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Social Organization Standard

T/CAOE 21.2-2020

Technical guideline on coastal ecological rehabilitation for hazard mitigation —

Part 2:

Mangroves

海岸带生态减灾修复技术导则 第 2 部分：红树林

（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 2 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 *National Marine Hazard Mitigation Service*; *Third Institute of Oceanography, Ministry of Natural Resources*; *Sichuan University*.

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Technical guideline on coastal ecological rehabilitation for hazard mitigation —

Part 2: Mangroves

1 Scope

This part of T/CAOE 21 specifies the working procedures of data collection and survey, suitability assessment, implementation plan preparation, ecological disaster reduction and restoration technology, tracking, monitoring and results evaluation, quality control, results and archiving of mangrove ecological disaster reduction and restoration.

This part is applicable to mangrove ecological disaster reduction and restoration work in coastal protection and restoration projects, which could be employed as reference of other related works.

2 Normative references

The following documents are essential for the application of this document. For reference documents with date, only the dated version applies to this document. For undated references, the latest edition of the referenced document (including any amendments) applies.

GB/T 12763.2 *Marine Survey Specification Part 2: Marine Hydrographic Observations*

HY/T 214-2017 *Technical Guidelines for Mangrove Vegetation Rehabilitation*

LY/T 1938-2011 *Technical Guidelines for Mangrove Plantations*

LY/T 2972-2018 *Technical Guidelines for Planting Mangroves on Biophysically Unfavorable Habitats*

T/CAOE 20.3 *Technical Guidelines for Survey and Evaluation of Coastal Ecosystem - Part 3: Mangroves*

T/ CAOE 21.1-2020 *Technical Guidelines on Coastal Ecological Rehabilitation for Hazard Mitigation - Part 1: General Considerations*

DB44/T 284-2005 *Technical Guidelines for Planting Mangroves*

3 Terminologies and definitions

For the purposes of this document, the following terms and definitions apply

3.1

mangrove

xylophyta, grow in the intertidal zone of tropical and subtropical regions.

3.2

mangroves; mangrove forest

tropical and subtropical coast biomes dominated by mangrove plants

4 Operation procedures

In accordance with the requirements given in T/CAOE 21.1-2020, Chapter 6.

5 Data collection and survey

5.1 Data categories for collection and surveys

The information required for the mangrove ecological restoration project shall include overview of the project area, mangrove vegetation, biological community, environmental elements, and threat factors, etc. The factors and survey methods are shown in Table 1.

Table 1—Categories of data for collection and surveys

The Scope of the Survey	Survey Descriptions	Survey methods
Overview of the project area	Environmental profile: natural conditions, ecological characteristics and environmental status	Data collection
	Geographic attributes: Specific location and geographic coordinates	Data collection and measurement
	Policies and regulations: laws and regulations, plans	Data collection
Mangrove vegetation	Mangrove vegetation: area and distribution, species, coverage, plant density, plant height, diameter at breast height, base diameter, root density, seedlings	Field survey
Biological community	Macrobenthos community: species composition, density, biomass	Field survey
	Bird community: species composition, number	Field survey
Environmental elements	Hydrological environment: water temperature, salinity, water level, wave elements (wave height, cycle, etc.)	Data collection, Field survey
	Substrate environment: sediment granularity, organic carbon, sulphides, total phosphorus, total nitrogen	Field survey
	Terrain: Beach elevation	Field survey
Threat factors	Natural factors: natural disasters such as storm surges, invasive alien species, etc.	Data collection, field survey, social survey, etc.
	Human factors: aquaculture activities, fishing, coastal zone engineering, sewage conditions, utilization of surrounding resources, tourism development activities, etc.	Data collection, field survey, social survey, etc.

5.2 Ecosystem status survey

5.2.1 Survey elements and methods

The field survey elements are set out in Table 1. The survey methods for the other survey elements, in addition to the water level and wave elements, are carried out in accordance with T/CAOE 20.3.

5.2.2 Survey time

A survey shall be carried out before the implementation of the mangrove ecological disaster reduction and restoration project. The survey time shall be arranged during July to October. Follow-up monitoring and survey shall be carried out during and after the implementation of the mangrove ecological disaster reduction and restoration project. The monitoring and survey time is shown in 9.1 of this document.

5.3 Field observation of disaster mitigation functions

5.3.1 Selection of measuring sections and points

Cross-shore observation method is used in field observation of mangrove disaster mitigation functions. The cross-section shall be as parallel as possible to the direction of wave arrival, and the plant density and the width of the vegetation zone shall be able to reflect the situation of the entire mangrove area. When the distribution of mangroves has large differences in regional characteristics, multiple sections shall be selected. There are no less than 2 measurement points for each section, which are located at the edge of the vegetation area facing the sea (the seaward point) and the edge of the vegetation area on the landward side (the landward point).

5.3.2 Elements of observation and methods

The field observation elements of the disaster mitigation function include the wave height and tide level at the seaward point and the landward point. The observation methods of wave elements and tide levels such as wave height and cycle are carried out in accordance with the relevant provisions of GB/T 12763.2.

5.3.3 Observation time

The Field observation period of the disaster reduction function shall include the entire storm surge impact period (1 to 3 days before the storm surge warning to the storm surge warning lifted).

6 Suitability evaluation

6.1 Evaluation scope

A suitability evaluation shall be carried out and a suitability evaluation report shall be prepared before the mangrove restoration project is implemented. The evaluation covers ecological status, disaster reduction functions, restoration suitability, etc. If there is no mangrove in the area, the disaster reduction function evaluation in 6.3 of this document is unnecessary.

6.2 Ecological status evaluation

The status evaluation contents and methods are performed in accordance with T/CAOE 20.3.

6.3 Functional evaluation for disaster reduction

6.3.1 Evaluation content

Mangroves attenuate the power of storm surges and waves, which contain a comprehensive disaster mitigation function of factors mangrove vegetation and topographic change.

6.3.2 Evaluation parameters

Wave dissipation rate.

6.3.3 Wave dissipation rate

Wave dissipation rate (R_{wL}) It is the ratio of the attenuation (H_0-H_L) of the wave height to the wave height (H_0) of the incoming wave after the wave passes a certain width of the mangrove vegetation zone during the storm surge. It is calculated according to formula (1).

$$R_{wL}=\frac{H_0-H_L}{H_0}\times 100\% \cdots\cdots (1)$$

Where

H_0 effective wave height at the edge of the coastal side of the vegetation area (front-measuring point), the unit is meter (m);

H_L effective wave height at the edge of the coastal side of the vegetation area (post-measuring point), the unit is meter (m).

6.3.4 Evaluation method

See Annex A.

6.3.5 Evaluation results

According to the evaluation results, the disaster reduction ability has been divided into four grades: excellent, good, medium, and weak based on the wave height attenuation rate, see Table 2. For the same wave level, the higher the wave height reduction rate, the better the disaster reduction effect of mangroves and the higher the evaluation level of disaster reduction function.

Table2--Disaster reduction capacities of mangroves corresponding to wave dissipation Rate

Wave dissipation rate	Level of Disaster Reduction Capacity
≥80%	Excellent
≥60%~<80%	Good
≥30%~<60%	Medium
<30%	weak

6.4 Suitability evaluation of restoration

6.4.1 Evaluation indicators

The suitability of mangrove ecological restoration is determined according to the habitat conditions of the restoration area and the planning and human interference of the surrounding area. Suitability evaluation indicators are included but not limited to the contents of Table 3.

