# Guidelines for Maintenance and Repair
# of
# Port and Harbour Facilities
# (draft)

**National Institute for Land and Infrastructure Management**

**Port Facilities Division**

# Preface

This document is a direct translation of the essential parts of the Technical Manual for Maintenance and Repair of Port and Harbour Facilities (Revised edition) published in July 2018 by the Coastal Development Institute of Technology, Japan. This document serves as a basis that provides standard procedures and methodologies for maintenance and repair of existing port and harbor facilities, including inspection, diagnosis and assessment, prediction, comprehensive evaluation, and countermeasures. The assessment of facilities is largely based on performance requirements. This document covers major port and harbor facilities, such as navigation channels and basins, protective facilities for harbors, mooring facilities and port traffic facilities.

Today, the number of officially designated commercial ports and harbors amounts to about 1000, and that of fishing ports exceeds 2700. There were so many demands for the expansion of port and harbor facilities throughout Japan. from 1960's through 1980's. Various facilities that were intensively constructed during the period are beginning to deteriorate rapidly. There is an urgent need to steadily implement efforts to ensure safety and security and to maintain the functions of facilities. Based on knowledge and experience gained in Japan so far, most of the port and harbor facilities in Japan are managed with systematic maintenance and repair procedures. Maintenance and repair of port and harbor facilities is implemented according to the "Technical Standards and Commentaries for Port and Harbour Facilities" in Japan. The "Public Notice Stipulating Matters Necessary for the Maintenance of Port and Harbour Facilities" was firstly enforced in March 2007 in which it has been specified that a maintenance plan shall be created by the owner of the facility and maintenance and repair shall be implemented with suitable methods. In response to this, the "Technical Manual for Maintenance and Repair of Port and Harbour Facilities" in Japanese was published, which summarizes the basic concept of port and harbor facility maintenance. After that, the Port and Harbor Act were amended in 2013, and the provisions for facility inspections necessary for proper maintenance were positioned as laws and regulations. Following it, the "Port Facility Inspection and Diagnosis Guidelines" was published in July 2014. This document is consistent with the guidelines but includes more detailed procedures.

Port and harbor facilities are exposed to very severe physical actions as well as harsh environmental actions. Physical actions such as waves and storm surges may cause damages to facilities. In addition, materials tend to deteriorate rapidly in marine environments and degradation of structural performance or even structural collapse may be consequences. It is important to retain the performance of the structure above the required levels during its service life, which maybe realized with maintenance planning, assessment of structure including inspection and evaluation of the performance of structure, planning and designing repair in case it is required due to wear, damage, or deterioration and execution of countermeasures. The goal of maintenance and repair strategies is to plan and execute systematic routines that minimize degradation of performance of a structure during its service life in the most cost-effective manner.

Parts of this documents have been originally prepared in consideration of the conditions of port and harbor facilities in Japan, but they would be applicable for those in the world. The editors are confident that this document will be used effectively for those who are involved in the maintenance and management of port and harbor facilities. We also believe that this document provides an outstanding contribution to knowledge extension and technology advancement in the field of maintenance and repair of port and harbor facilities. Finally, I would like to express my sincere gratitude to all the editorial committee members for enthusiastic discussion and consideration in compiling this document.

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（March 2022）

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# Part 1 General

## Chapter 1 General

| |
|---|
| (1) This document deals with the maintenance and repair of port and harbor facilities. |
| (2) This document specifies the standard methods for the maintenance and repair of port and harbor facilities to fulfill performance requirements during their service life. |

<Commentary>

(1)

This document specifies maintenance planning and a series of maintenance and repair for port and harbor facilities, including inspections, diagnoses, comprehensive assessments, countermeasures, and recording. This document provides technical information based on the latest knowledge to ensure the adequate maintenance and repair of port and harbor facilities.

(2)

Port and harbor facilities and other infrastructure commonly show visible signs of deterioration from material wear or external damages during their service life even though they are expected to contribute to society for a long time. Therefore, it is essential to design port and harbor facilities with sufficient durability, to construct based on the design and to implement maintenance and repair works to ensure expected functionality and performance. These tasks ensure that the facilities remain in good condition throughout their designated service life.

The “maintenance and repair” described in this document refers to a series of systems for efficiently identifying facility deterioration, rationally evaluating the deterioration, and implementing effective countermeasures, such as repair and strengthening.

Essentially, this document describes a single structure that is a part of multiple structures or facilities. In maintaining and repairing harbor facilities, it is common to perform such maintenance and repair for multiple structures or facilities of which the single structure is a part. It is also expected that the optimization of the maintenance and repair of each structure may be difficult due to factors such as budgetary constraints. In these cases, it is necessary to carry out inspection and diagnosis of each structure and comprehensive assessment based on the results. However, if countermeasures are implemented for multiple structures approximately at the same time, then the priority of each countermeasure should be determined, considering factors such as the structures’ importance, expected service life, life cycle cost, and extent of performance degradation. It is also necessary to carefully plan future maintenance and repair, as performance degradation may continue in cases of unavoidably delayed execution of countermeasures.

The maintenance and repair of harbor facilities and other infrastructure is difficult to implement based only on prescribed standards and manuals because various types of deterioration must be addressed. Therefore, engineers with the required capabilities should be involved in maintenance and repair. An implementation system should be developed, and the involvement of engineers with specialized knowledge and skills should be ensured.

## Chapter 2 Terms and Definitions

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

**Comprehensive assessment:** Actions to determine the policy for future maintenance and repair arising from evaluations of the performance of a structure or its components and materials based on inspection and diagnosis and on comprehensive assessment of factors, including remaining service life and importance of the structure

**Countermeasure:** Repair, strengthening, replacement, removal, or other actions executed to maintain a structure at a performance grade above the required level, including service restrictions and service suspensions

**Deformation:** A general term for defects occurring in a structure, such as material deterioration, damage, displacement, and changing form

**Deformation chain:** A series of events related to the cause of a structure's deformation, the occurrence of deterioration and its visibility, the impact of the deterioration, and the process of performance degradation

**Design service life:** The period for which a structure or structural element is to be used for its intended purpose with anticipated maintenance but without the need for substantial repair

**Deterioration level:** The level of performance deterioration of structural members and components, categorized into four grades (a, b, c, and d)

**Durability:** The ability of a structure or structural element to be free of deterioration that interferes with performance requirements in the relevant environment

**Inspection and diagnosis:** Actions based on previously determined methods, including assessment of deterioration level of structural members or materials

**Inspection and investigation:** General terms for actions that are conducted during inspection and diagnosis, such as investigations and examinations

**Life cycle cost (LCC):** The whole life cost of the structure including planning, design, construction, operations, maintenance, and repair costs. Only the total cost for operations, maintenance and repair for the existing structure is simply defined in this document as LCC.

**Lifetime:** The life of the materials that constitute a structure

**Maintenance and repair:** A set of activities performed to examine a structure, evaluate its performance, and preserve or restore it so that it satisfies the performance requirements

**Maintenance plan:** A plan describing the timing and methods of inspection and diagnosis, service life of the facilities, basic guidelines, and plans for maintenance and repairs that are required to maintain the port and harbor facilities

**Performance grade:** The performance grade of the whole facility, as comprehensively assessed by the deterioration level of the components and materials based on inspection and diagnosis of the items, categorized into four grades (A, B, C, and D)

**Performance requirement:** The performance required of the designed structures or facilities

**Repair:** Restoring the mechanical performance of components and materials or a structure that has degraded to a level not exceeding the original level, to restore degraded durability, or to increase durability

**Service life:** The working life of facilities

**Strengthening:** Enhancing the mechanical performance of a structure or its components beyond the original level

**Structural function:** The target role of a structure to ensure compliance with their purposes and requirements

**Structural performance:** Abilities of a structure to achieve its structural function, including safety, serviceability, usability, and restorability

**TSCPHF**: "Technical Standards and Commentaries for Port and Harbour Facilities in Japan", OCDI (The Overseas Coastal Area Development Institute of Japan), 2020.

**Time-dependent deformation:** Long-term deformation of the function and performance of structures, components and materials caused by environmental actions

<Commentary>

Design service life, lifetime, and service life

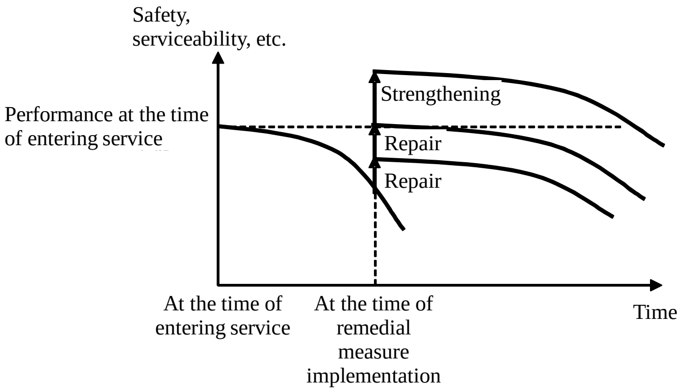
In this document, design service life refers to a facility's expected duration of use; in other words, the period during which the facility must fulfill its performance requirements. Lifetime is the specific duration of use for the materials and components that constitute a facility. Generally, the lifetime is required to be longer than the design service life of the facility, but in many cases, this requirement cannot be satisfied for various reasons. In these cases, the materials and components that have reached their lifetime during the design service life of the facility will be replaced, but this condition should be stated clearly in the maintenance and repair plan. Furthermore, the design service life corresponds to the expected duration of use in the plan or design of a port and harbor facility, whereas the working life is the actual working period.

Deformation

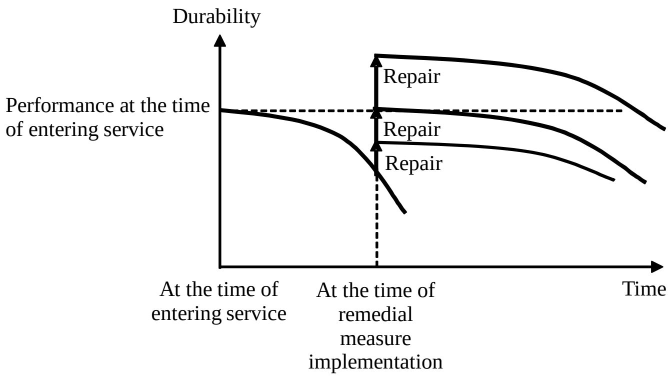
In this document, detectable defect that occurs on the surface of a structure or its components by inspection and diagnosis is termed deformation. Deformation includes material deterioration, damage, initial defects, and other undesirable features that degrade the performance of a facility. Damage refers to the deformation of a structure or its components from cracks, displacement or deformation caused by sudden physical impacts (e.g., earthquakes, wave forces, collisions with ships). Material deformation refers to a deformation form, such as crack and corrosion caused by the long-term degradation of the quality or characteristics of materials that progresses slowly through environmental action.

Repairs and strengthening

Figure-1.2.1is a schematic of the concept of repairs and strengthening as defined in this document.




(a) Repair and strengthening to recover mechanical performance, such as safety and serviceability




(b) Repair to recover durability

Figure-1.2.1 Concept of repair and strengthening

# Part 2 Maintenance and Repair Methods
## Chapter 1 General
### 1.1 General

(1) Port and harbor facilities must be properly maintained through initiatives such as maintenance and repair programs so that the performance requirements can be fulfilled over the entire service life of the facilities.
(2) In maintaining port and harbor facilities, various conditions should be considered, such as the natural conditions surrounding the facilities, usage, and structural and material characteristics.
(3) In maintaining port and harbor facilities, necessary measures should be implemented by appropriate comprehensive assessment for maintenance and repair which is evaluated based on the results of inspection and diagnosis of deformation.

<Commentary>

(1)

Port and harbor facilities must satisfy and maintain the performance requirements over the long period that the facilities are required. To achieve this target, certain considerations related to the initial design of the structure and its scheduled maintenance are indispensable.

Since port and harbor facilities are generally serviced under severe natural conditions, performance degradation often occurs during the facility's service life because of events such as deterioration of materials, damage to structural members, and scouring, subsiding, and burying of the foundations. To ensure a facility can fulfill performance requirements during its service life, properly planned maintenance is essential. For more efficient and accurate maintenance, it is necessary to formulate a maintenance plan before conducting maintenance. The plan should outline a fundamental policy for facility maintenance and the methods, contents, timing, frequency, and procedures of inspection and diagnosis.

(2)

Port and harbor facilities must be properly maintained, while considering the following: the structural type of the facility, the structural characteristics of the members that constitute the facility, and the types and quality of the materials used. In addition, the natural conditions surrounding the facility, facility usage, plans of the facility for the future, design service life, importance, replaceability, and difficulty of inspection, diagnosis, and repair should be considered.

(3)

The maintenance and repair of port and harbor facilities involve a series of procedures to accurately identify deterioration of the structures or of the structural members and components of a facility through timely and the proper inspection and diagnosis; these procedures aim to comprehensively evaluate the impact of the deterioration, as well as that of predicted deterioration, and to implement necessary measures.

Measures that are required based on comprehensive assessment include both physical measures, such as maintenance and repair to prevent performance degradation and strengthening to restore the performance of a structure or a member, and intangible measures, such as service stoppage, service restrictions, load restrictions, and emergency measures for ensuring safety.

# Chapter 2 Maintenance and Repair Based on Life Cycle Management

## 2.1 Outline

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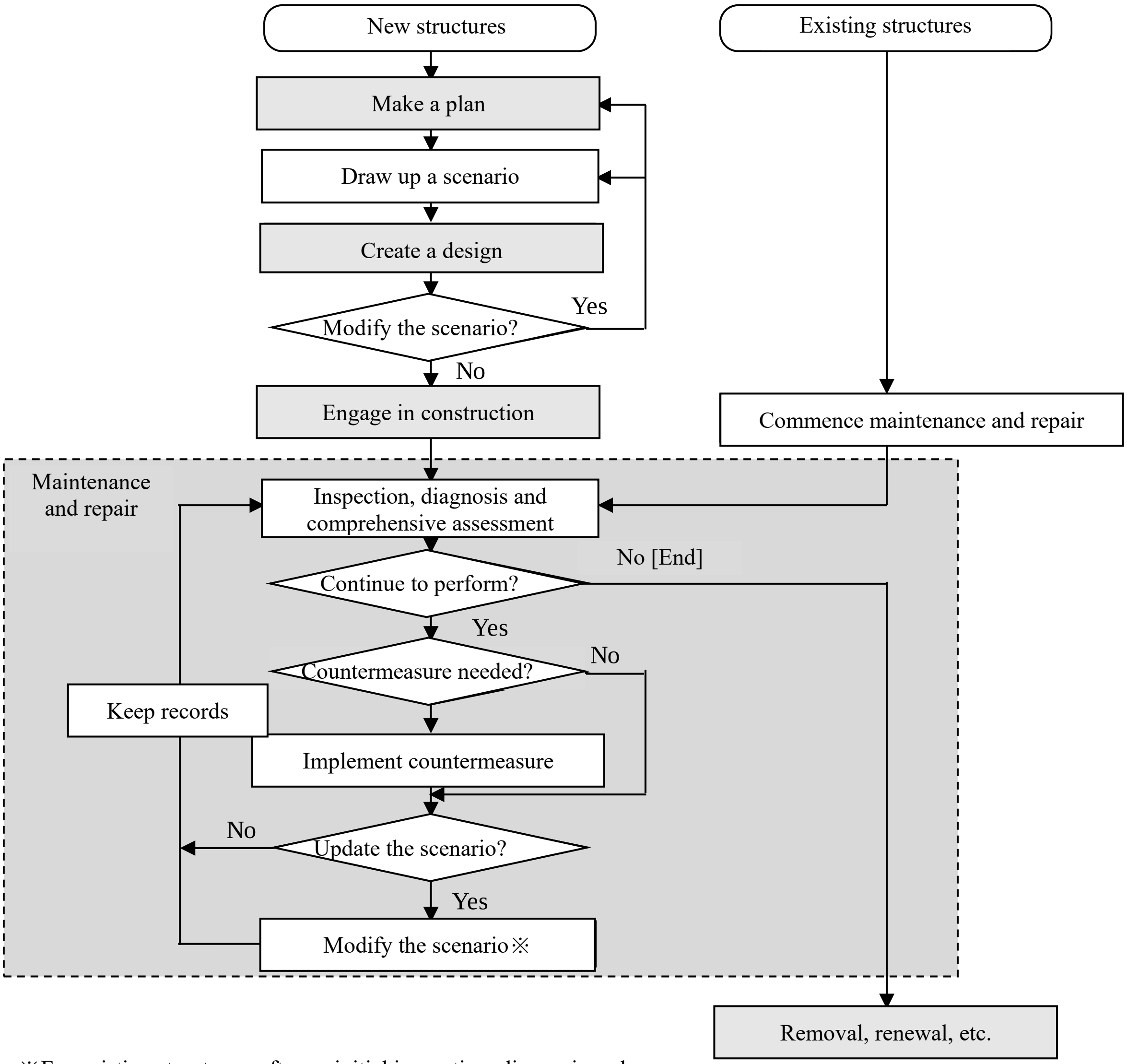
|---|
| Port and harbor facilities must be reasonably maintained in a planned manner based on framework of life cycle management. |

<Commentary>

The maintenance and repair of port and harbor facilities is performed in a series of procedures to accurately understand the deformation of structures or structural members through the inspection and diagnosis, assess the results comprehensively, and conduct any necessary measures. As shown in Figure-2.2.1, conducting maintenance and repair based on the framework of life cycle management helps ensure rational and efficient maintenance. The life cycle management is a system for managing the life cycle of a structure under an integrated policy or strategy. A basic strategy for ensuring that a structure fulfills its performance requirements is formulated in the planning and design stages as a "scenario" (this scenario may be rephrased as a "maintenance plan"). The scenario is then applied to construction and maintenance. To ensure optimal performance of the structure, the scenario should be updated as necessary based on the results of maintenance and repair. Therefore, maintenance and repair proceed according to a flow of inspection and diagnosis that assess the current situation based on the uniform criteria, the existing performance and the prediction of future performance degradation of structures or structural members. In addition to the results of performance evaluations, comprehensive assessment should consider factors such as a utilization plan of the facility for the future, the remaining service life, and the life cycle cost. If necessary, measures should carried out based on the comprehensive assessment. During the inspection and diagnosis, a quantitate evaluation of the performance of a structure or a structural member and the prediction of future performance degradation are particularly important.

In steadily carrying out the life cycle management, it is important to secure a management implementation system, budgetary provisions and organizations, and constitutive management technologies and to foster human resources. Notably, the concept of asset management has been recently introduced in the maintenance and repair of social infrastructure. Asset management is expected to be relevant for infrastructure management and for proper implementation of the PDCA cycle. For port and harbor facilities, it is necessary to coordinate the stages of planning, design, construction, maintenance and repair, removal, and renewal.




※For existing structures: after an initial inspection, diagnosis and assessment, draw up a scenario at this stage.

Figure-2.2.1 Flow of life cycle management

## 2.2 Inspection and Diagnosis

| |
|---|
| To efficiently detect deformation in port and harbor facilities, it is necessary to carry out inspection and diagnosis in a planned manner based on concept of deformation chain. |

<Commentary>

As deformation of the structural members constituting port and harbor facilities is closely related to facility management, it is necessary to fully understand the deformation chain and to select items that can be efficiently and effectively inspected by appropriate methods and procedures. Since port and harbor facilities are rather complicated structures in which structural members are interrelated, and many external agents act on structures, the phenomena involved in the occurrence and progression of deformation are complex. For rational maintenance and repair, it is recommended that deformation that exerts a considerable effect on the performance of a member and components and that is straightforward to inspect and diagnose be considered major deformation. The process whereby deformation progresses from the existence of factors causing deformation to the occurrence of damage and onward to the performance degradation of a facility is known as the deformation chain and should be fully considered in identifying major deformation. For rational maintenance and repair, it is useful to focus on the main deformation chain and to designate that chain as the target of inspection and diagnosis. The Performance degradation chain is fully described in Part 3.

The general flow of inspection and diagnosis is shown in Figure-2.2.2. The inspection and diagnosis may be divided into four types. In any type of inspection and diagnosis, appropriate surveying methods and techniques should be used to clarify the current status of a structure, its elements or members, and the degree of deformation should be graded in terms of remaining performance requirements.

**Initial inspection and diagnosis**

1) Newly constructed facilities
[Timing of implementation]
Immediately after construction or improvement
[Method]
Same as for detailed periodic inspection and diagnosis (maybe replaced by a completion inspection)

2) Existing facilities
[Timing of implementation]
In the stage of working out a maintenance program, etc.
[Method]
Same as for regular periodic inspection and diagnosis or detailed periodic inspection and diagnosis

**Under normal conditions**

**Daily inspection and diagnosis**

[Frequency]
・Manger sets proper frequency
[Method]
・Patrolling, information from users of the facilities, etc.

**Periodic inspection and diagnosis**

**Regular periodic inspection and diagnosis**

[Frequency]
(Normal facility)
At least once every 5 years, or less
(Important facility)
At least once every 3 years, or less
[Method]
・Visual inspection from land or sea

**Detailed periodic inspection and diagnosis**

[Frequency]
(Normal facility)
・At least once in the proper timing during the service life
・when the service life is extended
(Important facility)
At least once every 10~15 years, or less
[Method]
・Visual inspection in water by diving
・Data collection, investigation necessary for deterioration prediction, etc.

**Abnormal case**

**Extraordinary inspection and diagnosis**

**Extraordinary inspection and diagnosis**

[Timing of implementation]
As early as possible after abnormality such as earthquake or storm
[Method]
Same as for regular periodic inspection and diagnosis

**Detailed extraordinary inspection and diagnosis**

[Timing of implementation]
If any special deterioration is found in periodic inspection and diagnosis
[Method]
Same as for detailed periodic inspection and diagnosis

→ Flow for regular inspection and diagnosis
- - → Flow when particular deterioration is found

Figure-2.2.2 Flow of inspection and diagnosis

## 2.3 Comprehensive Assessment

| |
|---|
| Performance is graded based on results of inspection and diagnosis. Comprehensive assessment should be completed, considering factors such as remaining performance requirements of facility, possibility of fulfilling performance requirements during service life, utilization plan for facility, and degree of importance of facility. Comprehensive assessment should also determine necessity of countermeasures for maintenance. |

<Commentary>

In comprehensive assessment, the results of the inspection and diagnosis of structural members and components are summarized, major deformation and its progression throughout the facility as whole is identified, and the structural performance of the facility is graded. Then, the methods and timelines for performing proper measures are determined, depending on their necessity, the utilization plan of the facility for the future, the degree of importance of the facility, the restrictions on finances, and the restrictions on future maintenance and repair.

In determining emergency maintenance and repairs to address the occurrence and progression of deformation, a facility's performance grade should be taken into consideration. The performance grade corresponds to the deterioration level of a facility's members and components, as expressed in four grades: A, B, C, and D. Notably, the performance grade should not be determined based only on the deterioration level. Rather, the performance grade should be judged after a comprehensive examination in accordance with the category of items for the inspection and diagnosis, namely, criteria such as the impact on the facility's performance.

For comprehensive assessment, facility maintenance and repair policies should consider the following:

・Selection of members and components for which urgent repairs or strengthening should be performed and for which basic construction methods should be chosen

・Selection of members and components for which repairs or strengthening should be performed in a planned manner and for which basic methods should be chosen

・Selection of members and components for which the monitoring of progress is required at the current time

・Assessment of the necessity of countermeasures, such as restrictions on operations or suspension of operations

・Assessment of the necessity of reconsidering the inspection and diagnosis plan (the inspection and diagnosis plan is detailed in 1.2.2, Part 4), such as the timing or method of the next inspection

・Determination of renewal or removal

・Assessment of the necessity of other measures

In addition, to provide feedback on the results of maintenance and repair for maintenance plans for the future, the necessity of modifications to methods of the inspection and diagnosis should be noted. Maintaining the performance of a facility above a certain required level may involve repeated repair work to ensure the facility remains serviceable or completing large scale repair, or strengthening work before the end of a facility's service life.

A certain period is necessary for selecting measures for maintenance and preparing a proper plan. However, if deformation may cause serious harm to a third party, certain emergency measures must be taken.

Even if the current situation of performance degradation is not serious, if deformation is expected to progress, then countermeasures, such as enhancing inspections and diagnoses, must be taken.

## 2.4 Countermeasures

| |
|---|
| Based on results of comprehensive assessment, countermeasures should be performed as necessary. |

<Commentary>

Based on the results of comprehensive assessment, an implementation plan for countermeasures should be prepared, and measures to meet various situations and periods of implementation should be determined. Since the purpose of inspection and diagnosis is to collect basic information to determine the suitable measure, inspection to design for implementation of measures as necessary. A final decision should consider more precise information, such as the frequency of performance recovery, the required costs, and restrictions related to field conditions.

If comprehensive assessment of a facility shows that a certain measure is or will become necessary, a maintenance and repair plan that considers the future service life of the facility should be created. Measures for maintenance include enhancements to procedures such as inspections, repairs, strengthening, demolition, and removal. In determining the most appropriate countermeasure, factors such as the life cycle cost, available budget, technological factors, and social repercussions of the structures should be comprehensively considered. It is crucial to identify the cause of the deformation and to remove or mitigate it. If such removal or mitigation proves difficult, it is important to increase durability.

## 2.5 Life Cycle Cost

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|---|
| To effectively and economically perform maintenance and repair of port and harbor facilities, maintenance-related life cycle costs should be determined, and the results should be included in the maintenance plan. |

<Commentary>

The life cycle cost of a structure is the whole cost of the structure including planning, design, construction, operations, maintenance, and repair costs. For the existing structure, since it is impossible to adjust the acquisition costs such as planning, design and construction costs, the aggregate cost only for operations, maintenance and repair can be considered as the life cycle cost in this document. Demolition and removal costs are sometimes included in the repair cost. In addition, in certain cases, economic losses caused by service interruptions are recommended to be taken into consideration for calculating the life cycle cost.

## 2.6 Recording

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| Records of maintenance and repair must be maintained in certain format. |

# Chapter 3 Design and Construction on Considering Maintenance

## 3.1 Outline

> To ensure efficient maintenance, it is advisable to carefully consider at design or construction stages how a structure will be inspected or investigated or how measures will be applied, and to ensure that inspection and suitable measures can be easily conducted while the structure is being serviced.

<Commentary>

While the design service life of a port and harbor facility is generally 50 years or sometimes longer, it is challenging to adequately maintain the performance of a structure in a severe environment for such a long time. Therefore, it is necessary to develop a plan (maintenance plan or scenario) in advance that specifies how to ensure that a port and harbor facility fulfills its performance requirements. According to the basic approach to facility maintenance, one of the three levels of maintenance (I, II or III) should be established for the facility from various viewpoints, including the role of facility, the service life, the performance requirements, the design concept, and the facility substitutability. Then, the initial performance that matches the established level should be assigned to the facility, and a maintenance plan should be formulated accordingly.

• Maintenance level I

Maintenance at this level aims to maintain deterioration within a range where the structure will not fail to fulfill its performance requirements during its service life. This level is maintained through high quality measures. As shown in Figure-2.3.1, it is the maintenance level for a structural member or component for which it is verified that the deformation affecting the performance of that member or component during its service life is sufficiently minor (that is, above the line of the limit in maintenance). This determination is made according to the predicted progress of deformation at the time the maintenance plan is formulated.

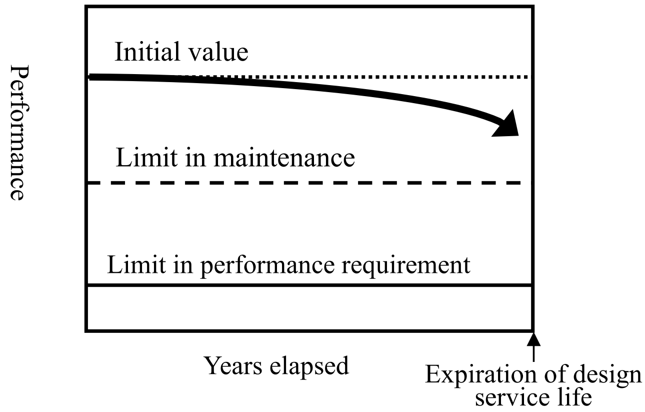



Figure-2.3.1 Maintenance level I

• Maintenance level II

Maintenance at this level aims to prevent performance degradation to prevent a state where the structure will fail to satisfy the performance requirements during its service life. This level is maintained through frequent small-scale measures when deformation is minor. As shown in Figure-2.3.2, while this maintenance level is reasonable, deformation that may affect the performance of a structural member or component will occur during its service life (the limit state of maintenance) and such deformation should be considered precisely at formulating the maintenance plan. The maintenance level for a member or component is taken care to ensure that maintenance or repair can be effectively implemented before the member reaches the limit state of maintenance. This level is maintained by implementing planned preventive measures.

