological technology system and efficient utilization of existing resources, the later maintenance of hard facilities and vegetation replanting costs are greatly reduced, and the sustainable operation capacity of the project is improved.

3.2.4. Economic Value

By maximizing the activation of existing resources on the site and adopting ecological technology to replace traditional hard engineering, the project has achieved dual optimization of construction investment and long-term operation and maintenance costs, with significant economic benefits. In terms of construction investment optimization, the total investment of the project is 150 million yuan (107 million yuan per kilometer). Compared with previous similar engineering schemes, it has obvious advantages: compared with the Lingshan Island Super Dike (300 million yuan per kilometer), it is reduced by 72%, directly saving 300 million yuan of funds; compared with the Huigu Ecological Dike (152 million yuan per kilometer), the investment is reduced by 34.2%, saving 78 million yuan of funds.

The cost savings are specifically reflected in three aspects: first, the reinforcement and reconstruction of the old dike replaces the new dike body, reducing the earthwork by about 19,000 m^3 and saving 3.8 million yuan; second, relying on the wave dissipation function of the plant forest belt, the consumption of hard facing (concrete, masonry with mortar) is reduced by about 21,700 m^3, saving 9.77 million yuan of material and construction costs; third, about 5760 m^3 of waste materials from the demolished original project are used in the terrain reshaping process, reducing the cost of purchased earthwork by about 1.15 million yuan, realizing the resource recycling mode (see Table 3).

In terms of long-term operation and maintenance, the ecological measures such as plant forest belts, ecological grids and wetland systems adopted by the project have the characteristics of long service life and simple maintenance procedures, which greatly reduce the later operation and maintenance labor and material costs compared with traditional hard facilities, and further improve the economic sustainability of the project.

Table 3. Economic Benefit Comparison of Different Dike Projects.

Type	Super Dike	Super Dike	Ecological Dike
Project	Lingshan Island Tip Super Dike	Huigu Ecological Dike	Dajiaoshan Coastal Park Dike
Total Investment (100 million yuan)	6.71	4.675	1.41
Area	250,000 m^2	440,000 m^2	76,000 m^2
Width	30 m–100 m	40 m–110 m	75 m–210 m
Total Length (km)	19.4	7.04	1.5
Investment per Kilometer (100 million yuan/km)	2.891	1.506	1.064
Investment Ratio	2.718	1.416	1

4. Research Results and Prospects

4.1. Theoretical Contribution: Realization of Multi-Dimensional Goal Coordination

This study puts forward the disaster prevention logic of “natural-artificial system coordination”, enriches the application connotation of resilient city theory in coastal micro-scenarios, and clarifies the coupling mechanism between engineering resilience and ecological resilience. By constructing a four-dimensional resilience system, the contradiction between safety and development is solved. It abandons the traditional flood control thinking of “high dike hard barrier”, puts forward the design concept of “dike is landscape”, promotes the transformation of flood control engineering from a simple protective facility to a “multi-functional safety barrier” integrating ecological conservation, public recreation and popular science education, and realizes the multi-dimensional transformation of flood control engineering from “engineering safety” to “ecological safety + landscape experience + public service”.

4.2. Key Results: Validated Technical Paradigm

This study constructs a four-dimensional framework system with engineering resilience, ecological resilience, social resilience and governance resilience as the core, and establishes a whole-chain technical paradigm including “numerical simulation–physical model–engineering practice”. In particular, it quantifies the parameters of vegetation wave dissipation under complex terrain, providing a repeatable design basis for similar projects.

Through the innovation of resource collaborative utilization, it is the first time to systematically integrate four types of existing resources, namely “vegetation, old dikes, demolished waste materials, and temporary fortification of original dikes” in the park scene, to construct an ecological flood control barrier system, minimize engineering disturbance and resource consumption, and realize the resource recycling mode of “treating waste with waste and turning waste into treasure”. The feasibility of “low cost, high resilience and excellent landscape” is implemented, breaking the inherent cognition that flood control engineering must sacrifice landscape, and providing a typical case of interdisciplinary integration for architectural science and urban planning disciplines. Verified by numerical simulation and field operation, the flood control standard is successfully increased from 20-year return period to 200-year return period, meanwhile, the landscape sight line connection and ecosystem restoration are realized, with significant wave dissipation effect and structural stability, and obvious whole life cycle cost advantages.

