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T/CAOE 21.7-2020

Technical guideline on coastal ecological rehabilitation for hazard mitigation —

Part 7:

Sandy coast

海岸带生态减灾修复技术导则 第7部分：砂质海岸

（English Translation）

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Contents

Foreword

The T/CAOE 21 *Technical guideline on coastal ecological rehabilitation for hazard mitigation* consists of the following eleven parts:

——*Part 1: General;*

——*Part 2: Mangroves;*

——*Part 3: Salt marshes;*

——*Part 4: Coral reefs;*

——*Part 5: Seagrass bed;*

——*Part 6: Oyster reef;*

——*Part 7: Sandy coast;*

——*Part 8: Technical guide for the ecological construction of sea walls (trial);*

——*Part 9: Renovation of island-connecting sea wall and coastal engineering;*

——*Part 10: Directives for sea dike ecological construction of sea reclamation and enclosure project;*

——*Part 11: Supervising and monitoring.*

This is part 7 of the T/CAOE 21.

This part is drafted in accordance with the rules given in the GB/T 1.1-2009.

This part was proposed by the *Marine Early Warning and Monitoring Division, Ministry of Natural Resources*.

This standard was prepared by *China Association of Oceanic Engineering*.

This part was drafted by *Third Institute of Oceanography, Ministry of Natural Resources; Island Research Center, Ministry of Natural Resources; National Marine Hazard Mitigation Service; Hohai University*.

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Technical guideline on coastal ecological rehabilitation for hazard mitigation —

Part 7: Sandy coasts

1 Scope

This part of the T/CAOE 21 includes the work procedure, data collection and survey, suitability assessment, preparation of implementation plan, rehabilitation technology of sandy coasts, post monitoring and efficiency evaluation, quality controll, achievements and archiving, etc.

This part applies to the loss reduction of ecological disaster, rehabilitation of sandy beaches in coastal protection, rehabilitation engineering. and other rehabilitation works.

2 Normative references

The following documents are essential to the application of this document. For all dated documents, only their dated versions are adapted to this document. For all undated documents, the newest version (including all revision lists) applies to this document.

GB/T 14914.2-2019 *The specification for marine observation Part 2: Coastal observation*

GB 17378.3 *The specification for marine monitoring Part 3: Sample collection, storage, and transportation*

GB 17378.4 *The specification for marine monitoring Part 4: Seawater analysis*

GB 17378.5 *The specification for marine monitoring Part 5: Sediment analysis*

GB 17378.7 *The specification for marine monitoring Part 7: Ecological survey and biological monitoring of offshore pollution*

GB/T 17501-2017 *Specification for marine engineering topographic surveying*

GB 18668-2002 *Marine sediment quality*

JTS 154 *Specification of design for breakwaters and revetments*

HY/T 255-2018 *Technical guide for beach nourishment and* restoration

SL 260-2014 *Specification for construction of dike works*

T/CAOE 20.8-2020 *Technical guideline for investigation and assessment of coastal ecosystem Part 8: Sandy coast*

T/CAOE 21.1-2020 *Technical guideline on coastal ecological rehabilitation for hazard mitigation— Part 1: General*

3 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

3.1

sandy coast

a coast consisting mainly of sands (gravels) dominated by wave actions
[GB/T 18190-2017, definition 2.2.7]

3.2

backshore

coastal zone between the shoreline and mean high water line
[GB/T 18190-2017, definition 2.1.5]

3.3

beach berm

flat and stepped landforms distributed along the frontier edge of backshore
[GB/T 18190-2017，definition 2.3.8]

3.4

dry beach

a part of beach not subjected to flow normally except for extreme hydrodynamical processes
[GB/T 18190-2017，definition 2.3.9]

3.5

breaker zone

a zone where waves from offshore become unstable and are broken.
[HY/T 254-2018，definition 3.4]

3.6

wave dissipative rate

percentage of decrease in the wave height of waves propagating shoreward over a beach.

3.7

overwashing elevation

difference between the highest water level and the dry beach elevation in the case of overwashing during a storm.

3.8

nourished beach stability assessment

Analysis and evaluation of the degree of sand loss after beach nourishment.

4 Work procedure

Prior to the implementation of the ecological disaster mitigation and rehabilitation project of sandy coast, it is necessary to fully collect and sort out the data, supplement the field investigation, fully grasp the situation of the project site, and carry out the suitability evaluation, so as to provide the basis for the formulation of the implementation plan. In the process of project implementation, site monitoring shall be strengthened, and effect evaluation shall be carried out after completion and acceptance of the project. The work procedure of ecological disaster mitigation and rehabilitation project of sandy coast is shown in Figure 1.

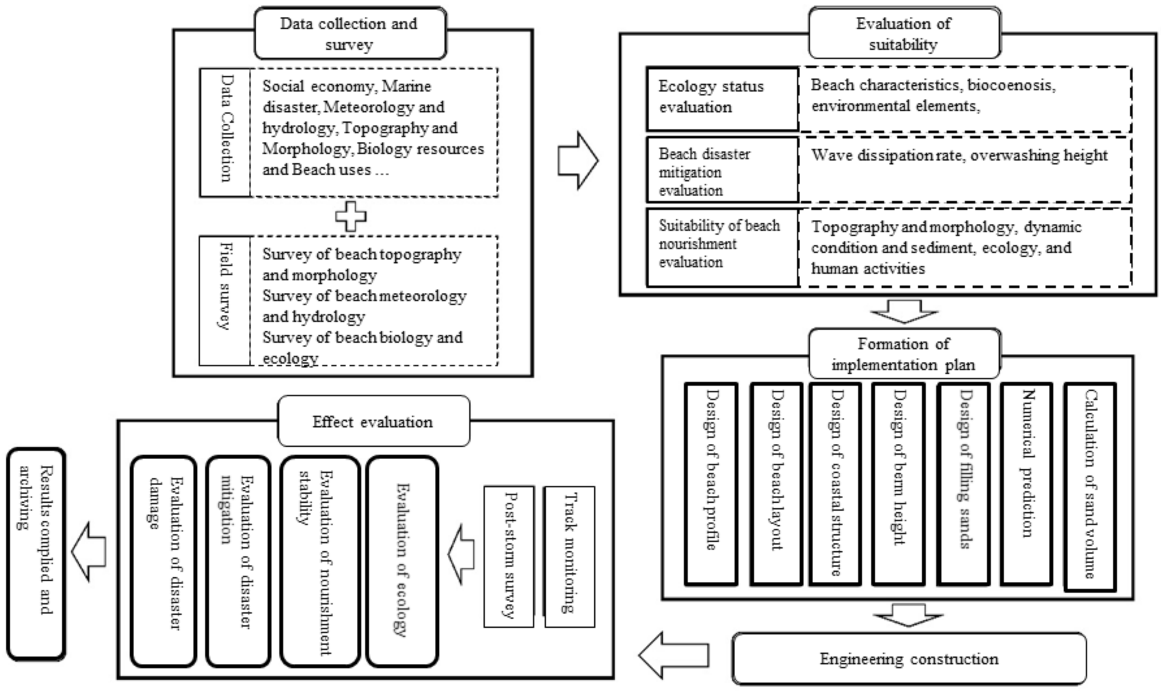


Figure 1 Work procedure of ecological disaster mitigation and rehabilitation project of sandy coast

5 Data collections and surveys

5.1 Data collections

Background information needed for the analysis of ecological disaster mitigation and rehabilitation project of sandy coast includes the overview of engineering area, beach features, biocoenosis, environmental elements, and threatening factors, see Table 1 for details.