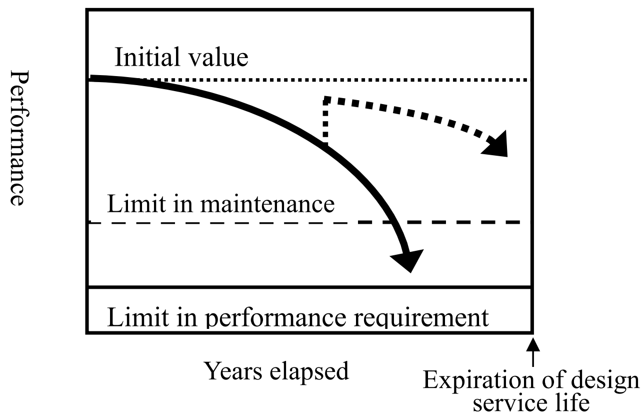



Figure-2.3.2 Maintenance level II

• Maintenance level III

At this maintenance level, a certain performance grade attributable to damage or deterioration is tolerated, provided that the performance requirements are satisfied, and damage or deterioration is addressed with large-scale measures once or twice during the service life. As shown in Figure-2.3.3, while it is reasonable, when formulating a maintenance plan, to expect that deformation may affect the performance of a structural member or component during its service life, a relatively large-scale measure is assumed necessary at this maintenance level before the member or component fails to satisfy its performance requirements because it is difficult or costly to take preventive measures.

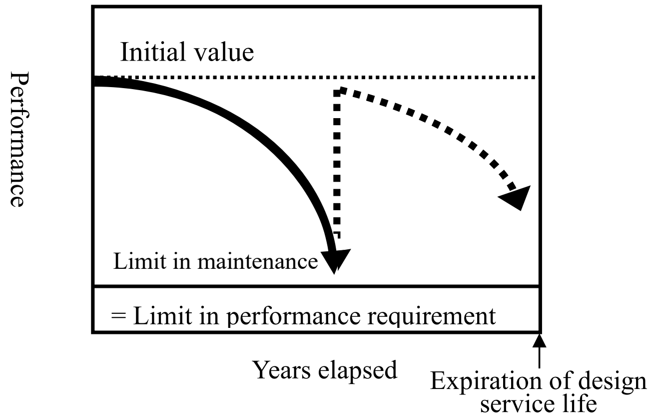



Figure-2.3.3 Maintenance level III

# Part 3 Trends in the Performance Degradation of Port Facilities and Their Maintenance

## Chapter 1 General

### 1.1 Scope of Application

This part is relevant to overall maintenance processes, including inspection, diagnosis, and prevention measure for deformation. Types of performance degradation that occur in port facilities, their causes, and their progression are shown in form of performance degradation .

<Commentary>

This part describes performance degradation chains, which are trends in performance degradation that occur in waterways and basins, protective facilities for harbors, and mooring facilities within port and harbor facilities.

It is important to detect deformation and deterioration as early as possible, accurately estimate the causes of those, and determine the degree of performance degradation. Thus, a complete understanding of performance degradation chains is necessary. A full understanding of performance degradation chains also ensure the effective implementation of inspection, diagnosis, and measures.

### 1.2 Purpose

(1) Port and harbor facilities should be properly maintained by identifying and addressing large scale deformation and/or deterioration.

(2) In identifying large scale deformation and/or deterioration, whole developmental process of deformation and/or deterioration should be considered, including their cause, occurrence, and effect, resulting in decline in facility performance.

### 1.3 Important Points Concerning Performance Degradation Chain and Maintenance

(1) Port and harbor facility maintenance should involve appropriate inspection, diagnosis and evaluation, and implementation of necessary measures, while considering structural type and performance degradation chain.

(2) Inspection and diagnosis methods and items should be selected by considering their ability to efficiently and effectively address performance degradation chain.

(3) Effects of deformation and/or deterioration on facility performance should be evaluated based on results of inspection and diagnosis.

(4) Necessity of measures to be taken for a facility should be determined by considering effects of deformation and/or deterioration and its progression on facility performance.

<Commentary>

A major performance degradation chain diagram is shown below. When maintaining port and harbor facilities, the performance degradation chain should be considered, appropriate inspection, diagnosis and evaluation should be conducted, and necessary measures should be taken.

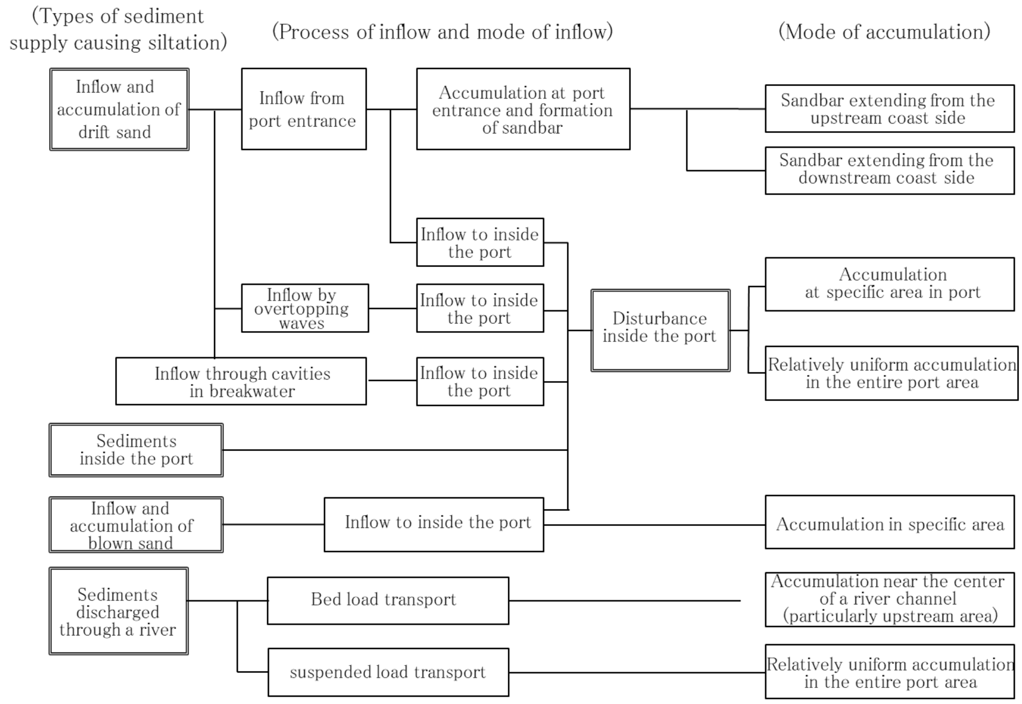



Figure-3.1.1 Performance degradation chain of siltation in waterways and basins

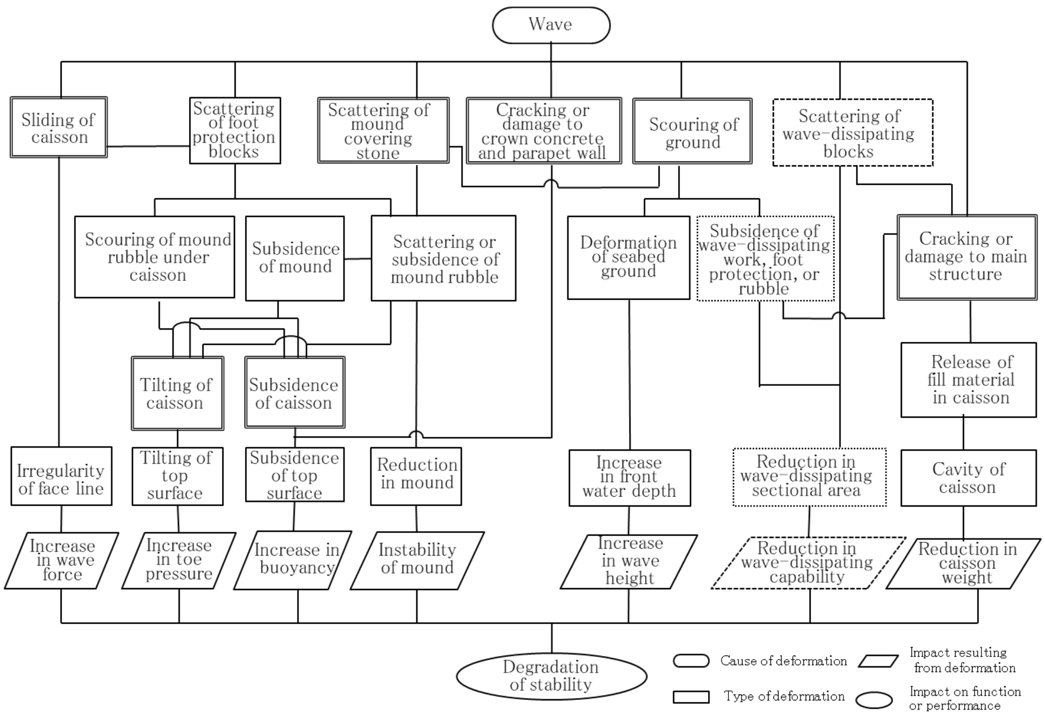



Figure-3.1.2 Performance degradation chain of caisson composite breakwater

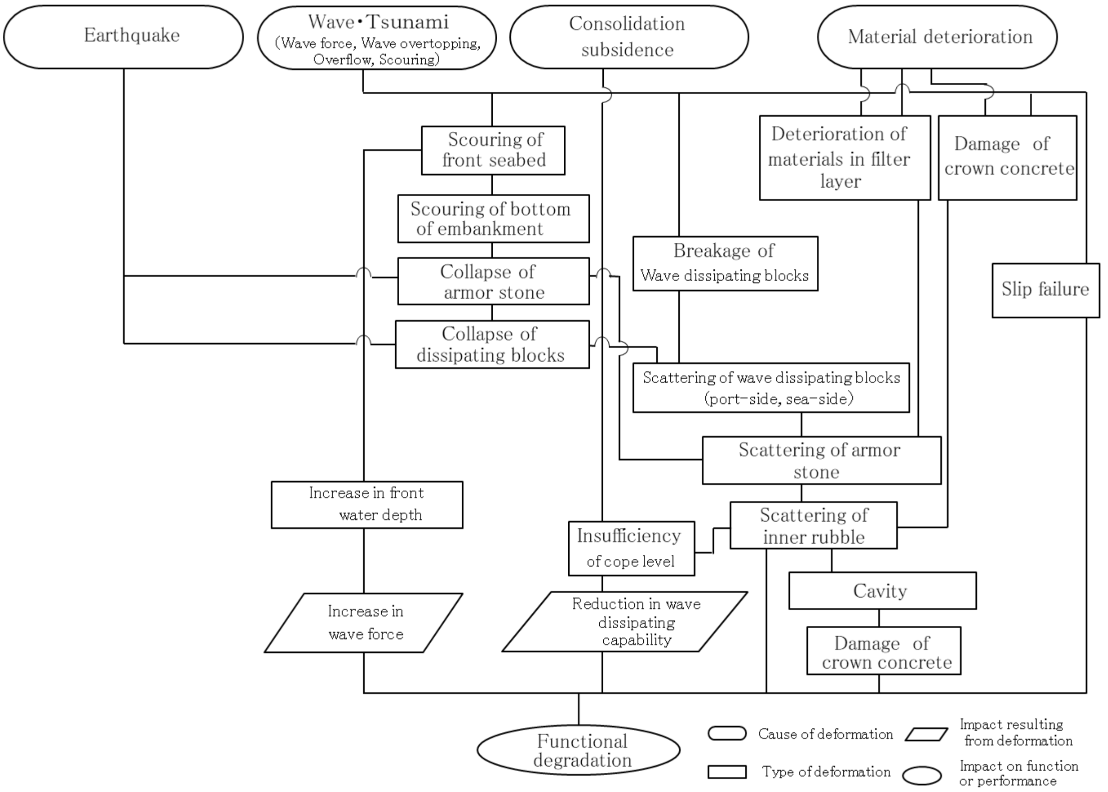



Figure-3.1.3 Performance degradation chain of sloping breakwater

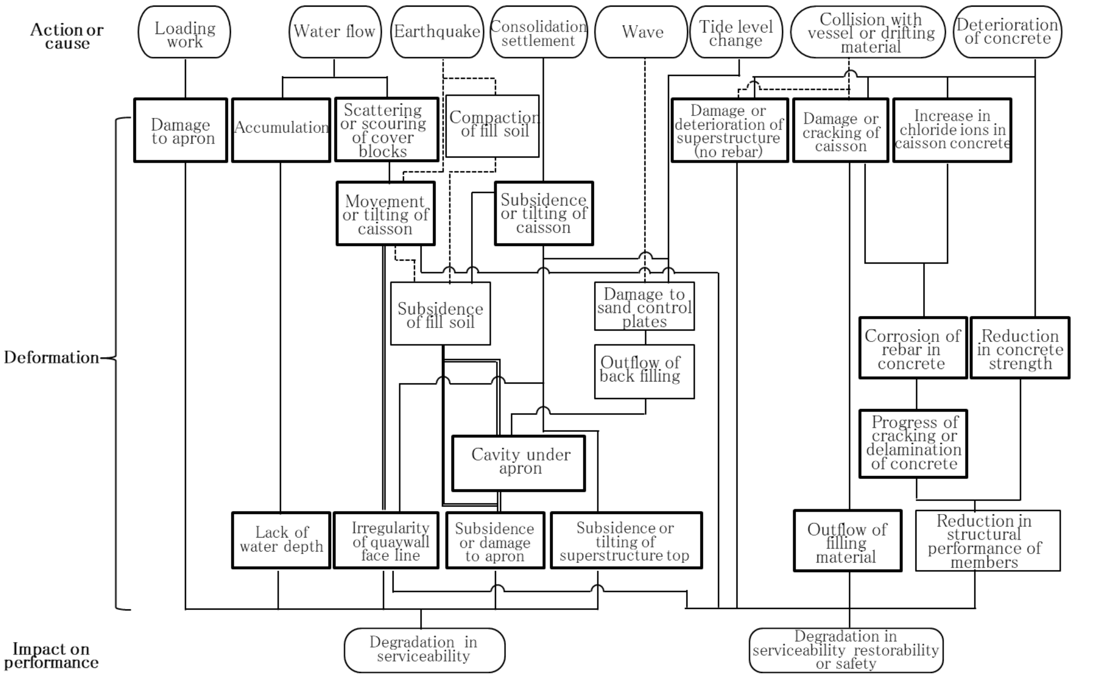



Figure-3.1.4 Performance degradation chain of caisson type quaywall

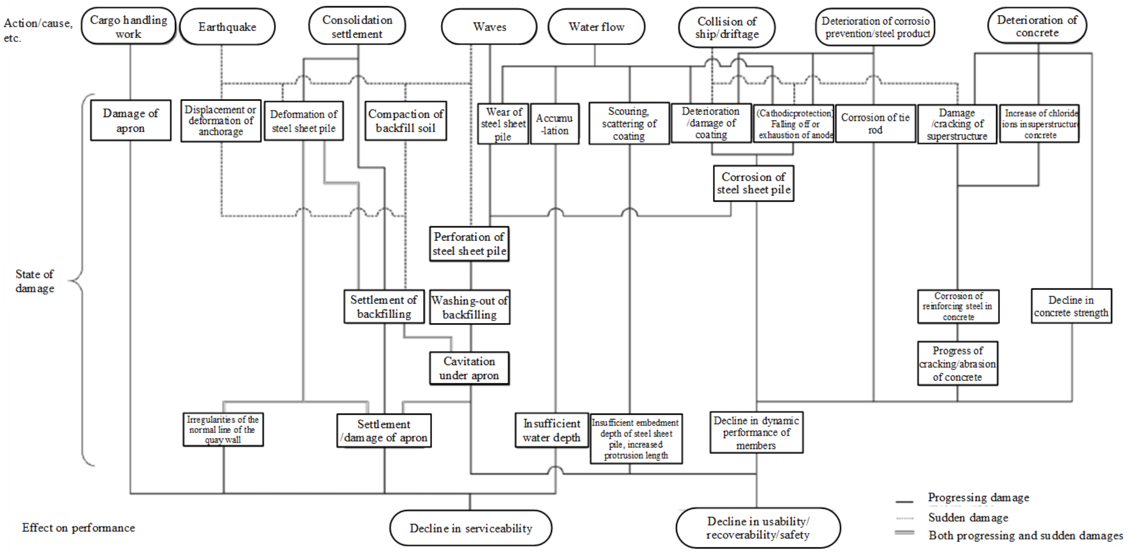



Figure-3.1.5 Performance degradation chain of sheet-pile quaywall

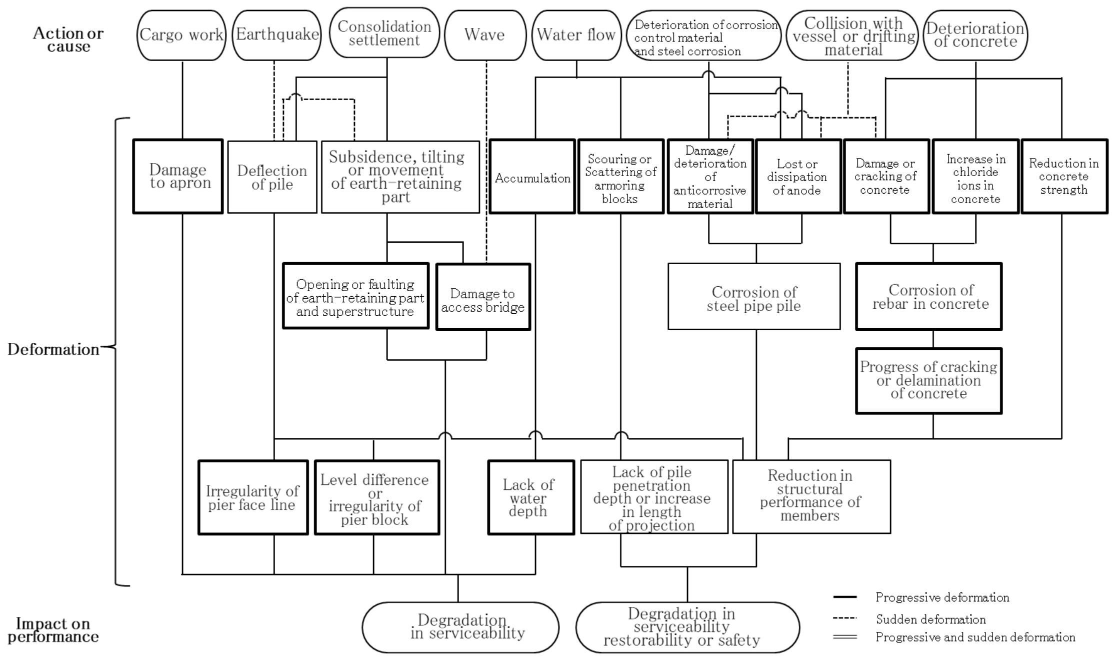



Figure-3.1.6 Performance degradation chain of open-type wharf

# Part 4 Inspection, Diagnosis, and Assessment of Port Facilities

## Chapter 1 General

### 1.1 Scope of Application

| |
|---|
| This part is relevant to the inspection and diagnosis of port and harbor facilities and judgement of performance grade of facility based on results. |

<Commentary>

This part concerns port and harbor facilities, such as waterways and basins, protective facilities for harbors, and mooring facilities. This part explains methods of the efficient and rational inspection and diagnosis of the deformations that occur in these facilities and the standard method of evaluating the influence of these deformations on the performance grade of these facilities.

This document defines "assessment” as the objective assessment of the degree of facility deformation observed through the inspection and diagnosis and the performance grade of facilities. The assessment enables the determination of the overall performance grade of facilities. This part explains the basic concept of assessment and its standard method.

When determining the necessity of repairs and other measures, it is necessary to both comprehensively prepare an evaluation based on the results of inspection and diagnosis and to consider factors such as the importance of the facilities, their service life, their usage, plans of the facilities for the future, their substitutability, the difficulty of measures, and the life cycle cost. Accordingly, concerning the maintenance and repair of port facilities, the maintenance plan should be determined with considerations such as economic problems, evaluations depending on engineer’s perspective and administrative perspective, and evaluations of the deformations of the targeted facilities and their degree of degradation (based on engineering knowledge and assessment). That is called comprehensive assessment.

## 1.2 Inspection and Diagnosis of Port Facilities

### 1.2.1 General

(1) Inspection and diagnosis should be periodically performed to efficiently identify deformation in port facilities.
(2) Inspection and diagnosis of port facilities involves initial inspection and diagnosis, daily inspection, periodic inspection and diagnosis, and extraordinary inspection and diagnosis. According to their purpose and timing implementation, periodic inspection and diagnosis, and extraordinary inspection and diagnosis can be either regular or detailed.
(3) Inspection and diagnosis of port facilities should be performed by an individual with specialized knowledge and skills in maintenance and repair.
(4) When performing inspection and diagnosis, a proper method must be selected for each step of inspection and diagnosis according to the purpose.
(5) The results of the inspection and diagnosis of port and harbor facilities should be recorded in a consistent form for easy reference.

<Commentary>

(2)

① Types of inspection and diagnosis

According to differences in the purpose and timing of implementation, the inspection and diagnosis of port facilities is divided into the following types: initial inspection and diagnosis, daily inspection, the periodic inspection and diagnosis, and the extraordinary inspection and diagnosis.

1) Initial inspection and diagnosis

The initial inspection and diagnosis of port and harbor facilities is performed to determine the initial maintenance status of the overall facilities, their structural parts and members and their ancillary facilities at the completion phase immediately after construction or improvement or during the first planning phase of the maintenance plan for existing facilities. The procedures of inspection and diagnosis in the initial inspection and diagnosis are identical to those of regular and detailed periodic inspection and diagnosis. The initial maintenance status can be determined based on the results of the quality control at the time of completion, while the initial inspection and diagnosis should be conducted within two years after completion.

The items for inspection, the method, and the decision criteria of the initial inspection and diagnosis should match those of the periodic inspection and diagnosis, as specified below. Regarding the maintenance and repair of existing facilities, as the initial inspection and diagnosis at the time of completion is not conducted in many cases, it must be performed before commencing maintenance, and data should be collected for comparison in subsequent periodic inspection and diagnosis. The results must be reflected in the maintenance plan.

2) Daily inspection

Daily inspections are performed to identify large-scale deformation in facilities and to identify obstacles to the utilization of facilities for handling cargo and similar uses. The daily inspection should be performed in an executable way, such as in conjunction with patrols and other duties that the facilities administrator must perform, and should utilize information from the users of the utilities and other individuals involved.

For example, the daily inspection of aprons and ancillary facilities of the mooring facilities may be conducted as often as once or twice daily. The method of inspection in this case is mostly visual inspection on foot or by car.

Some notable points regarding the daily inspection are listed below.

・Whether there is any significant change in the presumed usage of the facilities (e.g. usage patterns of cargo handling, use of heavy vehicles)
・Whether there is any trace or report of the impact of ships and other things
・Whether there is any considerable dislocation and tolerance from design face line of facility or a large uneven settlement in the ground level around joints
・Whether there is any precursor of settlement or collapse of the apron pavement
・Whether there are any abnormal sound, vibrations, or other unusual noises
・Whether there are any abnormalities in the ancillary facilities
・Whether there is any report of obstruction to the use of the facilities

3) Periodic inspection and diagnosis

The periodic inspection and diagnosis, which is performed to determine the occurrence and progression of deformation in the facilities efficiently and at an early stage, must be systematically and continuously conducted based on a predetermined plan. The rate of progression of deformation and the chain of different deformation can be determined by collecting data on deformations over time, which can also facilitate reviews of the maintenance plan.

i) Regular periodic inspection and diagnosis

The regular periodic inspection and diagnosis, which should be performed for each structural part and member of a structure, confirm deformation mainly visually and grade deterioration levels in accordance with proper standards. The electrical potential of steel members with cathodic protection should be measured. Scales, inspection hammers, binoculars, crack scales, and other tools should be utilized together.

ii) Detailed periodic inspection and diagnosis

The detailed periodic inspection and diagnosis is performed to identify deformations in the underwater parts surveyed by divers and other professionals and to grade the corresponding deterioration levels in accordance with appropriate standards. Measurement equipment may be used to collect quantitative data. When measuring devices, non-destructive inspection equipment or other devices are used. Items for measurement and tests must be selected based on a full understanding of the purpose of the measurements and tests, the usage of their results, and other information. Using equipment, the causes of deformations and the degree of their progression can be estimated by analyzing the acquired data.

4) Extraordinary inspection and diagnosis

i) Extraordinary inspection and diagnosis

Unexpected deformation is likely to occur and develop after excessive external force, such as that from earthquakes or typhoons. If unaddressed, these deformations might develop into progressive deformation and even accelerate the development of other deformation. The deformation might also lead to a serious accident or disaster, such as one involving human lives. The extraordinary inspection and diagnosis is performed to search for the existence and development of the deformation and to take necessary measures. It is necessary to efficiently utilize the results of past inspections and diagnoses and to prepare for emergency implementation.

In the case of the extraordinary inspection and diagnosis, on which the regular periodic inspection and diagnosis is based, deformation is often confirmed visually. For example, after high waves, breakwaters may be examined for the existence of damage. In this case, this inspection can be substituted for the regular periodic inspection and diagnosis.

ii) Detailed extraordinary inspection and diagnosis

When significant deformation is found in the daily inspection, the regular periodic inspection and diagnosis, the detailed extraordinary inspection and diagnosis, or the extraordinary inspection and diagnosis, it is desirable to perform a detailed extraordinary inspection and diagnosis to investigate their causes and to discern their influence on the performance of the facilities. In the detailed extraordinary inspection and diagnosis, a visual inspection of the external appearance by divers, data collection, a survey to estimate deterioration, and other surveys should be conducted.

② Procedures of detailed periodic inspection and diagnosis

The detailed periodic inspection and diagnosis is performed for the purposes described below, using divers, equipment, or other means and the partial destruction of a portion of the facilities The following list describes the purpose of this procedure from the perspective of the facilities administrator.

・To evaluate the condition of the structural parts that have not been visually inspected in the regular periodic inspection and diagnosis and, in particular, to evaluate underwater parts through a diving survey

・To determine the quantitative properties of the inspection points by visual inspection (the regular periodic inspection and diagnosis) and diving survey (detailed survey)

・To collect data to determine the causes of deformations

・To collect data to predict the progression of deterioration

The following describes the purpose of periodic inspection and diagnosis from the perspective of as facilities' owner.

・To conduct the necessary inspection and diagnosis when the owner is considered to be held liable (including cases due to causes that could not be predicted at soon after construction, which could cause fatal deterioration and damage if unaddressed).

Therefore, in the detailed periodic inspection and diagnosis, the procedures, the timing of implementation, and other aspects should be considered based on a full recognition of their purpose.

In selecting items and points for inspection in the detailed periodic inspection and diagnosis, the abovementioned purposes of detailed periodic inspection and diagnosis must be fully considered, but all items for inspection are not necessarily subject.

Regarding the survey and measurement techniques used in the detailed periodic inspection and diagnosis, it is advisable to consider the following criteria.

・The techniques should be sufficiently accurate to measure the allowable limits of the deformations.

・The techniques should require relatively simple equipment that is generally used.

・The techniques should ensure a high level of workability and safety even when used under or on the sea.

(3)

For port facilities, there are many restrictions under which the inspection and diagnosis is performed because port facilities include not only various structural types but also many parts that pose challenges to visual inspection, such as underwater sections. To perform the proper inspection and diagnosis, specialized knowledge and techniques or maintenance and repair skills, including inspection and diagnosis, are required. Therefore, the inspection and diagnosis of port facilities is required to be performed under the supervision of a specialized technical expert who possesses these capabilities. In addition, a technical expert involved in the inspection and diagnosis of port facilities should strive to maintain and improve their technical capabilities through continuing professional development.

(4)

In the inspection and diagnosis of port facilities, a proper method must be selected for each item of inspection and diagnosis according to its purpose. In principle, the general periodic inspection and diagnosis is performed by visual inspection of the external appearance because the extensive inspection and diagnosis is required to be performed in a relatively brief period of time, and an efficient comprehension of facility deformation is required. However, in the inspection and diagnosis of cathodic protection, the electric potential of the steel members is required to be measured because the effect of cathodic protection cannot be determined visually. This task is included in the regular periodic inspection and diagnosis even though it accompanies measurement because it is essential to confirm that the cathodic protection works effectively to ensure the safety of the steel structures. As visual inspection of the external appearance and measurement of the electric potential of steel members do not require specialized equipment, the port facilities administrator can directly manage their implementation.

If deformation is found in the visual inspection, it is advisable to prepare sketches or take photographs of them.

The purposes of detailed periodic inspection and diagnosis include the confirmation of the underwater part of the facilities and the collection of quantitative data. The confirmation of the underwater part is often performed visually by divers, but robots and other technology can be used to increase efficiency and reduce labor requirements. For quantitative data collection, the survey method, measurement method, and other methods must be properly selected for each item of inspection and diagnosis.

(5)

In addition to the daily inspection that has conventionally been performed by facilities administrators as a part of their administrative obligations, facility deformation must be found as early and efficiently as possible through the periodic inspection and diagnosis. It is desirable to systematically organize and preserve documents regarding design and construction, drawings, data collected during maintenance and repair, and other information, along with the maintenance plan concerning the facilities.

