ICS 07.060
A45

中国海洋工程咨询协会
China Association of Oceanic Engineering

Social Organization Standard

T/CAOE 21.6-2020

Technical guideline on coastal ecological rehabilitation for hazard mitigation —

Part 6:

Oyster reef

海岸带生态减灾修复技术导则 第6部分：牡蛎礁

（English Translation）

Issue date: 2020-07-21 Implementation date: 2020-07-21

Issued by China Association of Oceanic Engineering

Contents

Foreword

The T/CAOE 21 *Technical Guidelines for Ecological Rehabilitation for Hazard Mitigation in Coastal Zones* 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 6 of the T/CAOE 21, which is used together with Part 1.

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 *Second Institute of Oceanography, Ministry of Natural Resources; East China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences; National Marine Hazard Mitigation Service; Institute of Oceanology, Chinese Academy of Sciences; The Nature Conservancy*.

The main drafters of this part are SUN Li, QUAN Weimin, TAN Yonghua, WANG Degang, CHEN Xinping, LV duian, LI Li, CHENG Jie, CHENG Jun, WANG Wei.

The main translation organizations of the English version of this part are *National Marine Hazard Mitigation Service*, and *Hohai University*.

The main translators of the English version of this part are SHEN Xiaoteng, LIAN Yushun, TAO Aifeng, Chen Xinping, SONG Xiangzhou.

Technical guideline on coastal ecological rehabilitation for hazard mitigation —
Part 6: Oyster reef

1 Scope

This part of T/CAOE 21 specifies the working procedures, information collection and investigation, suitability evaluation, implementation plan preparation, oyster reef rehabilitation techniques for disaster mitigation, follow-up monitoring and effectiveness assessment, quality control, results and data archiving, etc.

This document is applicable to disaster reduction and restoration of oyster reef ecology in coastal zone protection and restoration projects, while serve as reference for other related works.

2 Normative references

The following documents are essential for the application of this document. In the following, for documents with date specified, only the version of the specific date is applicable to the current standard; for ones without date specified, the latest version (including any modified updates) applies.

GB/T 12763.2, *Specification for marine surveys* -- Part 2: Marine hydrologic observations

GB/T 12763.6, *Specification for marine surveys* -- Part 6: Marine biological surveys

GB 17378.4, *Specification for marine monitoring* -- Part 4: analysis of sea water

GB 17378.7, *Marine monitoring code* -- Part 7: Ecological survey of offshore pollution and biological monitoring

GB/T 17501, *Protocol for Topographic Survey of Marine Engineering*

SC/T 2026, *Pacific oyster spawning oyster*

SC/T 2027, *Pacific oyster seeding*

T/CAOE 20.7, *Technical guidelines for the investigation and assessment of the status of coastal ecosystems* - Part 7: Oyster reefs

T/CAOE 21.1-2020, *Technical guidelines for ecological disaster mitigation and restoration in coastal zones* - Part 1: *General*

3 Terms and definitions

The following terms and definitions apply to this document.

3.1

oyster reef

An aggregated reef consisting of living oysters, the shells of dead oysters, and other reef organisms that accumulated together.
[T/CAOE 20.7-2020, definition 3.1]

3.2

oyster recruitment

The number of oyster spat (post-larval juvenile oyster) per unit area.
[T/CAOE 20.7-2020, definition 3.5]

3.3

cultch

A substrate used to which a planktonic larvae of oyster may attach and undergo metamorphosis.

3.4

artificial oyster reef

A three-dimensional structure of clutches artificially arranged or stacked, forming base for oyster larvae to attach and undergo metamorphosis.

3.5

cultch-limited environment

Condition where the hydrological and ecological environment is suitable for oyster growth with sufficient oyster recruitment, but lacks hard substrate as cultch for oyster settlement.

3.6

recruitment-limited environment

Condition where the hydrological and ecological environment is suitable for oyster growth with sufficient cultch surface for settlement, but lacks sufficient oyster recruitment.