Table 3--Indicators to evaluate the suitability of mangrove ecological restoration area

Indicator types	Indicators	Applicable ranges	Habitat transformation possibilities
Habitat conditions	Temperature	Average temperature of the coldest month≥9.3℃; average	Cannot be modified

		sea temperature of the coldest month≥10.6℃	
	Salinity of seawater	2～30	Can be modified, can be improved by dredging section river channels
	Tidal flat elevation	Between the average sea level (or slightly higher) and the average high tide level of the regression tide	Can be modified, analyze feasibility according to specific conditions
	Substrate types	Silt, peat, sand, etc., preferably muddy beach	Can be modified, analyze feasibility according to specific conditions
Planning and human interference	Coastal engineering construction	There must be no large coastal construction around which will affect the change of substrate type	Can be modified, difficult, need to coordinate regional planning
	Waterway	There must be no large waterways around that affects the rehabilitation area	Can be modified, difficult, need to coordinate regional planning

6.4.2 Suitability analysis

Suitability is analyzed in accordance with the following requirements:

a) Analyzing whether the habitat conditions in the restoration area are suitable for mangrove ecological restoration. If the requirements for habitat conditions are not satisfied, further analysis needs to be conducted to ascertain whether the habitat can be transformed to a suitable level. If the temperature is not suitable then is not feasible.
b) Analyzing the adopted habitat modification measures and the feasibility of planting technology. If the technology is not feasible, then restoration is not feasible.
c) Analyzing whether the ecological restoration of mangroves is consistent with the relevant regional development plans, etc. If there is a conflict, then restoration is not feasible.
d) Analyzing the possible adverse effects of land use in the surrounding area, human activities on the restoration site, and the impact of the mangrove ecological restoration project on the surrounding ecological environment, etc. If incompatible, then restoration is not feasible.

6.4.3 Separation of suitability zone

Separation of suitability zone includes suitable restoration areas, reclaimable restoration areas and unsuitable restoration areas, which are delineated according to the following requirements:

— Areas that are assessed as unsuitable for all mangrove restorations through habitat modification, and are suitable areas for rehabilitation;

— Areas that meet the basic climatic and hydrological conditions, where habitat transformation is feasible, and where mangrove restoration conditions can be met after the modification, are reclaimable restoration areas;

— Areas that do not meet basic climatic and hydrological conditions, or where habitat modification is impossible, in conflict with local plans and have a high environmental impact, are unsuitable restoration areas.

7 Implementation programming

In accordance with the requirements given in T/CAOE 21.1-2020, 7.3.

8 Ecological restoration of mangroves

8.1 Habitat rehabilitation

For reclaimable restoration areas, habitat rehabilitation is carried out to enable habitat conditions to meet the requirements of mangrove vegetation restoration. The habitat rehabilitation program is implemented according to 8.1 of HY/T 214-2017.

8.2 Species selection and configuration

Species selection and configuration are based on the following requirements:

a) Species of mangroves and matching methods shall be determined according to local climatic conditions, substrate type, tidal flat elevation, salinity and hydrodynamic conditions of the restoration area, with climatic conditions and tidal flat elevation as the main basis for selection.

b) The mangrove species that can be planted in the climatic zone are determined in accordance with Annex A of LY/T 1938-2011, or according to mangrove species distributed in or around the area where the restoration is located.

c) Further selection of plantable species based on the tidal flat elevation of the planting area may also be considered based on the distribution of mangroves in adjacent areas with similar elevations. The selection of species at different tidal flat elevations can be found in Annex C and DB44/T 284-2005 in LY/T 1938-2011. For species selection for mangrove rehabilitation in difficult areas, refer to Annex A in LY/T 2972-2018.

d) According to the planting area, distribution characteristics of different species in planting areas and intertidal zones, the planting sections are reasonably allocated, key coordinate points are determined, and species are selected to be grown in combination (including single-species and mixed plants).

8.3 Planting

8.3.1 Methods

Mangrove planting methods shall be determined in combination with such factors as the type of breeding body of mangrove plants, project requirements and engineering costs. Planting methods include direct implantation of embryo shafts, seeding of embryo shafts (or seeds), planting of potted seedlings or transplantation of seedlings, etc. It is advisable to adopt two methods, directly planting hypocotyls and planting potted seedlings. See LY/T 214-2017 in 8.2.2.

8.3.2 Planting timing

The mangrove planting timing shall be determined according to the planting method, propagule maturity, climatic conditions and so on, as referred to under 8.2.3 HY/T 214-2017.

8.3.3 Planting density and width

Planting density can be set according to the morphological and growth characteristics of the planted species, as referred to in Annex LY/T 1938-2011. In addition, planting density and width shall also take specific circumstances such as project requirements, engineering costs and habitats into account.

8.3.4 Optimal planting design for hazard mitigation

8.3.4.1 Requirements of optimal design

Mangroves need to be planted in ways to maximize their roles in mitigating marine disasters such as storm surges (reaching maturity). In addition to considerations of the morphological and growth characteristics of plant species, optimal design of planting density and planting belt width can play a major function in reducing marine disasters, such as storm surges and enhancing the marine disaster reduction capacity of mangroves.

8.3.4.2 Methods of optimal design

The optimal design methods of planting density and width based on disaster reduction needs are provided below. According to the local marine disaster reduction requirements combined with regional wave conditions, a suitable expected wave dissipation rate for the planned planting area can be set, and the value shall be greater than 60% when the vegetation is mature;

- The method of planting density and width of common mangrove species in China can be implemented in accordance with the provisions of Annex C of this document;

- For the same expected wave dissipation rate, there are multiple combinations of vegetation planting density and planting belt width for reference. In actual planting design, the appropriate planting density and planting belt width shall be selected according to the most reasonable economic costs.

8.4 Management and protection

8.4.1 Management and protection timing

The period of management and protection shall be set to 3 years.

8.4.2 Management and protection measurements

Measurements include sealing the beach forest, cleaning up garbage and reseeding, etc., in accordance with HY/T 214-2017 10.1.3.

9 Monitoring and evaluation

9.1 Follow-up monitoring and survey

9.1.1 Follow-up monitoring

The survival rate of seedlings shall be monitored on a monthly basis within 6 months after mangrove restoration and planting. Mangrove restoration shall be followed up for at least 3 years. The content of follow-up monitoring shall include mangrove vegetation, biological community, environmental elements and threat factors (Table 1 for survey factors). Besides, it is advisable to carry out four surveys in spring, summer, autumn and winter. Survey elements and time can be adjusted appropriately according to the actual situation.

9.1.2 Post-disaster survey

The post-disaster survey of mangrove vegetation shall be conducted (Table 1). Other biological communities, environmental elements and threat factors can also be selected according to the actual situation. The methods can be found in 5.2 of this document. The survey shall be conducted within 10 days after the storm surge.

9.2 Evaluation of effectiveness

9.2.1 Evaluation of hazard mitigation functions

In accordance with the methods set out in 6.2 of this document.

9.2.2 Evaluation of ecological effects

9.2.2.1 Evaluation indicators

The evaluation of mangrove ecological status is conducted from three aspects: mangrove vegetation, biological community and environmental elements. Table 4 shows the specific evaluation indicators and weight assignments.

Table 4--Evaluation indicators and weight assignments of mangrove ecological status

The content of the evaluation	Evaluation indicators	Weight Assignments
Mangroves	Total area	15
	Coverage	15
	Planting survival rate	10
	Forest belt width	10
	Number of mangrove plant species	5
Biological community	Macrobenthic richness index	5
	Macrobenthic diversity index	5
	Number of bird species	5
Environmental elements	Water salinity	10
	DO	5
	Deposition rate	10
	Sediment type	5

9.2.2.2 Select the frame of reference

The pre-implementation of the mangrove ecological disaster reduction and restoration project was taken as the evaluation reference system.

9.2.2.3 Evaluation time and frequency

The evaluation of the ecological effect of mangrove restoration shall be carried out after the mangrove vegetation is stabilized. The evaluation shall be carried out after 1 year. According to the specific conditions of the project, an effect evaluation shall be carried out at an interval of 2 to 4 years.

9.2.2.4 Evaluation methods

9.2.2.4.1 Mangrove vegetation indicators assignment and calculation

Mangrove vegetation evaluation indicators, ratings and assignments are shown Table 5. Mangrove vegetation evaluation indicators are calculated in accordance with T/CAOE 20.3.