Table 1—Data collections and survey contents

Data collections and survey contents		The way of obtaining data	Application scopes					
			Evaluation of disaster mitigation	Evaluation of suitability	Formation of implementation plan	Evaluation of disaster damage	Evaluation of stability	Evaluation of ecological effect
Overview of engineering area	natural conditions, ecological features and environmental situations of	Data collection	★	★	★			

		engineering site							
		Specific location and geographical coordinates of the engineering area	Data collection and remote sensing measurements	★	★	★			
		Laws and regulations	Materials collection			★			
		Regulation cohesion	Materials collection			★			
Coastal features	Topography	Beach profile	Field survey	★	★	★	★	★	
		Nearshore subaqueous topography	Field survey		★	★	★	★	
		Shoreline change	Field survey	★	★	★	★	★	
		Backshore height	Field survey	★					
		Erosion hotspot	Field survey	★	★		★	★	
	Sediments	Coastal sediments	Field survey	★	★	★	★	★	
		Nearshore seafloor sediments	Field survey		★				
		Beach sediment thickness	Field survey		★				

		Boundary between sand and mud	Field survey		★				
		Waves	Data collection or field survey	★	★	★		★	
		Ocean currents	Data collection or field survey		★	★		★	
		Suspended sediments	Data collection or field survey		★	★			
	Coastal hydrodynamical environments	Tidal levels	Data collection or field survey	★	★	★			
		Winds	Data collection		★	★			
		Regional sea level	Data collection		★	★			
		Maximum overwashing height during storm surges	Field survey	★					
biocenosis		Intertidal benthic organisms	Field survey		★	★			★
		Backshore vegetations	Field survey		★	★			★
Environm	Water	Nearshor	Data		★	★			★

ental elements	environment	e seawater quality	collection or field						
	Sediment environment	Intertidal zone sediment quality	Data collection or field survey		★	★			★
Threatening factors	Ocean disaster (natural threatening factors)	Storm waves	Data collection or field survey	★		★		★	
		Typhoons	Data collection	★		★		★	
		Disastrous wave	Data collection	★		★		★	
	Coastal developments and utilizations (anthropogenic perturbations)	Coastal structures	Data collection or field survey		★	★	★		
		Reclamation	Data collection or field survey		★	★	★		
		Fishing and aquaculture	Data collection or field survey		★	★	★		★
		Artificial sand mining	Data collection or field survey		★	★	★		
		Travel and leisure activities	Data collection or field survey			★	★		★

5.2 Field survey

5.2.1 Survey contents

Survey contents needed for ecological disaster mitigation and rehabilitation project of sandy coasts are shown in Table 1.

5.2.2 Survey requirements

5.2.2.1 Beach features

Beach features to be surveyed include topographies, sediments and coastal hydrodynamical environments. Among them, the topography survey requirements are shown in Table 2.

Table 2— Requirements for topography survey

<table>
<tr><td>Contents</td><td colspan="2">Requirements</td></tr>
<tr><td rowspan="5">Beach profile monitoring</td><td>Measuring range</td><td>From backshore to mean low spring tide on sandy coasts</td></tr>
<tr><td>Measuring profile settings</td><td>Profiles shall be set perpendicular to shorelines, with alongshore resolution no less than 4/km and fixed benchmarks</td></tr>
<tr><td>Measuring scale</td><td>No less than 1:500</td></tr>
<tr><td>Measuring frequency</td><td>a) Normal monitoring: Not less than once per year within two years prior to engineering, and not less than once a quarter; Not less than once a quarter in the first year after engineering, and not less than twice a year thereafter;
b) Monitoring during storms: Completing the preliminary survey within 2 months before the storm. The first post-storm survey shall be completed within five days after the storm. The follow-up repeated survey shall be completed at 1 month and 3 months respectively. If there are storm clusters, the last storm shall be the benchmark of the follow-up investigations.</td></tr>
<tr><td>Measuring technical requirements</td><td>Comply with the standard 10.2 of GB/T 17501-2017</td></tr>
<tr><td rowspan="5">Nearshore subaqueous topography</td><td>Measuring range</td><td>From shoreline seaward to closure depth</td></tr>
<tr><td>Measuring profile settings</td><td>Measuring profiles shall be set perpendicular to shorelines and extending from the benchmark to the sea. If the beach alongshore length is shorter than 1km, at least 4 profiles shall be set. if profile length is longer than 1km, the alongshore resolution of measured profiles shall be no less than 4/km</td></tr>
<tr><td>Measuring scale</td><td>No less than 1:5000</td></tr>
<tr><td>Measuring frequency</td><td>a) Normal monitoring: current topography data shall comply with the standard 6.1 of HY/T 255-2018.
b) Monitoring during storms: the primary survey shall be completed within 2 months before the storm, and within 15 days after the storm.</td></tr>
<tr><td>Measuring technical requirements</td><td>Comply with the standard 6.3 of HY/T 255-2018</td></tr>
<tr><td>Shoreline</td><td>Measuring range</td><td>Shoreline on sandy coasts</td></tr>
</table>

change	Measuring scale	No less than 1:500
	Measuring frequency	a) Normal monitoring: No less than once per year within two years prior to engineering, and not less than once a quarter; Not less than once a quarter in the first year after engineering, and not less than twice a year thereafter; b) Monitoring during storms: Completing the preliminary survey within 2 months before the storm. The follow-up repeated survey was completed within 5 days, at 1 month and 3 months after storm respectively. If there are storm clusters, the last storm shall be the benchmark of the follow-up investigations.
	Measuring technical requirements	Comply with the standard 10.3 of GB/T 17501-2017
Backshore height	Measuring range	Position and elevation of the highest point of berm and dune in the frontier edge of backshore on sandy coasts; position and elevation of the crest of seawall for beaches without dunes or berms
	Measuring frequency and timing	The priory survey shall be completed within 2 months before the storm, and post-storm survey shall be completed within 5 days after the storm
	Measuring technical requirements	Comply with the standard 10.2 of GB/T 17501-2017
Erosion hotspot	Measuring range	Erosion cliff on backshore, scouring zones in front of seawalls, nearshore intense evolution areas caused by coastal structures and anthropogenic perturbations
	Measuring technical requirements	The follow-up repeated survey is completed within 5 days, at 1 month and 3 months after storm respectively
	Measuring contents	Range and height of backshore cliff, range and quantity of erosion hotspot
Note: The elevation datum is China1985 national elevation datum.		

Sediment survey requirements are shown in Table 3.

Table 3— Requirements for sediment survey

Contents	Requirements	
Sediments	Station settings	a) The sediment survey profile is consistent with the topography survey profile, and one surface sediment sampling point shall be set up at representative locations such as dune, berm, high tide zone, middle tide zone and low tide zone respectively; b) No less than 3 intertidal zone survey stations shall be set if the width of intertidal zone is shorter than 200/(m). No less than 5 intertidal zone survey stations shall be set if the width of intertidal zone is longer than 200/(m); c) The principle resolution of subaqueous sediment survey is one station every 500/(m).

	Sampling depth	5/(cm) to20/(cm) beneath the bed surface
	Sample frequency	In accordance with the topography survey
Boundary between sand and mud	Survey method	Obtain the planimetric position and elevation of the sand-mud transition by using high precision measuring equipment
	Survey frequency	Not less than once in summer and winter within recent 2 years
	Position	Beach surface sediment at sand-mud transition

Coastal hydrodynamical environment survey requirements are shown in Table 4.

Table 4—Requirements for coastal hydrodynamical environment survey

Contents	Requirements	
Waves	Monitoring time	a) The continuous monitoring of deep-water wave conditions in a typical season formore than one month in recent five years; b) During storm surges
	Monitoring bathymetry	a) The water depth of 10-20/(m) near the coast is appropriate; b) The intertidal and nearshore shallow water wave conditions during the storm
	Monitoring techniques	a) Comply with the section standard 7 of GB/T 14914.2-2019; b) The seabed dynamic observation shall be carried out in the area of 10-20m near the target beach before the storm, ADCP (Nortek) and RBR water level gauges can be used to measure wave, current and water level data in the targeted area; The selection of monitored beach profile shall be typical, generally in the middle zone of the whole sandy coast, and far from the erosion hotspot and artificial structures. The methods of wave observation in intertidal zone and nearshore shallow water are as follows: arranging observation arrays consisting of three tide gauges, covering subtidal zone, intertidal zone, and supratidal zone (in the front of seawall), the elevation difference between adjacent instruments: 0.1 to 2.0/(m), measuring frequency: 2 to 4/(Hz).
Ocean currents	Monitoring timing, station settings and technology requirements	Comply with the section standard 6.1 of HY/T 255-2018
Suspended sediments		
Tidal levels		
Winds		
Regional sea level	/	Comply with the section standard 6.1 of HY/T 255-2018
Maximum overwashing height during storm	Monitoring timing	Post-storm monitoring
	Monitoring methods	Combination of field observation and UAV remote sensing
NOTE The sea-level datum involved in the survey is regional mean sea level.		