Through technological integration and innovation, the integrated design of plant wave dissipation, graded wave attenuation, landscape-integrated dike and flood retention and storage regulation technologies is carried out, matched with temporary engineering measures adapting to time conditions. Through numerical simulation and on-site monitoring to optimize parameter matching, a synergistic efficiency enhancement mechanism of “wave dissipation–wave attenuation–dike integration–flood retention” is formed, which breaks through the limitations of single technology application and significantly improves the comprehensive ecological and landscape benefits of flood control engineering.

4.3. Impact on Other Coastal City Cases

The ecological flood control technology model proposed in this study can be widely used in diversified scenarios such as coastal parks, estuarine wetlands, coastal resorts and urban waterfronts, especially suitable for the economically developed, densely populated areas with high requirements for ecological landscape quality along the southeast coast of China. With the acceleration of global climate change and coastal urbanization, this technology model can provide a Chinese solution for the global coastal areas to deal with the core contradiction between flood control safety and ecological protection, and has broad application and promotion prospects.

In terms of promotion guarantee, it is suggested to incorporate the concept of ecological resilience into the institutional guarantee system of urban flood control planning, and promote the standardized and large-scale application of this model in similar projects through policy guidance, standard formulation and technical training.

4.4. Limitations of This Study in Theory and Methodology

First, restricted by the existing land use nature of the site, the engineering scheme is difficult to further supplement and improve the park supporting service facilities, resulting in obvious restrictions on the expansion space of the site’s public service functions, which fails to fully meet the diversified use needs of surrounding residents. Second, after the completion of the project, the continuous and complete tracking monitoring and systematic data recording of the core objectives set in this study have not been carried out, making it difficult to fully verify the long-term effectiveness and stability of the research conclusions, and unable to provide more comprehensive empirical support for the optimization and improvement of subsequent similar projects. Third, this study does not fully consider the differentiated needs of similar ecological sea dike construction. In the follow-up, on the basis of meeting the overall flood and storm surge prevention standard, differentiated protection standards should be designed in combination with the actual situation of different protection areas.

Based on the above limitations, in the design of such projects in the future, it is necessary to further strengthen the connection and cooperation between different government departments to ensure the compliance of land use; the later monitoring cost should be clearly included in the project construction budget to ensure the continuous development of tracking and monitoring; at the same time, promote the update and improvement of ecological sea dike construction standards and planning, to provide more scientific guidance for similar projects.

5. Conclusions

Aiming at the dual dilemma of storm surge prevention and landscape ecological protection in coastal parks, this study breaks the traditional research paradigm of separating ecological resilience from flood control engineering, constructs a four-dimensional collaborative framework with engineering resilience, ecological resilience, social resilience and governance resilience as the core, and clarifies the coupling mechanism and implementation path between them. By integrating four technical systems: dike-road integration, diversified engineering disaster mitigation, vegetation wave dissipation, ecological barrier disaster mitigation, renewal of existing parks, connective path reconstruction, and elastic adaptation, normal-emergency integrated policy management, the disaster prevention logic of "natural-artificial system coordination" is formed. Taking the dike improvement project of Dajiaoshan Coastal Park in Nansha as an empirical case, it successfully increases the flood and storm surge prevention standard from less than 20-year return period to 200-year return period, meanwhile realizes the multi-dimensional balance of landscape sight line connection, ecosystem restoration, public service upgrading and cost optimization, and effectively solves the pain points of ecological fragmentation and landscape occlusion caused by the "high dike hard barrier" of traditional flood control engineering.