Table 5—Mangrove vegetation evaluation parameters, ratings, and assignments

No.	Parameters	I	II	III
1	Changes in total area	≥10%	>5%~≤10%	≤5%
	Assignment	15	9	3
2	Changes in coverage	>10%	>5%~≤10%	≤5%
	Assignment	15	9	3
3	Planting survival rate	≥75%	≥45%~<75%	<45%
	Assignment	10	6	2
4	Forest belt width (m)	≥100	≥50~<100	<50
	Assignment	10	6	2
5	Changes in the number of mangrove species	>60%	>20%~≤40%	≤20%
	Assignment	5	3	1
NOTE 1: The width of the forest belt takes into account its effect of disaster reduction and shore protection, taking the width value of the forest belt. Note 2: The number of mangrove species refers to the number of native species. The number of alien species is not included in the evaluation.				

9.2.2.4.2 Biome assignment and calculation

Biological community evaluation parameters, ratings and assignments are illustrated in Table 6. The calculation method of community biological evaluation indicators is carried out in accordance with T/CAOE 20.3.

Table 6—Biological community evaluation indicators, ratings, and assignments

No.	Parameters	I	II	III
1	Macrobenthic richness index	≥2.5	≥1~<2.5	<1
	Assignment	5	3	1
2	Macrobenthic diversity index	≥2.0	≥1~<2.0	<1
	Assignment	5	3	1
3	Number of bird species	≥65	≥30~<65	<30
	Assignment	5	3	1

9.2.2.4.3 Environmental elements assignment and calculation

Environmental elements assignment, rating and calculation are performed in accordance with T/CAOE 20.3. The calculation method of sedimentary environmental evaluation indicators is implemented in accordance with T/CAOE 20.3.

9.2.2.4.4 Comprehensive evaluation of the ecological status of mangroves

The mangrove ecosystem evaluation index () calculation after restoration is carried out in accordance with T/CAOE 20.3. According to the values, the ecological status of mangroves is divided into three levels: level I, significantly improved; level II, improved; level III, basically unchanged (Table7).

Table 7—Ecological (restoration) effect evaluation standard

Effect level	I Significantly improved	II Improved	III Basically unchanged
Rate of change (%)	＞76	⩾52~＜76	⩾0~＜52

10 Quality Control

In accordance with the requirements given in T/CAOE 21.1-2020, Chapter 8.

11 Achievements and archiving

In accordance with the requirements given in T/CAOE 21.1-2020, Chapter 9.

Annex A
(annex informative)
Methods for Evaluation of Disaster Reduction Functions of Restored Mangroves

A.1 Field Observation

A.1.1 Applicability of Field Observation

The field observation method is suitable for areas where the disasters are frequent and the economic conditions permit. For the timing to carry out the evaluation of the marine disaster reduction functions of mangroves, there shall be at least one storm surge with significant impacts on the evaluated area.

A.1.2 Methods for data analysis and calculation

Based on the observed wave height sequences in the field (5.3 in this document), the wave dissipation rate is calculated as follows: calculating the effective wave height sequence, selecting one of the most unfavorable (The highest effective wave height) periods (The preferable period is 30 minutes.), substituting the effective wave height of the observation cross sections to the sea point and landward point into the formula (1) (6.3.3 in this document).

A.2 Empirical formula methods

A.2.1 The Applicability of empirical formula method

The empirical formula method is suitable for the evaluation of mangrove disaster reduction functions with relatively low cross-section slope (Because the flat bottom assumption is adopted in this method, it is suitable for the situation where the slope of the section is less than 0.02), single species of small vegetation and easy generalization of vegetation indicators. This method can also be used to quickly evaluate the disaster reduction capacity of mangroves.

A.2.2 Empirical formula method

Estimation of wave height attenuation rate by empirical formula, the calculation formula is as follows (A.1).

$$R_{wL}=\frac{\alpha L}{1+\alpha L}\times 100\% \cdots\cdots\cdots\cdots (A.1)$$

where

L The width of the vegetation belt of the mangroves evaluated, the unit is meter (m);

α Wave height attenuation coefficient, the unit is m-1, according to the linear wave theory, the theoretical expression is as follows (A.2).

$$\alpha=\frac{4}{9\pi}C_D D N H_0 k\frac{\sinh^3 kh_v+3\sinh kh_v}{(\sinh 2kh+2kh)\sinh kh}\cdots\cdots\cdots\cdots (A.2)$$

where

C_D Plant drag force coefficient, according to the empirical formula (A.3);

D Plant area per unit vertical height, the vertical average plant diameter, its value is $\frac{\int_0^{h_v} D(z)dz}{h_v}$, the unit is meter(m);

N Number of plants per unit area, the unit is per square meter (/m2);

H_0 Effective wave height in front of vegetation caused by storm surge, the unit is meter (m);

k Front-end wavenumber of plant area;

h Storm tide level calculated from the ground at the survey point in the vegetation area, water level in vegetation area, the unit is meter (m);

h_v The height of plants below the surface of the water, when the height of the plant is higher than the water level h, that is, the plant rises above the water, h_v=h; when the plant height is less than the water level h, h_v is the true height of the plant, the unit is meter(m).

For the specific meaning of some parameters, please refer to figure A.1.

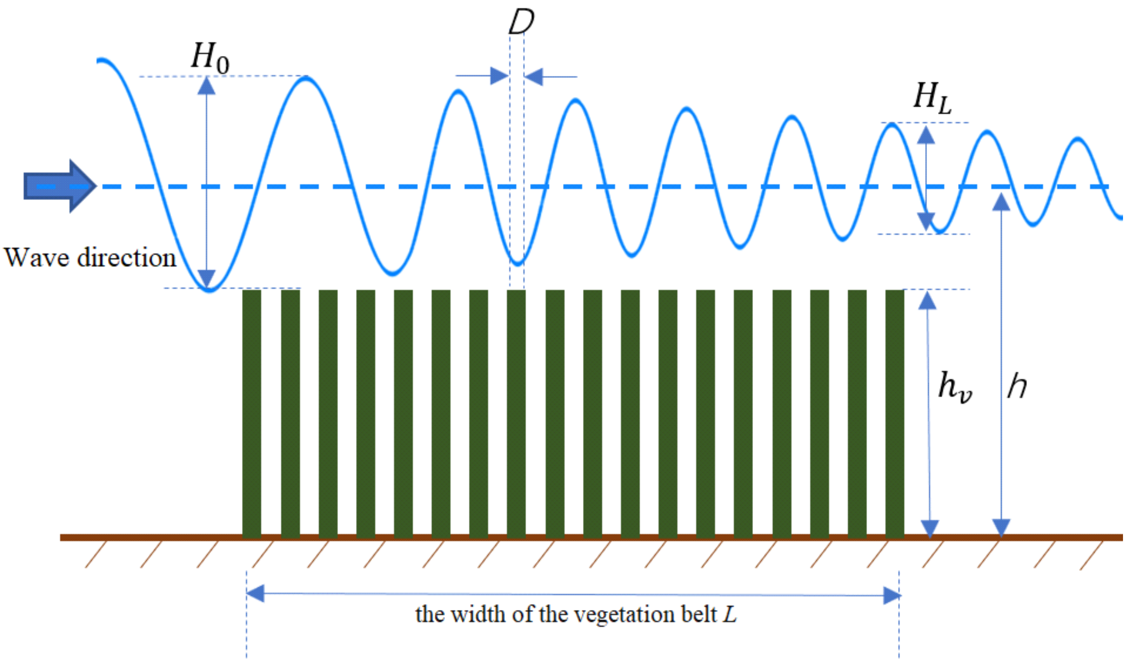

Figure A.1-- Schematic diagram of related parameters in empirical formula method

Plant drag force coefficient is related to vegetation and hydrodynamic parameters. The correct selection of its value is very important for accurately evaluating the wave height reduction rate of mangroves. The calculation formula is as follows (A.3).

$$C_D=2(\frac{\alpha_0}{R_e}+\alpha_1)\times(1+\frac{\alpha_2}{KC}) \cdots\cdots (A.3)$$

where

α_0 Empirical coefficient, related to the proportion of plant volume $\phi(=\pi\frac{D^2}{4}N\frac{h_v}{h})$, its value can be referred to the table A.1;

α_1 Empirical coefficient, related to the proportion of plant volume ϕ, its value can be referred to the table A.1;

α_2 Empirical coefficient, its value can be referred to the table A.1;

Re Reynolds number, the defining formula is $Re=\frac{|u|D}{\upsilon}$, in the formula, $|u|$ is the maximum velocity of water quality point under the action of waves, take the velocity at the highest height of the submerged plant, according to the linear wave theory, $|u|=\frac{\pi H_0}{T}\frac{cosh(kh_v)}{sinh(kh)}$, υ is the moving viscosity coefficient of sea water, its value is preferable to $1\times10^{-6}m^2/s$.