5.2.2.2 Biocoenosis

Biocoenosis survey requirements are shown in Table 5.

Table 5— Requirements for biocoenosis survey

Survey elements	Species, quantities and distribution patterns of intertidal benthic organisms
Station settings	a) Conducting survey on the section with integrated intertidal zone, stable shoreface, and non- or little anthropogenic perturbations; b) Setting 2 stations in the high tidal zone, 3 stations in the middle tidal zone and 1 or 2 stations in the low tidal zone for the width of intertidal zone longer than 200m. Otherwise, setting 1 station in the high tidal zone, 3 stations in the middle tidal zone and 1 station in the low tidal zone.
Survey frequency	Once during spring tides in spring and autumn every year.
Technology and methods	4~8 quadrates are taken from each station with a quantitative frame of 25cm×25cm×30cm for qualitative sampling and observation. When sampling, first insert the sampler baffle into the groove of the frame, then insert it into the beach, and then observe the visible organisms and quantity on the surface of the recording frame.

Backshore vegetation survey requirements are shown in Table 6.

Table 6— Requirements for backshore vegetations survey

Survey elements	Vegetation types, species, areas, quantity, height, DBH, canopy, coverage, and vitality
Station settings	a) Sample line settings Requirements for sample line settings include: --The establishment of survey lines shall take into account of the combination of representativeness, randomness, integrity, and accessibility; --The layout of the sample lines is as comprehensive as possible and is distributed in representative sections throughout the survey area to avoid leakage in some areas, and the route is recorded with GPS. b) Sample positions and quadrat settings Requirements for sample position and quadrat settings include: --Quadrat area of arbor species and large shrub is 100/(m^2)(10/(m)×10/(m)). The main quadrate is usually set as a square, or a rectangle under special circumstances, but its shortest side is not less than 5/(m); --Quadrat area of suffruticosa plants and tall herb is 25/(m^2)(5/(m)×5/(m)); --Quadrat area of herbaceous plants is 1/(m^2)(1/(m)×1/(m)); --Liana: Total quadrat area of liana growing in high-forest is 100/(m^2)(10/(m)×10/(m)). Quadrat area of liana growing in thicket is 25/(m^2)(5/(m)×5/(m)); --In order to ensure the required accuracy of the survey, the distance between two sample positions shall not be less than 100/(m), and each plant community shall have at least one sample position.
Survey frequency	a) Normal survey: Once a year, usually arranged during May to September; b) Survey during storms: Once within a month afte storm.

Survey elements	Vegetation types, species, areas, quantity, height, DBH, canopy, coverage, and vitality
Technology requirements	a) Arbor and small tree species with DBH larger than 5/(cm) need tally. Shrub species and herbaceous species are investigated and recorded in the unit of shrub or plant; b) The remote sensing image resolution shall be no less than 0.6m and the mapping scale precision shall be no less than 1:5000 when the backshore vegetation area is acquired through satellite remote sensing image interpretation. The remote sensing image resolution shall be no less than 0.3m, and the mapping scale precision shall be no less than 1:3000, when the backshore vegetation area is obtained through UAV remote sensing image interpretation.

5.2.2.3 Environmental elements

Nearshore seawater quality survey requirements are shown in Table 7.

Table 7— Requirements for nearshore seawater quality survey

Survey index	Fecal coliform, water color, water temperature, salinity, transparency, PH value, petroleum and dissolved oxygen (DO)
Station settings	a) The seawater quality monitoring section shall be perpendicular to the main tidal current direction or the shoreline, and the number of monitoring sections is determined according to the length of the beach. Setting no less than 1 monitoring section when beach length is not longer than 2/(km); Setting no less than 2 monitoring sections when beach length is from 2/(km) to 5/(km). Setting no less than 3 monitoring sections when beach length is longer than 5/(km); b) The total number of monitoring stations on the beach is no less than 3.
Survey frequency	Once in winter and summer every year.
Technical requirements	a) Sample collection complies with GB 17378.3 standard, and sample depth shall be 30cm below water surface; b) Analysis of fecal coliform shall comply with GB 17378.7 standard. Analysis of water color, water temperature, salinity, transparency, PH value, petroleum, dissolved oxygen and suspended materials shall comply with GB 17378.4 standard.

Intertidal sediment quality survey requirements are shown in Table 8.

Table 8— Requirements for intertidal sediment quality survey

Survey index	Fecal coliform, petroleum, organic carbon and sulfide
Station settings	Follow the requirements in Table 7
Survey frequency	In accordance with water quality survey
Technology requirements	a) Sample method complies with GB 17378.5 standard; b) Analysis of fecal coliform shall comply with GB 17378.7 standard. Analysis of fecal coliform, petroleum, organic carbon and sulfide shall comply with GB 17378.5 standard.

6 Evaluation of suitability

6.1 Evaluation of current ecological status

The evaluation of the current ecological status of the sandy coast is carried out quantitatively from three aspects: beach features, biocoenosis, and environmental elements. Contents, methods, and results of evaluation comply with section 7 of T/CAOE 20.8-2020 standard.

6.2 Evaluation of disaster mitigation

6.2.1 Evaluation contents

Ability to resist ocean waves and storm surges.

6.2.2 Evaluation index

6.2.2.1 Wave dissipation rate

Wave dissipation rate is calculated as the percentage of the wave height attenuation (H_1-H_2) to the original wave height H_1 after the wave propagates through a beach with width L:

$$R_{wL} = \frac{H_1 - H_2}{H_1} \times 100\% \qquad (1)$$

where:

R_{wL} wave dissipation rate;

H_1 wave height outside of breaker zone, in meters (m) ;

H_2 wave height inside of breaker zone, in meters (m);

6.2.2.2 Overwashing height

The difference between the highest water level and the dry beach elevation when the highest water level exceeds the dry beach elevation during a storm.

6.2.3 Evaluation methods

Wave dissipation rate in sandy coast disaster mitigation can be determined by field observation, empirical formulas, physical experiments, and numerical modelings, see Annex A for details.

6.2.4 Evaluation results

According to the selected method and the relevant data obtained from measurement or calculation, the formula proposed in 6.2.2 is used to calculate the wave dissipation rate of the sandy coast. The evaluation results can be divided into four levels according to the wave dissipation rate: excellent, good, medium, and poor. For the same wave level, the higher the wave dissipation rate is, the better the disaster mitigation effect and the higher the evaluation grade are (see Table 9). This evaluation grade is related to the overwashing height. If the overwashing height is negative, the parameter value is 100%, and all wave energy is dissipated before reaching the shoreline or dike.

Table 9— Disaster mitigation ability of sandy coast with different wave level and wave dissipation rate

Wave dissipation rate	Small waves (0.5≤$H_{1/3}$<1.25)	Medium waves (1.25≤$H_{1/3}$<2.5)	Large waves (2.5≤$H_{1/3}$<4.0)
100%	Excellent	Excellent	Excellent
≥80%~<100%	Good	Good	Excellent
≥60%~<80%	Medium	Good	Good
≥40%~<60%	Poor	Medium	Good

⩾30%~<40%	Poor	Poor	Medium
<30%	Poor	Poor	Poor

6.3 Evaluation of rehabilitation suitability

6.3.1 Evaluation index

Sandy coast rehabilitation zone shall meet the needs of sandy coastal development. The evaluation index used to determine the suitability of ecological disaster mitigation and rehabilitation is given in Table 10.