4 Work Procedure

Working procedure in accordance with requirements specified in Clause 6 of T/CAOE 21.1-2020.

5 Information collection and investigation

5.1 Information collection

5.1.1 Content of information collection

The following information are to be collected:

a) Historical distribution of oyster reefs or oysters in the project area: location, area, oyster species.
b) Local laws and regulations, spatial planning and zoning information.
c) Marine environmental factors within the project area and the surrounding 3km-radius: water temperature, salinity, dissolved oxygen, pH, sediment deposition rate, etc.
d) Marine disaster status: frequency and intensity of storm surges, typhoons, hazardous waves, red tides, etc.
e) Human activities within the project area and the surrounding 3km radius: fishery activities, marine construction, land-based pollution, etc.

5.1.2 Information validity

Generally, not more than 5 years.

5.2 Field survey

One comprehensive survey shall be conducted before implementing the restoration project. The contents of survey should include oyster reefs, biological communities, environmental factors and threat factors. The contents, factors, methods and requirements of the survey are shown in Table 1.

Table 1—The content, factors, methods and requirements of the site investigation in the project area

survey content	Survey factors	Investigation methods and requirements
Oyster reef	Reef: patch area, reef height and overall width of oyster reef footprint	The methods and requirements for investigation of oyster reef area and reef height should be measured in accordance with T/CAOE 20.7. Methods and Requirements for overall width of oyster reef footprint: a) Method: measure the width of oyster reef footprint perpendicular to the coastline, via on-site measurement or remote sensing image extraction by drones. b) Requirement: the resolution of remote sensing image of UAV (Unmanned Aerial Vehicle) shall be no less than 0.1 m.
	Oyster: species, density, recruitment, shell height, oyster condition index, peak reproduction period.	The survey methods and requirements of species, density, recruitment, shell height, and oyster condition index should be measured in accordance with T/CAOE 20.7. Investigation methods and requirements during peak reproduction period: a) Method: anatomical observation of oyster gonads and microscopic examination of oyster larvae. b) Requirement: when the plump, milky soft part of the oyster becomes thin and transparent, it is believed that the parent brood has released gametes. When the shell of juvenile oyster is larger than 300 μm and the proportion of eye-point larva is more than 30%, it is considered that the oyster spat is at the peak of settlement. c) Time: oyster spawning season. d) Frequency: once every three days.
Biological communities	Macrobenthos: species, density	In accordance with the provisions of GB/T 12763.6.
	Phytoplankton: species, density	
Environmental factors	Water environment: water temperature, salinity, flow rate, dissolved oxygen, pH value	In accordance with the provisions of T/CAOE 20.7.
	Bottom environment: substrate type, sediment deposition rate	
	Dynamic environment: water level, wave height	a) Methods and requirements: see Annex A.1, which shall be measured in accordance with the provisions of GB/T 12763.2. b) Time: during storm surge event.
	Bathymetry: water depth	In accordance with the regulations of GB/T 17501.

Threat factors	Natural factors: predation, competition	In accordance with the provisions of T/CAOE 20.7.
	Human factors: wild-catch fishery, filter-feeding shellfish aquaculture, marine construction/development, pollution discharge	

6 Suitability evaluation

6.1 Factors of suitability evaluation

Before the implementation of the oyster reef rehabilitation project, site suitability shall be evaluated and a suitability evaluation report should be prepared. The evaluation report should include ecological status assessment of the oyster reef area, evaluation of disaster mitigation function by the oyster reef, and evaluation of oyster habitat suitability. If there is no existing distribution of oyster reef in the area of interest, then omit the ecological status evaluation in 6.2 and the evaluation of disaster mitigation function in 6.3 of this document.

6.2 Ecological status assessment of oyster reef area

6.2.1 Target of assessment

Existing oyster reef area.

6.2.2 Evaluation content and method

The assessment of oyster reef ecological status should be implemented in accordance with the content and method specified in T/CAOE 20.7. If the oyster reef is degraded, then the cause of the degradation shall be analyzed.