KC The defining formula is $KC=\frac{|u|T}{D}$, T is a wave period.

Table A.1—Drag force coefficient calculation experience coefficient

Parameter	Calculation Formula or Range of Values
α_0	$\alpha_0=\begin{cases}25\pm12 & (\phi=0.091)\\ 84\pm14 & (\phi=0.15)\\ 83.8 & (0.15\le\phi\le0.35)\end{cases}$
α_1	$\alpha_1=(0.46\pm0.11)+(3.8\pm0.5)\phi$
α_2	$\alpha_2=5.5\sim9.5$

A.3 Physical experiments method

A.3.1 Applicability of physical experiment method

In case of low frequency of regional marine disasters (no storm surges affecting the area to be assessed in the evaluation year) or limitations of observation conditions, it is impossible to carry out physical model test method. Compared to the empirical formula method, the advantage of physical model test method is that it can evaluate the disaster reduction effect of mangroves with the characteristics of diverse species, complex morphology and unequal distribution.

A.3.2 Technical methods

A.3.2.1 Model plant selection

Physical models require selecting model plants based on the structural characteristics of the main stem, branches and leaves and canopy of wetland vegetation. The model plant size can be determined according to the length similarity criterion. Length similar scale λ_L is shown in formula (A.4). Plant height can be used as the calculation basis of length scale in the evaluation of marine disaster reduction function of mangroves, the value of the length scale λ_L shall no longer than 20.

$$\lambda_L=\frac{L_p}{L_m} \cdots\cdots (A.4)$$

where

L_p Feature length of prototype, the unit is meter(m);

L_m Feature length of the model, the unit is meter (m).

A.3.2.2 Layout of model plant

The model plants are arranged according to the actual wetland vegetation distribution characteristics (regular rectangle, regular triangle, plum blossom shape and random distribution form). The model plant layout density N_m and vegetation belt width L_m can be calculated according to formula (A.5) and formula (A.6), respectively according to the similar length scale. N_p and N_m are the are the feature density of prototype and model respectively. L_p and L_m are the characteristic widths of the prototype and the model vegetation belt, respectively.

$$N_m=N_p \lambda_L^2 \cdots\cdots (A.5)$$

where

N_p Feature density of prototype;

N_m Feature density of the model

$$L_m=\frac{L_p}{\lambda_L} \cdots\cdots (A.6)$$

where

L_p Characteristic width of the prototype vegetation zone, the unit is meter (m);

L_m Characteristic width of model vegetation zone, the unit is meter (m).

A.3.2.3 Water level and wave conditions

According to the characteristics of inshore tides and waves in the area to be evaluated, the wave height and water level in the hydrodynamic parameters of the model can be calculated by length scale. The calculation formulas are shown in formula (A.7) and formula (A.8). The model test and prototype parameters shall also conform to the gravity similarity criterion, the prototype Froude number Fr_p is equal to the model Froude number Fr_m, $\frac{v_p}{\sqrt{gh_p}}=\frac{v_m}{\sqrt{gh_m}}$, according to the length scale and gravity similarity criterion, the speed ratio of prototype to model is $\frac{v_p}{v_m}=\sqrt{\frac{h_p}{h_m}}=\sqrt{\lambda_L}$, the relationship between the model set wave period and the real sea condition period shall be consistent with the formula (A.9).

$$H_{0m}=\frac{H_{0p}}{\lambda_L} \cdots\cdots (A.7)$$

Where

H_{0p} Prototype effective wave height, the unit is meter(m);

H_{0m} Model effective wave height, the unit is meter(m).

$$\eta_m = \frac{\eta_p}{\lambda_L} \quad \cdots\cdots (A.8)$$

where

η_p Prototype characteristic water level, the unit is meter(m);

η_m Model characteristic water level, the unit is meter(m).

$$T_m = \frac{T_p}{\sqrt{\lambda_L}} \quad \cdots\cdots (A.9)$$

where

T_p Characteristic effective wave period of prototype hydrodynamic parameters, the unit is second(s).

Tm Characteristic effective wave period of the hydrodynamic parameters of the model, the unit is second(s).

A.3.2.4 Arrangement of flume and measuring instruments

A wave-making device with active wave-absorbing function shall be placed at the head of the water tank for physical model tests. The model vegetation is arranged in the middle of the flume at a certain distance from the wave-making equipment. After a certain distance in the plant area, the wave absorbing equipment is set up. The digital wave altimeter is usually used in the laboratory to measure the wave propagation and attenuation in the plant area. The wave altimeter can be arranged in the plant area and before and after the plant area, and the measuring points of the wave altimeter shall be no less than 3 (one at the front edge, the middle edge and the back edge of the plant zone). The location can be found in figure A.2. When the number of wave altimeters is limited, one wave altimeter can be fixed at the front of the plant area, and another wave altimeter can be installed on the sliding device to measure the change of wave height along the flume.

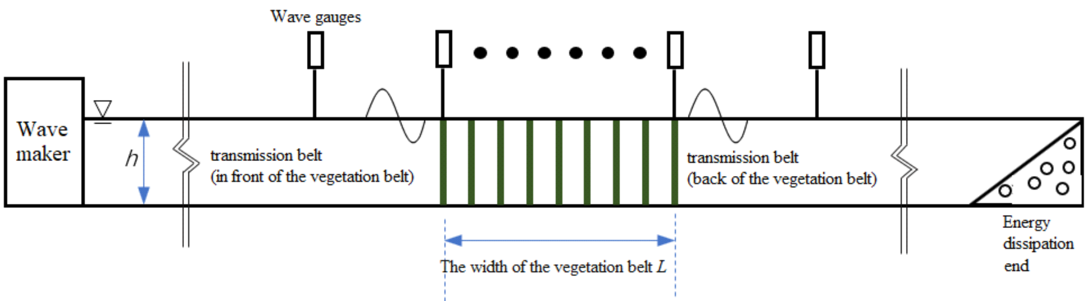

Figure A.2--Schematic diagram of model test layout

A.3.3 Analysis and calculation of test data

Based on the data obtained from the model test, the hydrodynamic parameters such as water level, wave height, period and vegetation parameters such as width, density and height of vegetation zone are calculated by formula (A.4) ~ formula (A.9), the wave height $H_0=H_{0p}$ and $H_L=H_{Lp}$ before and after the disaster reduction vegetation area of the prototype mangrove to be evaluated is brought into the formula (1), and the wave height attenuation rate R_{wL} can be calculated.

A.4 Numerical simulation method

A.4.1 Applicability of numerical simulation method

When the frequency of regional marine disasters is low (there is no storm surge affecting the area to be assessed in the evaluation year) or the field observation method is not allowed by economic and technical conditions, this method is not suitable. However, if the regional underlying surface, vegetation parameters and hydrodynamic conditions are mastered, and there are mature numerical simulation technical conditions, this method can be used to evaluate the disaster reduction functions of mangroves.