Table 10— Evaluation index of the feasibility of ecological disaster mitigation and rehabilitation for sandy coasts

Evaluation index categories	Names of index	Suitability condition
Topography	Coastline shape	Various types of open coastlines, mainly in embay beach
	Subaqueous beach slope	Less than 1/20
	Bathymetry in front of dike	Less than 3/(m)
Dynamic conditions	Waves	Annual-averaged significant wave height shall be larger than 0.5/(m)
Sediments	Intertidal sediments	Sands, gravels and sand-mud mixture
Biology and ecology	Intertidal benthic organisms	Unprotected benthic fauna and flora
Human activities	Fishing and aquaculture	No aquaculture in intertidal zone and backshore highland
	Nearshore sand mining area	No sand mining area within closure depth
	Reclamation	Areas outside jetty
	Planning compliance	Meet the requirements for coastal rehabilitation in the relevant guidance

6.3.2 Evaluation analysis

For the rehabilitation area conforming to the 6.3.1 index, suitability analysis shall be conducted according to the following requirements:

a) Analysis of damage mechanism of sandy coast. The analysis includes damage assessment of sandy coasts, sand transport status, human activities around, influence of coastal structures, and causes of erosion hotspot. The causes of coastal damage are analyzed by comparisons with historical changes and adjacent or similar coastal sections;

b) Suitability analysis of hydrodynamical conditions. Field survey and numerical simulation are used to analyze the offshore wave dynamical conditions in the rehabilitation area, to evaluate the influence of bathymetry, shoreline morphology and coastal structures on wave dynamics and the alongshore distribution characteristics of wave energy, and to analyze the potential area of erosion hotspots and the possibility of beach mud rehabilitation;

c) Suitability analysis of coastal topography. The analysis shall include whether the topography of engineering area can provide suitable surroundings for beach formation with or without artificial coastal structures, capacities of wave dissipation, and storm surge buffer of current sandy coastal topography;

d) Suitability analysis of ecology and environment. Nearshore seawater quality and sediment shall comply with 4.4 and 7.5 of HY/T 255-2018, respectively. The ecological effect of an ecologically sensitive target, beach filling implementation, and following beach profile evolution in rehabilitation areas shall also be considered.

6.3.3 Evaluation method and result

The index of sandy coast rehabilitation areas shall be in the appropriate range listed in Table 10. If any item is not satisfied, the area is considered to be unsuitable for rehabilitation. The feasibility shall be evaluated and analyzed in accordance with 6.3.2, and targeted rehabilitation methods and projects shall be proposed accordingly.

7 Formulation of implementation plan

The formulation of implementation plan of ecological disaster mitigation and rehabilitation on sandy coasts according to the suitability evaluations, see below for details:

a) The implementation plan shall comply with regional space planning, coastal zone protection and utilization planning, integrated river basin plan and professional tide (flood) prevention plan. It shall also meet the requirements of ecological red line protection and coastline control;

b) The implementation plan shall fully consider the connectivity, integrity and ecological buffering of the marine and land ecosystems, and proposed the layout of the sandy coast ecological rehabilitation based on the spatial division and different coast type, combined with the suitability evaluation results;

c) The implementation plan shall detail the technical requirements, construction methods, scope and scale of specific measures, and the scheme and measures shall focus on ecological friendliness to avoid new ecological environment problems caused by engineering constructions;

d) The design of the implementation plan shall focus on the comprehensive benefits of ecology and disaster mitigation, to reduce the consumption of coastal space resources caused by ecological construction. It is not suitable to build pure landscape projects;

e) After comprehensive analysis and demonstration from the aspects of economy, society and environment, the implementation plan can be recommended, which shall be regarded as the main content of the engineering construction and meet the requirements of the project feasibility study report;

f) Projects involving sea use and environmental assessment shall be carried out in accordance with relevant regulations. The project proposal and feasibility study report shall also be compiled in accordance with the construction water conservancy projects, but the ecological and disaster mitigation functions shall be highlighted.

The preparation outline of the implementation plan shall be carried out in accordance with Annex D in T/CAOE 21.1-2020.

8 Technology of sandy coast rehabilitation

8.1 Design of engineering

8.1.1 Design of beach profile

The profile analogy method is used to design the profile shape with reference to the typical profile shape and sedimentary characteristics of the adjacent coast in the engineering area with similar nearshore dynamical environment and topography type. For other cases, Dean (1977) formula for calculating equilibrium profile or the locally applicable equilibrium profile model can be used, and the calculation method is as follows:

$$h = Ay^{2/3} \qquad \cdots\cdots (2)$$

$$A = 0.067\omega^{0.44} \quad \cdots\cdots (3)$$

$$\omega = 14D^{1.1} \quad \cdots\cdots (4)$$

where:

h depth relative to high spring tide level, in meters (m);

y distance from shoreline, in meters (m);

A beach profile scale coefficient;

ω sediment fall velocity, in meters to seconds (m/s);;

D sediment mean grain size, in millimeters (mm);

The design of the cross-shore beach profile needs to consider the following points:

a) The natural beach profiles are mainly low-tide terrace type and completely dissipative type, as well as transition states between them (see Masselink & Short, 1993 for classifications). The design of beach profile shall refer to its original shape and the characteristics of adjacent beach profiles;

b) When the beach profile is designed in bays with weak dynamic conditions, in order to prevent or slow down the "mudification" trend of the beach, the grain size of the beach sediment can be appropriately increased to obtain a larger slope angle;

c) The recommended construction beach slopes for beach nourishment is 1/8～1/15;

d) It is recommended that the economic width of beach berm shall be 30 ~ 60/(m);

e) In a coastal environment with weak hydrodynamics, proper dredging can be carried out on the seaside of the original coast to create a stable beach profile.

8.1.2 Beach layout design

Beach layout design shall combine the ancillary engineering and simulation of coastline evolution after rehabilitation.

Parabolic model proposed by Hsu & Evans (1989) is recommended for beach layout design on equilibrium embay beach, the Formula is expressed as follows:

$$\frac{R_n}{R_0} = C_1 + C_2\frac{\beta}{\theta} + C_3\left(\frac{\beta}{\theta}\right)^2 \quad \cdots\cdots (5)$$

where:

R_n arbitrary polar radius, in meters (m);

θ corresponding polar angle, in angles (°);

R_0 -- length of control line, in meters (m)(m);

B -- the angle between the wave crest line and the control line, in angles(°).

C_1, C_2 and C_3 are functions of β, where β ranges from 10º to 80º. The expressions of these functions are as follows:

$$C_1 = 0.0707 - 0.004\,7\beta + 0.000\,349\beta^2 - 0.000\,008\,75\beta^3 + 0.000\,000\,047\,65\beta^4$$

$$C_2 = 0.9536 + 0.007\,8\beta - 0.000\,048\,79\beta^2 + 0.000\,018\,2\beta^3 - 0.000\,001\,281\beta^4$$

$$C_3 = 0.0214 - 0.007\,8\beta + 0.000\,300\,4\beta^2 - 0.000\,011\,83\beta^3 + 0.000\,000\,093\,43\beta^4$$

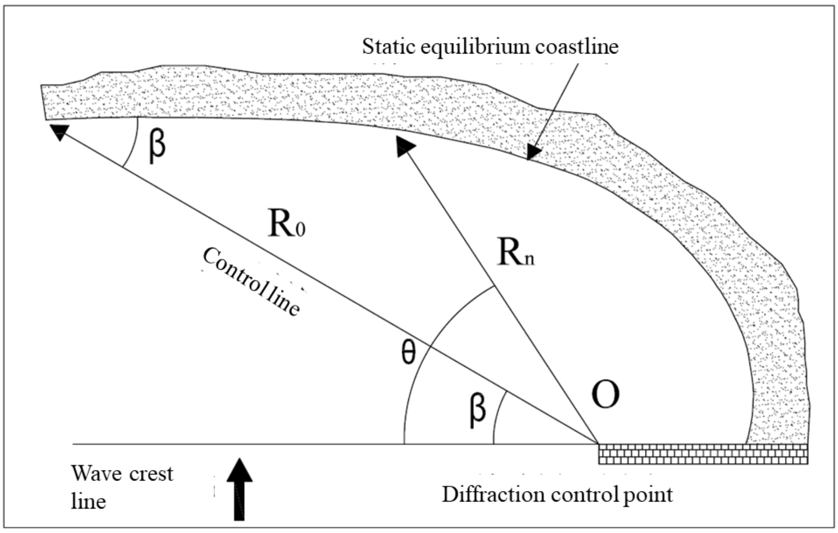


Figure 2 Equilibrium patterns of parabolic coast (Hsu and Evan, 1989)

The layout design of a straight coast shall be based on the long period (no less than 5 years' nourishment cycle) shoreline evolution model with full consideration of the background sediment transport rate and the relation between upstream and downstream sediment transport. When beach rehabilitation needs to be carried out in combination with auxiliary projects, the shoreline evolution model can be used for prediction (see 8.1.6), and the sand replenishment area and shoreline shape can be rationally designed.

8.1.3 Design of artificial structures

8.1.3.1 Groins

The groins shall be built in the downstream section of the nourished beach, and shall be consistent with the shape of the shoreline to form an artificial headland. It is recommended that the angle of intersection between the main incident wave direction and the groin be 100°~110°. The most effective setting distance of a groin in water is 40%~60% of the distance from the shoreline to the breaking point.