In the assessment, it is useful not to depend on the results of one-time inspection and diagnosis but rather to periodically perform the inspection and diagnosis and accumulate data to improve maintenance and repair. For example, during each inspection and diagnosis, it is important to accurately record and preserve the locations where deformations occur and their conditions and to note the initial values of the items affected by deformations that develop over time, such as the corrosion of steel members.

The results of inspection and diagnosis should be preserved appropriately with the data of the facilities concerned, such as data on design and construction, as these inform subsequent inspections and diagnosis and the planning of measures for large-scale maintenance.

Changes in the person in charge, the maintenance system, and other events are anticipated because of the long-term operation of port facilities. The results of inspection and diagnosis should be recorded in a consistent form in which the contents can be easily interpreted. Since a large amount of data must be handled, data should be efficiently managed with database systems when managing many facilities.

Records of the results and other data concerning inspection and diagnosis should be preserved during the service life of the facilities, as changes in deformations over time can be ascertained by accumulating data on deformation, thus ensuring efficient maintenance and repair. As these records are useful for understanding patterns in deformation of similar facilities, it is desirable to preserve records even after the termination of their operations to help recognize patterns in the occurrence of deformations.

### 1.2.2 Formulation of the inspection and diagnosis program

(1) Prior to performing inspection and diagnosis, inspection and diagnosis program, which establishes timing, targeted structural parts and members, methods of inspection and diagnosis, and decision criteria for degradation levels and other measures, should be specified in maintenance plan. That is, this information should be specified to ensure efficient inspection and diagnosis, considering timing and other factors of inspection and diagnosis of other facilities.

(2) Inspection and diagnosis program should be provided by facilities owner. An individual with specialized knowledge and techniques or skills in maintenance should be consulted.

(3) When changes occur in progression of facility deformations or in usage of these facilities or when large-scale maintenance works are performed, contents of maintenance plan, including inspection and diagnosis program, should be reviewed as necessary.

<Commentary>

(1)

The inspection and diagnosis program must be formulated before performing the inspection and diagnosis. The items for the inspection and diagnosis, their frequency, the method for evaluating them, and the criteria for grading their degradation levels must be specified. This information ensures the objectivity, reliability, and consistency of the results.

Frequent inspection of facilities cannot be performed in many cases because port and harbor facilities are located in a harsh chloride-induced corrosion-causing environment where they are consistently subjected to seawater. Moreover, most portions of the facilities are submerged in seawater or underground, and breakwaters and other structures are consistently subjected to the action of waves on a scale that impedes the work and causes other difficulties. Therefore, in the inspection and diagnosis of port facilities, the periodic inspection and diagnosis becomes highly important. For structural parts and members above sea level, the periodic inspection and diagnosis is divided into the regular periodic inspection and diagnosis, which is simple and mainly conducted by visual inspection, and the detailed periodic inspection and diagnosis, which involves the inspection and diagnosis of the structural parts and members that pose challenges for visual inspection and captures the causes of deformation and the speed of progression of deformation. These two types of the inspection and diagnosis should be combined in the performance of the inspection and diagnosis program as necessary.

The regular periodic inspection and diagnosis is performed for each structural part and member of the facilities and must be periodically and continuously performed to understand the condition and progression of the deformations over time. In principle, deformations in the external appearance of the facilities should be confirmed by visual inspection, and their deterioration levels should be graded with respect to the proper criteria. To facilitate visual inspection, equipment, such as simple measuring devices, including scales, rods, levels, transits, inspection hammers, binoculars, crack scales, and other devices, may be used. To increase the accuracy of the inspection and diagnosis and the efficiency of inspection, specially developed simple equipment should be included in the inspection and diagnosis program. However, as such equipment only supports visual inspection and diagnosis, inspectors must also confirm the present conditions of the facilities.

The regular periodic inspection and diagnosis is often performed with visual inspection for both land and sea. The inspection and diagnosis should be performed for the entire facility. Therefore, the inspection results of a part of the facility cannot represent those of the entire facility.

The inspection is performed at the closest distance from the facilities to the extent that the safety of the inspector is ensured because in many cases, the deterioration of concrete and the corrosion and cracks of steel members cannot be confirmed if the inspector is not in close proximity to them. In the case of seaside inspection, it is important to visually confirm the conditions of the entire facility from longer distances as well as short distances to identify the movements and deformations of the entire facility, which are hardly noticeable from a short distance, or the conditions surrounding the facilities.

As the contents of this document and the criteria described in the Appendix only represent a standard, the specific method and other factors regarding the inspection and diagnosis must be individually and appropriately determined by considering the circumstances of the site. For parts that differ from the actual conditions, the items for inspection, the inspection method, the frequency of inspection, the inspection points, or the criteria may be revised for each individual facility as necessary. These changes must consider the structural type, design conditions, environment conditions, and other factors. When a distinct structural type or material is adopted in the facility, the method of the inspection and diagnosis must be individually considered and determined in advance.

Furthermore, the method of the inspection and diagnosis and the criteria described in this part cannot apply directly to the facilities that have already been repaired or reinforced, such as parts of the superstructure of a piled pier where surface coating or sectional repairing has been conducted. The method of the inspection and diagnosis and the criteria is required to be appropriately determined, considering the condition of the repaired parts.

To facilitate the inspection and diagnosis of port and harbor facilities, it is important to increase the efficiency of the inspection and diagnosis program. For example, when securing personnel and financial resources is difficult due to a large number of the facility unsettled inspections and diagnoses, the efficient inspection and diagnosis program can be developed by considering the schedule of the inspection and diagnosis for other facilities, as described below.

・Perform the inspection and diagnosis of the same items during the same period to decrease expenses.

・Establish timings for the inspection and diagnosis that balance the number of facilities targeted each fiscal year.

(2)

The inspection and diagnosis program should be developed by the facilities owner. When the facilities owner and administrator are different individuals, the inspection and diagnosis of the facilities should be performed efficiently and effectively based on discussion between facilities owner and administrator.

To ensure the proper maintenance and repair of port facilities, the program should be formulated to ensure the efficient and effective performance of the inspection and diagnosis. The inspection and diagnosis program should include a comprehensive understanding of the structural types of the facilities concerned, the contents of their inspection, and other factors. Therefore, it is necessary to consider creating a workable inspection and diagnosis program in advance, upon obtaining the advice of an individual with specialized knowledge and techniques or skills in maintenance and repair.

(3)

When the progression of the deformation deviates from that outlined in the initial maintenance plan, changes occur in the usage of the facilities, or maintenance and other works are performed, the maintenance program must be revised, and the contents of the inspection and diagnosis program must be reviewed as necessary.

1.2.3 Timing of inspections and diagnoses

(1) Inspection and diagnosis of port facilities should be systematically performed upon determination of their proper timing, considering the facility's importance and other factors necessary to comprehend occurrence and progression of deformations.

(2) Periodic inspection and diagnosis should be performed once at least every five years. However, the periodic inspection and diagnosis should be performed once at least every three years for facilities in which a major damage poses serious risks to human lives, property, and/or socioeconomic activity. Frequency of detailed periodic inspection and diagnosis should be determined by considering the importance of facilities and other factors.

<Commentary>

(1)

The periodic inspection and diagnosis must be performed upon determining the timing of the inspection and diagnosis and considering the importance of the facilities to adequately comprehend the occurrence and progression of deformations during their service life.

TSCPHF specify the minimum required frequency of the periodic inspection and diagnosis according to the importance of facilities and other factors. In terms of the importance of facilities, the frequency of the periodic inspection and diagnosis is required to be determined through consultation with the facilities owner, administrator, and other relevant individuals.

Table-4.1.1 Definition of ordinary inspection and diagnosis facilities
and prioritized inspection and diagnosis facilities

| | Definition |
|---|---|
| Ordinary inspection and diagnosis facilities | Facilities subject to technical standards (TSCPHF), excluding prioritized inspection and diagnosis facilities |
| Prioritized inspection and diagnosis facilities | Facilities determined by comprehensively considering the degree of deformation progression with reference to examples below and the occurrence of damage that could pose serious risks to human lives, property, and/or socioeconomic activity<br>(Examples of facilities considered to be of high importance)<br>① Facilities at risk of seriously impacting socioeconomic activity (e.g., trunk-line freight transport facilities, facilities handling hazardous materials, facilities facing to main waterways)<br>② Facilities important for disaster prevention and mitigation (e.g., High earthquake-resistance quaywalls, tsunami protection breakwaters)<br>③ Facilities with damage that poses serious risks to human life (e.g., facilities used by passengers) |

Table-4.1.2 Timing of periodic inspection and diagnosis

| Kind of inspection and diagnosis | | Ordinary inspection and diagnosis facilities | Prioritized inspection and diagnosis facilities |
|---|---|---|---|
| Periodic inspection and diagnosis | Regular periodic inspection and diagnosis | ・At least once every five years | ・At least once every three years |
| | Detailed periodic inspection and diagnosis | ・At least once for a proper period within the service life of the facilities<br>・When the service life of the facilities is extended | ・At least once every 10 to 15 years<br>・At least once every 10 years for Specific facilities subject to the technical standards(TSCPHF) and that face main waterways and other facilities |

(2)

Definition of the ordinary inspection and diagnosis facilities and the prioritized inspection and diagnosis facilities is shown in Table-4.1.1 and the timing of the periodic inspection and diagnosis is outlined in Table-4.1.2. The periodic inspections and diagnoses based on TSCPHF should be performed once at least every five years. Therefore, the inspection and diagnosis program should ensure the completion of the periodic inspection and diagnosis at least once every five years (ordinary inspection and diagnosis facilities). Regarding facilities subject to technical standards and to which damage poses a serious risk to human lives, property, and/or socioeconomic activity (prioritized inspection and diagnosis facilities), the periodic inspection and diagnosis should be performed once at least every three years. Therefore, the inspection and diagnosis program must be ensured the performance of the periodic inspection and diagnosis at least once every three years.

The detailed periodic inspection and diagnosis should be performed at least once during a proper period within the service life of the facilities. In addition, when the original service life is to be extended, the detailed periodic inspection and diagnosis should be performed before the end of the service life. Particularly for prioritized inspection and diagnosis facilities, the detailed periodic inspection and diagnosis should be performed once at least every 10 to 15 years to regularly confirm the rate of deformation progression and the correlation between different deformation to ensure appropriate maintenance and repair. For facilities that face main waterways and whose earthquake-resistant performance and other performance may be lacking due to deformation and other issues, including damage and deterioration, the detailed periodic inspection and diagnosis should be performed at least once every 10 years because when facilities are damaged by disasters on an unexpected scale, the damage may have an enormous impact on the entire port’s operations.

1.2.4 Items for inspection and diagnosis

| |
|---|
| Items for inspection and diagnosis should be selected by considering the structural type of facilities concerned, maintenance levels of structural parts and members, and other factors. |

<Commentary>

To ensure the efficient inspection and diagnosis, it is important to choose the appropriate items for the inspection and diagnosis, based on a full understanding the contents of these items and consideration of the structural types of the facilities concerned, the condition of their deformations, and other factors. Items should be selected in consultation with specialized technical experts.

The items for the inspection and diagnosis vary depending on the kind and structural type of facilities. It is not necessary to address all items for the inspection and diagnosis described in this document and the Appendix, and new items can be added as necessary.

Items for the inspection in both the regular periodic inspection and diagnosis and the detailed periodic inspection and diagnosis can be divided into the three kinds described below, by considering the types of performance that the targeted deformations influence, whether they directly influence the performance of facilities, and whether they are structural members. The following points should be fully considered in formulating the inspection and diagnosis program.

① Category I

[The items for inspection and diagnosis of the structural parts and members when their performance degradation directly affects the safety and serviceability of facilities]

These items for inspection and diagnosis are related to the movements or settlement of the entire facility, and deformations in superstructure, main body, foundation, wave-dissipating block, or other types of structure or member, which exert direct structural influence on facility performance, particularly structural safety.

② Category II

[The items for the inspection and diagnosis of the structural parts and members when the accumulated performance degradation influences the safety and serviceability of the facilities]

These items for the inspection and diagnosis are related to the elements, such as the proactive coating of steel members, for which performance degradation does not necessarily decrease the performance of the facilities directly and immediately but will influence their performance if the condition is unaddressed for a long time.

③ Category III

[The items for the inspection and diagnosis in ancillary facilities and other facilities]

These items for the inspection and diagnosis are related to elements that may influence the use of facilities, such as fenders and mooring posts, for which damage and other factors may result in a serious accident or disaster if left unaddressed; these elements include curbing, safety fences, ladders, and other members.

1.2.5 Units for inspection and diagnosis and criteria for grading deterioration levels

(1) Grading deterioration levels based on the inspection and diagnosis of port facilities should be completed by specifying the appropriate unit to determine the occurrence and progression of deformation.

(2) Criteria for grading deterioration levels should be specified in advance.

<Commentary>

(1)

In the inspection and diagnosis of port facilities, it is necessary to determine the unit of the structural parts and members for which deterioration levels are assessed according to the kind and structural type of the facilities to understand the occurrence and progression of deformations. The units used for each facility in the regular periodic inspection and diagnosis are provided in Table-4.1.3.

Table-4.1.3 Standard unit for regular periodic inspection and diagnosis and judgement of performance grade

| Type of facility | | Grading of deterioration levels (a, b, c, and d) | Judgement of performance grade (A, B, C, and D) |
|---|---|---|---|
| Waterways and basins | | Each planned water depth | Each planned water depth |
| Breakwaters | | Each caisson | This judgement applies to each facility, but it should be specified using a range of 200 m to 500 m as a guide when the facility length of longitudinal direction is long, considering the structural type and service life. |
| Revetments/ dikes | Gravity type | Each caisson | This judgement applies to each facility, but it should be specified using a range of 200 m to 500 m as a guide when the facility length of longitudinal direction is long, considering structural type and service life. |
| | Sheet-pile | Each span of superstructure | |
| Mooring facilities | Gravity type | Each caisson | Each berth |
| | Sheet-pile | Each span of superstructure | |
| | Open-type | Each span of superstructure | |

(2)

The results of the inspection and diagnosis should be described as the deterioration levels of structural parts and members of the facilities. The definition of the deterioration levels of structural parts and members is shown in Table-4.1.4.

In the regular periodic inspection and diagnosis, which is performed mainly through visual inspection, grading deterioration level of the same deformation may vary among inspectors. Therefore, deterioration levels should be assessed based on determining the criteria for all items included in the regular periodic inspection and diagnosis.

The criteria applied in the regular periodic inspection and diagnosis should be expressed as quantitatively as possible to ensure the consistent collection of highly objective results. However, some criteria in this document and the Appendix are described in a partially qualitative manner because the data are currently insufficient. These criteria should be revised to reflect more quantitative parameters as additional data is gathered in the future.

In the detailed periodic inspection and diagnosis, the items for inspection can be divided into those for which the criteria are specified and those for which the criteria are not specified, depending on the characteristics of the individual items. In conducting underwater inspection by divers, which are mainly performed visually, the criteria should be provided to minimize inconsistency in the results. The criteria in this case should be identical to those applied to the items for inspection in the regular periodic inspection and diagnosis. The criteria do not need to be provided in the specific measurement and other surveys accompanying inspection because in performing measurements using equipment, it is important to record and preserve the measured values themselves, but ranking them according to their deterioration levels (i.e., a, b, c, and d) is not important. The recorded and preserved measurements, if specifically analyzed and studied, can be utilized not only to estimate the causes of deformation and determine the degree of deformation but also to review the results of regular periodic inspection and diagnosis regarding the items inspected. In addition, these data, if accumulated, can be reflected in the review and revision of the criteria for the degradation levels of the items for inspection.

Table-4.1.4 Criteria for grading deterioration levels

| Deterioration levels | Criteria for grading deterioration level of structural members |
|---|---|
| a | The performance of the structural member is significantly reduced. |
| b | The performance of the structural member is reduced. |
| c | Deformations are apparent, but reduced performance of the structural member is hardly detectable. |
| d | Deformations are not apparent. |

Note: If it is difficult to decide between degradation levels “b” and “c,” then deterioration level “b” is recommended to provide a more conservative assessment.

## 1.3 Concept of Judgement

| |
|---|
| In judgment of performance grade based on the results of inspection and diagnosis, the evaluation criteria, the units used for judgement, and the judgment process, the results from the inspection and diagnosis for each structural part or member and those from the judgment of the entire facility should be provided in advance to ensure objectivity of the judgement results. |

<Commentary>

When judging the performance grade of the facilities based on the results of inspection and diagnosis, which is essentially the responsibility of the implementing entity, the criteria, the units used for judgement, and the judgement process, the results of inspection and diagnosis for each structural part or member and those from the judgement of the facility should be provided in advance to ensure objectivity of the judgement results. However, currently, there is insufficient technical knowledge to determine a method for objectively judging the performance of facilities based on the results of inspection and diagnosis. Therefore, the general concepts commonly applied to this judgement for port facilities in Japan is described in this document as a reference. It is desirable to review these concepts as necessary in the future through practical cases.

The standard units used for judging the performance grade are specified in Table-4.1.3. For facilities with specialized structural types, the units should be established appropriately based on Table-4.1.3.

Table-4.1.5 Definition of performance grade

| Performance grade | Judgment criteria for performance grade |
|---|---|
| A | The performance of the facility is substantially reduced. |
| B | The performance of the facility is reduced. |
| C | Deformations are apparent, but reduced performance of the facility is hardly detectable. |
| D | Deformations are not apparent, and the performance of the facility is fully intact. |

Table-4.1.6 Categorization of inspection and diagnosis items
based on their influence on safety of facility

| Categorization of inspection and diagnosis items | Influence on facility performance |
|---|---|
| Category I | Influences the safety of the facility if one to several units are considered “a.” |
| Category II | Influences the safety of the facility if many units are considered “a.” |
| Category III | No direct influence on the safety of the facility. |

Table-4.1.7 judgement method of performance grade of facility

| Categorization of inspection and diagnosis items | Performance grade for each item for inspection and diagnosis | | | | Performance grade of facility |
|---|---|---|---|---|---|
| | A | B | C | D | |
| Category I | One to several units for inspection and diagnosis are considered “a”. | The performance of the facility has been reduced, while one to several items for inspection and diagnosis can be considered “a” or “b”. | Other than “A,” “B,” or “D” | “d” for all | The grade judged the worst among all the performance grade for each item of inspection and diagnosis |
| Category II | The performance of the facility has been substantially reduced. Many units for inspection and diagnosis are considered “a,” or most of them are considered “a” or “b”. | The performance of the facility has been reduced. Several items for inspection and diagnosis are considered “a,” or many items are considered as “a” or “b”. | Other than “A,” “B,” or “D” | “d” for all | |
| Category III | – | – | Other than “D” | “d” for all | |

Note: "Many" can be considered as approximately 50% of units, whereas "most" amounts to approximately 80% of units.

The definitions of the performance grade (A, B, C, and D) of the facility based on the results of the inspection and diagnosis are described in Table-4.1.5. As the judgement is affected by environmental conditions and other conditions at the facility location and must consider the changes in deformations over time, the results of the inspection and diagnosis for each structural part and member should be examined and studied, and the results of a more sophisticated examination, such as through structural analysis, should be considered as necessary.

The procedure for deriving the judgement results from the results of the inspection and diagnosis is described below. In terms of the influence on performance, particularly the safety of the facility, the items for the inspection and diagnosis should be categorized into three categories as shown in Table-4.1.6, and the performance grade (A, B, C, and D) for each item should be determined based on the explanation of categories in Table-4.1.7. Eventually, as shown in Table-4.1.7, the most strictly graded among all the performance grade of the items for the inspection and diagnosis is considered the performance grade of the corresponding facility.

Notably, the judgement results (A, B, C, and D) cannot be derived from merely the quantity of the results (a, b, c, and d) of the inspection and diagnosis for each item. That is, even if one inspection item is graded “a” as Category I, the performance grade should not be simply considered “A,” but should be judged as “A” or “B” based on a comprehensive consideration of influences on the performance of that facility.

As the result of this “judgement” of performance grade of facility is a qualitative representation of the performance degradation of a facility from technical and engineering viewpoints, the necessity of measures for the facility cannot be determined only by this result. It is important to judge the necessity of measures based on a comprehensive study of various aspects, including the maintenance strategy of the facility, the importance of the facility, its service life, the usage and plans of the facility for the future, its substitutability, the difficulty of maintenance and other works of the facility, and its life cycle cost.

The flow of the evaluation method of a facility’s performance grade is shown in Figure-4.1.1 and Figure-4.1.2. A sample evaluation is shown in Table-4.1.8.

[STEP 1]: Grading the deterioration levels (a, b, c, and d) of each item for inspection and diagnosis
The deterioration level of each item for inspection and diagnosis is graded based on the standard shown on Table-4.1.4 for each unit used to grade deterioration levels.

⇩

[STEP 2]: Judgement of the performance grade (A, B, C, and D) of each item for inspection and diagnosis
The performance grade for each "item for inspection and diagnosis" is judged based on the standard shown on Table-4.1.5, in reference to Table-4.1.6.

⇩

[STEP 3]: Judgement of the performance grade (A, B, C, and D) of the facility
The most strictly judged performance grade results of the judgement for each item for inspection and diagnosis, which are obtained in [STEP 2], is considered the performance degradation of the facility.

Figure-4.1.1 Flow of judgement method for performance grade of facility

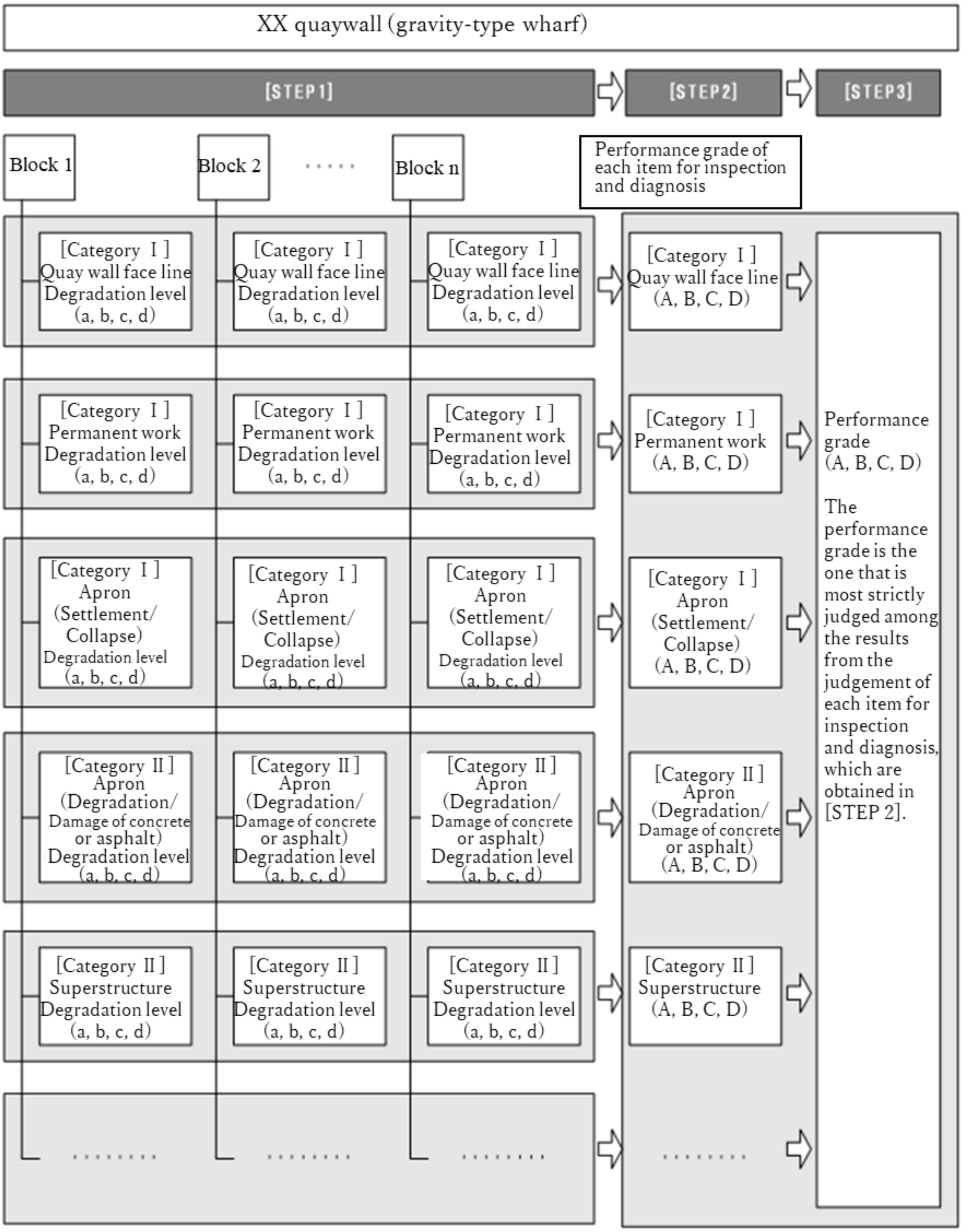



Figure-4.1.2 Flow of judgement method for performance grade of facility (Case of gravity-type quaywall)

Table-4.1.8 Sample evaluation of performance grade of facility (Case of gravity-type wharf)

[STEP1] ⇒ [STEP2] ⇒ [STEP3]

| Items for inspection and diagnosis | | Categorization of items for inspection and diagnosis | Results of determination of degradation levels | | | | | | | | | | Total | | | | | Performance grade of each item for inspection and diagnosis | Performance grade of facility |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1BL | 2BL | 3BL | 4BL | 5BL | 6BL | 7BL | 8BL | 9BL | 10BL | a | b | c | d | Total | | |
| Quay wall face line | Dislocation and tolerance from design face line of quaywall | Category I | a | c | c | b | c | b | c | c | d | d | 1 | 2 | 5 | 2 | 10 | B | A |
| Caisson | Deterioration /damage of concrete | Category I | c | c | c | b | b | b | b | c | c | c | 0 | 4 | 6 | 0 | 10 | B | |
| Apron | Settlement/ collapse | Category I | d | c | c | c | c | a | b | c | c | b | 1 | 2 | 6 | 1 | 10 | A | |
| | Deterioration /damage of concrete or asphalt | Category II | d | c | c | c | c | a | a | c | c | c | 2 | 0 | 7 | 1 | 10 | B | |
| Seabed | Scour/sediment accumulation | Category I | c | c | c | b | b | b | b | c | c | c | 0 | 4 | 6 | 0 | 10 | B | |
| Super-structure | Deterioration /damage of concrete | Category II | c | c | c | c | c | c | c | c | c | c | 0 | 0 | 10 | 0 | 10 | C | |
| ⋮ | | | | | | | | | | | | | | | | | | | |

① Although the deterioration level of "the dislocation and tolerance from design face line of quaywall (Category I)" at 1BL is judged "a,", the performance grade of each item for the inspection and diagnosis is determined to be "B" because it is located at the edge of the quaywall, and the influence of possible deformations on the use of the quaywall is relatively minor.

② As the degradation level of "settlement and collapse of the apron (Category I)" at 6BL is considered "a,", the performance grade for the inspection and diagnosis is judged to be "A."

③ The most strictly judged result, "A", among the performance grades of each item for inspection and degradation is judged as the performance grade of the corresponding facility.

# Chapter 2 Waterways and Basins

## 2.1 Scope of Application

| Chapter 2 is relevant to periodic inspection and diagnosis of waterways and basins. |
|---|

<Commentary>

Chapter 2 summarizes the methods, items, and other aspects of the periodic inspection and diagnosis to maintain the performance required for waterways and basins.

## 2.2 Purpose of Inspection and Diagnosis

| Inspection and diagnosis of waterways and basins should be appropriately performed to satisfy performance requirements throughout their service life. |
|---|

<Commentary>

(1) The inspection and diagnosis of waterways and basins should be performed to identify deformation in waterways, basins for anchorage, and basins for small craft, thus ensuring the safe and smooth navigation and use of ships.

(2) Adjustment and preparation should be made before the inspection and diagnosis of waterways and basins because the hours and content of the work are limited by the anchoring, sailing, and other uses of ships.

(3) As siltation becomes the main cause of performance degradation in waterways and basins, changes in the depth of water must be understood. The causes of siltation include the following:

① Intrusion and accumulation of littoral drift by waves or flows

② Accumulation of sediment discharged from rivers

③ Wind-blown sand and its sediment accumulation

④ Formation of sand waves

⑤ Side slope failure of waterways

⑥ Resuspension of sediment and change in the location of its accumulation caused by disturbances within the harbor

## 2.3 Daily Inspection

Daily inspection of waterways and basins is typically performed with an executable method to identify deformation in entire facility.

<Commentary>

The daily inspection is performed to identify large-scale deformations and obstacles to the utilization of facilities. The daily inspection should be performed to identify damage to facilities in accordance with patrols and other duties conducted by the facilities administrator and with an executable method, such as using information and other data provided by facility users and other relevant persons.

The following are examples of the matters that require attention during the daily inspection of waterways and basins.

・Visual inspection of floating obstacles that may directly influence the sailing and anchoring of ships

・Reports by facility users of obstructions in facility usage

## 2.4 Regular Periodic Inspection and Diagnosis

The regular periodic inspection and diagnosis of waterways and basins are typically performed with visual inspection or simplified depth sounding.