A.4.2 Numerical model

There are mainly two kinds of numerical models for the interaction between plants and waves. One is in the ocean wave model, such as the SWAN (Simulating WAves Nearshore) model, which directly adds a plant force term to characterize the plant interaction and modifies the relevant parameters of the model in the mangrove area. The other is to use special wave and current motion models in mangroves, which also have different treatment methods, such as the governing equations of wave and current motion in plant areas derived from the spatial average of plants as porous media. The third is statistical models, which are mainly based on the quantitative relationship between mangrove vegetation parameters (such as plant height, density, coverage, etc.) and wave interaction. The specific numerical simulation can choose the appropriate numerical model according to the actual demand and computing power.

This guide shows the calculation method of the governing equation of wave-current motion in porous media, the details are as follows:

In this model, the plant in the vegetation area is regarded as a porous medium, and the N-S equation is derived by spatial average. The governing equations of the model are as follows: formula (A.10) and equation (A.11). The model can well simulate the process of wave propagation and attenuation in the vegetation area.

$$\frac{\partial \langle u_i \rangle}{\partial x_i}=0 \cdots\cdots (A.10)$$

$$\frac{\partial \langle u_i \rangle}{\partial t}+\langle u_j \rangle \frac{\partial \langle u_i \rangle}{\partial x_j}=-\frac{1}{\rho}\frac{\partial \langle P \rangle}{\partial x_i}+g_i+\nu\frac{\partial^2 \langle u_i \rangle}{\partial x_i \partial x_j}-\frac{\partial^2 \langle u_i' u_j' \rangle}{\partial x_j}-\langle f_i \rangle \cdots\cdots (A.11)$$

where

$\langle u_i \rangle$ (In the two-dimensional problem, i=1, 2; In the three-dimensional problem, i=1, 2, 3) Spatial average velocity of direction i;

$\langle P \rangle$ Spatial mean pressure;

ρ Fluid density;

g_i Gravitational acceleration in i direction;

ν Kinematic viscosity of fluid;

$\langle u_i' u_j' \rangle$ Spatial mean Reynolds stress, the flow model can be used to solve the problem;

$\langle f_i \rangle$ Spatial average plant force;

The acting force $\langle f_i \rangle$ in the vegetation area can be generalized as drag force and inertia force. For a single cylinder, the drag force and inertia force acting on the water body can be calculated by using formula (A.12) and formula (A.13) respectively.

$$f_D = \frac{1}{2} \rho C_D D u|u| \quad \text{(A.12)}$$

$$f_I = \rho C_m \frac{\pi D^2}{4} \frac{\partial u}{\partial t} \quad \text{(A.13)}$$

where

f_D Drag force;

f_I Inertia force;

C_D Drag force coefficient (It can be determined according to the specific characteristics of different mangrove species);

C_m Inertia force coefficient (It can be determined according to the specific characteristics of different mangrove species);

ρ Density of fluid, the unit is kilogram per cubic meter (kg/m3);

D- Vertical average plant diameter (For specific calculations, see A.2.2 in this document), the unit is meter(m);

u Flow velocity, the unit is meters per second (m/s).

A.4.3 Analysis and calculation of numerical simulation results

When the numerical simulation method is used to evaluate the disaster reduction function, the real scale shall be used for simulation calculation, and the wave height H_0 and H_L before and after the simulation of the mangrove vegetation area to be evaluated and the width $L=L_v$ of the cross-section vegetation zone are brought into the formula (1) (6.3.3 in this document), the wave height attenuation rate R_{wL} can be calculated.

A.5 Selection of evaluation methods

The selection of evaluation methods shall be comprehensively considered according to the field conditions, economic conditions, technical equipment and experimental conditions of the region. If conditions permit, the field observation method shall be preferentially considered to directly measure and calculate the wave height reduction rate of mangroves during the storm surge. If the conditions are limited, for instance, there is no storm surge impact evaluation area in recent years, and the field observation during the storm surge disaster cannot be carried out, the other three methods can be used; if the experimental conditions of the physical model permitted, the physical model can be used to evaluate the prototype vegetation parameters and ocean hydrodynamic parameters. The physical model can be established according to the similarity criterion proposed in 6.5.3. If the experimental conditions are limited, the empirical formula method can be used to ensure that the parameters used in the formula truly reflect the characteristics of wetland vegetation and nearshore marine dynamic characteristics. When using numerical simulation method to evaluate, attention shall be paid to selecting reliable numerical models and ensuring reasonable and accurate parameterization of plant action. If the conditions are limited and the above methods cannot be used, we shall refer to the reference table data in Annex B to obtain the required wave height attenuation rate.

Annex B
(annex informative)
Reference description of wave height attenuation rate of mangroves

This document selects some of the most common mangroves, including native varieties such as *Rhizophora stylosa*, *Avicennia marina*, *Bruguiera gymnorrhiza*,, *Aegiceras corniculatum*, and *Kandelia obovata*, and common introduced species *Sonneratia apetala* and *Laguncularia racemosa*.

In this document, the empirical formula method is used to calculate the wave height attenuation rate of four kinds of wave height (0.5m, 1.25m, 2.5m and 4m), six kinds of water level (1m, 2m, 3m, 4m, 5m and 6m) and one cycle (4s). Several kinds of mangrove plants selected one kind of tree height and diameter at maturity, two kinds of planting density and four kinds of vegetation belt width (50m, 100m, 200m and 400m). The mangrove vegetation information needed in the calculation process is shown in document 5. The authenticity of various parameters is considered when combining various parameters (for example, when the wave height is 1m, the corresponding water level shall not be less than 2m). The calculated results of wave height attenuation rate are shown in Table B.1 to Table B.6.

Table B.1--Reference table of wave dissipation rate of mangroves (*Kandelia Candel*) under different combination conditions

Mangrove type: Arbor						Species: Kandelia Candel			
Plant height: 4m						Tree diameter: 15cm			
Sea condition		Plant density: 75 plants/100m2				Plant density: 50 plants/100m2			
		Width of planting belt/(m)				Width of planting belt/(m)			
Wave height/（m）	Water level/（m）	50	100	200	400	50	100	200	400
0.5	1	31%	48%	65%	79%	23%	37%	54%	70%
	2	20%	33%	50%	66%	14%	24%	39%	56%
	3	15%	26%	41%	58%	10%	18%	31%	47%
	4	13%	22%	37%	54%	9%	16%	27%	43%
	5	6%	12%	22%	36%	4%	8%	15%	27%
	6	4%	7%	13%	23%	2%	5%	9%	16%
1.25	2	34%	51%	68%	81%	25%	40%	57%	73%

	3	27%	42%	59%	74%	19%	32%	48%	65%
	4	23%	37%	54%	70%	16%	28%	43%	60%
	5	12%	21%	35%	52%	8%	15%	26%	41%
	6	6%	12%	21%	35%	4%	8%	15%	26%
2.5	3	41%	58%	73%	85%	31%	47%	64%	78%
	4	35%	52%	69%	81%	26%	41%	59%	74%
	5	20%	33%	49%	66%	14%	24%	39%	56%
	6	11%	19%	32%	49%	7%	13%	24%	38%
4	5	27%	43%	60%	75%	20%	33%	49%	66%
	6	15%	26%	42%	59%	10%	19%	32%	48%
NOTE：The water level in the table refers to the tidal level calculated from the ground in the vegetation area.									