6.2.3 Evaluation result

If the result of ecological status assessment of the oyster reef is "damaged" or "severely damaged", then ecological rehabilitation for disaster mitigation of the oyster reef shall be carried out.

6.3 Evaluation of disaster mitigation function of oyster reefs

6.3.1 Evaluation content

The effect of oyster reefs on reducing waves and disaster risks caused by storm surge.

6.3.2 Evaluation index

Wave height attenuation rate.

6.3.3 Wave height attenuation rate

The wave height attenuation rate is the percentage ratio of the wave height attenuated after passing through the oyster reef to the effective wave height of the incoming wave during a storm surge. The calculation method is shown in Eq. (1):

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

where

R_{wL} Wave height attenuation rate;

H_0 The effective wave height at the seaward edge (the seaward point) of the oyster reef area, in meters (m);

H_L The effective wave height at the landward edge (landward point) of the oyster reef area, in meters (m).

6.3.4 Evaluation method

According to Annex A.

6.3.5 Evaluation result

According to the wave height attenuation rate, the disaster reduction function is ranked into four levels: excellent, good, medium, and poor, as shown in Table 2. For the same wave energy level, the higher the wave height attenuation rate, the better the disaster reduction effect of the oyster reef, and the higher the disaster mitigation function level.

Table 2—Oyster reef disaster reduction function level corresponding to wave height attenuation rate

Wave height attenuation rate	Disaster mitigation function level
>=50%	Excellent
>=30% to ＜ 50%	Good
>=10% to ＜ 30%	Medium
＜10%	Bad

6.4 Evaluation of Oyster Habitat Suitability

6.4.1 Evaluation metrics

Refer to Table 3 for the evaluation metrics of oyster habitat suitability.

Table 3—Evaluation metrics table of oyster habitat suitability

Evaluation metrics	Evaluation factors	Suitable range
Natural factors	Oyster distribution	Sea areas with historical or current oyster reef or oyster distribution, or sea areas with suitable environment that require ecological disaster mitigation by oyster reefs.
	Water temperature	The water temperature is suitable for oysters to survive. Please refer to Annex B for tolerance range of water temperature for key reef-building oyster species.
	Salinity	The salinity is suitable for oysters to survive. Please refer to Annex B for the tolerance range of salinity for key reef-building oyster species.
	Dissolved oxygen	Out of any consecutive 24 hours, dissolved oxygen greater than 5mg/L over at least 16 hours, and no less than 3mg/L at any other time.
	pH	7.8 to 8.5.
	Bathymetry	The bottom topology is gentle or flat, and the slope is less than 5°.
	Water flow	The tidal current is unobstructed, no vortex flow or collision

		flow, and flow rate during oyster breeding period is less than 60cm/s.
	Sediment deposition rate	The sediment deposition rate is less than the growth rate of oyster reef height.
	Substrate type	Select areas with hard bottom while avoiding soft bottoms with deep silt and fine sand where water flow rate is high.
Human Factors	Sea area utilization	Avoid areas that are severely impacted by human activities such as marine debris areas, salt farms, power plant inlet and outlets, docks, and shipping channels. .

6.4.2 Evaluation results

Evaluation result is considered as “suitable” if all suitable range of all metrics in Table 2 are met, indicating suitable habitat for oyster growth; if suitable range of any of the metrics in Table 2 is not met, then the evaluation result is considered “unsuitable”, indicating the area evaluated is not suitable for oyster growth.

7 Implementation plan preparation

The preparation of the implementation plan should be conducted in accordance with the provisions of 7.3 of T/CAOE 21.1-2020.

8 Oyster reef ecological rehabilitation techniques for disaster mitigation

8.1 Restoration approach selection

According to results of the suitability evaluation in session 6, select from the following restoration approaches:

a) In cultch-limited environment, need to supply cultch substrate and construct artificial oyster reef;

b) In recruitment-limited environment, need to add targeted oyster species to the reef;

c) In environment limited with both cultch and recruitment, need to construct artificial reefs before transplanting oysters.