<Commentary>

The regular periodic inspection and diagnosis of waterways and basins should confirm the existence of floating obstacles by visual inspection and ensure that the required depth of the water is secured by interviewing facility users and employing simplified depth sounding and other techniques.

When the area for inspection to identify floating obstacles is extensive, floating obstacles can be confirmed by a distant view with binoculars and telescopes from a hill, surveillance cameras and other devices.

When it is expected that the required water depth will not be achieved, any sounding devices should be utilized to confirm the required water depth. Because the accuracy of water depth measurements varies with positioning and depth-sounding methods, careful handling is required. The area and intervals for depth sounding should be specified while considering the likelihood of siltation and other conditions.

## 2.5 Detailed Periodic Inspection and Diagnosis

(1) In detailed periodic inspection and diagnosis for waterways and basins, facility damage should, as a standard, be understood specifically through collection of quantitative data on water depth as necessary.

(2) Inspections and surveys should be performed according to a definite purpose in the case of collecting necessary data to estimate degradation and analyze the causes of deformation that influence performance of waterways and basins.

<Commentary>

(1)

The detailed periodic inspection and diagnosis of waterways and basins should target deformation that cannot be detected by the regular periodic inspection and diagnosis. Ensuring the required water depth in waterways and basins is important. It is generally difficult to determine the water depth for all facilities through visual inspection or simplified depth sounding. Therefore, in the detailed periodic inspection and diagnosis, quantitative data should, as a standard, be collected with echo sounders and other devices. The spatial intervals of the survey lines should be determined considering the likelihood of siltation and other conditions.

(2)

Analyzing the causes of deformation, predicting the progression of degradation, and other tasks require quantitative data. Therefore, inspections and surveys should be performed to acquire necessary data. For quantitative data collection, it is effective to utilize a bathymetry survey system to capture the bottom topography, including surveying with a multi-narrow-beam echo sounder.

## 2.6 Items for Inspection and Diagnosis and Their Categorization

The items for inspection and diagnosis of waterways and basins and their categorization should be specified by considering influence of deformation on performance of facilities.

<Commentary>

For the inspection and diagnosis items of waterways and basins, the **forms for inspection and diagnosis in the Appendix** can be used as a reference.

However, all items for the inspection and diagnosis indicated in the attached documents do not need to be addressed. The facilities owner should specify the necessary items for the inspection and diagnosis by adding items and performing other tasks as necessary.

The standard categorizations of the items for inspection and diagnosis of waterways and basins are shown in Table-4.2.1. These categorizations should be appropriately determined by considering the conditions to which the facilities are subjected and, specifically, their influence on facility performance.

Table-4.2.1 Standard categorization of items for inspection and diagnosis of waterways and basins

| Category / Targeted facility | Category I | Category II | Category III |
|---|---|---|---|
| Waterways and basins | ・Depth of the water<br>・Condition of the waterway or the basin for anchorage | – | – |

## 2.7 Unit for Grading Deterioration Level and Judging Performance Grade

| |
|---|
| Units for grading deterioration levels and judging performance grades in inspection and diagnosis of waterways and basins should be defined according to a type of facilities, planned water depth, and other criteria. |

<Commentary>

When grading the deterioration level and judging the performance grade, the unit should be defined based on the type of facilities, the planned water depth, and other criteria. The standard unit for grading the deterioration level and judging the performance grade of waterways and basins are shown in Table-4.2.2.

Table-4.2.2 Standard unit for grading deterioration level
and judging performance grade of waterways and basins

| Type of facilities | | Grading of deterioration levels (a, b, c, and d) | Judgment of performance grade (A, B, C, and D) |
|---|---|---|---|
| Waterways and basins | Waterways | Each area of the same planned water depth | Each area of the same planned water depth |
| | Basins for anchorage | | |
| | Basins for small craft | | |

# Chapter 3 Protective Facilities for Port and Harbor

## 3.1 General

### 3.1.1 Scope of application

| Chapter 3 is relevant to periodic inspection and diagnosis of protective facilities for port and harbor. |
|---|

<Commentary>

Chapter 3 mainly summarizes the methods, items, and other aspects of the periodic inspection and diagnosis to maintain the performance required for breakwaters in protective facilities for port and harbor.

### 3.1.2 Purpose of inspection and diagnosis

| Inspection and diagnosis of protective facilities for port and harbor should be appropriately performed to satisfy performance requirements throughout their service life. |
|---|

<Commentary>

(1) The inspection and diagnosis of protective facilities for port and harbor should be performed to evaluate the deformation of breakwaters, sediment control groins, seawalls, and revetments to maintain calm water areas within harbor, control the siltation of waterways and basins caused by littoral drift, and protect the hinterland.

(2) When performing the seaside inspection and diagnosis of protective facilities for port and harbor, restricting the working conditions and hours based on tide levels, waves, and other conditions should be considered.

### 3.1.3 Daily inspection

| Daily inspection of protective facilities for port and harbor is typically performed with an executable method to identify deformations in the entire facility. |
|---|

<Commentary>

The daily inspection is performed to identify large-scale deformations and obstacles to the utilization of facilities. The daily inspection should be performed to identify damage to facilities in accordance with patrols and other duties conducted by the facilities administrator and with an executable method, such as using information and other data provided by facility users and other relevant persons.

The following are examples of the matters that require attention during the daily inspection of protective facilities for port and harbor:

・Are there any levee crown subsidence or dislocation and tolerance from design face lines of the structures?

・Are there any displacements, scatterings or subsidence in the wave-dissipating blocks?

・Is there damage to the superstructures?

・Are there any traces of impacts from ships?
・Have users reported issues that prevent them from using a facility?

3.1.4 Regular periodic inspection and diagnosis

| |
|---|
| Regular periodic inspection and diagnosis of protective facilities for port and harbor are typically performed with visual inspection from land and sea. |

<Commentary>

The regular periodic inspections and diagnosis of protective facilities for port and harbor should be examined to the following items and evaluate any deformations in these items to be graded the deterioration level of facilities: displacement and subsidence of each facility; cracks and other damage to the superstructures and main structure; displacement, scattering, subsidence, and other deformations of the wave-dissipating blocks; and deformation in the external appearance of each structure.

During visual inspection, simple measurements should be performed using a scale, rod, simple survey instruments, inspection hammer, binoculars, crack scale, and other tools.

In addition, it is advisable to confirm the state of the facilities by performing interviews with facility users.

3.1.5 Detailed periodic inspection and diagnosis

| |
|---|
| (1) Method for performing detailed periodic inspections and diagnosis of protective facilities for port and harbor should be underwater visual inspection of the external appearance of facilities.<br>(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress of deterioration and analyze the causes of deformation that influence performance of protective facilities for port and harbor. |

<Commentary>

(1)

When performing the detailed periodic inspection and diagnosis of protective facilities for port and harbor, the underwater of the main body, seabed, wave-dissipating works, armoring works, foot protection works, etc. should be inspected to evaluate deformations that cannot be identified through the regular periodic inspection and diagnosis.

These deformations may damage the main body, for example, by sliding and overturning, so it is necessary to periodically evaluate the deformations of the external appearance of the underwater.

(2)

Quantitative data are required to investigate the possible causes of deformation and to predict their progression, so inspections and investigations should be performed to acquire the relevant data.

3.1.6 Items for inspection and diagnosis and their categorization

| |
|---|
| items for inspection and diagnosis of protective facilities for port and harbor and their categorization should be specified by considering influence of deformation on performance of facilities. |

<Commentary>

For the inspection and diagnosis items of protective facilities for port and harbor, the **forms for inspection and diagnosis in the Appendix A and B (Part9)** can be utilized as a reference.

However, all the items for inspection and diagnosis indicated in the attached documents are not necessary to be addressed. The facilities owner should specify the necessary items for inspection and diagnosis by adding items and performing other tasks as necessary.

The standard categorizations of the items for inspection and diagnosis of protective facilities for port and harbor are shown in Table-4.3.1. These categorizations should be appropriately determined by considering the conditions to which the facilities are subjected and, specifically, their influence on facility performance, particularly with respect to safety.

Table-4.3.1 Standard categorization of items for inspection and diagnosis of protective facilities for port and harbor

| Category / Target facility | Category I | Category II | Category III |
|---|---|---|---|
| Breakwater | • Overall displacement of facility<br>• [Caisson] Deterioration of/damage to concrete<br>• [Caisson] Cavity inside caisson<br>• [Foundation] Displacement, subsidence, and damage<br>• [Seabed] Scouring and sediment deposition | • Overall subsidence of facility<br>• [Superstructure] Deterioration of/damage to concrete<br>• [Armoring works] Displacement, scattering, and subsidence<br>• [Foot protection blocks] Displacement, scattering, and subsidence<br>• [Wave-dissipating blocks] Displacement, scattering, and subsidence<br>• [Wave-dissipating blocks] Damage and cracking | – |
| Revetment and dyke | • Overall displacement of facility, subsidence<br>• Apron<br>• [Main body] Deterioration of/damage to concrete<br>• [Recurved parapet] Deterioration of/damage to concrete<br>• [Steel sheet pile] Corrosion, cracking, and damage to steel materials<br>• [Foundation] Displacement, subsidence, and damage<br>• [Backside of revetments, dykes, and main body of dykes] Collapse and sucking<br>• [Seabed] Scouring and sediment deposition | • [Permanent work] Deterioration of/damage to concrete (plain concrete)<br>• [Steel sheet pile] protective coating<br>• [Steel sheet pile] Cathodic protection<br>• [Armoring works] Displacement, scattering, and subsidence<br>• [Foot protection blocks] Displacement, scattering, and subsidence<br>• [Wave-dissipating blocks] Displacement, scattering, and subsidence<br>• [Wave-dissipating blocks] Damage and cracking | Other items not listed to the left |

3.1.7 Units for grading deterioration level and judging performance grade

| Units for grading deterioration level and judging performance grade in inspection and diagnosis of protective facilities for port and harbor should be defined according to type of facilities and other criteria. |
|---|

<Commentary>

When grading the deterioration level and judging the performance grade, it is necessary to define the unit based on the type, structural shape, and other relevant features of the protective facility for port and harbor. The standard unit used for grading the deterioration level and judging the performance grade of protective facilities for port and harbor is shown in Table-4.3.2.

The unit may differ according to not only the type, structural shape, and other relevant features of facilities but also the design method, construction materials used, and other elements related to the construction of facilities, such as different periods of construction; therefore, the appropriate unit should be determined accordingly.

If a facility is relatively long (such as breakwater, revetment, and seawall), it is necessary to determine the execution unit while considering the implementation system (e.g., period and number of inspections) for performing the periodic inspection and diagnosis, in addition to considering the above points, so that the feasible practicable inspection and diagnosis plan can be developed.

Table-4.3.2 Standard unit for grading deterioration level and judging performance grade of protective facilities for port and harbor

| Type of facility | | Grading of deterioration level (a, b, c, and d) | Judgement of performance grade (A, B, C, and D) |
|---|---|---|---|
| Breakwater | Caisson type | Per box of caisson | The standard unit should be determined for each facility, but if the facility is long, the appropriate unit should be determined while considering the type and service life of the structures within a range of 200 to 500 m. |
| | Block type | Per span of superstructure | |
| | Rubble type | Every 15 to 20m | |
| Revetment and dyke | Caisson type | Per box of caisson | |
| | Sheet pile | Per span of superstructure | |

## 3.2 Inspection and Diagnosis of Caisson Type Breakwater

### 3.2.1 Regular periodic inspection and diagnosis

With respect to regular periodic inspection and diagnosis of caisson type breakwaters, deterioration level should be graded such as displacement and subsidence of breakwaters and deformation of superstructures, caisson, and wave-dissipating blocks. method for inspection and diagnosis should be visual inspection of external appearance from land and sea.

1) Displacement and subsidence of breakwater

For displacement and subsidence of breakwaters, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformations, such as dislocation and tolerance from design face lines of caisson type breakwater and uneven settlement superstructures.

<Commentary>

It should be noted if significant displacements (dislocation and tolerance) or subsidence can be observed at examining the face line of breakwaters, they cause degraded performance.

A diagram of inspection of the displacement and subsidence of a breakwater is shown in Figure -4.3.1.

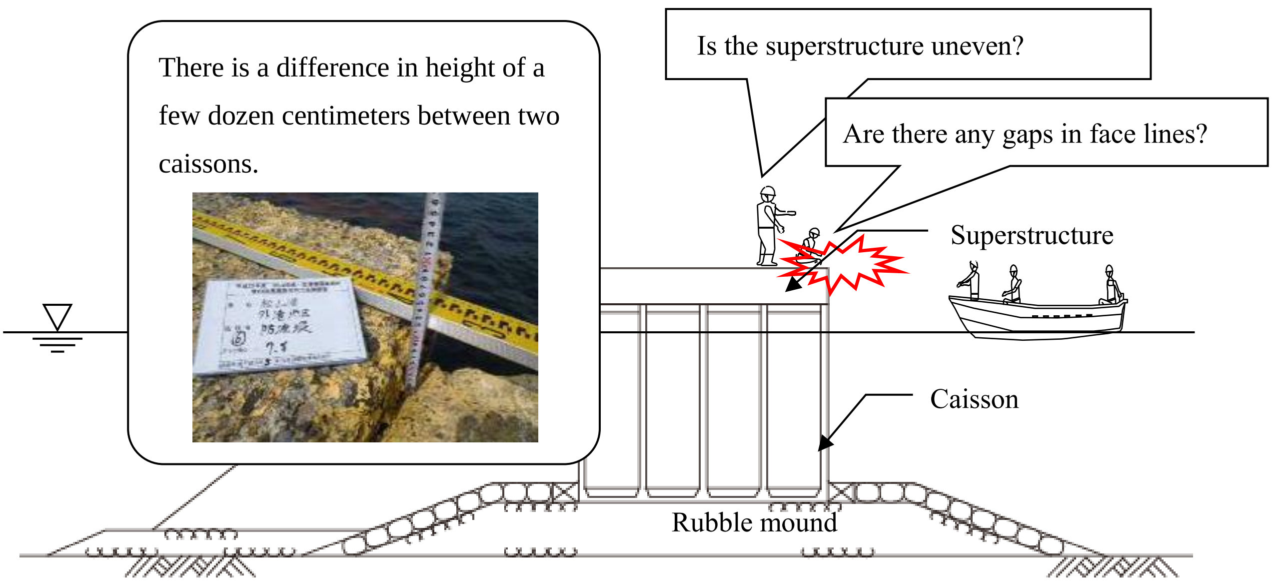



Figure-4.3.1 Diagram of inspection of displacement and subsidence of a breakwater

2) Caisson

| |
|---|
| For caissons, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deterioration or damage of concrete. |

<Commentary>

If there are multiple cracks, or if reinforcing bars are exposed in the caisson, the structure should be examined for holes in the sidewalls that may result in the outflow of infill materials.

For caissons, the inspection and diagnosis must generally be performed by visual inspection from the sea, but for the sidewalls of caissons equipped with wave-dissipating blocks, visual inspection must be conducted from the crown part of breakwaters, and the corresponding methods should be further elaborated. A diagram of a caisson inspection is shown in Figure-4.3.2.

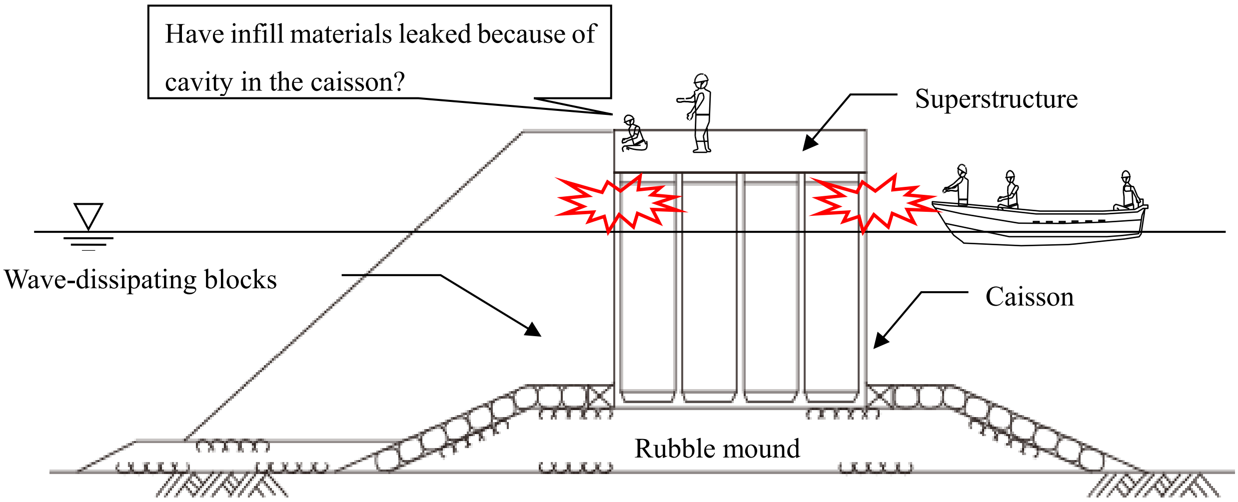




Figure-4.3.2 Diagram of inspection of a caisson

3) Superstructure

| |
|---|
| For superstructure, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deterioration or damage of the concrete. |

<Commentary>

In addition to deformation caused by wave actions, deformation may occur in superstructures from such as the impact of wave-dissipating blocks and deteriorations in concrete. Any damage or cracks in the concrete should be identified through visual inspection from land and sea.

Although the deformation in superstructures rarely affect the performance of facilities directly, any large-scale damage that affects the structural stability of the facilities should be noted. A diagram of a superstructure inspection is shown in Figure-4.3.3.

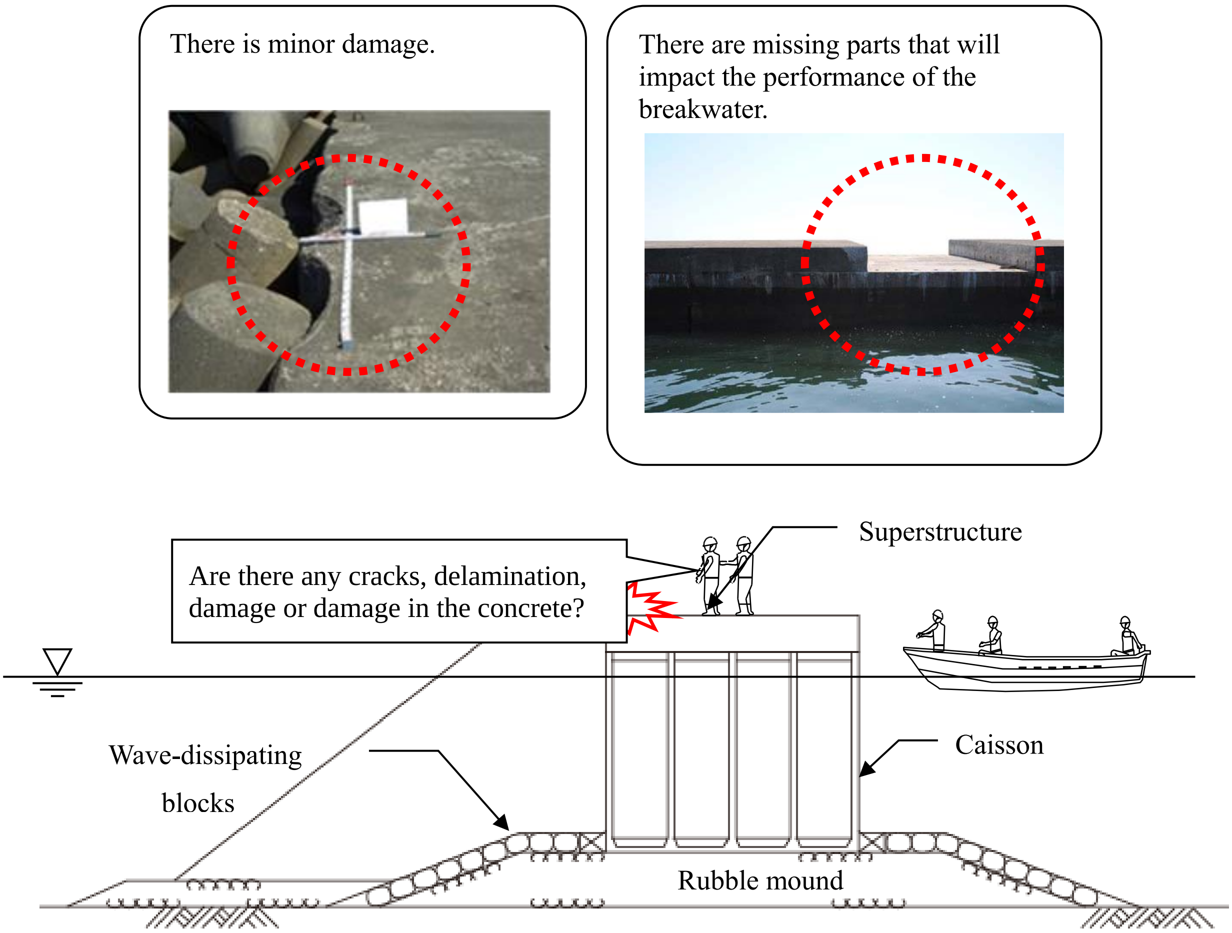



Figure-4.3.3 Diagram of inspection of a superstructure

4) Wave-dissipating blocks

| |
|---|
| For wave-dissipating blocks, method of inspection and diagnosis should be visual inspection from land and sea to evaluate displacement, scattering, subsidence, and damage in wave-dissipating blocks. |

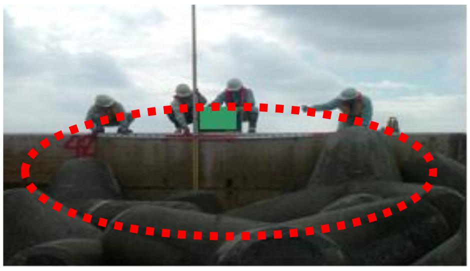
<Commentary>

In wave-dissipating blocks, deformation such as displacement, scattering, subsidence, damage, and deterioration, may occur due to wave actions, concrete deterioration, and similar events, and they should be identified by visual inspection from land and sea.

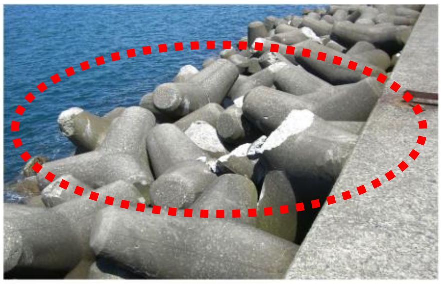
Locations where the cross-section of wave-dissipating blocks has changed discontinuously or the sectional area of wave-dissipating blocks has shrunk due to the subsidence of wave-dissipating blocks should be noted, as caisson deformations are likely to occur from the convergence of waves.

A diagram of inspection of wave-dissipating blocks is shown in Figure-4.3.4.

The sectional area of wave-dissipating blocks has shrunk.



There are several blocks with damage and partial deformations.



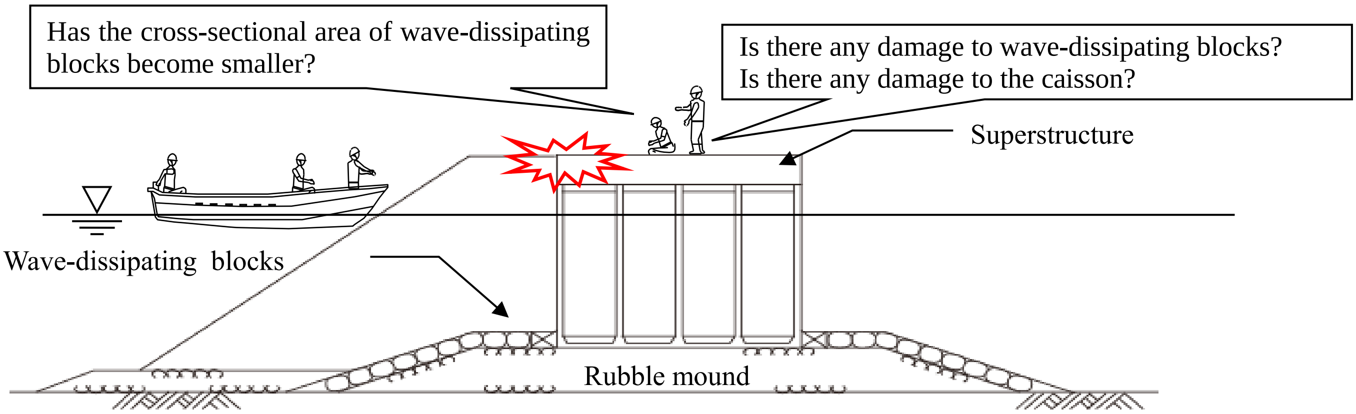



Figure-4.3.4 Diagram of inspection of wave-dissipating blocks

3.2.2 Detailed periodic inspection and diagnosis

(1) With respect to detailed periodic inspection and diagnosis of caisson type breakwaters, the inspection and diagnosis should be performed to identify underwater deformations in that cannot be observed by the regular periodic inspections and diagnosis.

(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress of deterioration and analyze the causes of deformation that influence performance of caisson type breakwaters.

1) Caisson

(1) For caisson, method of inspection and diagnosis should be underwater visual inspection of the to evaluate for cracks, delamination, and damage of concrete.

(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress of deterioration and analyze causes of deformation of caisson.

<Commentary>

(1)

If there are multiple cracks, or if the reinforcing bars in the caisson are exposed, it should be noted that the sidewall of the caisson would have cavity and that may flow out infill materials.

For breakwaters covered with wave-dissipating blocks, underwater visual inspection is sometimes difficult to grasp deformation of caisson because caisson is covered with wave-dissipating blocks. Some of the inspection and diagnosis is performed using a video camera to perforate at the superstructure of the caisson. There are some caisson walls covered with wave-dissipating blocks with installed inspection holes at the superstructure to expect the inspection.

A diagram of inspection of a caisson is shown in Figure-4.3.5.

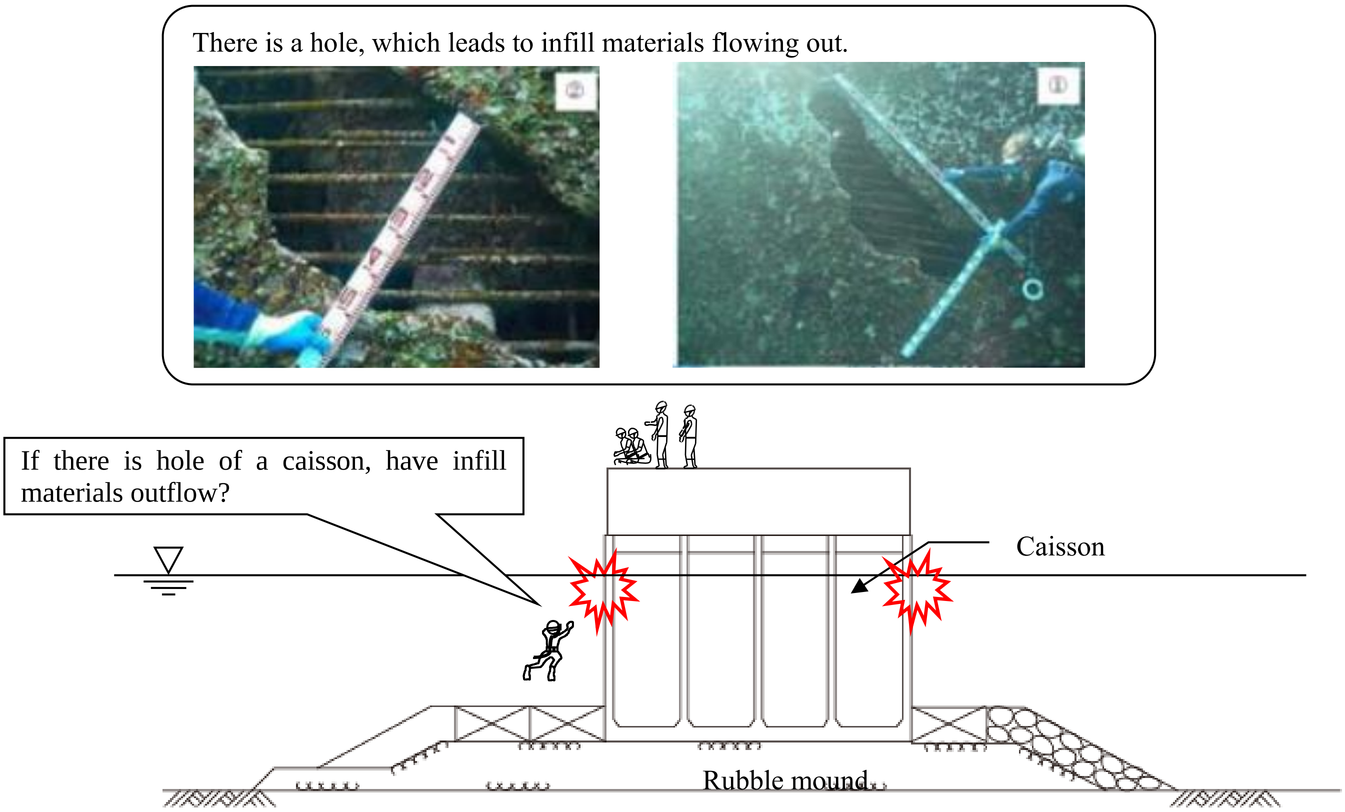



Figure-4.3.5 Diagram of inspection of a caisson

(2)

・When creating deformation record sketch

Photos should be taken or sketches should be drawn of cracking condition, delamination, damage, exposed reinforcing bars, and other deformation after removing any marine organisms that have adhered to the target inspection location using a scraping device or other tools.