Table B.2 --Reference Table of wave dissipation rate of mangrove (Bruguiera gymnorhiza) under different combination conditions

Mangrove type: Arbor					Species: Bruguiera gymnorhiza				
Plant height: 3.5 m					Tree diameter: 10 cm				
Sea condition		Plant density: 75 plants/100m2				Plant density: 50 plants/100m2			
		Width of planting belt/(m)				Width of planting belt/(m)			
Wave height/（m）	Water level/（m）	50	100	200	400	50	100	200	400
0.5	1	21%	35%	52%	69%	15%	26%	42%	59%
	2	13%	22%	37%	54%	9%	16%	27%	43%
	3	9%	17%	29%	45%	6%	12%	21%	35%
	4	6%	11%	19%	33%	4%	7%	14%	24%
	5	3%	6%	11%	19%	2%	4%	7%	13%
	6	2%	3%	6%	11%	1%	2%	4%	8%
1.25	2	24%	39%	56%	72%	17%	30%	46%	63%
	3	18%	31%	47%	64%	13%	23%	37%	54%
	4	11%	20%	34%	51%	8%	14%	25%	40%
	5	6%	11%	19%	32%	4%	7%	14%	24%
	6	3%	6%	11%	19%	2%	4%	7%	14%
2.5	3	30%	46%	63%	77%	22%	36%	53%	69%
	4	20%	33%	49%	66%	14%	24%	39%	56%
	5	10%	18%	31%	47%	7%	13%	23%	37%
	6	5%	10%	18%	30%	3%	7%	13%	22%
4	5	15%	26%	41%	58%	10%	19%	31%	48%
	6	8%	14%	25%	40%	5%	10%	18%	31%
NOTE: The water level in the table refers to the tidal level calculated from the ground in the vegetation area.									

Table B.3--Reference table of wave dissipation rate of mangroves (Rhizophora stylosa) under different combination conditions

Mangrove type: Tree		Species: Rhizophora Stylosa
Plant height: 4 m		Diameter: 20 cm
Sea state	Plant density: 50 plants	Plant density: 25 plants

		/100m2				/100m2			
		Planting band width/(m)				Planting band width/(m)			
Wave height/(m)	The water levels/(m)	50	100	200	400	50	100	200	400
0.5	1	30%	47%	64%	78%	17%	29%	45%	62%
	2	19%	32%	49%	66%	10%	19%	31%	48%
	3	15%	26%	41%	58%	8%	14%	25%	39%
	4	13%	22%	37%	54%	6%	12%	21%	35%
	5	7%	12%	22%	36%	3%	6%	12%	21%
	6	4%	7%	13%	23%	2%	3%	7%	13%
1.25	2	33%	49%	66%	79%	19%	31%	48%	65%
	3	25%	40%	58%	73%	14%	24%	39%	56%
	4	22%	36%	53%	69%	12%	21%	35%	52%
	5	11%	21%	34%	51%	6%	11%	20%	33%
	6	6%	12%	21%	34%	3%	6%	11%	20%
2.5	3	39%	56%	72%	83%	23%	37%	54%	71%
	4	34%	50%	67%	80%	19%	32%	49%	66%
	5	19%	31%	48%	64%	10%	18%	30%	46%
	6	10%	18%	31%	47%	5%	10%	18%	30%
4	5	26%	41%	58%	73%	14%	25%	40%	57%
	6	14%	25%	40%	57%	7%	14%	24%	39%
NOTE: The water level in the table refers to the tide level calculated from the surface of the vegetation area.									

Table B.4--Reference table of wave dissipation rate of mangroves (Sonneratia apetala) under different combination conditions

Mangrove type: Tree					Species: Sonneratia Apetala			
Plant height: 10 m					Diameter: 30 cm			
Sea state		Plant density: 75 plants /100m2				Plant density: 25 plants /100m2		
		Planting band width/(m)				Planting band width/(m)		
Wave height/(m)	The water levels/(m)	50	100	200	400	50	100	200	400
0.5	1	58%	73%	85%	92%	27%	43%	60%	75%
	2	44%	61%	76%	86%	17%	29%	45%	62%
	3	36%	53%	69%	82%	13%	23%	38%	55%
	4	31%	48%	64%	78%	11%	20%	33%	49%
	5	28%	44%	61%	76%	10%	17%	30%	46%
	6	26%	42%	59%	74%	9%	16%	28%	43%
1.25	2	59%	74%	85%	92%	28%	44%	61%	76%
	3	50%	67%	80%	89%	21%	35%	52%	69%
	4	44%	62%	76%	87%	18%	30%	46%	63%
	5	41%	58%	73%	85%	16%	27%	42%	60%
	6	38%	55%	71%	83%	14%	25%	40%	57%
2.5	3	64%	78%	88%	93%	32%	49%	66%	79%
	4	58%	74%	85%	92%	27%	43%	60%	75%
	5	54%	70%	83%	90%	24%	39%	56%	72%
	6	51%	68%	81%	89%	22%	36%	53%	69%
4	5	64%	78%	88%	93%	33%	49%	66%	79%
	6	61%	76%	86%	93%	30%	46%	63%	78%
NOTE: The water level in the table refers to the tide level calculated from the surface of the vegetation area.									

Table B.5—Reference table of wave dissipation rate of mangroves (Aegiceras corniculatum) under different combination conditions

Mangrove type: Shrub					Species: Aegiceras Corniculatum			
Plant height: 2.5 m					Diameter: 10 cm			
Sea state		Plant density: 200 plants /100m2				Plant density: 100 plants /100m2		
		Planting band width/(m)				Planting band width/(m)		
Wave height/(m)	The water levels/(m)	50	100	200	400	50	100	200	400
0.5	1	44%	61%	76%	86%	27%	42%	60%	75%
	2	29%	45%	62%	77%	16%	28%	44%	61%
	3	17%	30%	46%	63%	9%	17%	29%	45%
	4	9%	16%	27%	43%	4%	8%	15%	26%
	5	4%	9%	16%	27%	2%	4%	8%	15%
	6	2%	5%	9%	17%	1%	2%	5%	9%
1.25	2	48%	65%	79%	88%	30%	47%	64%	78%
	3	31%	47%	64%	78%	18%	30%	46%	63%
	4	16%	28%	43%	61%	8%	16%	27%	43%
	5	8%	16%	27%	43%	4%	8%	15%	26%
	6	5%	9%	16%	28%	2%	4%	9%	16%
2.5	3	46%	63%	77%	87%	29%	45%	62%	77%
	4	26%	42%	59%	74%	15%	26%	41%	58%
	5	14%	25%	40%	57%	8%	14%	25%	40%
	6	8%	15%	25%	40%	4%	8%	14%	25%
4	5	21%	34%	51%	68%	11%	20%	34%	50%
	6	11%	21%	34%	51%	6%	11%	20%	34%
NOTE: The water level in the table refers to the tide level calculated from the surface of the vegetation area.									

Table B.6—Reference table of wave dissipation rate of mangroves (Laguncularia racemosa) under different combination conditions

Mangrove type: Tree Single plant/cluster: Fascicled					Species: Laguncularia Racemosa Branch density: 30 branches/cluster				
Plant height: 3.5 m					Diameter: 4 cm				
Sea state		Plant density: 50 plants /100m2				Plant density: 25 plants /100m2			
		Planting band width/(m)				Planting band width/(m)			
Wave height/(m)	The water levels/(m)	50	100	200	400	50	100	200	400
0.5	1	69%	81%	90%	95%	51%	67%	80%	89%
	2	53%	69%	82%	90%	35%	52%	68%	81%
	3	44%	61%	76%	86%	27%	42%	60%	75%
	4	31%	47%	64%	78%	17%	30%	46%	63%
	5	17%	29%	45%	62%	9%	16%	28%	44%
	6	9%	17%	29%	45%	5%	9%	16%	28%
1.25	2	73%	84%	92%	96%	56%	72%	83%	91%
	3	65%	79%	88%	94%	47%	64%	78%	87%
	4	51%	67%	81%	89%	33%	49%	66%	80%
	5	32%	48%	65%	79%	18%	31%	47%	64%
	6	18%	31%	47%	64%	10%	18%	30%	46%
2.5	3	78%	88%	94%	97%	63%	77%	87%	93%
	4	67%	80%	89%	94%	49%	66%	79%	88%
	5	47%	64%	78%	88%	30%	46%	63%	77%
	6	30%	46%	63%	78%	17%	29%	45%	62%
4	5	59%	74%	85%	92%	40%	58%	73%	84%
	6	40%	58%	73%	84%	25%	40%	57%	72%
NOTE: The water level in the table refers to the tide level calculated from the surface of the vegetation area.									