8.2 Artificial oyster reef construction

8.2.1 Cultch material

Cultch materials include shells, concrete pieces, cured fly ash, stone (carbonate) and other hard substrates. When choosing cultch material, consider the following:

a) Choose materials that are pollution-free, environmentally friendly, durable, easy to obtain, and low-cost;

b) Choose materials according to the scope of application and advantages/disadvantages of the cultch material;

c) Experiment with different cultch materials, and choose the material that local oyster species prefer to settle on.

8.2.2 Reef design requirement

The reef design shall meet the following requirements:

a) The reef can maintain good stability without risks of slipping, overturning, and burying after construction;

b) The cultch material must be able to sustain the process of placement, transportation and deployment, and withstand erosion and wear from waves and currents;

c) Maximize surface area and surface roughness of the reef;

d) At locations with high sediment deposition rate, the reef structure should adopt larger base area

8.2.3 Reef construction site and layout

Artificial oyster reefs should be constructed in the range from lower intertidal zone (average low tide water level below 1m) to subtidal zone (average low tide water level less than 5m), or areas with damaged oyster reef distributed. The best reef site, reef structure and layout plan should be determined according to the goal of rehabilitation project, the following principles shall be followed:

a) For maximizing ecological disaster mitigation functions, the reefs should be constructed in the intertidal zone, while using heavy materials such as stones and concrete blocks, with layout of single-layer or multi-layer strips of reefs distributed intermittently parallel to the coastline.

b) For projects with biodiversity or fish production as the main goal, the reef should be constructed into a complex three-dimensional structure.

c) For improving water quality, the reef should be constructed in the subtidal zone with even distribution across large scale.

8.2.4 Reef construction time

For cultch-limited environments, the time for reef construction shall be within 1 month before the peak of oyster reproduction; for recruitment-limited environments, the reef shall be constructed prior to transplanting oyster seeds.

8.2.5 Reef height

The reef height is determined according to the rehabilitation site, rehabilitation goal, and sediment deposition rate, in general reefs are constructed at height of 0.2m to 2m. The height of subtidal reefs should be greater than 0.5m. If the sediment deposition rate is high, then increase reef height.

8.3 Oyster recruitment

8.3.1 Oyster species selection

Choose adult or juvenile individuals of locally occurring oyster species.

8.3.2 Source

Adult oysters from artificial culture.

Juvenile oysters from either hatchery or semi-artificially collected seeds from the wild.

8.3.3 Transportation

The transportation of adult oysters should be carried out according to the requirements of SC/T 2026.

The transportation of juvenile oysters should be carried out according to the requirements of SC/T 2027.

8.3.4 Deployment

8.3.4.1 Site of deployment

On natural reefs or artificial oyster reefs.

8.3.4.2 Deployment method

Select from the following deployment arrangements based on characteristics of the restoration site:

a) If the restoration site is located in intertidal zone, then place or fix cultch with oyster seeds onto reef surface at low tide.

b) When the restoration site is located in subtidal zone if the cultch material is made of concrete, cured fly ash, stones, bagged shells, etc., then transfer cultch substrate via boat and slowly lower cultch onto surface of the reef at low tide. If the cultch is made of strings of shells, etc., then cultch should be deployed by divers and fixed manually to surface of the reef.

8.4 Post-restoration management

8.4.1 Duration of conservation

More than 2 years.

8.4.2 Reef characterization

Within one month of the oyster reef rehabilitation constructions, measure the restored reef area, record GPS positions, produce digital map of the oyster reef distribution, and mark the reefs.

8.4.3 Cleaning and maintenance

Routine maintenance should be carried out at least once a year, and additional emergency maintenance shall be conducted after marine disasters such as strong typhoons, storm surges, red tides, green tides, and marine pollution events, etc. Inspect the integrity and stability of artificial oyster reefs, and take remedial and repair measures for overturned, damaged or displaced artificial reefs. Inspect if sediment and debris accumulate on the surface of or around the oyster reefs, and perform cleaning and maintenance work according to the degree of sedimentation.