・When investigating strength of the concrete and the corrosion of reinforcing bars

If there are concerns that concrete has weakened, the strength should be evaluated by a compressive strength test of core samples, and estimating the compressive strength using a rebound hammer or by another method. If the reinforcing bars are exposed, the diameter of the reinforcing bars should be measured using an instrument such as a vernier caliper so that effective information can be obtained to evaluate the structural performance, such as the load carrying capacity of the structural members.

・When investigating holes in the sidewalls of a caisson

Examples of methods used to investigate the sidewalls of a caisson are shown in Figure-4.3.6.

①Underwater camera is inserted into the gap between the caisson and wave-dissipating blocks from the top part of the superstructure, and the state is confirmed via a monitor or similar device. The concrete surface of the caisson is then recorded as digital moving images.

② Confirming whether reinforcing bars are exposed or not, and also damage level such as deficit of concrete by video record, then make deformation record sketch to clip wall's condition images from the video record.

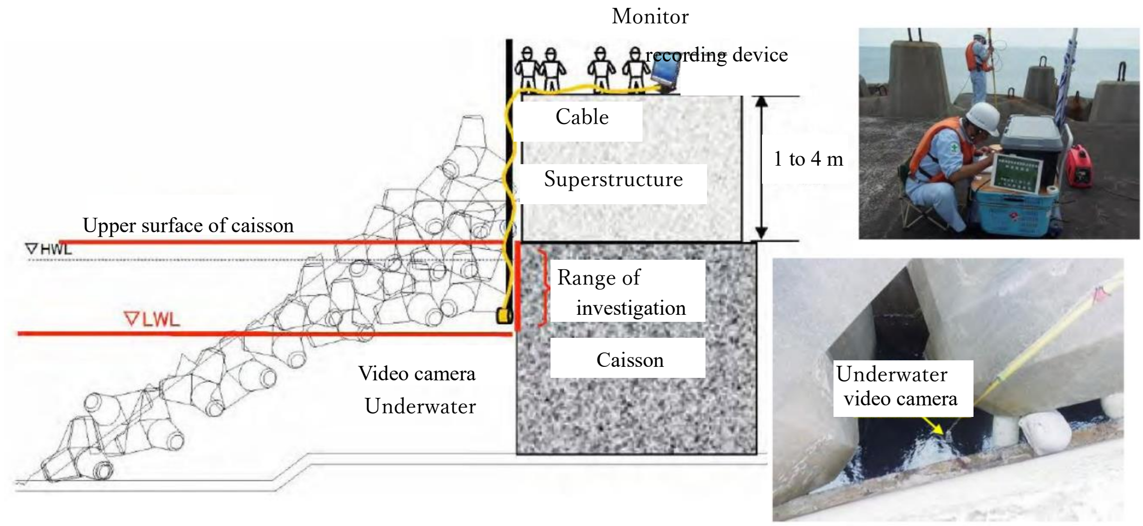



Figure-4.3.6 Examples of an investigation of the sidewalls of a caisson

2) Seabed

| | |
|---|---|
| (1) | Inspection and diagnosis of seabed should be performed to evaluate deformations, such as scouring and sediment deposition. |
| (2) | Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress of deterioration and analyze the causes of deformation of seabed. |

<Commentary>

(1)

Deformation caused by seabed scouring may result in the scattering of armoring rubbles or rubbles in the foundation and the tilting and subsidence of caissons. Deformation that affects the performance of facilities, particularly their structural stability, should be noted. A diagram of seabed inspection is shown in Figure-4.3.7.

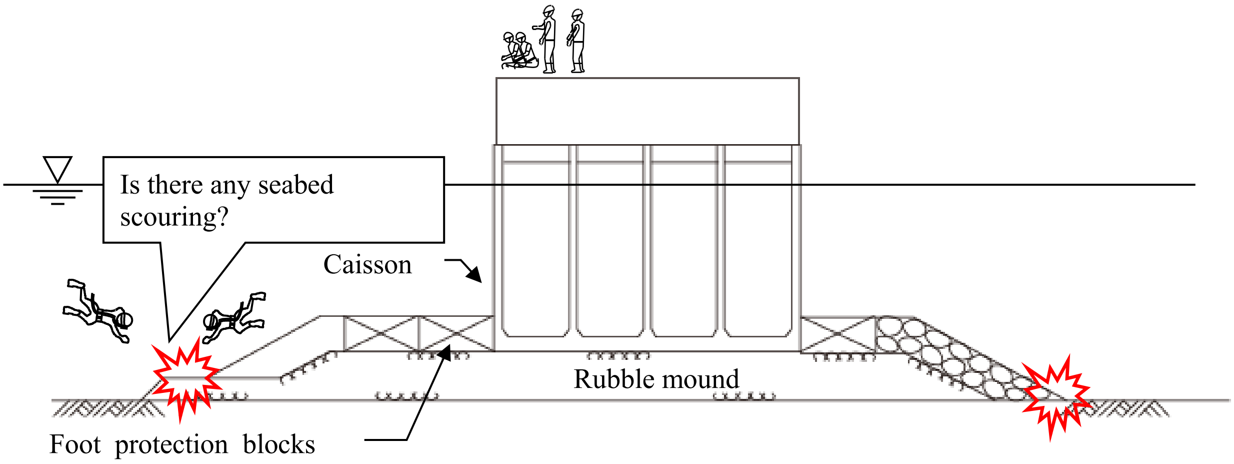



Figure-4.3.7 Diagram of inspection of seabed

(2)

This commentary is same as commentary of Part4 Chapter2 2.5 (2).

3) Wave-dissipating blocks, armoring works and foot protection blocks

(1) For wave-dissipating blocks, armoring works and foot protection blocks, the method of inspection and diagnosis should be underwater visual inspection to evaluate deformations, such as movement, scattering, and subsidence.

(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress of deterioration and analyze the causes of deformation of wave-dissipating blocks, armoring works and foot protection blocks.

<Commentary>

(1)

Movement, scattering and subsidence may occur in wave-dissipating blocks, armoring works and foot protection blocks. Any scattering or subsidence of armoring rubbles or rubbles in the foundation should be noted, as these changes may result in the tilting and subsidence of caissons, which will affect the performance of facilities, particularly their structural stability.

Any displacement, scattering and subsidence of wave-dissipating blocks should be noted, as these changes may reduce the sectional area of wave-dissipating blocks and increase the likelihood of deformation in caissons.

A diagram of inspection of wave-dissipating blocks is shown in Figure 4.3.8, while a diagram of inspection of armor and foot protection blocks is shown in Figure-4.3.9.

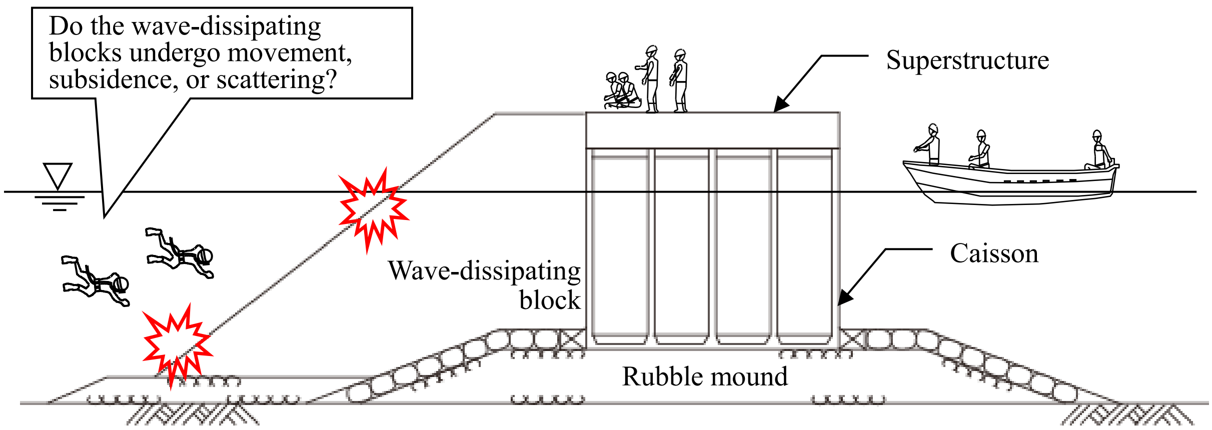



Figure-4.3.8 Diagram of inspection of wave-dissipating blocks

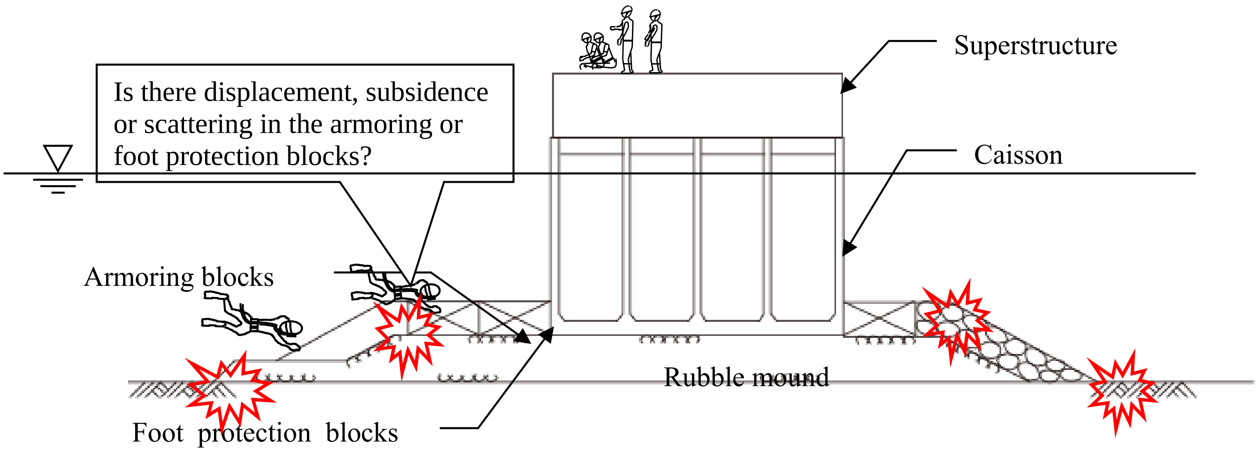



Figure-4.3.9 Diagram of inspection of armoring and foot protection blocks

(2)

Investigating the possible causes of deformation and predicting their progression can be performed using a hydraulic model test, numerical simulation, or similar procedure. The overall condition of the seabed can be evaluated by underwater inspection for shape of structures, in addition to bathymetry.

4) Movement, subsidence and tilting of breakwaters

| |
|---|
| Measurements of the movement, subsidence and tilting of breakwaters should be performed if required to assess deterioration over time, stability, and so forth.. |

<Commentary>

(1) The movement of a caisson can be determined by measuring the coordinates of four measuring points (four corners) for each caisson.

(2) The subsidence of a caisson can be determined by measuring the elevations at the four corners of

the top surface of the corresponding superstructure.

(3) The tilting of a caisson can be determined by either measuring the tilting using an inclinometer mounted on top of the relevant caisson or by calculating the difference in elevation measured at the top of the superstructure.

5) Superstructures

| |
|---|
| Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress of deterioration and analyze the causes of deformation of superstructures. |

<Commentary>

(1) When creating deformation record sketch

A photo should be taken or sketches should be drawn of the cracks, delamination, damage, exposed reinforcing bars (for reinforced concrete), and similar deformations after any marine organisms that have adhered to the target inspection location have been removed using a scraping device or other tools if necessary.

(2) When investigating the strength of the concrete and the corrosion of the reinforcing bars

If the superstructures are made of reinforced concrete, a detailed investigation of the strength of concrete and the corrosion of the reinforcing bars should be performed as necessary. If there are concerns that the concrete has weakened, the strength should be evaluated by performing a compressive strength test of core samples, estimating the compressive strength using a rebound hammer or another method. If the reinforcing bars are exposed, the diameter of the reinforcing bars should be measured using a vernier caliper or other instrument so that useful information can be obtained to evaluate the structural performance, such as the load carrying capacity of structural members.

## 3.3 Inspection and Diagnosis of Protective Facilities for Port and Harbor Other Than Caisson Type Breakwaters

(1) For regular periodic inspection and diagnosis of protective facilities for port and harbor other than caisson type breakwaters, method should be visual inspection from land and sea.

(2) For detailed periodic inspection and diagnosis of protective facilities for port and harbor other than caisson type breakwaters, method should be underwater visual inspection of external appearance.

(3) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress of deterioration and analyze the causes of deformation that influence performance of protective facilities for port and harbor other than caisson type breakwaters.

<Commentary>

With respect to protective facilities for port and harbor other than caisson type breakwaters, refer to the descriptions of the **inspection and diagnosis of caisson type breakwaters (Part4 Chapter3 3.2)** and **mooring facilities (Chapter 4)**. In addition to caisson type breakwaters, there are other types of breakwaters, such as concrete-block breakwaters and mound-type breakwaters. It is necessary to determine the proper items to be evaluated in the inspection and diagnosis of each structural type in advance.

1) Concrete block breakwater (Figure-4.3.10)

When conducting the inspection and diagnosis of concrete block breakwaters, deformations, such as the collapse and falling out of concrete blocks, should be identified (see Photo-4.3.1).

For the inspection and diagnosis of concrete block breakwaters (other than concrete blocks), refer to the descriptions of the **inspection and diagnosis of caisson type breakwaters (Part4 Chapter3 3.2)**.

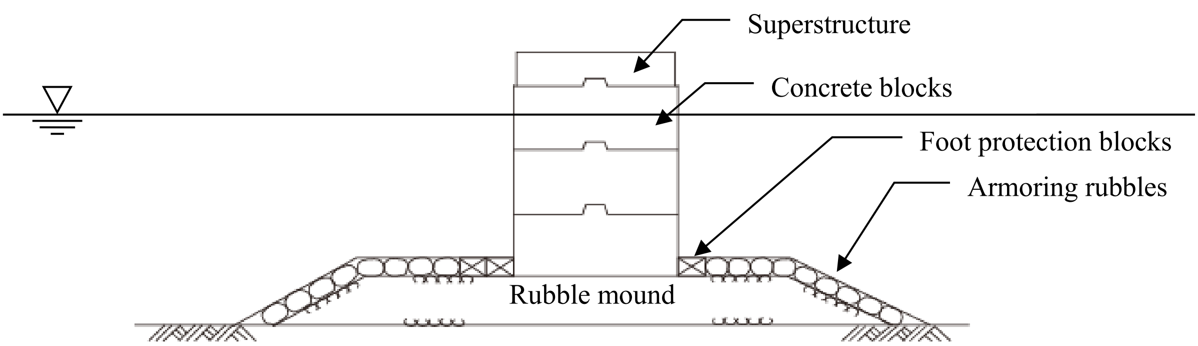


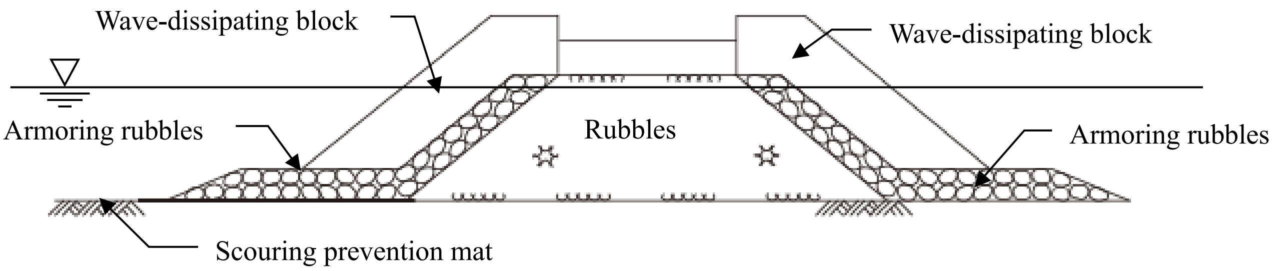

Figure-4.3.10 Concrete block-type upright breakwater

Photo-4.3.1 Deformations of concrete block-type breakwaters

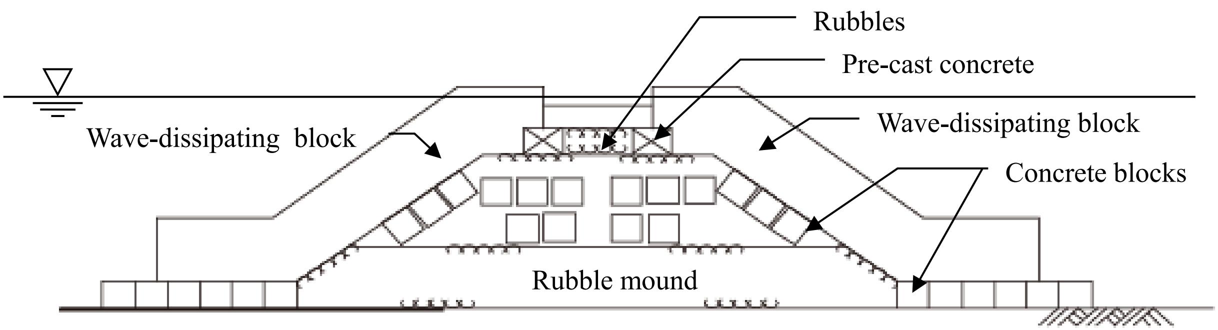
2) Mound-type breakwater (Figure-4.3.11)

When performing the inspection and diagnosis of mound-type breakwaters, deformations in rubbles and any movement, scattering, subsidence, and similar changes in wave-dissipating blocks and rubbles should be identified (see Photo-4.3.2).

For the inspection and diagnosis of mound-type breakwaters, refer to the descriptions of the **inspection and diagnosis of caisson type breakwaters (Part4 Chapter3 3.2)**.




(a) Rubble mound-type sloping breakwater




(b) Concrete block-type sloping breakwater

Figure-4.3.11 Sloping breakwater

Photo-4.3.2 Deformations of rubble mound-type sloping breakwaters

3） Seawall, revetments, dykes, and related structures

For the inspection and diagnosis of seawall, revetments, dykes, and related structures, refer to the descriptions of the **inspection and diagnosis of caisson type breakwaters (Part4 Chapter3 3.2)**. However, deformation should be identified by methods suited to the structural type.

The outflow of backfill materials and refill materials in sheet pile revetments and gravity-type revetments and that of embankment materials in dykes represent significant deformation that threaten the stability of revetments and dykes and user safety. It is necessary to identify signs of these phenomena as soon as possible through the regular periodic inspection and diagnosis. For the inspection and diagnosis of gravity-type revetments, refer to the descriptions of the **inspection and diagnosis of caisson type quaywall (Part4 Chapter4 4.2)**.

In sheet pile revetments, the corrosion of the steel sheet piles significantly affects the performance of the entire facility, so the main items evaluated during the inspection and diagnosis are not only the corrosion state of steel materials but also corrosion protection coating and cathodic corrosion protection. When conducting the regular periodic inspection and diagnosis for cathodic corrosion protection, potential measurement should be conducted on sheet piles. For the regular inspection and diagnosis of sheet pile revetments, refer to the descriptions of the **periodic inspection and diagnosis of sheet-pile quaywall (Part4 Chapter4 4.3)**.

# Chapter 4 Mooring Facilities

## 4.1 General

### 4.1.1 Scope of application

| Chapter 4 is relevant to periodic inspection and diagnosis of mooring facilities. |
|---|

<Commentary>

Chapter 4 summarizes the methods, items, and other aspects of the periodic inspection and diagnosis to maintain the performance required for mooring facilities.

### 4.1.2 Purpose of inspection and diagnosis

| Inspection and diagnosis of mooring facilities should be appropriately performed to satisfy performance requirements throughout their service life. |
|---|

<Commentary>

(1) The inspection and diagnosis of mooring facilities should be performed to evaluate deformations of quaywalls or piled piers to ensure safe and smooth mooring of vessels, embarkation, and disembarkation of passengers, and loading and unloading of cargo.

(2) The inspection and diagnosis of the ancillary equipment of mooring facilities should be appropriately performed to satisfy performance requirements consistent with the equipment type.

(3) When performing the inspection and diagnosis of a mooring facility, the working hours or the content of the work must be restricted, depending on the height of the tide or the status of facility usage.

### 4.1.3 Daily inspection

| |
|---|
| Daily inspection of mooring facilities is typically performed with an executable method to identify deformations in entire facility. |

<Commentary>

The daily inspection is performed to identify large-scale deformation and obstacles to the utilization of facilities. The daily inspection should be performed to identify damage to facilities in accordance with patrols and other duties conducted by the facilities administrator and with an executable method, such as using information and other data provided by facility users and other relevant persons.

The following are examples of the matters that require attention during the daily inspection of mooring facilities:

- Are there any major changes in the original utilization status (the mode of using goods or vehicles)?
- Are there any signs of impact from vessels or reports of such incidents?
- Is there any large dislocation and tolerance from design face line of mooring facilities or a large uneven settlement in a joint?
- Are there any signs of subsidence or collapse of the apron pavement?
- Is there any abnormal noise or vibration?
- Are there any anomalies in the ancillary equipment?
- Have any hindrances to use been reported?

### 4.1.4 Regular periodic inspection and diagnosis

| |
|---|
| Regular periodic inspection and diagnosis of mooring facilities are typically performed with visual inspection from land and sea. |

<Commentary>

The regular periodic inspection and diagnosis of a mooring facility is performed to grade deterioration level of facilities by generally evaluating the facility for various conditions, including movement or subsidence of the entire facility, subsidence or collapse of the apron, cracks or damage to the main body or superstructure, damage to ancillary facilities, or deformational changes in the appearance of the structure. Regarding the appearance from land or sea, when the structure is made of concrete, deformation, such as damage or cracks, should be identified. When the structure is made of steel, the corrosion of the steel or deformation of the protective coating or cathodic protection should be evaluated.

During visual inspection, simple measurement using tools, including a scale, rod, simple measuring equipment, inspection hammer, binoculars, and crack scale, is recommended.

In addition, it is advisable to confirm the state of the facilities by performing interviews with facility users.

4.1.5 Detailed periodic inspection and diagnosis

| |
|---|
| (3) Method for performing detailed periodic inspection and diagnosis of mooring facilities should be underwater visual inspection of external appearance of the facilities.<br>(4) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation that influence the performance of mooring facilities. |

<Commentary>

(1)

When performing the detailed periodic inspection and diagnosis of mooring facilities, the underwater of the main body, seabed, etc. should be inspected to evaluate deformation that cannot be identified through the regular periodic inspection and diagnosis.

The deformation may damage the main body, for example, by sliding and overturning, collapse of the apron, so it is necessary to periodically evaluate the deformation of the external appearance of the underwater.

(2)

This commentary is same with commentary of Part4 Chapter3 3.1.5 (2)

4.1.6 Items for inspection and diagnosis and their categorization

| |
|---|
| Items for inspection and diagnosis of mooring facilities and their categorization should be specified by considering influence of deformation on performance of facilities. |

<Commentary>

For the inspection and diagnosis items of mooring facilities, the **forms for inspection and diagnosis in the Appendix** can be used as a reference.

However, all items for the inspection and diagnosis indicated in the attached documents do not need to be addressed. The facilities owner should specify the necessary items for the inspection and diagnosis by adding items and performing other tasks as necessary.

The standard categorizations of items for the inspection and diagnosis of mooring facilities are shown in Table-4.4.1. These categorizations should be appropriately determined by considering the conditions to which the facilities are subjected and, specifically, their influence on facility performance, particularly with respect to safety.

Table-4.4.1 Standard categorization of items for inspection and diagnosis of mooring facilities

| Category / Target facility | Category I | Category II | Category III |
|---|---|---|---|
| Mooring facility (gravity type) | • [Quaywall face line] dislocation and tolerance from design<br>• [Apron] Outflow, cavities, subsidence, or collapse<br>• [Caisson] Deterioration of/ damage to concrete or asphalt paving Cavities of caisson<br>• [Seabed ground] Scouring and sediment accumulation | • [Apron] Deterioration of/ damage to concrete or asphalt paving<br>• [Superstructure] Deterioration of/ damage to concrete | Other items not listed to the left |
| Mooring facility (sheet-pile) | • [Quaywall face line] dislocation and tolerance from design<br>• [Apron] Outflow, cavities, subsidence, or collapse<br>• [Steel sheet pile] Corrosion, cracking or damage to steel<br>• [Seabed ground] Scouring and sediment accumulation | • [Apron] Deterioration of/ damage to concrete or asphalt paving<br>• [Superstructure] Deterioration of/ damage to concrete<br>• [Steel sheet pile] Protective coating<br>• [Steel sheet pile] Cathodic protection | Other items not listed to the left |
| Mooring facility (open-type) | • [Pier face line] dislocation and tolerance from design<br>• [Apron] Outflow, cavities, subsidence, or collapse<br>• [Superstructure (bottom | • [Apron] Deterioration of/ damage to concrete or asphalt paving<br>• [Superstructure (side)] Deterioration of/ damage to concrete<br>• [Superstructure (bottom | Other items not listed to the left |

| | | | |
|---|---|---|---|
| | surface)]<br>Deterioration of/ damage to concrete (PC)<br>• [Steel pipe pile]<br>Corrosion, cracking or other damage to steel<br>• [Seabed ground]<br>Scouring and sediment accumulation<br>• [Earth retaining part] | surface)]<br>Deterioration of/ damage to concrete (RC)<br>• [Steel pipe pile]<br>Protective coating<br>• [Steel pipe pile]<br>Cathodic protection<br>• [Access bridge]<br>Movement or damage | |

4.1.7 Unit for grading deterioration level and judging performance grade

| |
|---|
| Units for grading deterioration level and judging performance grade in inspection and diagnosis of mooring facilities should be defined according to type of facilities, planned water depth, and other criteria. |

<Commentary>

When grading the deterioration level and judging the performance grade, it is necessary to define the unit based on the type, structural shape, and other relevant features of the mooring facility. The standard unit used for grading the deterioration level and judging the performance grade of mooring facilities are shown in Table-4.4.2.

The unit may differ according to not only the type, structural shape, and other relevant features of facilities but also the design method, construction materials used, and other elements related to the construction of facilities, such as different periods of construction; therefore, the appropriate unit should be determined accordingly.

Table-4.4.2 Standard unit for grading deterioration level and judging performance grade of mooring facilities

| Type of facility | | Grading of deterioration level (a, b, c, and d) | Judgement of performance grade (A, B, C, and D) |
|---|---|---|---|
| Mooring facility | Gravity type | Per caisson | Per berth |
| | Sheet-pile | Per span of superstructure | |
| | Open-type | Per span of superstructure | |

## 4.2 Inspection and Diagnosis of Caisson Type Quaywall

4.2.1 Regular periodic inspection and diagnosis

| |
|---|
| With respect to regular periodic inspection and diagnosis of caisson type quaywall, deterioration level should be graded such as vertical or lateral irregularities of quaywall face line, and deformations of apron, superstructure, caisson and ancillary facility. Method for inspection and diagnosis should be visual inspection of external appearance from land and sea. |

1) Quaywall face line

| |
|---|
| For irregularities in the quaywall face line, the method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformations. |

<Commentary>

A vertical irregularity in the quaywall face line or a gap or uneven settlement between the superstructure and the apron may suggest that the backfill soil has been outflowed through the caisson joints. A large vertical irregularity in the quaywall face line may inconvenience the mooring of vessels. A diagram of inspection of a quaywall face line is shown in Figure-4.4.1.