Annex C
(annex informative)
Description of optimal planting design of vegetation based on disaster mitigation

C.1 Setting of expected wave dissipation rate

According to the local demand for marine disaster mitigation, combined with the regional wave conditions, the appropriate expected wave dissipation rate is set for the mangroves area to be planted, and the value shall be greater than 60% in the mature period of vegetation growth.

C.2 Optimal calculation of planting belt width and density

In order to achieve the expected high wave attenuation rate, the required vegetation density and planting band width under different sea conditions shall be calculated according to the selected growth parameters of vegetation maturity. Empirical formula method (C.2.1) and reference table (C.2.2) are given in this document. If there are calculation conditions, the empirical formula can be used for calculation. If there is no calculation condition, the reference table (Table C.1 ~ Table C.6) can be referred to find the corresponding reference value.

C.2.1 Empirical formula

The planting band width shall be calculated according to the expected wave dissipation rate and planting density value according to formula (C.1), and the planting density shall be calculated according to the expected wave dissipation rate and planting band width value according to formula (C.2). The vegetation parameters referred to in the empirical formula shall be determined in sections 5.1 and 5.2 of this document.

$$L = \frac{9\pi}{4}\frac{R_L}{C_D D H_0 N k (1-R_L)}\frac{(\sinh 2kh + 2kh)\sinh kh}{\sinh^3 kh_v + 3\sinh kh_v} \quad \text{(C.1)}$$

$$N = \frac{9\pi}{4}\frac{R_L}{C_D D H_0 L k (1-R_L)}\frac{(\sinh 2kh + 2kh)\sinh kh}{\sinh^3 kh_v + 3\sinh kh_v} \quad \text{(C.2)}$$

Where

L Width of planting belt, in meters (m);

R_L High attenuation rate of expected wave;

C_D The drag force coefficient of plants can be calculated according to the empirical formula (A.3);

N Number of plants per unit area, plant /m2;

H_0 The wave height, in meters (m), in front of the vegetation area caused by the historical storm surge or the imaginary storm surge;

D The plant area per unit vertical height, namely the vertical average plant diameter, is $\frac{\int_0^{h_v} D(z)dz}{h_v}$(m);

k Front-end wave number of planting area;

h_v The submergence height of plants, in meters(m);

h The storm surge level, in meters(m), calculated from the ground of the measuring point in the vegetation area.

C.2.2 Reference table of mangrove planting density and planting band width based on marine disaster mitigation

According to 7 common mangrove plants in China, including native species of Rhizophora stylosa, Avicennia marina, Bruguiera gymnorrhiza and Aegiceras corniculatum, as well as the commonly used mangrove restoration introduced species of Mapetala tree, through field survey and data collection of several mangrove plants expected mature vegetation indexes. By empirical formula method to calculate two expected wave height attenuation rate (60%, 80%), 4 kinds of wave height (0.5 m, 1.25 m, 2.5 m and 4 m), 6 kinds of water (1 m, 2 m, 3 m, 4 m, 5 m and 6 m), 1 kind of cycle (4 s) as a condition of sea condition, 7 kinds of mangrove choose 1 tree height and diameter, 4 planting density, between groups and conditions calculated by using type (1) the corresponding planting belt width are shown in table C. Table 1 ~ C. 6. Under some calculation conditions, the width of the planting belt can extend up to thousands of meters. If this situation is not desirable in practice, a suitable planting width can be selected according to the actual planting situation to reduce the requirements for disaster reduction functions.

Table C.1—Reference table of mangrove (*Kandelia obovata*) planting density and width corresponding to expected wave dissipation rate

Kandelia obovata stands 4m high and 15cm in diameter						
Wave height, water level and dissipation rate			Planting density /(plant /100m2)			
			80	60	40	20
Wave height/(m)	Water level/(m)	High wave dissipation rate	Planting width/(m)			
0.5	1	60%	150	200	300	650
		80%	400	550	850	1700
	2	60%	300	400	600	1200
		80%	750	1000	1500	3200
	3	60%	400	550	800	1700
		80%	1000	1400	2200	4400
	4	60%	500	650	1000	2100
		80%	1300	1800	2700	5600
	5	60%	1100	1500	2300	4700
		80%	2900	4000	6100	12400
	6	60%	2300	3100	4800	9700
		80%	6200	8400	13000	26000
1.25	2	60%	150	200	250	550
		80%	350	450	750	1500
	3	60%	200	250	400	800
		80%	500	700	1000	2100
	4	60%	250	300	500	1000
		80%	650	850	1300	2700
	5	60%	550	750	1100	2300
		80%	1400	2000	3000	6100
	6	60%	1100	1600	2400	4800
		80%	3100	4200	6300	13000
2.5	3	60%	100	150	200	450
		80%	250	350	550	1200
	4	60%	150	150	250	550

		80%	350	450	700	1500
	5	60%	300	400	600	1300
		80%	800	1100	1600	3300
	6	60%	650	850	1300	2600
		80%	1700	2300	3400	7000
4	5	60%	200	250	400	800
		80%	500	700	1100	2200
	6	60%	400	550	850	1700
		80%	1100	1500	2200	4500
NOTE: The water level in the table refers to the height of the water level from the surface of the vegetation area.						

Table C.2--Reference table of mangrove (*Bruguiera gymnorrhiza*) planting density and width corresponding to expected wave dissipation rate

Bruguiera gymnorrhiza, the height of the tree is 3.5 m, the diameter of the tree is 10 cm						
Wave height, water level and dissipation rate			Planting density/(plant /100m2)			
			80	60	40	20
Wave height/ (m)	Water level/ (m)	High wave dissipation rate	Planting width/(m)			
0.5	1	60%	250	350	500	1000
		80%	650	900	1400	2800
	2	60%	500	650	950	2000
		80%	1300	1700	2600	5200
	3	60%	700	900	1400	2800
		80%	1800	2400	3700	7500
	4	60%	1200	1600	2400	4900
		80%	3200	4300	6500	13000
	5	60%	2600	3500	5300	11000
		80%	7000	9400	14200	29000
	6	60%	5400	7300	11000	22000
		80%	14000	19000	29000	59000
1.25	2	60%	200	300	450	900
		80%	550	750	1200	2400
	3	60%	300	400	650	1300
		80%	850	1100	1700	3400
	4	60%	550	750	1100	2300
		80%	1500	2000	3000	6100
	5	60%	1200	1600	2500	5000
		80%	3300	4400	6600	13400
	6	60%	2500	3400	5200	10400
		80%	6800	9100	13800	27600
2.5	3	60%	150	200	350	650
		80%	450	600	900	1800

	4	60%	300	400	600	1200
		80%	800	1000	1600	3200
	5	60%	650	850	1300	2700
		80%	1700	2300	3500	7100
	6	60%	1300	1800	2700	5500
		80%	3600	4800	7300	14600
4	5	60%	400	550	850	1700
		80%	1100	1500	2200	4500
	6	60%	850	1200	1700	3500
		80%	2300	3100	4700	9400
NOTE: The water level in the table refers to the height of the water level from the surface of the vegetation area.						