8.4.4 Removal of natural enemy

Irregular remove natural enemy of oysters such as predators, competitors and invasive species by capturing and expelling.

8.4.5 Regular patrol

Regular patrol and inspection to prevent fishing and destruction.

8.4.6 Adaptive management

When density of living oysters in the reef area is low, factors leading to low survival rate need to be analyzed and the rehabilitation plan should be adjusted accordingly.

9 Follow-up monitoring and effectiveness assessment

9.1 Follow-up monitoring

9.1.1 Routine monitoring

The first monitoring activities should be conducted 3 months after completion of the oyster reef rehabilitation project and regular monitoring should last for more than 2 years. Once timing and frequency of routine investigation have been determined, they shall remain the same for long-term to allow for inter-annual data comparisons. The monitoring content includes oyster reefs, biological community and water environment. Specific monitoring metrics, methods and frequencies are shown in Table 4.

Table 4 —Metrics, methods and frequency of follow-up monitoring of ecological rehabilitation for disaster mitigation of oyster Reefs

Monitoring content	Monitoring metrics	Monitoring methods	Monitoring frequency
Oyster reef	Oyster reef area (hm2)	In accordance with the provisions of T/CAOE 20.7.	Once during oyster spawning season (usually in late spring or early summer) and once at the end of growing season (usually in winter) in the same year
	Reef height (m)		
	Oyster population density (ind/m2)		
	Oyster recruitment (ind/m2)		
	Proportion of mature oyster (%)		
Biological community	Population density of sedentary animal (ind/m2)	Quadrat methods in accordance with the provisions of GB/T 12763.6.	Once in spring and once in autumn.
	Biomass of sedentary animal (g/m2)		
Water environment	Water temperature (℃)	In accordance with the provisions of T/CAOE 20.7.	
	Salinity		
	Dissolved oxygen (mg/L)		
	pH value		
	Suspended matter concentration (mg/L)	Sampling methods in accordance with the provisions of GB 17378.4.	
	Chlorophyll a concentration (μg/L)	Sampling methods in accordance with the provisions of GB 17378.7.	

9.1.2 Emergency monitoring

The contents, time and frequency of emergency monitoring are as follows:

a) Determine the content and frequency of emergency monitoring based on the extent and scope of the disaster event’s impact, such as red tide, oil spills and pollutant discharge;

b) Frequent monitoring should be carried out at least once a week for water temperature, salinity, dissolved oxygen, pH value and other environmental metrics during special periods such as prolonged period of high temperature, low temperature (<0 ℃) event, extensive rainfall and flood discharge.

c) During a storm surge event (since 1to3 days ahead of storm surge warning to the lifting of storm surge warning), water level and wave height monitoring should be conducted. Within 10 days after the lifting of the storm surge warning, assessment of ecosystem status should be carried out, with survey contents shown in table 4.

9.2 Effectiveness assessment

9.2.1 Mitigation effectiveness assessment

Refer to the methods specified in section 6.3 of this document.

9.2.2 Ecological effectiveness assessment

9.2.2.1 Timing of assessment

Two years after the completion of the oyster reef rehabilitation project.

9.2.2.2 Content of assessment

Footprint of restored oyster reef.

9.2.2.3 Reference ecosystem

The condition before the rehabilitation of oyster reef or the ecological condition of oyster reefs in waters adjacent to the rehabilitation site can be used as the reference ecosystem.

9.2.2.4 Assessment metrics and calculation

The assessment metrics are shown in Table 5 and the calculation method is given as Eq. (2)

$$S_i = \frac{R_i - R_0}{R_0} \times 100\% \qquad \text{..................................} (2)$$

where

Si is the relative change value in the i^{th} metric;

Ri is the monitoring result after rehabilitation of the i^{th} metric,;

Ro is the reference value of the i^{th} metric.

9.2.2.5 Assessment metrics and score designation

The classification and evaluation score designation for various metrics are shown in Table 5.