8.1.3.2 Detached breakwater

Detached breakwater includes emerged detached breakwater and submerged breakwater, see below for details:

a) The design of emerged detached breakwater shall follow the relationship between the shoreline change of nourished beach behind the breakwater and influencing factors, the relationship is as follows

$$\frac{X_S}{K} = f\left(H_0/L_0\ , S/K, \tan\theta, \alpha, G_o, \gamma\right) \quad \cdots\cdots (6)$$

where,

X_s length of sandspit behind the breakwater, in meters (m);

K length of breakwater, in meters (m); H_0 deep-water wave height, in meters (m); L_0 deep-water wave length, in meters (m); $\tan\theta$ beach slope;

S distance from shoreline, in meters (m);

α wave angle near the breakwater, in angles : (°);

G_0 opening width, in meters (m);

γ porosity of breakwater (%).

In the case that there is enough sand in the upstream, when the ratio of X_B to L_B is 1~2, a salient extending from the shore to the sea will be formed behind the breakwater. When the ratio of X_B to L_B is less than 1, a salient will develop to a tombolo.

b) The top elevation of submerged breakwater shall be lower than the lowest low tide level, which is suitable for coast areas with a small tidal range.

The transmission coefficient for a submerged breakwater at the mean low tide level is recommended in the range of 0.2~0.3, and not less than 0.6 at the mean high tide level. The relationship between submerged breakwater transmission coefficient and the height from the breakwater crest to the calculation water level shall comply with the JTS 154 standard.

8.1.3.3 Structural design of artificial structures

The structural design of artificial structures shall comply with JTS 154 standard.

8.1.4 Design of berm elevation

The design of beach berm elevation shall take the local historical high-water level, wave runup, landscape elevation, existing beach elevation, adjacent beach elevation, and nourishment cost into consideration. A degree of overwashing is allowed under extreme weather. This can be calculated by the following formulas:

$$H_B = H + R_2 \quad \cdots\cdots (7)$$

$$R_2 = 1.1\left\{0.35\beta_f (H_0 L_0)^{1/2} + \frac{\left[H_0 L_0 (0.563\beta_f^2 + 0.004)\right]^{1/2}}{2}\right\} \quad \cdots\cdots (8)$$

where,

H_B beach berm elevation, in meters (m);

H extreme high water level with 20-year return period, in meters (m);

R_2 wave runup, in meters (m);

β_f beach slope, in angles (°);

H_0 deep-water wave height, in meters (m);

L_0 deep-water wavelength, in meters (m);

8.1.5 Nourishment sand requirements

8.1.5.1 Basic requirements

Acquirement, quality, and grain size parameters shall meet the following requirements:

a) Conforming to the relevant national regulations on sand mining;

b) Conforming to the relevant requirements of national standards for sediment quality:

--Bathing beach: sediment quality shall comply with the first class of marine sediment quality requirement in GB 18668-2002 standard;

--Tourism landscape beach: sediment quality shall not be lower than the second class of marine sediment quality requirement in GB 18668-2002 standard;

c) Sediment parameters shall take the sediment grain size of natural beach, sediment grain size on an adjacent similar beach, wave condition in the engineering area, purpose of rehabilitation, and nourishment into consideration.

8.1.5.2 Sediment grain size requirements

In line with the requirements of sediment compatibility, the average sediment grain size of the nourishment is taken as the design index, and the basic principle of determining the average sediment grain size is that the average grain size of the filling sand shall be equal to or slightly larger than the natural beach sand in the engineering area.

8.1.6 Numerical prediction

Numerical simulation and prediction of beach nourishment project shall include hydrodynamical environmental simulation, coastal sediment transport simulation, coastline evolution in long-period, adaptive adjustment of beach profile and short-period response under extreme conditions. It can be used to predict the designed lifetime of the beach, and numerical models of beach evolution recommended in this section are as follows:

a) Simulation of short-period profile evolution of beach nourishment projects under extreme wave or storm wave condition, typical modes such as, UNIBEST-TC, CROSS, XBeach, SBEACH, CROSPE and NearCoM;

b) Simulation of long-period coastline evolution of beach nourishment projects, typical mode such as, GENESIS based on one line model.

8.1.7 Calculation of nourishment volume

The sand filling volume is recommended to be 1.3~1.5 times larger than calculated volume from calculation, considering the volume difference between nourished beach and natural beach, filling volume calculated with the prediction of sand loss and nourishment period, natural adjustment and loss of sands during and after the nourishment project.

8.2 Engineering construction

8.2.1 Construction preparation

Prior to the construction, the construction organization shall survey the construction conditions, conduct in-depth research on contract or design documents as well as work out the construction plan according to the specific construction condition, complete the necessary administrative examination and approval procedures, and make safety warnings at the construction site.

8.2.2 Nourishment approaches

Nourishment type includes dry beach nourishment, beach face nourishment, subaqueous nourishment, dune nourishment and artificial sand engine nourishment, see Annex E for their basic features. Dry beach nourishment and beach face nourishment is recommended for beach nourishment and rehabilitation, and the actual construction can also choose a combination of the two..

8.2.3 Construction of artificial structures

The requirement for coastal engineering and hydraulic structures shall comply with section 3 to 7 in SL 260-2014 standard.

9 Tracking monitoring and effect evaluation

9.1 Post monitoring

During the implementation of the project and after the completion of the construction, attentions shall be paid to the disaster damage of the nourishing area after the storm surge, the changes of disaster reduction function and ecological status, as well as the beach stability. The monitoring scope and elements shall be specifically determined, the monitoring plan shall be formulated, and the project tracking monitoring shall be carried out. See 5.2 for specific monitoring contents and methods.

9.2 Effect evaluation

9.2.1 Disaster damage evaluation

9.2.1.1 Evaluation index

Damage evaluation index for sandy coasts is shown in Table 11.

Table 11— Damage evaluation index for sandy coasts

Indexes		Types	Damage degree		
			Low	Medium	High
Coastline position	The variation of the mean spring tide, which is negative for erosion and positive for deposition	Major index	Advanced deposit or stable	Erosion retreat distance is 5%~25% of the original dry beach width	Erosion retreat distance is more than 25% of the original dry beach width
Seawall frontier/backshore elevation	The mean elevation of natural backshore such as dune and berm, or the elevation of foreshore of the seawall, adopts the difference value from the pre-disaster, the down-erosion is negative, and the up-accretion is positive	Major index	Up-accretion or stable	Local down-erosion	Overall down-erosion
Intertidal slope	Beach slope from mean high tide level to mean low tide level, represented by "vertical variance/horizontal distance"	Secondary index	Getting mild	Fixed	Getting steeper
Erosion hotspot	The number or proportion of erosion hotspots along the shoreline	Secondary index	None	Less than 2 hotspots and 10% of shoreline	More than 2 hotspots and 10% of shoreline
Sediment grain size	Sediment grain size in dune or berm, high tide zone, middle tide zone and low tide zone	Secondary index	Almost unchanged	Locally coarsen	Overall coarsen

9.2.1.2 Survey requirements and methods for evaluation index

Survey requirements and methods for evaluation indexes are shown in 5.2.2.

9.2.1.3 Evaluation methods

Taking the north or east of the sandy coast as the benchmark, every 200m of the sandy coast is taken as an evaluation unit. According to the comparison of the before and after changes of the evaluation index, the damage of the sandy coast is determined and divided into three levels: destroyed, damaged and stable. The details are as follows:

a) When one of the major indexes has a high degree of damage, the unit is determined to be destroyed;

b) When the damage degree of the two major indexes is not higher than medium, or one of the secondary indexes is greater than medium, the unit is determined to be damaged;

c) When the degree of damage of the two major indexes is low, and the secondary indexes are high, the unit is determined to be stable;

d) The first tracking survey shall be conducted within 15 days after storm to evaluate the damage to the sandy shorelines caused by the storm;

e) Surveys shall be conducted one month and three months after the storm to evaluate the recovery of the sandy coast and to determine the extent of irreversible damage to the sandy coast resulting from the storm disaster.

9.2.2 Evaluation of disaster mitigation

Evaluation of disaster mitigation is provided in 6.2.