Table C.3—Reference table of planting density and width of mangrove (*Rhizophora stylosa*) corresponding to expected wave dissipation rate

Rhizophora stylosa, tree height 4m, tree diameter 20cm						
Wave height, water level and attenuation rate			Planting density/(plant /100m2)			
			80	60	40	20
Wave height/ (m)	Water level/ (m)	High wave dissipation rate	Planting width/(m)			
0.5	1	60%	100	150	200	450
		80%	250	350	550	1200
	2	60%	200	250	400	800
		80%	450	650	1000	2100
	3	60%	250	350	550	1100
		80%	650	900	1400	3000
	4	60%	300	450	650	1400
		80%	800	1100	1800	3700
	5	60%	700	950	1500	3100
		80%	1900	2600	4000	8300
	6	60%	1500	2000	3200	6500
		80%	4000	5500	8400	17200
1.25	2	60%	90	100	200	400
		80%	250	300	500	1100
	3	60%	100	150	250	550
		80%	350	450	700	1500
	4	60%	150	200	350	700
		80%	400	600	900	1900
	5	60%	350	500	800	1600
		80%	950	1300	2100	4300
	6	60%	800	1100	1600	3400
		80%	2100	2800	4400	9100
2.5	3	60%	70	90	150	300
		80%	200	250	400	850
	4	60%	90	100	200	400

		80%	250	300	500	1100
	5	60%	200	300	450	900
		80%	550	750	1200	2400
	6	60%	450	600	900	1900
		80%	1200	1600	2400	5000
4	5	60%	150	200	300	600
		80%	350	500	750	1600
	6	60%	300	400	600	1200
		80%	750	1000	1600	3300
NOTE: The water level in the table refers to the height of the water level from the surface of the vegetation area.						

Table C.4—Reference table of planting density and width of Aegiceras corniculatum corresponding to expected wave dissipation rate

The tree is 2.5m high and 10cm in diameter						
Wave height, water level and dissipation rate			Planting density/(plant /100m2)			
			200	100	75	25
Wave height/(m)	Water level/(m)	High wave dissipation rate	Planting width/(m)			
0.5	1	60%	90	200	250	850
		80%	250	550	700	2200
	2	60%	200	400	500	1600
		80%	500	1000	1400	4200
	3	60%	350	750	1000	3200
		80%	1000	2100	2800	8500
	4	60%	900	1800	2500	7500
		80%	2400	4900	6500	20000
	5	60%	1900	3900	5200	16000
		80%	5000	10000	14000	42000
	6	60%	3800	7800	10000	32000
		80%	10000	21000	28000	85000
1.25	2	60%	80	150	250	700
		80%	200	450	600	1900
	3	60%	150	350	450	1500
		80%	450	950	1300	3900
	4	60%	400	850	1100	3500
		80%	1100	2300	3000	9300
	5	60%	900	1800	2400	7400
		80%	2300	4800	6400	19600
	6	60%	1800	3700	4900	14800
		80%	4800	9700	13000	39600
2.5	3	60%	90	200	250	750
		80%	250	500	650	2000
	4	60%	200	450	600	1800

		80%	550	1200	1600	4900
	5	60%	450	950	1300	3900
		80%	1200	2500	3400	10400
	6	60%	950	1900	2600	7900
		80%	2500	5200	6900	21000
4	5	60%	300	600	800	2500
		80%	800	1600	2200	6600
	6	60%	600	1200	1700	5000
		80%	1600	3300	4400	13400
NOTE: The water level in the table refers to the height of the water level from the surface of the vegetation area.						

Table C.5—Reference table of planting density and width of Avicennia marina corresponding to expected wave dissipation rate

The forest tree is 2m high and 20cm in diameter						
Wave height, water level and dissipation rate			Planting density/(plant /100m2)			
			80	60	50	40
Wave height/(m)	Water level/(m)	High wave dissipation rate	Planting width/(m)			
0.5	1	60%	100	150	200	450
		80%	250	350	550	1200
	2	60%	200	250	400	800
		80%	450	650	1000	2100
	3	60%	550	750	1100	2300
		80%	1400	1900	3000	6200
	4	60%	1200	1700	2600	5300
		80%	3300	4500	6900	14000
	5	60%	2600	3500	5300	10800
		80%	6900	9300	14200	29000
	6	60%	5200	7000	10600	21600
		80%	14000	19000	28000	57000
1.25	2	60%	90	100	200	400
		80%	250	300	500	1100
	3	60%	250	350	550	1200
		80%	700	1000	1500	3100
	4	60%	650	850	1300	2700
		80%	1700	2300	3500	7200
	5	60%	1300	1800	2800	5600
		80%	3600	4800	7400	15000
	6	60%	2700	3600	5600	11200
		80%	7200	9700	14800	30000
2.5	3	60%	150	200	300	650
		80%	400	550	850	1700
	4	60%	350	500	750	1500

		80%	950	1300	1900	4000
	5	60%	750	1000	1500	3100
		80%	2000	2700	4100	8400
	6	60%	1500	2000	3100	6300
		80%	4000	5400	8300	16800
4	5	60%	500	650	1000	2000
		80%	1300	1800	2700	5400
	6	60%	1000	1300	2000	4100
		80%	2600	3500	5400	11000
NOTE: The water level in the table refers to the height of the water level from the surface of the vegetation area.						

Table C.6--Reference table of planting density and width of Sonneratia apetala corresponding to expected wave dissipation rate

Tree is 10m high and 30cm in diameter						
Wave height, water level and dissipation rate			Planting density/(plant /100m2)			
			80	60	40	20
Wave height/(m)	Water level/(m)	High wave dissipation rate	Planting width/(m)			
0.5	1	60%	50	70	100	250
		80%	150	200	300	650
	2	60%	90	100	200	450
		80%	250	350	550	1200
	3	60%	100	150	300	600
		80%	300	450	750	1600
	4	60%	150	200	350	750
		80%	400	550	900	2000
	5	60%	150	250	400	850
		80%	450	650	1100	2300
	6	60%	200	250	450	950
		80%	500	700	1200	2500
1.25	2	60%	50	70	100	250
		80%	100	150	300	600
	3	60%	60	90	150	350
		80%	150	250	400	900
	4	60%	80	100	200	400
		80%	200	300	500	1100
	5	60%	90	150	200	500
		80%	250	350	600	1300
	6	60%	100	150	250	550
		80%	300	400	650	1400
2.5	3	60%	40	50	90	200
		80%	100	150	250	500
	4	60%	50	70	100	250

		80%	100	200	300	650
	5	60%	50	80	150	300
		80%	150	200	350	750
	6	60%	60	90	150	300
		80%	150	250	400	850
4	5	60%	40	50	80	200
		80%	100	150	250	500
	6	60%	40	60	90	200
		80%	100	150	250	550
NOTE: The water level in the table refers to the height of the water level from the surface of the vegetation area.						

Table C.7--Reference table of mangrove (*Laguncularia racemosa*) planting density and width corresponding to expected wave dissipation rate

The height of the tree is 3.5m, and the average tree is formed by 30 branches with a diameter of 4cm						
Wave height, water level and dissipation rate			Planting density/(plant /100m2)			
			80	60	40	20
Wave height/(m)	Water level/(m)	High wave dissipation rate	Planting width/(m)			
0.5	1	60%	20	30	40	90
		80%	50	70	100	250
	2	60%	40	50	80	200
		80%	100	150	200	450
	3	60%	60	80	100	250
		80%	150	200	300	700
	4	60%	100	150	200	450
		80%	250	350	600	1200
	5	60%	250	300	500	1000
		80%	600	850	1300	2700
	6	60%	500	650	1000	2100
		80%	1300	1800	2700	5600
1.25	2	60%	20	20	40	70
		80%	40	60	90	200
	3	60%	20	30	50	100
		80%	60	90	150	300
	4	60%	40	60	90	200
		80%	100	150	250	500
	5	60%	100	150	200	450
		80%	250	350	550	1200
	6	60%	200	300	450	900
		80%	550	750	1200	2400
2.5	3	60%	10	20	30	60
		80%	30	40	70	150

	4	60%	20	30	50	100
		80%	60	80	150	250
	5	60%	50	70	100	200
		80%	150	200	300	600
	6	60%	100	150	200	450
		80%	300	400	600	1200
4	5	60%	30	40	70	150
		80%	80	100	200	350
	6	60%	70	90	150	300
		80%	200	250	400	800
NOTE: The water level in the table refers to the height of the water level from the surface of the vegetation area.						