Table 5—Evaluation of the ecological effects of oyster reefs

No.	Indicators	Ⅰ	Ⅱ	Ⅲ
1	Change in oyster reef area	＞50%	＞10%~≤50%	≤10%
2	Change in oyster recruitment	＞50%	＞10%~≤50%	≤10%
Evaluation score designated		100	75	50
3	Change in mean reef height	＞50%	＞10%~≤50%	≤10%
4	Change in oyster population density	＞50%	＞10%~≤50%	≤10%
5	Change in proportion of mature oyster	＞50%	＞10%~≤50%	≤10%
6	Change in population density of sedentary animal	＞50%	＞10%~≤50%	≤10%
Evaluation score designated		50	37.5	25
7	Change in suspended matter concentration	＜-50%	≥-50%~＜-10%	≥-10%
8	Change in Chlorophyll a concentration	＜-50%	≥-50%~＜-10%	≥-10%
Evaluation score designated		30	22.5	15

NOTEs:

1. In metrics No.1-2 grade Ⅲ, if the relative change value is within ≥-50% -＜-10%, then designate a score of 25; if＜-50%, then designate as 0.
2. In No.3-6 indicators grade Ⅲ, if the relative change value is within ≥-50% -＜-10%, then designate a score of 12.5; if＜-50%, then designate as 0.

3. In No.7-8, if the relative change value is within＞10% - ≤50%, then designate a score of 7.5; if ＞50%, designate as 0.

9.2.2.6 Ecological effectiveness evaluation

The ecological effectiveness indicator can be calculated as Eq. (3)

$$V = \frac{\sum_{i=1}^{n} V_i}{\sum_{i=1}^{n} V_{iMAX}} \quad \text{...} (3)$$

Where

V is the ecological effectiveness indicator;

Vi is the score designated to the i^{th} evaluation metric;

ViMAX is the total score of the i^{th} metric.

The classifications for ecological effectiveness assessment of oyster reef are given in Table 6.

Table 6—The classifications for ecological effectiveness assessment of oyster reef

Classification	Range of V	rehabilitation effectiveness
I	≥75%	significantly improved
II	≥50%~＜75%	improved
III	＜50%	Basically, no change

10 Quality control

In accordance with the provisions of clause 8 in T/CAOE 21.1-2020.

11 Results and data archiving

In accordance with the provisions of clause 9 in T/CAOE 21.1-2020.

Annex A
(annex normative)
Assessment methods for disaster mitigation function of oyster reef

A.1 Field observation

A.1.1 Applicability of field observation

The field observation is applicable for areas with sufficient socio-economic support where disaster occurs frequently. In the year when the disaster mitigation assessment takes place, the area needs to have experienced at least one storm surge event that caused severe impact.

A.1.2 Selection of cross-section and measuring point

The water level and wave height survey adopt cross-sectional observation method. The cross-section should be as parallel to the direction of wave propagation as possible, and the selection of the cross-section should be able to reflect the distribution characteristics of the oyster reef. If the oyster reefs distribution in the area shows high level of spatial variation, then multiple cross-sections should be selected. There should be at least two measuring points along each cross-section, located at the seaward edge (the seaward point) of the oyster reef area and the landward edge (the landward point) respectively. The specific investigation method should be implemented in accordance with the provisions of GB/T 12763.2.

A.1.3 Observation metrics

Field observation metrics include the wave height and water level at the seaward point and the landward point.

A.1.4 Observation duration

The in-situ observation duration should include the entire duration of the storm surge event (from 1 to 3 days ahead of the storm surge event to lifting of the storm surge warning).

A.1.5 Data analysis and calculation method

Select the most unfavorable (the highest and the largest significant wave height) period of field observed sequence of significant wave height (the duration could be 30 minutes). The wave height attenuation rate can be calculated by Eq. (1) using the significant wave height measured at the seaward point (H0) and the landward (HL) of the observed cross-section.