This study verifies the feasibility and effectiveness of the ecological flood control technology model of "low cost, high resilience and excellent landscape", enriches the application of resilient city theory in coastal micro-scenarios, and provides a replicable and popularizable theoretical and practical reference for coastal areas around the world facing similar disaster challenges. At the same time, this study also has limitations such as insufficient expansion of public services caused by land use constraints, lack of long-term monitoring data, and insufficient consideration of differentiated protection standards. In the future, it is necessary to further improve the scientificity and sustainability of the coupling between ecological resilience and flood control engineering by strengthening departmental collaboration, improving the monitoring system, optimizing construction standards, etc., so as to promote the ecological and diversified development in the field of coastal disaster mitigation.

Author Contributions

Y.W.: data curation, drafting of the original manuscript, visualization, investigation work; M.M.: research conceptualization, methodology design, software application, manuscript review and editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data supporting the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used Doubaotool to translate and polish the language expression of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

References

1. Luo, Y.M. Sustainability Associated Coastal Eco-environmental Problems and Coastal Science Development in China. *Bull. Chin. Acad. Sci.* **2016**, *31*, 1133–1142. https://doi.org/10.16418/j.issn.1000-3045.2016.10.001.
2. Dai, W.; Meng, M.; Lu, P.J. A Study on the Strategies of Flood Control Planning for Coastal City from the Perspective of Nature-Based Solutions. *City Plan. Rev.* **2023**, *47*, 66–78. (In Chinese)
3. Zhong, W. Research on Vulnerability Assessment of the West Coast of Shenzhen under Typhoon Disaster Risk. Master's Thesis, Harbin Institute of Technology: Harbin, China, 2023. https://doi.org/10.27061/d.cnki.ghgdu.2023.001289.
4. Bu, L. Resilience Response Strategies of Coastal Cities Under the Background of Climate Change: A Case Study of the Rainstorm Disaster in Zhuhai. *Urban Dev. Stud.* **2025**, *32*, 60–66. (In Chinese)