9.2.3 Evaluation of stability of beach nourishment

9.2.3.1 Construction of index system

The rehabilitation of the sandy coast focuses on habitat rehabilitation, and its stability is the fundamental factor that determines its ecological function. In this part, a beach nourishment stability index system is constructed based on natural dynamic conditions, beach physical characteristics, and beach adaptability, including 11 indexes. The interpretation and data resources of the evaluation index are shown in Table 12.

Table 12— The interpretation and data resources of the evaluation index

Category	Number	Indexes	Index interpretation	Data resources
Marine dynamic environment	1	Wave condition	Reflecting the wave energy acting on the beach and it is indicated by nearshore mean significant wave height	Wave station or buoy
	2	Storm intensity	Reflecting the influence of storms on the beach, and it is represented by the historical largest wave height	Historical meteorological statistics
	3	Storm frequency	Reflecting the frequency of storm actions, and it is represented by the annual-average of effective storm numbers	Historical meteorological statistics
Beach physical characters	4	Nourishment length	Length of nourishment in the longshore direction	Field observation or image

Category	Number	Indexes	Index interpretation	Data resources
	5	Nourishment grain size	Reflecting the grain size of beach nourishment, and it is indicated by the ratio between medium grain size of currently surface sediment and original beach sands or adjacent beach sands	Field observation
	6	Sands supply per unit width	Reflecting sands supply intensity, and it is represented by the sands filling volume per unit width of the beach	Data collection
	7	Beach layout	Reflecting the refraction processes of nearshore waves and exposure of the beach to wave action	Field observation or image
	8	Auxiliary structure	Reflecting the influence of nearshore structures on wave attenuation and refraction, and the interception of longshore sediment transport	Field observation or image
Beach adaptation	9	Width of the intertidal zone	Reflecting the effective zone of nearshore wave dissipation, and it is indicated by the horizontal distance between mean high tide level and mean low tide level in the cross-shore direction	Field observation
	10	Width of dry beach	Reflecting the capacity of beach to encounter erosion, and it is represented by the horizontal distance from backshore dune or seawall frontier to mean spring high tide level	Field observation or image
	11	Erosion hotspot density	Reflecting the local beach features, and is indicated by the number of erosion hotspot per unit width of the beach	Field observation

According to the stability of beach nourishment from high to low, the indexes are divided into 5 levels: extremely stable, stable, relatively stable, unstable, and extremely unstable, and are assigned to 5, 4, 3, 2, and 1 respectively (see Table 13).

Table 13— Index levels for the stability of beach nourishment

Number	Evaluation index	Description	Index levels				
			5	4	3	2	1
1	Wave condition	Significant wave height (m)	≤0.3	(0.3,0.6]	(0.6,0.9]	(0.9,1.2]	>1.2
2	Storm intensity	Historical recorded largest wave	≤5.0	(5.0,6.0]	(6.0,7.0]	(7.0,9.0]	>8.0

Number	Evaluation index	Description	Index levels				
			5	4	3	2	1
		height (m)					
3	Storm frequency	Annual-averaged number of storms (times/yr)	⩽0.5	(0.5, 1.0]	(1.0, 1.5]	(1.5, 2.0]	>2.0
4	Nourishment length	Length in longshore direction (km)	⩾2.0	[1.5, 2.0)	[1.0, 1.5)	[0.5, 1.0)	<0.5
5	Nourishment sand grain size	Ratio of mean grain size between nourishment sands and original beach sands	⩾1.75	[1.5, 1.75)	[1.25, 1.5)	[1.0, 1.25)	<1.0
6	Sands supply per unit width	Sands supply per unit width on the beach (m3/m)	⩾400	[300, 400)	[200, 300)	[100, 200)	<100
7	Beach layout	Layout	Tombolo	Headland	Salient	Straight	Sandspit
8	Auxiliary structure	Type and relative positions of auxiliary structure	Detached breakwater (S/L<2)	Downstream groin	Detached breakwater (S/L>2)	Midstream groin	None
9	Width of intertidal zone	Horizontal distance from high tide level to low tide level (m)	⩾80	[60, 80)	[40, 60)	[20, 40)	<20
10	Width of dry beach	Distance from berm frontier to backshore dune or seawall (m)	⩾80	[60, 80)	[40, 60)	[20, 40)	<20
11	Erosion hotspot density	Number of erosion hotspot on per unit width of beach (/km)	0	(0, 1.0]	(1.0, 2.0]	(2.0, 3.0]	>3.0

9.2.3.2 Evaluation methods

The weights of the indexes are shown in Table 14.

Table 14— The weights of the evaluation indexes for beach nourishment stability

Evaluation index	Wave intensity	Storm intensity	Storm frequency	Nourishment length	Relative grain size	Sands supply per unit width	Beach layout	Auxiliary structure	Width of intertidal zone	Width of dry beach	Erosion hotspot density
Weight	0.093	0.050	0.094	0.082	0.126	0.104	0.045	0.066	0.119	0.086	0.135

The weighted sum method is used to evaluate the stability of beach nourishment. According to the classification method of the indexes in Table 13, the score of each index is determined. Combined with the corresponding weights of each index in Table 14, the Nourished Beach Stability Index, (NBSI) is calculated by the weighted sum method. The calculation formula is as follows:

$$NBSI = \sum_{i=1}^{m}\left(P_i \times \omega_i\right) \qquad \cdots\cdots (9)$$

where,
m number of evaluation index;
P_i score of each index;
ω_i corresponding weight.

9.2.3.3 Evaluation results

Evaluation results for sandy beach stability can be divided into five levels (see Table 15 for details).

Table 15— Five levels of sandy beach stability evaluation results

Levels	Extremely low	Relatively low	Medium	Relatively high	Extremely high
Description	Extremely unstable	Unstable	Relatively stable	Stable	Extremely stable
Classification (NBSI)	≥1~<2.41	≥2.41~<2.92	≥2.92~<3.08	≥3.08~<3.59	≥3.59~<5

9.2.4 Evaluation of the ecological effect

In accordance with T/CAOE 20.8-2020 7.2.2.

10 Quality control

Quality control shall be carried out in accordance with the requirements in Clause 8 of T/CAOE 21.1-2020.

11 Achievements and archiving

11.1 Results complied

11.1.1 Report

Reports include:
a) <Evaluation report on engineering suitability of sandy coastal ecological rehabilitation for hazard mitigation>, report outline shall comply with Annex C of T/CAOE 21.1-2020;

b) <Engineering implementation plan on sandy coastal ecological rehabilitation for hazard mitigation>, report outline shall comply with Annex D of T/CAOE 21.1-2020;
c) <Engineering effect evaluation on sandy coastal ecological rehabilitation for hazard mitigation>, report outline shall comply with Annex E of T/CAOE 21.1-2020;
d) <Project summary report on sandy coastal ecological rehabilitation for hazard mitigation>, report outline shall comply with Annex F of T/CAOE 21.1-2020.

11.1.2 Thematic graph

Special images include:
a) Basic images include orthophotoquad and remote sensing identification images of sandy coast;
b) The evaluation result images include evaluation images of sandy coastal ecological status, evaluation images of damage, evaluation images of disaster mitigation, and evaluation images of beach stability;
c) Engineering design images include beach layout image, beach profile image, and artificial structure image.

11.1.3 Datasets

Datasets include:
a) Survey datasheet, monitoring sheet, field images, and remote sensing images on sandy coasts;
b) Laboratory test analysis report of sandy coast survey data.

11.2 Archiving

Requirement archiving shall comply with T/CAOE 21.1-2020 9.2.

Annex A
(annex informative)
Common evaluation methods for disaster mitigation function

A.1 Field observation method

A.1.1 Measuring section and measuring point

The section observation can be adopted in the field observation. The selected beach section shall be typical, and the section near the center of the entire beach is usually selected. When the characteristics of the sandy coastal evaluation area are quite different, multiple sections shall be selected to represent the characteristics of each beach section in the assessed area. At least two measuring points in each section are needed, which are located near the low spring tide level and on beach backshore (seawall frontier), and additional measuring points can be placed between these points when necessary.

A.1.2 Observation elements and methods

The observation of beach morphological features mainly includes shoreline position, the elevation of backshore or seawall frontier, beach profile, erosion hotspot, sediment particle size, coastal protection, and structures, etc. Coastal dynamic environmental parameters include water level and wave train parameters in the nearshore area during the storm, wave parameters in the low tide zone, high tide zone, and upper tide zone (in front of the seawall), and maximum overwashing height during a storm surge. Refer to the methods specified in Tables 2 and 4 in this section.