A.2 Physical modeling experiment

A.2.1 Applicability of physical modeling experiment

Physical modeling experiment can be used in the case where the frequency of marine disasters in the region of interest is low (no storm surge occurrence affecting the area to be assessed during the assessment year) or access to field observation is limited. Comparing with the empirical formula method, physical model experiment method has the advantage in that it can evaluate disaster mitigation effects of oyster reefs with complex shapes and inconsistent distribution.

A.2.2 Technique

A.2.2.1 Determine of reef model

First, a modeled reef is needed for physical modeling experiment. The size of the model can be determined according to the structural characteristics of the oyster reef following the similar figure principle. The scale factor is given as Eq. (A.1)

$$\lambda_L = \frac{L_p}{L_m} \quad \cdots\cdots (A.1)$$

Where

λ_L is the length similarity scale factor;

L_p is the characteristic length of the actual reef;

L_m is the characteristic length of the modeled reef.

A.2.2.2 Model layout

Arrange modeled reef layout according to the actual reef distribution characteristics. Width of the modeled reef can be calculated as Eq. (A.2) according to the similar figure.

$$L_{vm} = \frac{L_{vp}}{\lambda_L} \quad \cdots\cdots (A.2)$$

Where

L_{vp} is the characteristic width of the actual reef;

L_{vm} is the characteristic width of the modeled reef.

A.2.2.3 Water level and wave conditions

Based on characteristics of nearshore tide and waves surrounding the reef area, the modeled hydrodynamic parameters, wave height and water level, can be calculated according to the similar figure formula (Eq. (A.3) and Eq. (A.4). The parameters of model experiments and the actual reef should also adhere to the gravity similarity criterion, that is, the actual Floyd number and the modeled Floyd number are consistent. According to the scale factor and gravity similarity criterion, the relationship between the modeled wave period and the actual wave period can be obtained by Eq. (A.5).

$$H_{0m} = \frac{H_{0p}}{\lambda_L} \quad \cdots\cdots (A.3)$$

where

H_{0p} is the characteristic significant wave height of the actual hydrodynamic parameters;

H_{0m} is the characteristic significant wave height of the modeled hydrodynamic parameters.

$$\eta_m = \frac{\eta_p}{\lambda_L} \quad \cdots\cdots (A.4)$$

where

η_p is the characteristic water level of the actual hydrodynamic parameters;

η_m is the characteristic water level of the modeled hydrodynamic parameters.

$$T_m = \frac{T_p}{\sqrt{\lambda_L}} \quad \cdots\cdots (A.5)$$

where

T_p is the characteristic significant wave period of the actual hydrodynamic parameters;

T_m is the characteristic significant wave period of the modeled hydrodynamic parameters.

A.2.2.4 Tank and instrument layout

The tank for physical modeling experiment should be equipped with a wave-making device, which has active wave-absorbing function and is installed at the head end of the tank. Place the modeled reef in the center of the tank, allowing distance from the wave-making device. Install wave-dissipating device at a distance behind the modeled reef. Digital wave gauges are usually used to measure the attenuation of wave propagation in the reef area. The wave gauges should be placed within, behind and in front of the reef area, as the minimal 3 wave gauge measurement points (one at the front, middle and rear edge of the reef).

A.2.3 Data analysis and calculation method

Input the modeled hydrodynamic parameters (including water level, wave height, and wave period) and reef parameters (including reef width and height) from physical modeling experiment into Eq. (A.3) ~ Eq. (A.5) to calculate the corresponding parameters. Subsequently, the wave height attenuation rate can be calculated by Eq. (1) using the wave height at seaward point (H0) and landward point (HL) of the disaster mitigating oyster reef area.

A.3 Numerical simulation

A.3.1 Applicability of numerical simulation

The numerical simulation is suitable for situations below to assess the disaster mitigation function of oyster reef:

a. The area has low frequency of coastal disaster (no storm surges event affecting the area occurred during the assessment year).

b. Access to in-situ field observation is limited by economic and technical conditions.

c. The distribution characteristics such as the length and width of the reef area, the characteristic of oyster reefs such as surface roughness, and the hydrodynamic conditions can be obtained, and that there are numerical simulation techniques developed and available.