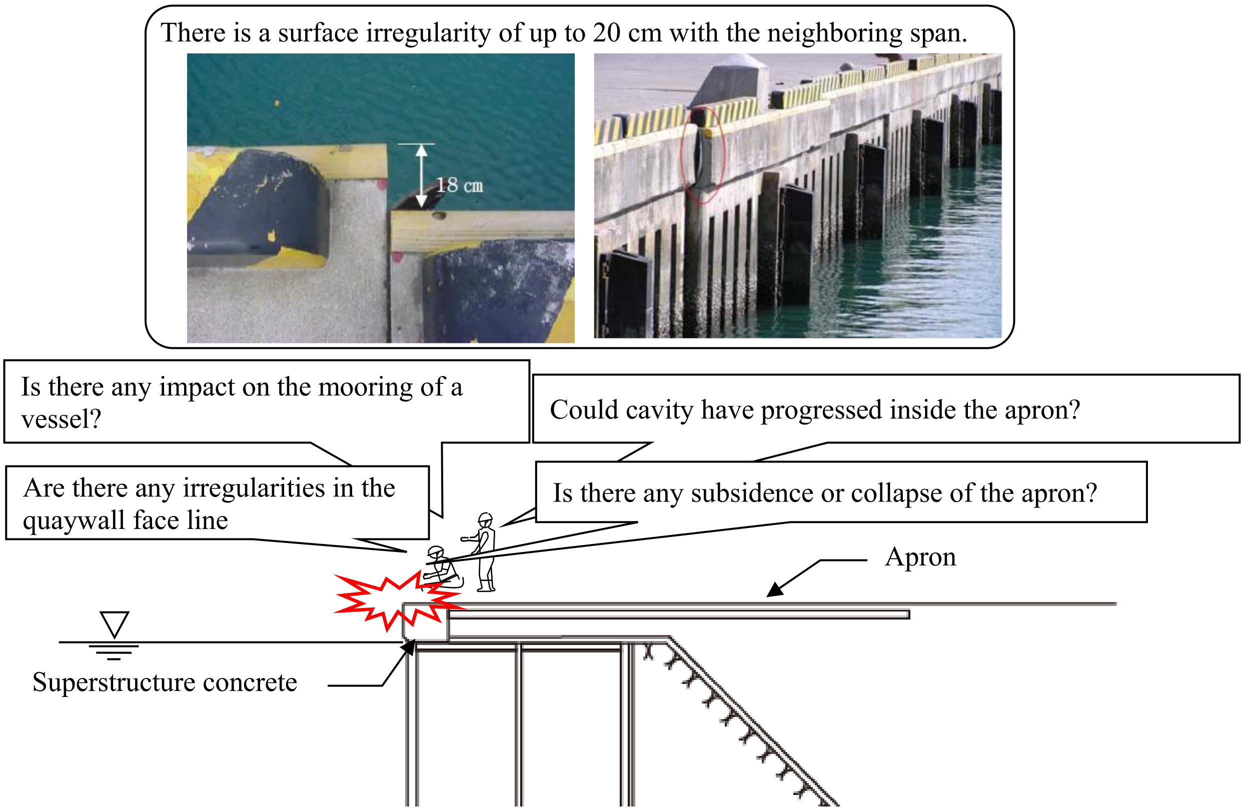



Figure-4.4.1 Diagram of an inspection of quaywall face line

2) Apron

| |
|---|
| For subsidence, collapse, deterioration or damage to the apron, method of inspection and diagnosis should be visual inspection to evaluate openings, gaps, uneven settlement, or any other deformations of a joint. |

<Commentary>

The inspection and diagnosis of an apron includes a survey of (1) and (2), as follows:

(1) Subsidence and collapse of apron (Photo-4.4.1)

For the inspection and diagnosis of the subsidence or collapse of an apron, the surface of the apron should be visually inspected, and the location and size of the area to be examined should be appropriately determined.

The regular periodic inspection and diagnosis mainly focuses on the following points:

- Subsidence of the apron, uneven settlement of the apron, uneven settlement between the apron and the hinterland, and collapse locations

The subsidence or collapse of the apron can be caused by outflow or compaction of backfill or fill materials or outflow of fills in caissons. In these cases, it is possible that cavities have formed under the apron surface.

For asphalt pavement, the occurrence of cavity may be estimated to some extent by investigating the state of the deformation of the apron or by surveying the tapping sound with inspection hammer.

Photo-4.4.1 Example of a subsidence or collapse of the apron

When the presence of a cavity is suspected based on the results of general periodic inspection and diagnosis, the detailed extraordinary inspection and diagnosis should be performed, cavity should be surveyed with an electromagnetic wave radar technique, or the pavement should be drilled or cut to directly evaluate the scale of cavities. A diagram of inspection of an apron is shown in Figure-4.4.2.

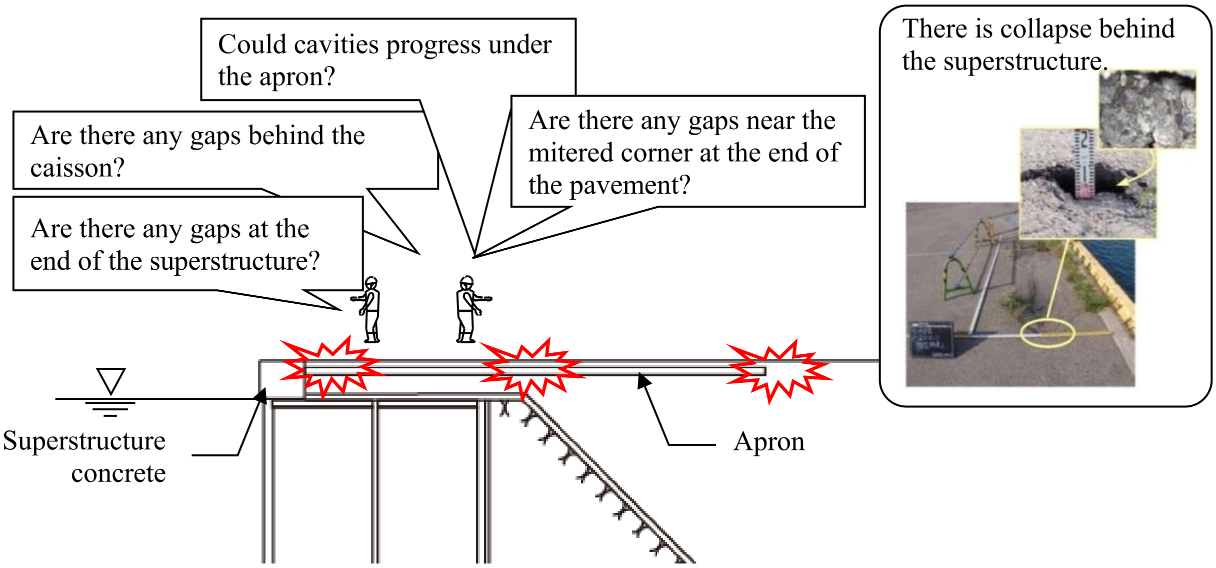



Figure-4.4.2 Diagram of inspection of an apron

(2) Deterioration or damage to apron (Photo-4.4.2)

Deterioration or damage of the concrete or asphalt of the apron should be evaluated in visual inspection. The entire area of the apron should be inspected, paying particular attention to the following:

- Degree of cracking
- Degree of uneven settlement
- Damage to joints

The degree of cracking of an apron may be assessed in terms of a cracking index for concrete pavement and a cracking ratio for asphalt pavement. The cracking index is the sum of the lengths of all the cracks on the concrete pavement divided by the apron area and is calculated as follows:

Cracking index (m/m$^2$) = sum of crack lengths (m) / apron area (m$^2$)

The cracking ratio is the area on the asphalt pavement where the cracks occurred divided by the apron area and is calculated as follows:

Cracking ratio (%) = area where cracks occurred (m$^2$) / apron area (m$^2$) x 100


Photo-4.4.2 Examples of apron deformation

3) Caisson

| |
|---|
| For caisson, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformation such as deterioration or damage of the concrete. |

<Commentary>

The timing of visual inspection of a caisson from sea to evaluate deterioration or damage should be determined based on environmental conditions such as when the tide level is low and waves are small. When concrete is examined for spalling or delamination, since such anomalies can be difficult to examine by only surveying the appearance, it is advisable to use inspection hammer in addition to the visual inspection. A diagram of inspection of a caisson is shown in Figure-4.4.3.

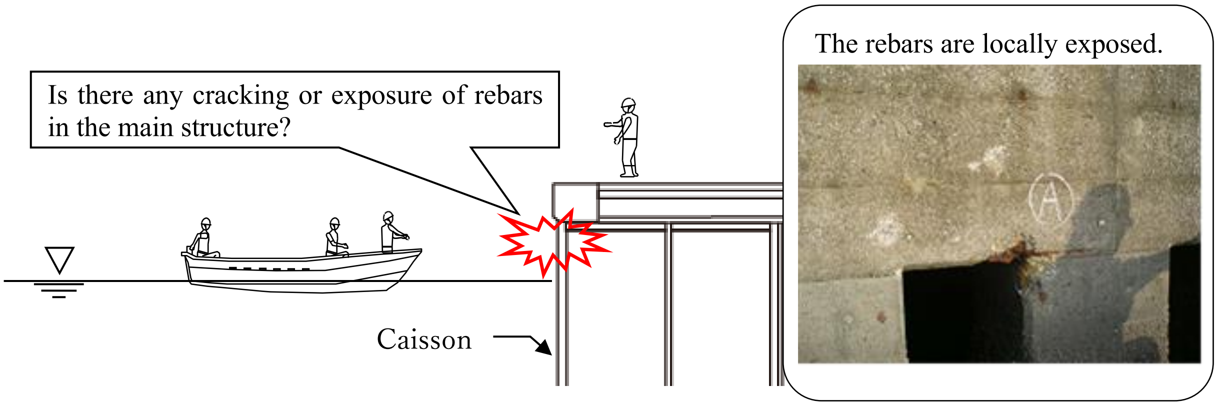



Figure-4.4.3 Diagram of inspection of a caisson

4) Superstructure

| |
|---|
| For superstructure, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformation such as deterioration or damage of the concrete. |

<Commentary>

The effects of severe deterioration or damage may disrupt load handling work. Diagram of inspection of a superstructure is shown in Figure-4.4.4.

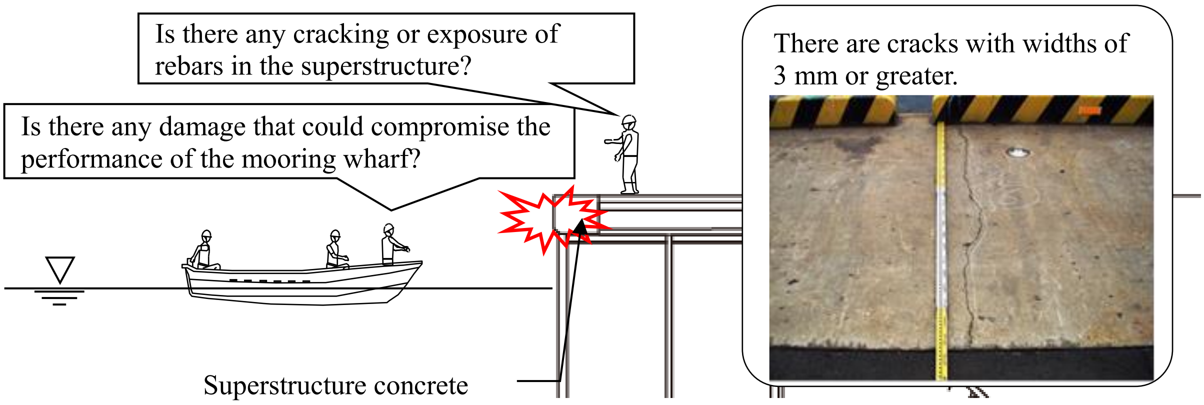



Figure-4.4.4 Diagram of inspection of a superstructure

5) Ancillary facility

| |
|---|
| For ancillary facility, the method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformation such as damage, change form, spalling of paint. |

4.2.2 Detailed periodic inspection and diagnosis

| |
|---|
| (3) With respect to detailed periodic inspection and diagnosis of caisson type quaywall, inspection and diagnosis should be performed to identify underwater deformations that cannot be observed by regular periodic inspections and diagnosis. |
| (4) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation that influence the performance of facilities for port and harbor. |

1) Apron

| |
|---|
| Inspection and diagnosis of an apron should be performed to evaluate deformation, such as outflow of materials and cavity under apron. |

<Commentary>

An apron should be investigated for the presence of cavities and their sizes by performing cavity detection with an electromagnetic wave radar, visual inspection through drilling or cutting pavement slab, or an endoscopic survey. In such cases, the entire length of the facility should be examined. Caution is necessary for inspecting concrete pavement in particular because in the early stages of deformation, no change is often visible on the exterior of the facility.

2) Caisson

| |
|---|
| (3) For caisson, the method of inspection and diagnosis should be underwater visual inspection to evaluate deformation such as deterioration or damage of the concrete. |
| (4) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation of caisson. |

<Commentary>

(1)

It is necessary to pay attention that infill materials could be outflowed if there are multiple cracks, or if the reinforcing bars in the caisson are exposed at inspection for caisson.

A diagram of an inspection of a caisson is shown in Figure-4.4.5.

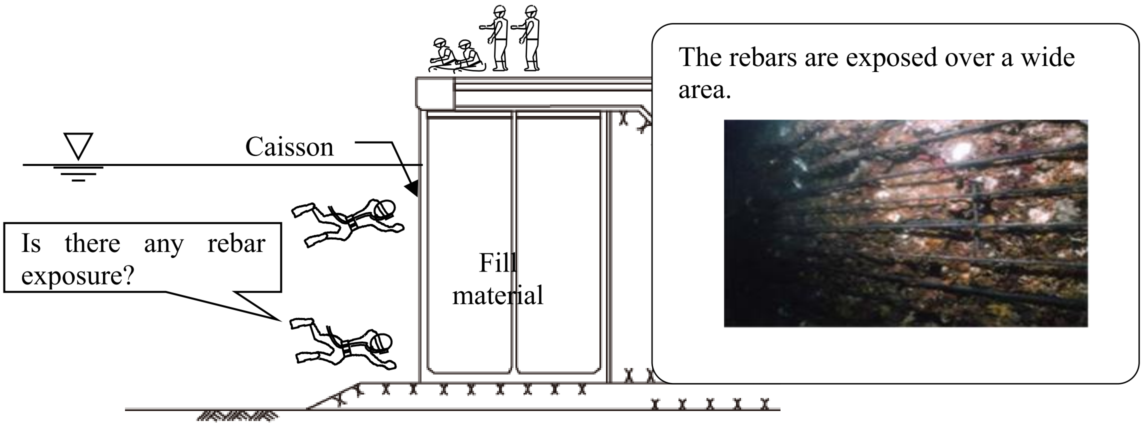


Figure-4.4.5 Diagram of inspection of caisson

(2)

・When creating deformation record sketch

Photos should be taken or sketches should be drawn of cracking condition, delamination, damage, exposed reinforcing bars, and other deformation after removing any marine organisms that have adhered to the target inspection location using a scraping device or other tools.

・When investigating strength of the concrete and the corrosion of reinforcing bars

If there are concerns that concrete has weakened, the strength should be evaluated by a compressive strength test of core samples, and estimating the compressive strength using a rebound hammer or by another method. If the reinforcing bars are exposed, the diameter of the reinforcing bars should be measured using an instrument such as a vernier caliper so that effective information can be obtained to evaluate the structural performance, such as the load carrying capacity of the structural members.

3) Seabed

(1) Inspection and diagnosis of seabed should be performed to evaluate deformations, such as scouring and sediment deposition.
(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation of seabed.

<Commentary>

(1)

Deformation by scouring of the seabed can be caused by the stirring of water by screws as vessels leave or arrive at the wharf. Such deformation may lead to facility destruction because of slope slip caused by the facility's own dead or live loads and may directly affect the performance (particularly structural safety) of the facility. Sediment deposited near the caisson joints indicates possible outflow of filling material. A diagram of an inspection of a seabed ground is shown in Figure-4.4.6.

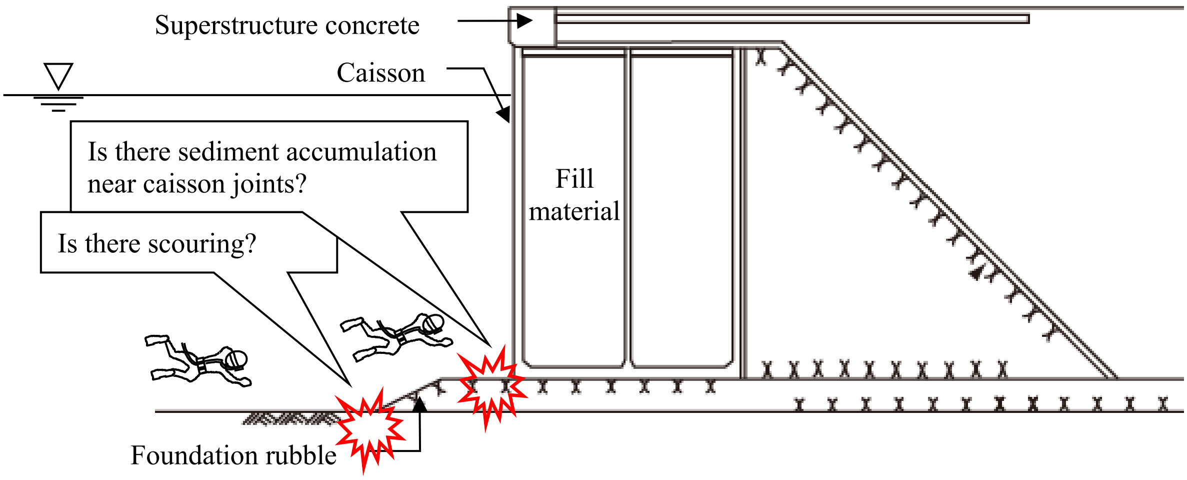



Figure-4.4.6 Diagram of inspection of seabed

(2)

This commentary is same with commentary of Part4 Chapter2 2.5 (2).

4) Movement, subsidence or tilting of the entire facility

| |
|---|
| Measurements of the movement, subsidence and tilting of caissons should be performed if required to assess deterioration over time, stability, and so forth. |

<Commentary>

This commentary is same with commentary of Part4 Chapter3 3.2.2 4).

5) Superstructures

| |
|---|
| Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation of superstructures. |

<Commentary>

This commentary is same with commentary of Part4 Chapter3 3.2.2 5).

## 4.3 Inspection and Diagnosis of Sheet-Pile Quaywall

### 4.3.1 Regular periodic inspection and diagnosis

| |
|---|
| With respect to regular periodic inspection and diagnosis of sheet-pile quaywall, deterioration level should be graded such as vertical or lateral irregularities of quaywall face line, and deformation of apron, superstructure, steel sheet piles and ancillary facility. Method for inspection and diagnosis should be visual inspection of external appearance from land and sea. |

1) Quaywall face line

| |
|---|
| For vertical or lateral irregularities in quaywall face line, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformation. |

<Commentary>

For the items and methods of the inspection and diagnosis of the quaywall face line, **Quaywall face line (Part4 Chaper4 4.2.1 1)** should be followed.

2) Apron

| |
|---|
| For subsidence and collapse of an apron, method of inspection and diagnosis should be visual inspection to grasp deformation such as opening of joint, gaps, or uneven settlement. |

<Commentary>

For the items and methods of the inspection and diagnosis of an apron, **Apron (Part4 Chaper4 4.2.1 2)** should be followed. For a sheet-pile quaywall it should be noted that cracks can occur on the apron located on the anchorage. When the anchorage is located behind the apron or at the quay shed, cracks and other deformation in the pavement or floor near the anchorage should be evaluated. A diagram of inspection of apron is shown in Figure-4.4.7.

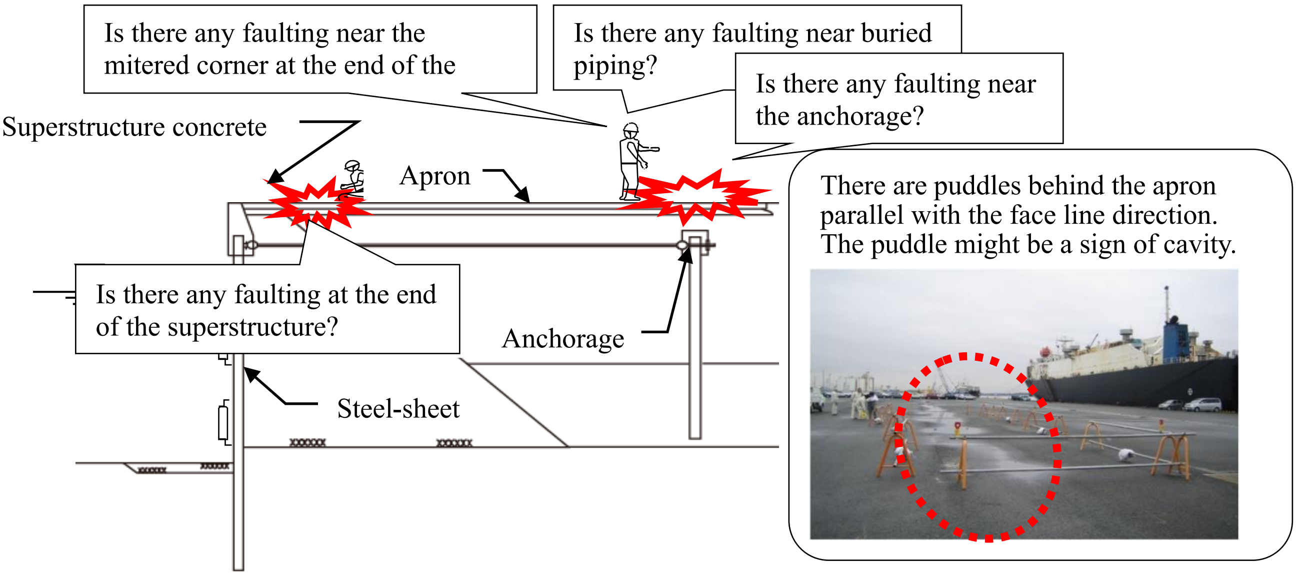



Figure-4.4.7 Diagram of inspection of an apron

3) Steel sheet pile

| |
|---|
| For steel sheet piles, method of inspection and diagnosis should be visual inspection from sea to evaluate deformation such as corrosion, cracking and damage of the steel. |

<Commentary>

The corrosion, cracking or damage of steel sheet piles is caused mainly by corrosion resulting from direct contact with the seawater. Damage can also be caused by collision with floating objects. The resulting deformation reduces the bearing capacity of steel sheet piles, compromising their function as an earth-retaining wall. In addition, if corrosion penetrates the sheet piles to create holes, the backfill and fill materials can be flown out, causing subsidence or collapse of the apron, and eventually affecting the cargo handling.

The corrosion of steel sheet piles is generally likely to occur between L.W.L. and M.L.W.L. Therefore, as far as possible, it is advisable to perform inspection and diagnosis at low tide and under conditions of gentle waves.

The regular periodic inspection and diagnosis of steel sheet piles mainly addresses the presence of holes and the corrosion of steel members above the seawater level. A diagram of an inspection of a steel sheet pile is shown in Figure-4.4.8.

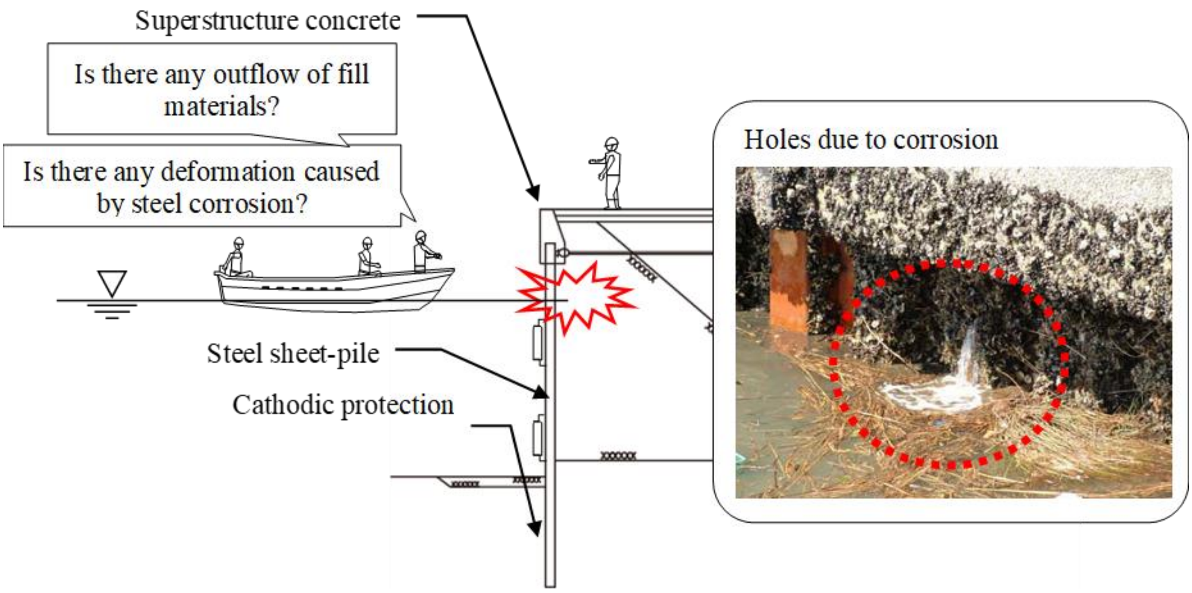



Figure-4.4.8 Diagram of inspection of steel sheet piles

4) Superstructure

| |
|---|
| For superstructure, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformation such as deterioration or damage of concrete. |

<Commentary>

The effects of outstanding deterioration or damage may disrupt cargo handling. Diagram of inspection of superstructure is shown in Figure-4.4.9.

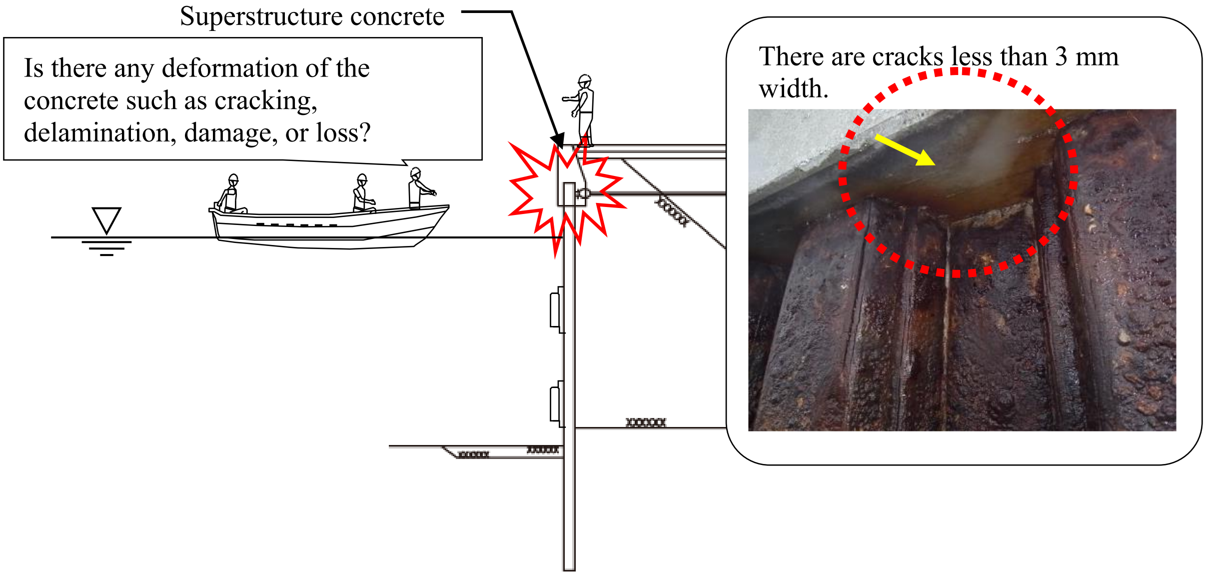



Figure-4.4.9 Diagram of inspection of superstructure

5) Protective coating for steel

| |
|---|
| For protective coating for steel, method of inspection and diagnosis should be visual inspection from sea to evaluate deformation of part such as coating materials and protection covers. |

<Commentary>

The general procedure of the inspection and diagnosis of protective coating entails evaluating the area up to at least 1 m below L.W.L. because the corrosion of steel sheet piles tends to occur between L.W.L. and M.L.W.L. Therefore, as far as possible, it is advisable to conduct inspection at low tide and under conditions of gentle waves.