A.1.3 Analysis and calculation of observation data

One observation lasts for several hours to several days. The significant wave heights of H_1 and H_2 at the measuring points before and after the observation section are used to calculate the wave dissipation rate R_{wL} when the wave propagates through the beach.

A.2 Empirical formulas for the wave dissipation rate

The empirical formula method is only applicable to the case where the section bathymetry is relatively simple, and there is no obvious shielding between the wave observation station and the assessed beach. The whole profile will be divided into several sections, and calculate the mean length Δx, mean water depth d, mean wave length L, and relative water depth d/L for each section.

Empirical formulas are used to quantify wave energy dissipation, the wave dissipation $K_{f(i-1,i)}$ between position i-1 and position i is shown in Formula (A.1):

$$K_{f(i-1,i)} = \frac{1}{1+\frac{32\pi^3 H_i}{3 g^2 T^4}[k_f B_1 + M B_2 H_i + N B_3 H_i^2] K_{s(i-1,i)}^2 K_{r(i-1,i)}^2 \Delta x} \quad \text{(A.1)}$$

$$H_i = K_{f(i-1,i)} K_{s(i-1,i)} K_{r(i-1,i)} H_{i-1} \quad \text{(A.2)}$$

$$k_f = \exp[5.213 \left(\frac{B}{\Delta}\right)^{-0.194} - 5.977] \quad \text{(A.3)}$$

$$B_1 = \frac{k_f}{sinh^3(kd)} \quad \text{(A.4)}$$

$$M = \frac{24 f g T^2}{\pi^3 L d} \quad \text{(A.5)}$$

$$B_2 = \frac{\sinh(kd)\cosh(kd) - kd}{sinh^2(kd)} \quad \text{(A.6)}$$

$$N = \frac{6f_0T}{\pi^3L^2}(\frac{g}{d})^{1/2} \quad \text{(A. 7)}$$

$$B_3 = \frac{[2\sinh^2(kd)-3]\coth(kd)+\frac{3kd}{\sinh^2(kd)}}{\sinh^2(kd)} \quad \text{(A. 8)}$$

$$K_{s(i-1,i)} = \sqrt{\frac{(Cn)_{i-1}}{(Cn)_i}} \quad \text{(A. 9)}$$

$$K_{r(i-1,i)} = \sqrt{\frac{b_{i-1}}{b_i}} \quad \text{(A. 10)}$$

$$B = \frac{H_b}{2\sinh(kd_b)} \quad \text{(A. 11)}$$

$$n = \frac{1}{2}[1 + \frac{2kd}{\sinh(2kd)}] \quad \text{(A. 12)}$$

where:

$K_{f(i-1,i)}$ Wave energy dissipation between i-1 and i;

H_i Wave height in position i;

g gravity acceleration;

T wave period;

L wave length;

k wave number;

d water depth;

f_0 constant of 0.242;;

k_f bottom friction coefficient;

$K_{s(i-1,i)}$ shoaling coefficient between i-1 and i;

$K_{r(i-1,i)}$ refraction coefficient between i-1 and i;

Δx distance between two positions;

B maximum amplitude of wave particle near the bottom;

Δ bottom roughness, for a general sandy coast, take its sediment particle size.

C wave phase celerity;

N Wave energy transfer coefficient;

b_i the distance between two adjacent wave crest lines in position I;

H_b breaking wave height;

d_b breaking water depth.

Wave dissipation rate K_{ft} under protection of sandy beach is Eq. (A. 13):

$$K_{ft} = 1 - \sum_{i=2}^{m} K_{f(i-1,i)} \quad \text{(A. 13)}$$

where:

m the number of sections divided over the whole beach.

A.3 Physical model experiments method

When the physical model experiment method is adopted, the technical scheme shall be designed according to the needs of the evaluation of the disaster mitigation function of the sandy coast, which mainly includes the selection of model scale, the determination of the beach topography and sediment, the design of water level and wave conditions, the arrangement of flume and measuring instruments, and the analysis and calculation of experiment data. Among them, three important technical scheme parameters are explained as follows:

A.3.1 Model of shoreline topography

The physical model needs to select the beach topography and sediment, and determine the beach topographic scale and sediment scale according to the criterion of length similarity, which is provided in A.14; According to the features of the specific coast, the similarity of beach profile shape, sediment transport, sediment fall velocity, and seabed deformation shall be considered to select appropriate model sands. The intertidal topography can be used as the calculation basis for the length scale when evaluating the marine and coastal disaster mitigation function of sandy coasts. The value of the length scale L shall not be greater than 50.

$$\lambda_L = \frac{L_p}{L_m} \quad \cdots\cdots (A.14)$$

where:

L_p representatively prototype length;

L_m representatively model length.

A.3.2 Water level gauges and wave conditions

The water level and wave height in the hydrodynamic parameters of the model can be calculated by using the length scale according to the characteristics of the nearshore tide and wave in the sandy coast to be evaluated. The calculation formulas are shown in Formulas (A.15) and (A.16). The model and prototype parameters shall also conform to the gravity similarity criterion, that is, the prototype Froude number (Fr_p) is equal to the model Froude number (Fr_m). According to the length scale and gravity similarity criterion, the relationship between wave period and real-world sea and in the model is shown in Formula (A.17).

$$L_{vm} = \frac{L_{vp}}{\lambda_L} \quad \cdots\cdots (A.15)$$

$$H_{0m} = \frac{H_{0p}}{\lambda_L} \quad \cdots\cdots (A.16)$$

$$T_m = \frac{T_p}{\sqrt{\lambda_L}} \quad \cdots\cdots (A.17)$$

where:

L_{vm} model water level;

L_{vp} prototype water level;

H_{0m} model wave height;

H_{0p} prototype wave height;

T_m model wave period;

T_p prototype wave period.

A.3.3 Water flume and instruments arrangement

The first end of the experimental flume shall be equipped with a wave-making device, which shall have the function of active wave absorption. The model beach is arranged in the middle of the flume and separated from the wave-making equipment. At the back of the beach, a wave elimination device is set after a certain distance. Digital wave gauges are usually used in laboratory to measure wave propagation and attenuation on beach faces. The wave gauges can be arranged on the beach face and its front and back. The measuring points of the wave gauges shall be at least 2 (one at the front and rear edge of the beach). The layout position can be referred to Figure A.1.

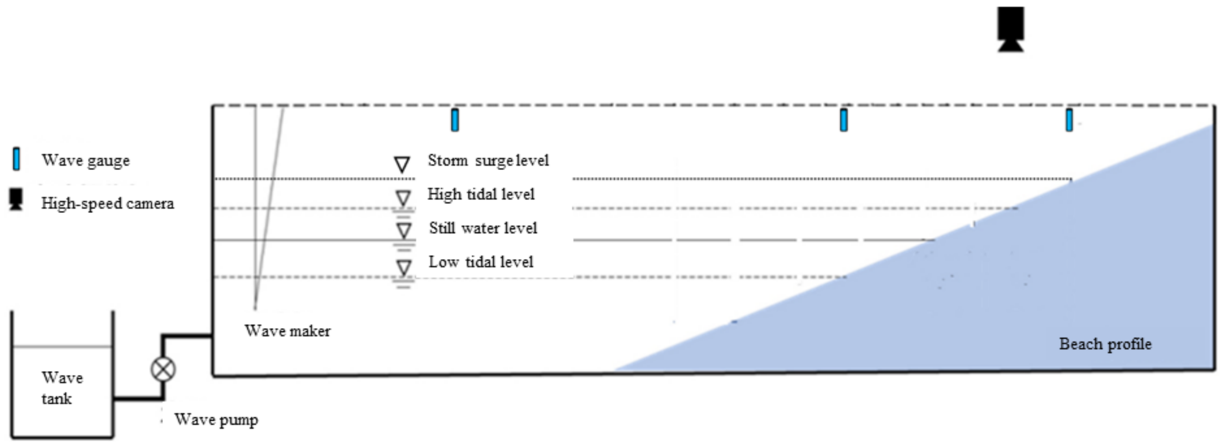


Figure A.1 Schematic diagram of sandy coastal model experiments

A.4 Numerical simulation methods

The numerical simulation method for disaster mitigation function of sandy coast shall include two parts: the large coast area and the small beach area. The numerical simulation of waves in the large coast area is mainly used for prediction in the frontier edge of the beach with the offshore observed data, thus providing boundary conditions for the numerical model of the small beach area. The numerical model for the small beach area is mainly used to simulate wave runup, breaking, refraction, diffraction, and reflection.