A.3.2 Numerical model

Wave models commonly used by engineers, such as SWAN (Simulating Waves Nearshore) can be adapted to simulate the interaction between oyster reefs and waves by calibrating relevant parameters for oyster reef. For specific numerical simulation, suitable numerical model should be selected according to actual needs and computing capacity. When using the model, one can refer to the technical manual and combine the measured data to calibrate the simulation model.

A.3.3 Analysis and calculation of numerical simulation results

Real-life scales should be used for the simulating calculations when using numerical simulation methods to assess disaster mitigation functions. The wave height attenuation rate can be calculated by Eq. (1) using the wave height at the seaward point (H0) and the landward (HL) of the disaster mitigating area simulated by the model.

A.4 Determine assessment method

To determine which assessment method should be used, one should comprehensively consider the field conditions, socioeconomic conditions, technical equipment and experimental conditions. Priority should be given to choosing field observation method over others to directly measure and calculate the wave height attenuation rate of the oyster reef during a storm surge event, if conditions permit. When conditions are limited, for instance, if there has been no storm surge event impacting assessment area in recent years, therefore field observations during storm surge disasters are not feasible, then other methods (e.g., physical modeling experiments and numerical simulation) can be used. When using physical models for assessment, ensure that the actual reef parameters and ocean hydrodynamic parameters are true and reliable. While using numerical simulation model, ensure reliability of the numerical models to generate reasonable and accurate parameterization of reef characteristics.

Annex B
(annex informative)
Tolerance range of key indicators for main reef-building oyster species in China

Table B.1—Tolerance range of key indicators for main reef-building oyster species in China

Oyster species	Main distribution	Spawning season duration	Spawning season conditions		Growing season conditions	
			Temperature	Salinity	Temperature	Salinity
Crassostrea hongkongensis	Coastal areas of Guangdong, Guangxi and Hainan Provinces; intertidal zone to shallow subtidal waters of 10-meters depth.	April -July September - November	24℃to31℃	3to20	6℃to32℃	3to20
Crassostrea angulata	Coastal areas of Zhejiang, Fujian, Guangdong, Guangxi, Taiwan and Hainan Provinces; intertidal zone to shallow subtidal waters of 10-meters depth.	April - October	22℃to30℃	20to30	5℃to30℃	25to30
Crassostrea gigas	Coastal area of Liaoning to Jiangsu Provinces; intertidal zone to shallow waters of 10-meters depth.	May - August	20℃to26℃	20to30	5℃to30℃	20to32
Crassostrea sikamea	In intertidal zone of bays and estuaries along the coast in the south of Nantong, Jiangsu.	June - August	20℃to28℃	18to35	5℃to30℃	7to30
Crassostrea ariakensis	In bays, estuaries and surrounding areas from mouth of Yalu River to the coast of Hainan; from low tide line to shallow subtidal waters of 10-meters depth.	May - August	24℃to31℃	15to25	3℃to32℃	6to33

References

[1] GB11607—89 Water quality standard for fisheries.
[2] NY/T 5155—2002 Technical specifications for the cultivation of pollution-free food Oyster.
[3] SC/T 9416—2014 Technical specifications for artificial reef construction.
[4] DB33/T 457—2014 Technical specification for oyster culture.
[5] DB37/T 458—2010 Non-polluted food Pacific oyster breeding technical regulations.
[6] DB37/T 716—2007 Technical Regulations for Mudflat Shellfish Cultivation.
[7] DB33/T 846—2011 Technical specification for the release and enhancement of ocean benthic mussels
[8] Baggett, L. P., Powers, S. P., Brumbaugh, R., Coen, L. D., DeAngelis, B., Green, J., Hancock, B., Morlock, S., 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA. 96 pp.
[9] Fitzsimons, J., Branigan, S., Brumbaugh, R.D., McDonald, T., zu Ermgassen, P.S.E. (eds), 2019. Restoration Guidelines for Shellfish Reefs. The Nature Conservancy, Arlington VA, USA.