5. Hou, P.; Wang, Q.; Chen, J.A.; et al. Research on the technical system of high-standard seawall construction in the Guangdong-Hong Kong-Macao Greater Bay Area based on wave-tide separation. *China Water Resour.* **2023**, *17*, 47–52. (In Chinese)
6. Shao, Y.W.; Xu, J. Understanding Urban Resilience: A Conceptual Analysis Based on Integrated International Literature Review. *Urban Plan. Int.* **2015**, *30*, 48–54. (In Chinese)
7. Holling, C.S. Engineering Resilience versus Ecological Resilience. *Eng. Ecol. Constraints* **1996**, *31*, 32.
8. Liao, K.H. A Theory on Urban Resilience to Floods—A Basis for Alternative Planning Practices. *Ecol. Soc.* **2012**, *17*, 48. https://doi.org/10.5751/ES-05231-170448.
9. Walker, B.; Holling, C.S.; Carpenter, S.R.; et al. Resilience, Adaptability and Transformability in Social-ecological Systems. *Ecol. Soc.* **2004**, *9*, 5.
10. Li, G.Q. Construction concepts and practical paths of resilient cities. *People's Trib.* **2021**, *25*, 86–89. (In Chinese)
11. Meyer, H. Sustainable delta landscapes need smarter port city regions. *Portusplus* **2019**, *8*, 1–22.
12. Wu, Z.Q.; Feng, F.; Lu, F.D.; et al. Space Design for Urban Resilience. *Time Archit.* **2020**, *4*, 84–89. https://doi.org/10.13717/j.cnki.ta.2020.04.011.
13. Zheng, X.C. Ecological resilient city construction from the NbS perspective: Construction and reflection of the Netherlands Delta Works. In *Proceedings of the 2025 Annual National Conference on Urban Planning*; Shandong Jianzhu University: Jinan, China, 2025; pp. 445–454. https://doi.org/10.26914/c.cnkihy.2025.045729.
14. Fu, B.J.; Wang, J. Theoretical connotation and Chinese practice of nature-based solutions. *Bull. Chin. Acad. Sci.* **2025**, *40*, 1157–1167.
15. Asl, R.S.; Tate, E.; Pearsall, H. SECURE-NBS: A conceptual framework for integrated nature-based flood risk reduction. *Landsc. Urban Plan.* **2026**, *271*, 105637. https://doi.org/10.1016/J.LANDURBPLAN.2026.105637.
16. Wang, X.R. From High-Density Built Environments to Natural and Cultural Cities. *Chin. Landsc. Archit.* **2025**, *41*, 2–3. (In Chinese)
17. Li, C.L.; Tan, Y.; Li, S.T.; et al. Advances on the Urban Resilience of Global Coastal Communities in Coping with Extreme Climates. *J. Metrop. Dev. Res.* **2025**, *6*, 85–103. (In Chinese)
18. Zeng, X.; Zhu, J.; Chen, Q.; et al. Satellite observations and hydrodynamic simulations of harmful algal blooms in Guangdong coastal waters. *Acta Oceanol. Sin.* **2025**, *44*, 69–89. https://doi.org/10.1007/s13131-025-2545-6.
19. Li, B.X.; Zhu, Y.J.; Yang, H.G.; et al. Ecosystem health assessment of mangrove wetlands in Beibu Gulf of Guangxi, China. *Acta Sci. Circumstantiae* **2026**, *46*, 439–455. https://doi.org/10.13671/j.hjkxxb.2026.0012.
20. Godschalk, D.R. Urban Hazard Mitigation: Creating Resilient Cities. *Nat. Hazards Rev.* **2003**, *4*, 136–143. https://doi.org/10.1061/(ASCE)1527-6988(2003)4:3(136).
21. Meng, M.; Li, W.Z.; Wang, S.F.; et al. Governing Climate Adaptation Planning: The Integration Between Water Management and Spatial Planning in the Netherlands. *Urban Plan. Int.* **2021**, *36*, 41–51. https://doi.org/10.19830/j.upi.2021.428.
22. Pickett, S.T.A.; McGrath, B.; Cadenasso, M.L.; et al. Ecological resilience and resilient cities. *Build. Res. Inf.* **2014**, *42*, 143–157. https://doi.org/10.1080/09613218.2014.850600.
23. The World Bank. *Building Urban Resilience: Principles, Tools, and Practice*; The World Bank: Washington, DC, USA, 2013. https://doi.org/10.1596/978-0-8213-8865-5.
24. Liu, C.Z.; Huang, S.; Wang, J.X.; et al. Theoretical Issues of Resilience-Based Disaster Prevention and Mitigation. *Adv. Eng. Sci.* **2026**. (In Chinese)
25. Zhang, W. Research on Wave Dissipation Capacity of Coastal Wetlands and Dyke Risk Assessment of Chongming Island. Master's Thesis, East China Normal University, Shanghai, China, 2023. https://doi.org/10.27149/d.cnki.ghdsu.2023.004178.
26. Chen, B.L. Adaptive Planning and Design of High-Density Coastal Cities Oriented to Flood Resilience. Ph.D. Thesis, South China University of Technology, Guangzhou, China, 2024. https://doi.org/10.27151/d.cnki.ghnlu.2024.000035.
27. Li, B.; Cai, H.; Yang, H.; et al. Mechanism and Evolution of Water Level Changes in Transverse Channel Systems in the Zhujiang (Pearl) River Network. *Oceanol. Limnol. Sin.* **2023**, *54*, 313–330. https://doi.org/10.11693/hyhz20220600164.
28. Hang, C.; Pan, J.N.; Ju, L.H.; et al. Wave attenuation characteristics of Kandelia obovata mangroves and their synergistic coastal protection with a dike. *Hydro-Sci. Eng.* **2025**, *5*, 147–161. https://doi.org/10.12170/20250630003.
29. Available online: https://rcsd.fudan.edu.cn/info/1083/1527.htm (accessed on 28 February 2026).
30. Available online: https://baijiahao.baidu.com/s?id=1834470439842853207&wfr=spider&for=pc (accessed on 9 May 2025).