The regular periodic inspection and diagnosis of protective coating is performed mainly to evaluate the following items:

(1) Paint coating

- Blistering, cracking, delamination, and rust
- Defect area ratio (criterion diagram (Figure-4.4.10) for the rating of painted steel surfaces as a

function of area percent rusted determined by reference to ASTM-D610)

(2) Organic coating

• Delamination or cracking of coating material

(3) Petrolatum coating

• Detachment, cracking, deformation or delamination of protective cover

• Corrosion or loosening of bolts

(4) Mortar coating

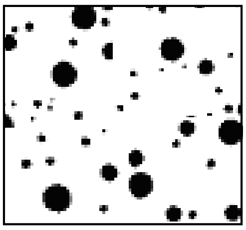
• Loss, cracking or delamination of mortar (without protective cover)

• Detachment, cracking, or deformation of protective cover (with protective cover)

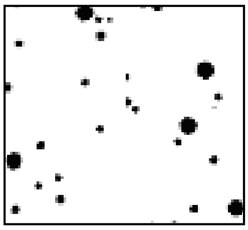
• Corrosion or loosening of bolts (with protective cover)

(5) Metallic coating

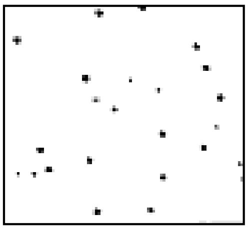
• Rust, damage, or detachment



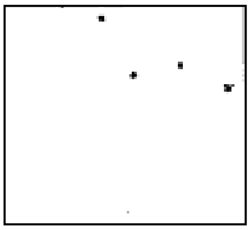
Deterioration level : a
(defect area ratio = 10%)



Deterioration level : b
(defect area ratio = 3%)



Deterioration level : b
(defect area ratio = 0.3%)



Deterioration level : c
(defect area ratio = 0.03%)

Figure-4.4.10 Rating of painted steel surfaces as a function of area percent rusted

A diagram of inspection of protective coating is shown in Figure-4.4.11

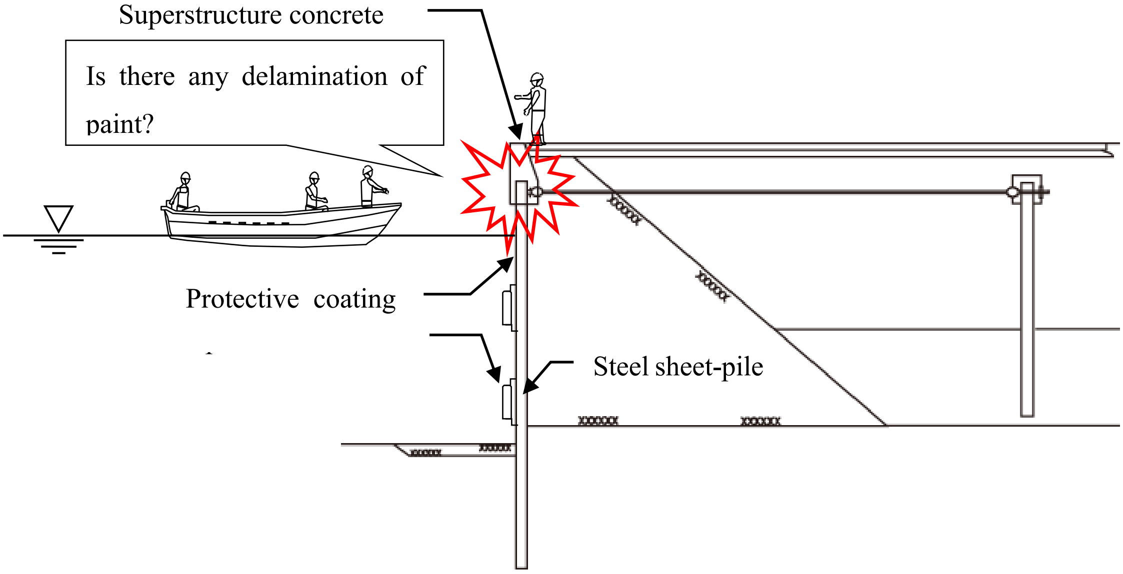



Figure-4.4.11 Diagram of inspection of protective coating

6) Cathodic protection

| |
|---|
| For cathodic protection, electrical potential should be measured to evaluate whether protective potential is maintained. |

<Commentary>

When seawater silver chloride electrode is used, the cathodic protection standard potential that indicates the theoretical boundary for effective anti-corrosion performance is −780 mV. Technical Standards for Port and Harbor Facilities in Japan are more conservative and establish −800 mV as the protective potential boundary, given the variations in the measured values. When the protective potential is not maintained, possible causes may be the loss or total consumption of the anode.

It is advisable to measure the potential at locations where the potential measurement terminals are placed, at their intermediate locations, and to capture the depth direction, at an interval of 1 m from M. L.W.L. and L.W.L., which marks the start of the measurement level, to the seabed surface. A diagram of the inspection of cathodic protection is shown in Figure-4.4.12 and Figure-4.4.13.

Potential measurement terminal

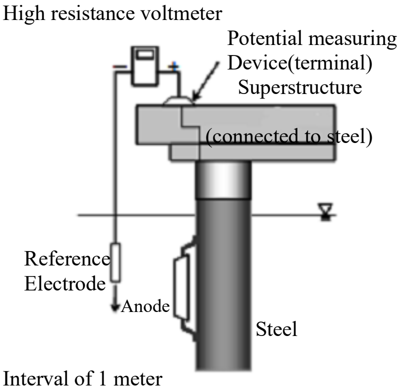



Figure-4.4.12 Potential Measurement method

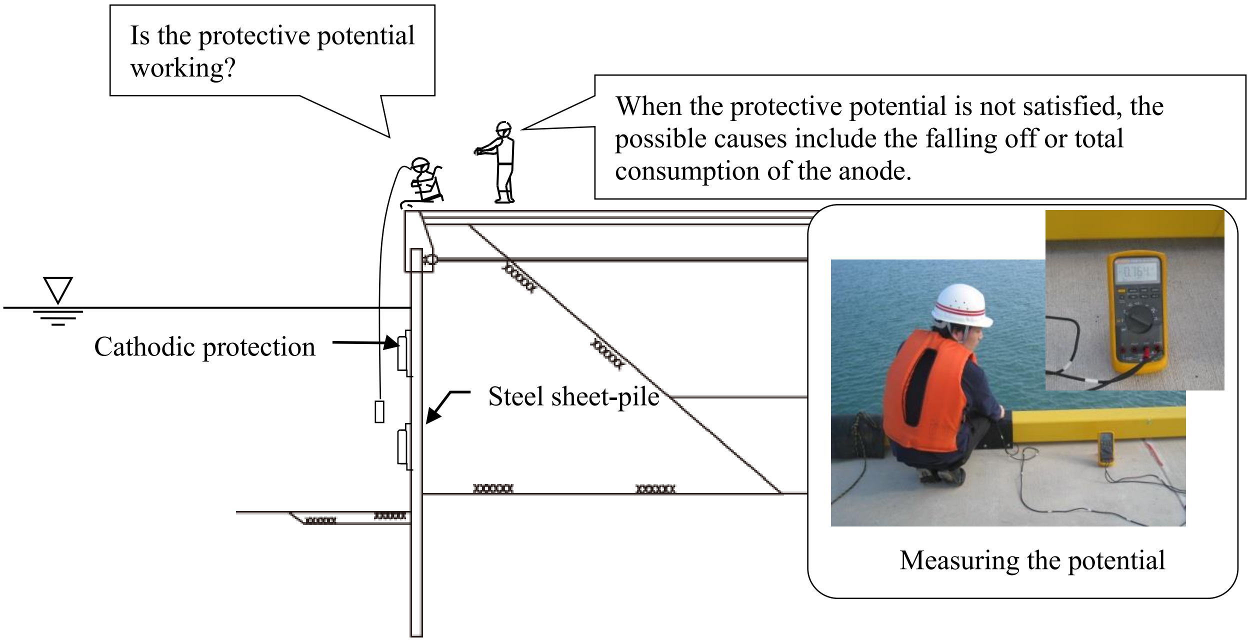



Figure-4.4.13 Inspection of cathodic protection work

7) Ancillary facility

| |
|---|
| For ancillary facility, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformation such as damage, change form, corrosion paint delamination. |

4.3.2 Detailed periodic inspection and diagnosis

| | |
|---|---|
| (5) | With respect to detailed periodic inspection and diagnosis of sheet-pile quaywall, the inspection and diagnosis should be performed to identify underwater deformations that cannot be observed by the regular periodic inspection and diagnosis. |
| (6) | Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation that influences the performance of sheet-pile quaywalls. |

1) Apron

| |
|---|
| Inspection and diagnosis of an apron should be performed to evaluate deformation, such as outflow of materials and cavity under apron. |

<Commentary>

For the inspection and diagnosis of an apron, **Apron (Part4 Chapter4 4.2.2 1)** should be followed.

2) Steel sheet pile

(1) For steel sheet piles, method of inspection and diagnosis should be underwater visual inspection to evaluate deformation such as corrosion, cracking and damage of the steel.

(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation of steel sheet pile.

<Commentary>

(1)

Visual inspection of the underwater for steel sheet piles may be omitted when corrosion protection is consistently working. Photo-4.4.3 shows a scene from visual inspection of the underwater for steel sheet piles.

However, when no corrosion protection (such as cathodic protection or protective coating) is provided, concentrated corrosion can occur on steel sheet pile. Therefore, visual inspection must be performed by divers to evaluate the corrosion condition of steel members. A diagram of inspection of steel sheet pile is shown in Figure-4.4.14.

Photo-4.4.3 Visual inspection of the underwater of steel sheet piles

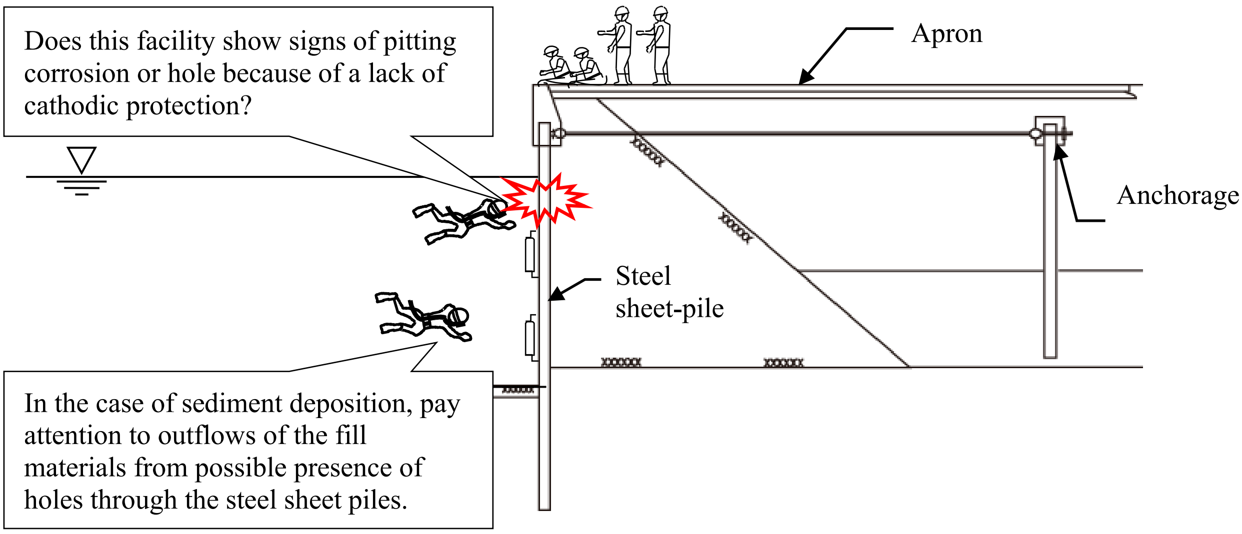



Figure-4.4.14 Diagram of inspection of steel sheet-pile

(2)

• Drawing deformation record sketch

A photo should be taken or sketches should be drawn of deformation such as corrosion, crack and damage after any marine organisms that have adhered to the target inspection location have been removed using a scraping device or other tools if necessary.

• Measuring steel thickness to understand the rate of corrosion or predict the progress of corrosion

The steel thickness should be measured at a total of four locations, including two locations higher than L.W.L. where concentrated corrosion is likely to occur and at two locations near a point where the maximum bending moment is likely to occur in the design.

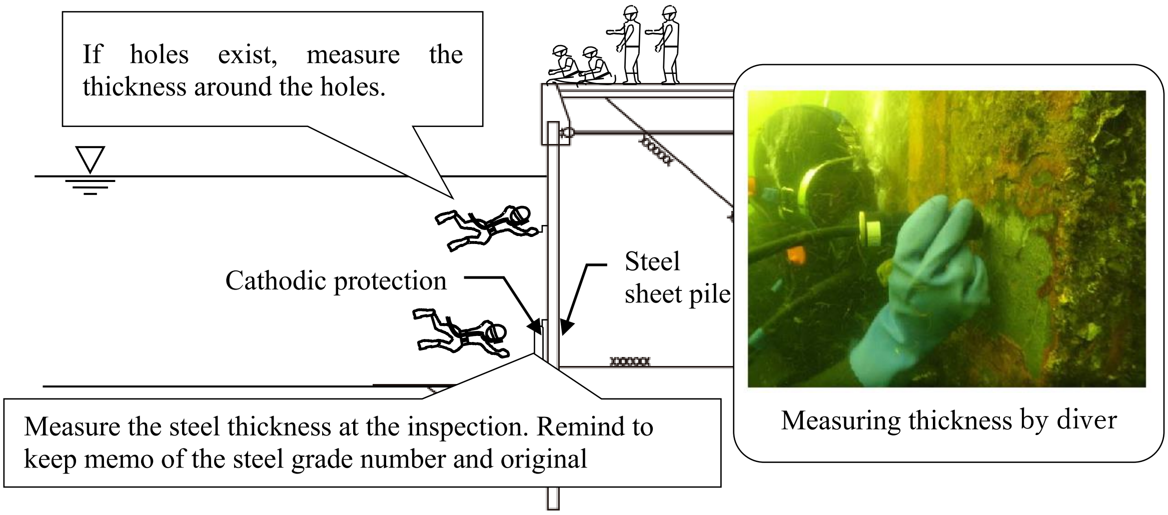



Figure-4.4.15 Diagram of measurement of thickness of steel sheet-pile

3) Protective coating

(1) For protective coating, method of inspection and diagnosis should be underwater visual inspection to evaluate deformation of part such as coating materials and protection covers.

(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation of protective coating.

<Commentary>

(1)

For the inspection and diagnosis of protective coating, **Protective coating for steel (Part4 Chapter4 4.3.1 5)** should be followed.

(2)

• Drawing deformation record sketch

A photo should be taken or sketches should be drawn of deformation such as corrosion, crack and damage after any marine organisms that have adhered to the target inspection location have been removed using a scraping device or other tools if necessary.

4) Cathodic protection

(1) For cathodic protection, method of inspection and diagnosis should be underwater visual inspection to evaluate deformation of part such as coating materials and protection covers.

(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation of cathodic protection.

<Commentary>

(1)

Anodes should be visually inspected for deformation, such as loss, degree of consumption, or the condition of installation. A diagram of inspection of cathodic protection is shown in Figure-4.4.16.

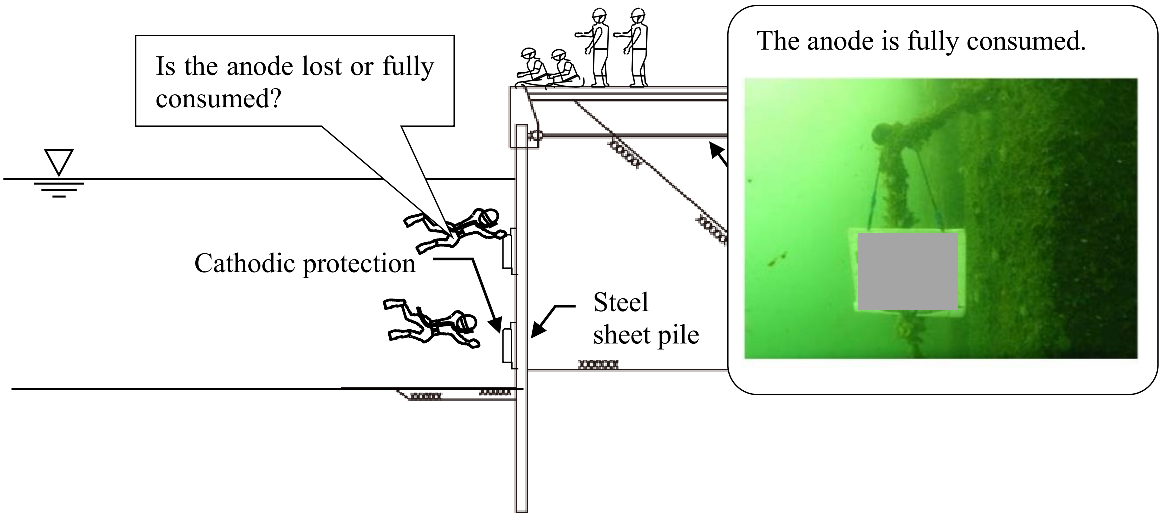



Figure-4.4.16 Diagram of inspection of cathodic protection

(2)

Measuring the amount of anode consumption allows for determining the remaining lifetime of the anode and the density of the protection current of the entire structure. The amount of consumption is estimated by either measuring the shape and dimensions of the anode underwater or weighing the anode after bringing it up on land.

Setting the timing to replace anodes is estimated by predicting result of anode consumption period.

• Surveying remaining mass based on shape measurement

When measuring the shape and dimensions of an anode, corroded products sticking to the anode surface should be removed by underwater removal work. Then, the procedure shown in Figure-4.4.17 should be followed to complete the measurements. Photo-4.4.4 shows an image of measuring the shape and dimensions of the anode. It is also recommended that photos should be taken of the work, if deemed necessary. The remaining mass of the anode is calculated using the following equation:

Photo-4.4.4 Image of measuring shape and dimensions of anode

$$\text{Remaining mass of anode} = [(D / 4)^2 \cdot L - \text{volume of core metal}] \times \text{density of anode}$$

where $D$: average perimeter = $(D_1 + D_2 + D_3) / 3$

$D_1$, $D_3$: Perimeter at a position approximately 100 mm from the edge of the remaining anode

$D_2$: Perimeter at the center of the remaining anode

$L$: Length of remaining anode

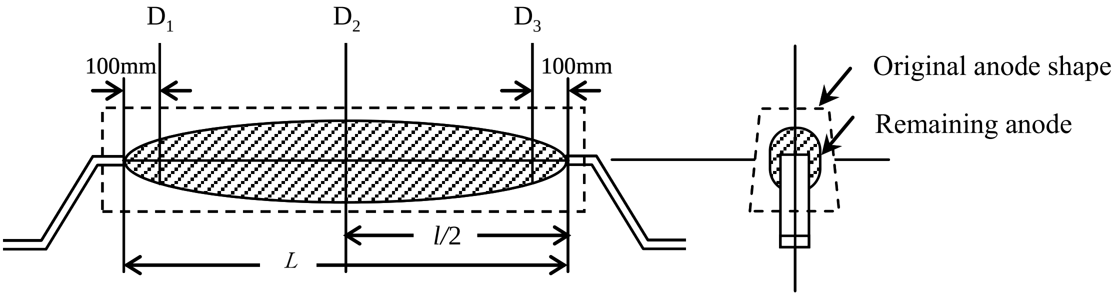



Figure-4.4.17 Method for measuring anode shape and dimensions

• Estimating the remaining life based on mass measurement

When weighing an anode, the core metal part of the anode should be cut and brought to land, and the remaining mass of the anode should be calculated by subtracting the core metal part. The remaining life of the anode is calculated from the amount consumed, remaining mass, and number of years elapsed.

Average annual consumption of anode

= (initial mass of anode − remaining mass of anode) / years elapsed

Remaining life = remaining mass of anode / average annual consumption of anode

5) Seabed

(1) Inspection and diagnosis of seabed should be performed to evaluate deformation, such as scouring and sediment deposition.

(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation of seabed.

<Commentary>

For the inspection and diagnosis of the seabed, **Seabed (Part4 Chapter4 4.2.2 3)** should be followed. Sediment deposition in front of steel sheet piles indicates the possible presence of holes through the steel sheet piles and resultant outflow of the fill materials.

6) Movement, subsidence or tilting of the entire facility

| |
|---|
| Measurements of movement, subsidence and tilting of breakwaters should be performed if required to assess deterioration over time, stability, or a similar variable. |

<Commentary>

This commentary is same with commentary of **Part4 Chapter3 3.2.2 4**.

7) Superstructures

| |
|---|
| Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate progress deterioration and analyze the causes of deformation of superstructure. |

<Commentary>

This commentary is same with commentary of **Part4 Chapter3 3.2.2 5**.

## 4.4 Inspection and Diagnosis of Pile-Supported Open-Type Wharf

### 4.4.1 Regular periodic inspection and diagnosis

| |
|---|
| With respect to regular periodic inspection and diagnosis of pile-supported open-type wharf, the deterioration level should be graded such as the vertical or lateral irregularities of face line of pile-supported open-type wharf, and deformations of apron, superstructure, caisson, and ancillary facility. Method for inspection and diagnosis should be visual inspection of external appearance from land and sea. |

1) Face line of pile-supported open-type wharf

| |
|---|
| For vertical or lateral irregularities in face line of pile-supported open-type wharf, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformations. |

<Commentary>

For items and methods of the inspection and diagnosis of the face line of pile-supported open-type wharf, **Quaywall face line (4.2.1 1)** should be followed.

2) Apron

| |
|---|
| For subsidence, collapse, deterioration, or damage to apron, method of inspection and diagnosis should be visual inspection to evaluate openings, gaps, uneven settlement, or any other deformations of a joint. |

<Commentary>

For items and methods of the inspection and diagnosis of an apron, **Apron (4.2.1 2)** should be followed.

3) Steel pipe piles

| |
|---|
| For steel pipe piles, method of inspection should be visual inspection from sea to evaluate deformation such as corrosion, cracking and damage of the steel. |

<Commentary>

For the inspection and diagnosis of steel pipe piles, **Steel sheet piles (4.3.1 3)** should be followed.

4) Protective coating

| |
|---|
| For protective coating, method of inspection and diagnosis should be visual inspection from sea to evaluate deformation of part such as coating materials and protection covers. |

<Commentary>

For the inspection and diagnosis of protectiive coating, **Protective coating for Steel (4.3.1 5)** should be followed.

A diagram of an inspection of a protective coating is shown in Figure-4.4.20.

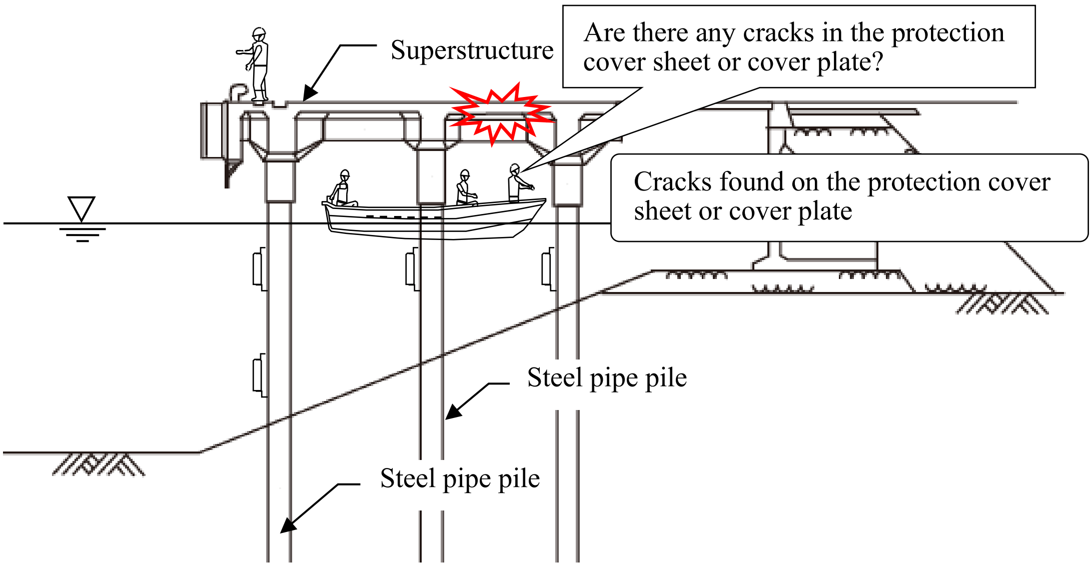



Figure-4.4.20 Diagram of an inspection of the pile-supported open-type wharf (bottom surface)

5) Cathodic protection

| |
|---|
| For cathodic protection, electrical potential should be measured to evaluate whether protective potential is maintained. |

<Commentary>

For the inspection and diagnosis of cathodic protection, **Cathodic protection (4.3.1 6)** should be followed.

6) Superstructure (bottom surface, surface, and sides)

| |
|---|
| For superstructure (bottom surface, surface, and sides), method of inspection and diagnosis should be visual inspection from sea to evaluate deformation such as deterioration or damage of concrete. |

<Commentary>

Photo-4.4.5 An example of deterioration on the bottom surface of a wharf superstructure

Deformation of the concrete of a wharf superstructure is caused mainly by external forces, such as surcharges, damage from collision with a vessel, and natural disasters, or deterioration, such as by chloride-induced corrosion. Since rebar corrosion on the bottom surface of the wharf superstructure progresses quite rapidly, if this phenomenon is unaddressed, safety or functionality will be quickly compromised.

The inspection and diagnosis of the bottom surface of the wharf superstructure should be visually conducted from a small boat. When it is impossible for even a small boat to go under the wharf, visual inspection should be made by divers. It is generally difficult to have sufficient time to work or good working conditions because of the impact of tides or ship waves. Hence, an appropriate work plan should be prepared in advance.

When the bottom surface of a wharf superstructure is covered by paint coating, deformation, such as cracking or delamination, should be checked. When a deformation is found, anomalies in the concrete, such as cracking, may have already occurred. Since deformation progresses at different rates depending on the type and location of a member, all the members should be inspected in principle. However, if the rate of deformation progression can be ascertained for a member based on the results of the previous inspection and diagnosis, then a more efficient inspection and diagnosis can be undertaken by examining only those members that must be thoroughly checked to determine the progression of deformation and necessary actions.

If it is too difficult to inspect visually concrete delamination or spalling, it is effective to conduct a hammering test.

When the superstructure is made of prestressed concrete, cracking in the concrete or corrosion of the reinforcing bars or prestressing steel immediately affects the safety of members. Therefore, it is necessary to carefully inspect those points. When cracking or rust strain is observed, it is urgent to investigate the causes and review what measures should be taken and by what methods.

A diagram of an inspection of a wharf superstructure (surface and bottom surface) is shown in Figure-4.4.21.

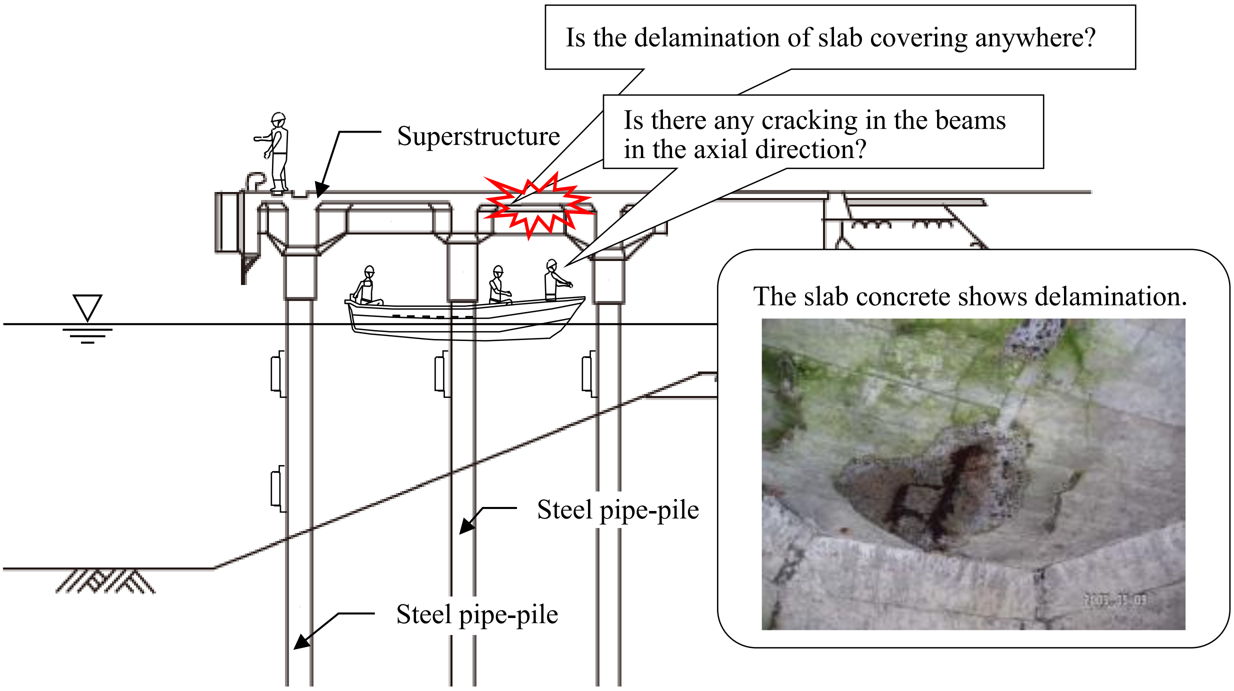
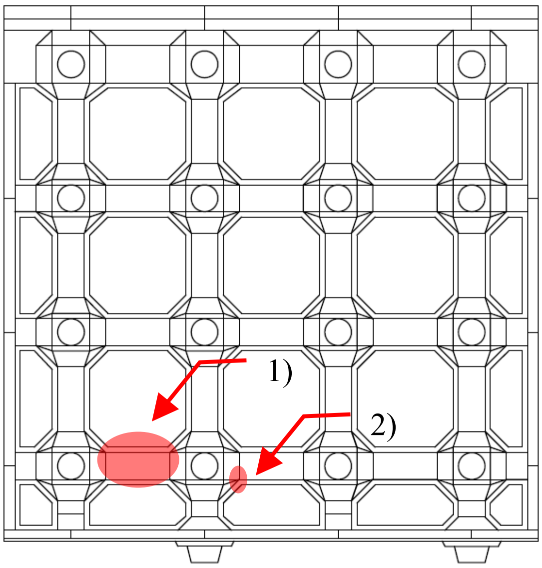



Figure-4.4.21 Diagram of an inspection a wharf superstructure (bottom surface)

7) Example of method for grading deterioration level of a wharf superstructure (bottom surface)
As the wharf superstructure is an important member for which preventive maintenance measures is required to be taken, the deterioration level of a wharf should be determined for "every span (block) in the superstructure." However, the methods for determining the deterioration tend to be complex, since the structure is composed mainly of slabs, beams, and haunches. An example of the methods is shown below:

Figure-4.4.22 shows an example of visual inspection of wharf superstructure (bottom surface) from sea. In this case, the inspection from sea indicated the sporadic occurrence of rust strain over all the blocks and partial "delamination of concrete".