Simulation for the large coast area can conducted with the phase-averaged wave model (such as SWAN), and simulation for the small beach area can be conducted with the phase-resolved wave model (such as, NHWAVE).

When numerical simulation method is adopted to evaluate the marine and coastal disaster mitigation function of sandy coast, simulation shall be carried out at real scale, and the wave heights of H_1 and H_2 obtained before and after the simulated beach to be evaluated shall be substituted into Eq. 1 to calculate the wave dissipation rate R_{wL} of sandy coast.

A.5 Applicability of evaluation methods for disaster mitigation functions of sandy coasts

Applicability and priority of evaluation methods for disaster mitigation functions of sandy coasts are shown in Table A.1.

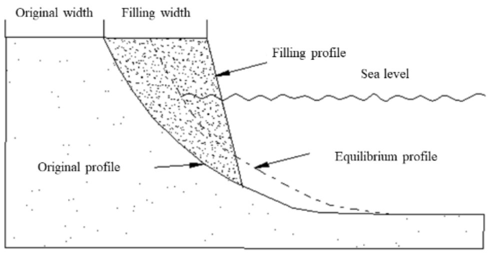
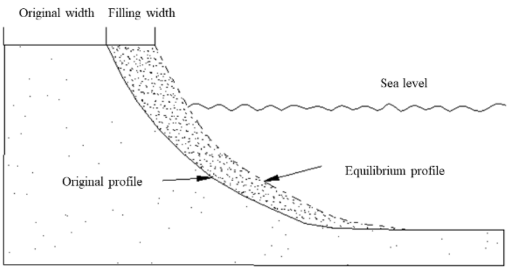
Table A.1— Applicability of evaluation methods for disaster mitigation functions of sandy coasts

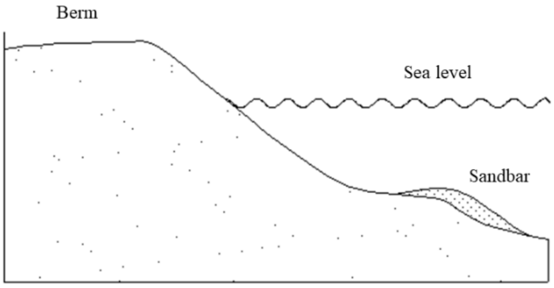
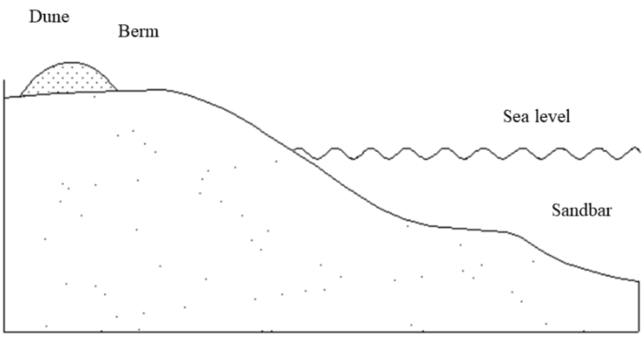
Methods	Applicability	Priority
Field observation	The open, natural and stable coast is applicable, not suitable for the strong erosion damage of the coastline, islands and bedrock shelter, or more artificial structures of the coastline. Observation with the contrast of two features, "seawall+beach" and the complete beach morphology.	High
Physical model experiments	The frequency of regional marine disaster is low (storm surges affecting the evaluation area did not happen in the evaluation years) or field observation is limited by the economic and technical conditions	Medium
Numerical simulation	The frequency of regional marine disaster is low (no storm surges affecting the evaluation area during the evaluation years) or field observation is limited by the economic and technical conditions or the beach morphology parameters, nearshore hydrodynamics are obtained as well as numerical simulation software and technical conditions	Medium
Empirical formulas	The empirical formula method is only applicable to the case with simple beach morphology. In the calculation process, only the frictional energy loss and turbulent energy loss are considered, and the wave energy loss caused by seabed permeation is not considered temporarily.	Low

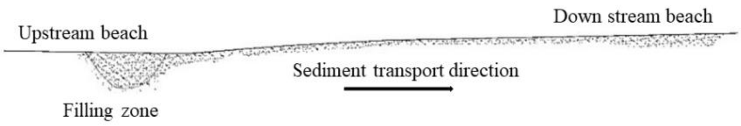
Annex B
(annex informative)
Nourishment approaches and features

Nourishment approaches and features are shown in Table B.1.

Table B.1—Nourishment approaches and features

Nourishment approaches	Diagrams	Features
Dry beach nourishment		Advantages: Increase dry beach width, remarkable effect in constructing beach, convenient construction, save sands, quick returns Disadvantages: The subsequent adjustment of the profile is larger, and the sand loss to the sea is rapid.
Beach face nourishment		Advantages: Increase dry beach width, construction equilibrium profile, good long-term effects. Disadvantages: Sand filling technique is difficult and not easy to construct.

<table>
<tr>
<td>Subaqueous nourishment</td>
<td>
</td>
<td>Advantages: Waves are small offshore and sediment transport is limited; nourishments can feed shoreface gradually. Submerged artificial sandbar can trigger wave dissipation and weaken waves on the shoreface to promote sediment deposition.
Disadvantages: A large amount of sand; Difficult to see the effect of beach nourishment in a short time period.</td>
</tr>
<tr>
<td>Dune nourishment</td>
<td>
</td>
<td>Advantages: Prevent overwashing during storm surges, plants on the dune improve the impact resistance of the upper part of the beach and expand the tourist leisure space; dune nourishes beach when berm is eroded by the storm waves.
Disadvantages: A large amount of sand, long transportation line freom the open sea, high cost.</td>
</tr>
</table>

Artificial sand engine nourishment		Advantages: Suitable for straight beach with obvious longshore sediment transport, supply artificial sand source in the upstream and transport to downstream by natural forces, maintain the sustainable natural balance of the coast. Disadvantages: A large amount of sand, sand transport cannot be interrupted by coastal structures.

Annex C
(annex informative)
Coefficient of the variation weighting method

The coefficient of variation is a normalized measure of the dispersion degree of probability distribution, and it is defined as a ratio of its standard deviation to its average value. In any evaluation model, each index has its own coefficient of variation. For any evaluation instance, if there are m evaluation indexes and q evaluation beaches, then the evaluation instance can use the matrix $V=(a_{ij})_{m\times q}$ (i=1, 2, …, m; j=1, 2, …, q), that is:

$$V=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1q} \\ a_{21} & a_{22} & \cdots & a_{2q} \\ \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & \cdots & a_{mq} \end{bmatrix}$$

For any evaluation index $i(a_{i1}, a_{i2}, \cdots, a_{iq})$, and its arithmetic mean value can be expressed by Formula (C.1), namely:

$$\mu_i=\frac{1}{q}\sum_{j=1}^{q}a_{ij} \qquad \text{(C.1)}$$

where:

μ_i the arithmetic mean of the i^th^ index;

q the number of evaluated beaches;

a_i the i^th^ index of the j^th^ beach.

Its standard difference can be expressed by Formula (C.2), namely:

$$\sigma_i=\sqrt{\frac{1}{q-1}\sum_{j=1}^{q}\left(a_{ij}-\mu_i\right)} \qquad \text{(C.2)}$$

where:

σ_i the standard deviation of the i-th index.

The variation coefficient of evaluation index i $(a_{i1}, a_{i2}, \cdots, a_{iq})$ can be expressed by Formula (C.3), namely:

$$c_i=\frac{\sigma_i}{\mu_i} \qquad \text{(C.3)}$$

where:

c_i the variation coefficient of i^th^ index.

Then the weight of evaluation index i in all evaluation index systems can be expressed by Formula (C.4), namely:

$$\omega_i=c_i/\sum_{i=1}^{m}c_i \qquad \text{(C.4)}$$

where:

ω_i the weight of the i^{th} index.

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