Rust stain occurs in a spotted pattern in most members. The result is "c."

1) Delamination of concrete. The result is "a."

2) Delamination of concrete. The result is "a."

Figure-4.4.22 An example of visual inspection of wharf superstructure (bottom surface) from sea

An example of the result of determining the deterioration level per member is shown in Figure-4.4.23

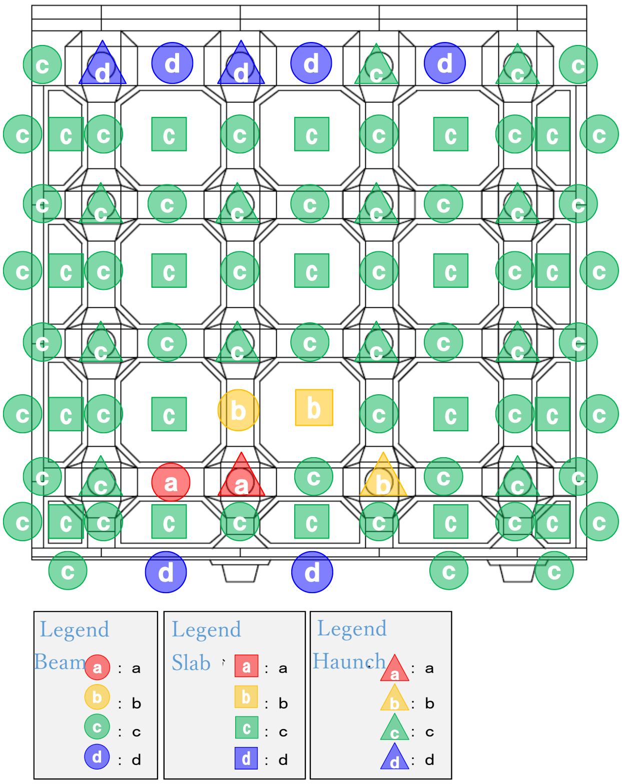



Figure-4.4.23 An example of result of determining deterioration level per member

Representative value of the deterioration level of a single block is determined by the following method.

Considering the wharf superstructure (bottom surface) belongs to category II, the representative value of deterioration level is given as follows, for example.

| Member | The deterioration level per member | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | a | Ratio | b | Ratio | c | Ratio | d | Ratio | | |
| Slab | 0 | 0% | 1 | 5% | 19 | 95% | 0 | 0% | 20 | 100% |
| Beam | 1 | 2% | 1 | 2% | 42 | 86% | 5 | 10% | 49 | 100% |
| Haunch | 1 | 6% | 1 | 6% | 12 | 75% | 2 | 13% | 16 | 100% |
| Total | 2 | 2% | 3 | 4% | 73 | 86% | 7 | 8% | 85 | 100% |
| Representative value of deterioration level for a block | | | | | | | | | deterioration level of this example | |
| Representative value of deterioration level “a” | Ratio of members with deterioration level a ≥ 30% | | | | | | | | – | |
| Representative value of deterioration level “b” | Ratio of members with deterioration level a +b ≥ 30% | | | | | | | | – | |
| Representative value of deterioration level “c” | Ratio of members with deterioration level d < 70% | | | | | | | | ✔ | |
| Representative value of deterioration level “d” | Ratio of members with deterioration level d ≤ 70% | | | | | | | | – | |

8) Earth-retaining part

| |
|---|
| For earth-retaining, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformation with considering structural type of earth-retaining part. |

<Commentary>

The deformation at earth-retaining part is similar with the deformation at caisson type quaywall and sheet-pile quaywall. For the inspection and diagnosis of the earth-retaining part, that of **Caisson type quaywall(4.2) and Sheet-pile quaywall(4.3)** should be followed.

The method of inspection and diagnosis should be visual inspection from a small boat. When it is impossible for even a small boat to go under the wharf, visual inspection should be performed by divers. It is difficult to secure sufficient time to work or good working conditions because of the impact of tides or ship waves. Hence, an appropriate work plan should be prepared in advance.

9) Access bridge

| |
|---|
| For access bridge, method of inspection and diagnosis should be visual inspection from land and sea to evaluate deformation such as deterioration or damage. |

<Commentary>

Serious deformation of an access bridge prevents smooth movement from the wharf superstructure to the hinterland. Moreover, serious deformation could result in not only disrupting cargo handling but also an accident, such as a fall.

The regular periodic inspection and diagnosis of an access bridge focuses mainly on damage, cracking, dislocation, or movability (that is, whether the movable or fixed condition of the bridge as designed is maintained) of the access bridge.

If possible, the use a small boat is recommended, for example, to go under the wharf and inspect the condition of the bottom surface of the access bridge or the condition of the bearings.

9) Ancillary facility

| |
|---|
| For ancillary facility, method of inspection and diagnosis should be visual inspection from land and sea to evaluate for deformation such as damage, deformation, corrosion paint delamination. |

4.4.2 Detailed periodic inspection and diagnosis

(1) With respect to detailed periodic inspection and diagnosis of pile-supported open-type wharf, inspection and diagnosis should be performed to identify underwater deformation that cannot be observed by regular periodic inspections and diagnosis.
(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate degradation and analyze the causes of deformation that influence performance of pile-supported open-type wharf.

1) Apron behind the earth-retaining part

Inspection and diagnosis of an apron behind earth-retaining part should be performed to evaluate deformation, such as washout of materials and cavity under the apron.

<Commentary>

For the inspection and diagnosis of an apron behind the earth-retaining part, **Apron (4.2.2 1)** should be followed.

2) Steel pipe pile

(1) For steel pipe piles, method of inspection and diagnosis should be underwater visual inspection to evaluate deformation such as corrosion, cracking and damage of steel.
(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate degradation and analyze the causes of deformation of steel pipe pile.

<Commentary>

For the inspection and diagnosis of steel pipe piles, **Steel sheet piles (4.3.2 2)** should be followed.

3) Protective coating

(1) For protective coating, method of inspection and diagnosis should be underwater visual inspection to evaluate deformation of part such as coating materials and protection covers.
(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate degradation and analyze the causes of deformation of protective coating.

<Commentary>

For the inspection and diagnosis of protective coating, **Protective coating (4.3.1 5) and (4.3.2 3)** should be followed.

4) Cathodic protection

(1) For cathodic protection, method of inspection and diagnosis should be underwater visual inspection to evaluate deformation of part such as coating materials and protection covers.
(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate degradation and analyze the causes of deformation of cathodic protection.

<Commentary>

For the inspection and diagnosis of cathodic protection, **Cathodic protection (4.3.2 4)** should be followed.

5) Wharf superstructure (bottom surface, surface, and sides)

When the data necessary for investigating possible causes of deformation of wharf superstructure (bottom surface, surface and sides) or for predicting their progression are collected, surveys that are suited to specific purpose should be conducted.

<Commentary>

Quantitative data should be collected in accordance with the following methods:

• When creating deformation record sketch

Photos should be taken or sketches should be drawn of cracking condition, delamination, damage, exposed reinforcing bars, and other deformation after removing any marine organisms that have adhered to the target inspection location using a scraping device or other tools.

• When predicting the deterioration of a wharf superstructure by measuring chloride ion content

Chloride ion content should be measured when visual inspection finds no deformations such as cracking. If deformation such as cracking has already occurred, rebar corrosion is likely underway. Therefore, measuring chloride ion content may not necessarily provide useful information.

The chloride ion concentration is measured using a core sampled from a reinforced concrete structure or concrete powder obtained from drilling. Measuring chloride ions in concrete is generally conducted for a rebar location (cover depth) and certain points in the depth direction from the surface.

The chloride ion concentration at a rebar location serves as a basis for determining whether rebar corrosion has started.

Technical Standards for Port and Harbor Facilities in Japan adopt 2.0 kg/$m^3$ as the lowest critical corrosion concentration of chloride ions, based on the independent survey result in Japan. This standard, 2.0 kg/$m^3$, can be approved as a reference value for other countries depending on the condition.

6) Seabed

(1) Inspection and diagnosis of seabed should be performed to evaluate for deformations, such as scouring and sediment deposition.
(2) Inspections and surveys should be performed according to definite purpose in the case of collecting necessary data to estimate degradation and analyze the causes of deformation of seabed.

<Commentary>

For the inspection and diagnosis of the seabed, **Seabed (4.2.2 3)** should be followed.

7) Movement, subsidence or tilting of the entire facility

Measurements of the movement, subsidence and tilting of breakwaters should be performed if required to assess deterioration over time, stability, or a similar variable.

<Commentary>

For the inspection and diagnosis of movement, tilting or subsidence of the entire facility **Movement, subsidence and tilting of breakwaters (3.2.2 4)** should be followed.

# Part 5 Investigation Technologies

## Chapter 1 General

### 1.1 Scope of Application

| |
|---|
| This part specifies investigation technologies used in inspection and diagnosis of port and harbor facilities. |

<Commentary>

This part specifies investigation technologies, fundamental to the maintenance and repair of facilities, used in the inspection and diagnosis of port and harbor facilities.

When performing investigations, due consideration is required to be given to the safety of the persons overseeing the inspection or investigation and the investigation equipment, ensuring no third-party interference. Furthermore, adequate safety equipment should be installed.

## Chapter 2 Visual Inspection

### 2.1 Outline

(1) Visual inspection should be properly and objectively performed, ensuring that important deformations are not overlooked.

(2) Visual inspection is classified into inspection on land, inspection above sea level, and inspection below sea level.

(3) Results of visual inspection should be appropriately recorded and preserved in consideration for future inspection and diagnosis programs for the corresponding facilities.

<Commentary>

(1)

Visual inspection is fundamental for comprehending the condition of a whole structure. Deformation generated on the surface of a structure or displacement and deformation due to the tilting or settling of the whole structure can be identified by visual inspection. When deformation appears to be progressive and is therefore a concern, a continuous visual inspection enables the understanding the progression of the deformation, which can be useful after the implementation of effective and efficient countermeasures for maintenance and repairment.

The form, type, and cause of deformation of port and harbor facilities vary, so it is difficult to surmise the factors in and the locations of deterioration in advance. Therefore, when performing visual inspection, every part of the whole structure should be investigated to the greatest extent possible while remaining objective. However, there are often cases in which visual inspection is difficult because of the area, member, or location of the investigated structure. In these cases, the inspection may be supplemented with instruments as necessary.

Moreover, determining the state of the deformation present in the whole structure or on its surface

with photographs or measuring the size of deformations is also important.
(2)
The subjects of visual inspection are divided into the following: the structures or structural members on land; those above and below sea level; and the seabed, rubble mounds, wave-dissipating blocks, and other features below sea level.
Reconnaissance is fundamental to visual inspection on land. Therefore, the conditions of the structures should be observed from land to the extent possible. When a structure is not approachable, a pair of binoculars or similar equipment may be useful. In the case of visual inspection above sea level, the conditions of a structure may be generally observed on board a ship. Photo-5.2.1 shows an inspection above sea level using a boat.

Photo-5.2.1 A visual inspection above sea level using a boat

Visual inspection below sea level is required to be carried out by divers or by using instruments such as underwater cameras. Inspection in conditions such as highly turbid seawater should be avoided, as phenomena such as turbidity greatly affects work efficiency. In addition, as is often the case, structural members in the tidal zone are covered by the adherence of living organisms; hence, more exact results can be obtained if the structure is observed after the removal of such organisms, when possible.

# Chapter 3 Measurement of Displacement and Water Depth

## 3.1 Measurement of Displacement

| |
|---|
| (1) In measuring displacement of structures, methods should be selected according to deterioration of structure and required measurement accuracy.<br>(2) Measurement results of displacement should be adequately recorded and preserved, considering future inspection and diagnosis programs for target structure. |

<Commentary>

(1)

Displacement is the movement of structure certain parts or members constituting the structure from their prescribed position. Displacement is caused by environmental hazards, such as natural disasters and ground settlement, and can be divided into two types: “unexpected,” which occurs once, and “progressive,” in which the situation continues to change. This section specifies the measurement of displacement caused by the horizontal movement of port and harbor facilities and vertical displacement caused by settlement and tilting. When measuring the displacement of port and harbor facilities, it is important to select adequate inspection and survey methods based on the deterioration of the target structure and factors such as the planning conditions and natural conditions of the facilities. Displacement measurement includes simple instruments, such as measuring tape, leveling rods and inclinometers as well as methods, including surveys that use instruments such as total stations and leveling instruments, surveys that use UAVs[1)], and GNSS surveys[2)].

In recent years, a system has been developed that can simultaneously measure structural deformation and settlement by taking digital photos, mapping the results, and obtaining visual inspection data, thus offering an effective survey method for measuring the movement and settlement of structures[3)].

In survey methods that use total stations and leveling instruments, measurement points are established in the structure (facility), and displacement is quantified by measuring their position coordinates and heights. The coordinates of a measurement point (x, y) are chosen as follows: the main reference point and supplementary reference points are set and surveyed, the measurement points are surveyed from each reference point, and the height (z) is chosen by leveling. Although the measurement points are set at the four corners of the superstructure, as concrete around corners is often broken or cut, it is reasonable to drive a simple survey rivet at a certain distance (approx. 50 to 200 mm) from each corner. As a reference, the overview for setting each reference and measurement point are shown in Table-5.3.1. Examples of survey rivets and their positions are shown in Photo-5.3.1, and examples of setting each reference and measurement point in a breakwater are shown in Figure-5.3.1 and Figure-5.3.2.

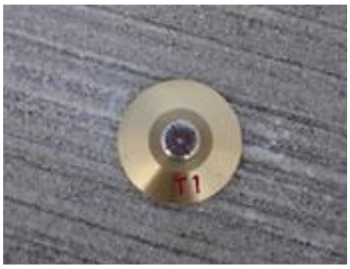
In the second or later examinations, the measurement points are surveyed after confirming that there is no movement or settlement of the preset main and supplementary reference points (these reference points are measured again).

Table-5.3.1 Reference points and measurement points for surveys

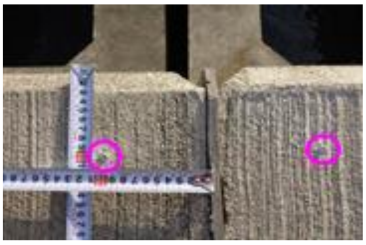
| Category / Item | Main reference point | Supplementary reference point | Measurement point |
|---|---|---|---|
| Setting purpose | Reference points as a survey base for facility displacement | Reference points to confirm measurement points | Measuring points to confirm displacement of structure; confirm displacement by measuring at the same positions for a long period. |
| Known point (given point) | Electronic reference points, grade 1 and grade 2 reference points, grade 1 to grade 4 triangulation points, and reference points for port and harbors | Main reference points | Main reference points and supplementary reference points |
| Setting place | Set at both ends of the structure (facility)<br>• Approx. 500 m intervals (grade 2 reference points)<br>•Approx. 200 m intervals (grade 3 reference points)<br>Also set between intervals for long facilities<br>If the main reference points are set at an adjoining facility, these points may be used. | Set at approx. 50-100 m intervals | (Reference example)<br>Breakwater: Near the four corners of the superstructure<br>(Positioned approx. 50-200 mm from each corner of the superstructure)<br>Quaywall: Near both ends of each block on the ocean side and several lines in a direction normal to the face line<br>(Confirmation of settlement of the apron) |
| Observation method (survey instrument) | Grade 2 and grade 3 reference point survey level<br>(static method (GNSS) and total station)<br>Grade 4 leveling | Grade 4 reference point survey level<br>(total station)<br>Grade 4 leveling | Angle and distance measurements<br>(total station),<br>Grade 4 leveling |

Survey rivet


Main reference point

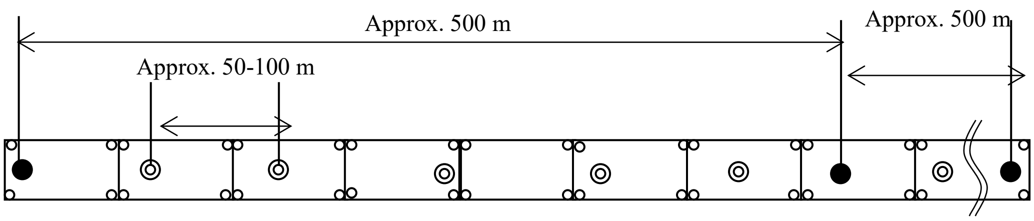



Supplementary reference point



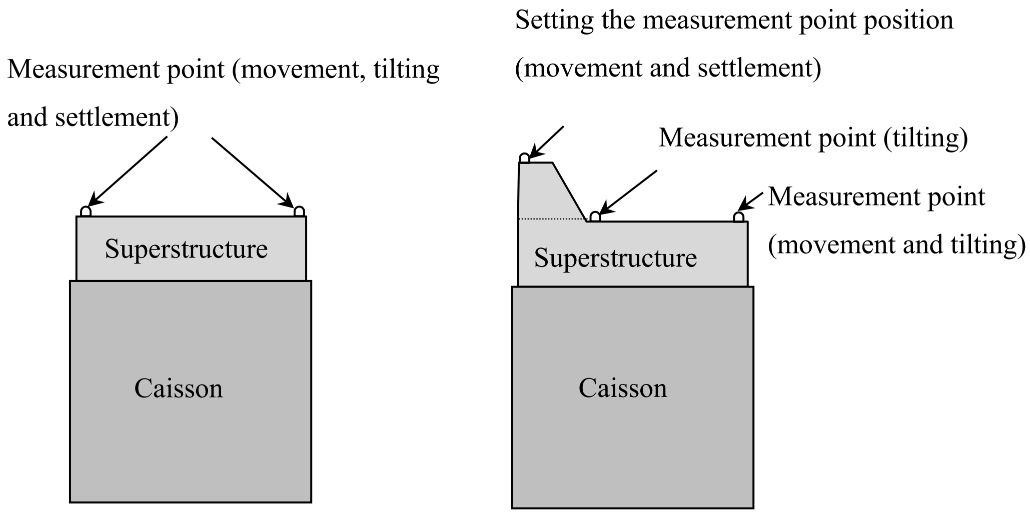
Measurement point

Photo-5.3.1 Example of survey rivets




Legend: ●Main reference point, ◎supplementary reference point, ○measurement point

Figure-5.3.1 Example of setting reference points and measurement points for a breakwater (plan)




Structure without parapet

Structure with parapet

Figure-5.3.2 Example of setting measurement points for a breakwater (cross section)

In recent years, surveys using the Global Navigation Satellite System (GNSS) are often performed to make surveys more efficient and to cover wider ranges. GNSS is a general term for position determination systems that use navigation satellites, such as the global positioning system (GPS) developed in the USA, the Russian GLONASS and the Japanese Quasi-Zenith Satellite System. Survey methods using GNSS are classified as shown in Figure-5.3.3.

Single point positioning is a method to determine the position of a receiver by measuring the distance from a satellite using a single receiver. However, this method is unsuitable for work that requires a high degree of accuracy.

Relative positioning is a method for measuring positions using multiple receivers. Although the differential method (D-GPS) is slightly less accurate than the interference positioning methods, it can carry out surveys quickly and is therefore utilized for work such as guiding ship positions in bathymetric surveys. In contrast, the interference positioning method is used for reference point surveys, topography surveys and displacement surveys concerning the maintenance and repair of facilities, such as revetments and breakwaters. The characteristics of each type of interference positioning method are shown in Table-5.3.2.

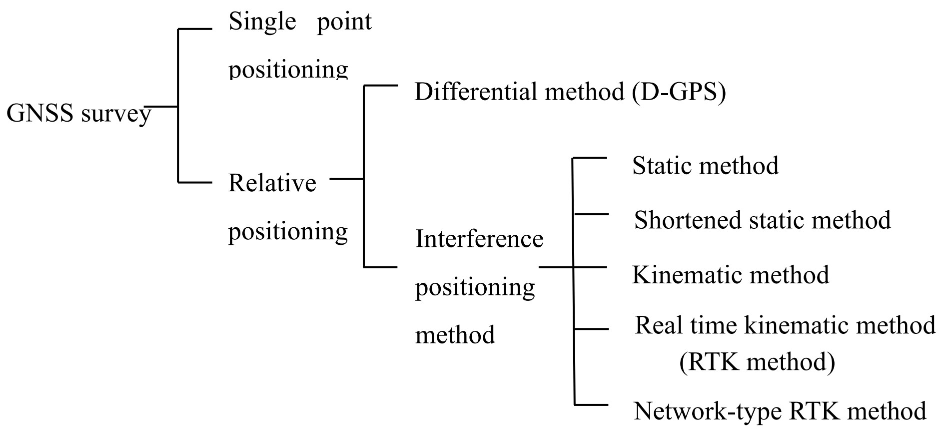



Figure-5.3.3 Classification of GNSS position determination methods

Table-5.3.2 Characteristics of each type of interference positioning method

| Positioning method | Characteristics |
|---|---|
| Static method (Static interference positioning method) | Positions are decided through long-term continuous observation of radio waves from four or more satellites with multiple receivers. Compared with other methods, this method provides considerably more accurate observations. In shortened static methods, the same types of observation as in the statistic method are performed, albeit with greater efficiency due to briefer data acquisition intervals from receiving more satellite waves. |
| Kinematic method | One receiver is installed at a reference station (fixed station), and another receiver performs observations while moving (mobile station). The relative positions of the fixed station and the mobile station are determined using this method. |
| RTK method | A type of kinematic method that rapidly determines the coordinates as observational data from receivers are exchanged through radios and mobile phones. Although this method is not as accurate as the conventional static method, it offers greater work efficiency because the observation time is shorter, and observations can be made with fewer workers. When the distance between the reference station and the mobile station increases, the observation accuracy decreases. |
| Network-type RTK method | This method offers the same level of accuracy as the RTK method, even if the reference stations and mobile stations are far apart, by utilizing real-time data from three or more reference stations (electronic reference points). |

These GNSS position determination techniques are applied to facilitate the continuous monitoring of changes or disaster situations in a wide area.

(2)

The observation results of displacement are preserved for use in determining the necessity of measures and in understanding the chronological behavior of the structure. The details concerning the recording of the observation results are provided in Part 8.

### 3.2 Measurement of Water Depth and Survey of Underwater Shape

| |
|---|
| (1) When measuring water depth and surveying underwater shape, adequate methods should be selected according to target facilities and required measurement accuracy.<br>(2) Results of water depth measurement and underwater shape surveys should be properly recorded and preserved, considering future inspection and diagnosis programs for the target facilities. |

<Commentary>

(1)

This section is mainly relevant to measuring the water depth of navigation channels, basins and small craft basins and also to measuring the underwater configurations around breakwaters, quaywalls, and revetments.

When measuring depth, it is important to cautiously plan and measure while considering that most work is completed at sea. Inspection and survey methods should be chosen, considering the planning conditions of the facilities (e.g., area and form of the facilities), natural conditions (e.g. depth, tidal current, soil on the sea bottom) and the required measurement accuracy.

The following are the principal methods for measuring depth:

① Using a sounding scale

② Lead depth measurements

③ Using an echo sounder

To accurately measure depth, the observed data is required to be corrected based on inspection and survey equipment. In addition, errors in the obtained water depth data and the expressed topography should be identified. For details of the methods for measuring depth, refer to the related manuals[4)-6)].

The multibeam depth measurement system, which can measure a wide range of water depth data in two dimensions, has often been used in recent years[7)]. This system is used for not only performing bathymetric surveys but also understanding the scattering of foot protection blocks and wave-dissipating concrete blocks in the sea, scouring, and sedimentation. In addition, it is possible to obtain three-dimensional location information (topography and displacement data) from underwater to above sea level by surveying the water depth and seabed shape using the multibeam depth measurement system, performing three-dimensional surveys of the topography above sea level using UAVs and other equipment, and then correcting and integrating the data from both surveys. However, it is necessary to plan the measurements based on the object of the survey, as observation data are often unavailable near the water surface, and there are differences in the density of point group data underwater and above sea level.

(2)

It is preferable to save the measurement results of the water depth in forms such as isobath diagrams to determine the necessity of measures or to understand chronological changes in water depth. For details regarding measurement result records, refer to Part 8.

# Chapter 4 Cavity Investigation

## 4.1 Cavity Investigation under Apron

(1) Cavities in lower part of apron should be investigated by combining appropriate methods and considering types or construction of structures.

(2) Cavity investigation results should be appropriately recorded and preserved, considering future inspection and diagnosis programs for target structure.

<Commentary>

Cavity investigations clarify the condition of cavity around a structure. Cavity investigations are critical, as their results are used to determine the necessity of detailed surveys or additional measures. For a structure for which there is concern about the progression of deformation, the continuous implementation of cavity inspection helps determine the status of the deformation.

Conditions that suggest cavities include the formation of water puddles at caisson joints or at the boundary between caisson and its rear ground, the presence of cracking in the apron parallel to the face line of quaywall, and the accumulation of backfill or fill materials on the seabed.

Cavities in the lower part of an apron is a typical deformation that occurs to a revetment, dyke, gravity quaywall, or sheet-pile quaywall. For example, the typical progression of deformations in a gravity quaywall is suggested by the subsidence or tilting of the main structure or fill materials by the consolidation settlement of the ground or subsidence, breakage, or collapse of the apron by outflow of backfill or fill materials through joints. For concrete pavement, in particular, cavity occurs in the lower part of the apron without causing subsidence.

The characteristics of cavity investigation methods are as follows:

1) <u>Using an electromagnetic wave radar</u>

As shown in Figure-5.4.1, the electromagnetic (EM) wave radar method is a nondestructive testing method that utilize the property of EM waves emitted from a transmitter antenna reflecting at the boundary of materials with different electrical properties (such as electric permittivity or specific resistance)[8), 9)]. When an EM radar method is used to perform cavity investigation of under apron, for example, the received waves show regular shapes when no cavities exist at the inspection point. When cavities exist, the received waves include the reflections from not only the under apron but also the surfaces of the cavities. Hence, in theory, the waveforms are more complicated than when no cavities exist. In addition, focusing on changes in the waveforms (such as amplitude or phase) may allow for the estimation of the planar or spatial spread of cavities. Figure-5.4.2 shows an image obtained with the electromagnetic wave radar method.

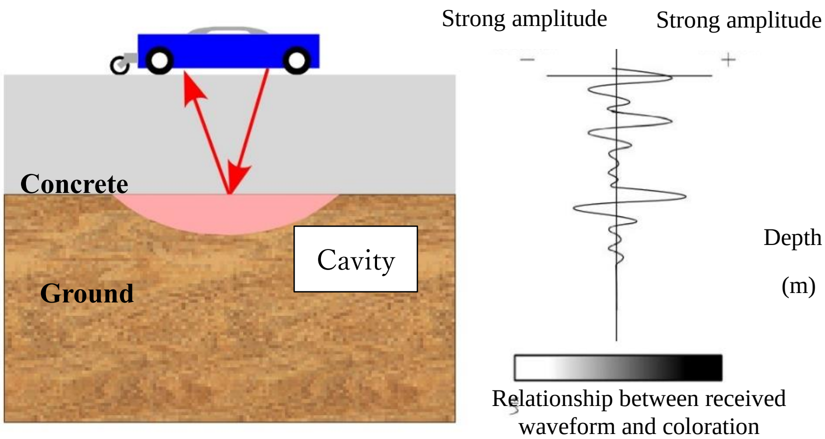



Figure-5.4.1 Conceptual diagram of measurement with the electromagnetic wave radar method

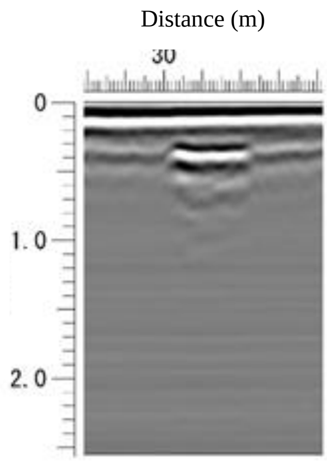



Figure-5.4.2 Example of an image from the electromagnetic wave radar method

The EM radar method currently utilized in cavity investigation is largely divided into several types, as shown in Table-5.4.1. An approximate guide for the relationship between the frequency and survey depth of EM waves is shown in Table-5.4.2[10)]. The advantages of the higher frequencies of EM waves include greater resolution and the ability to inspect smaller cavities. However, a major disadvantage is a shallower inspection depth. Therefore, in the actual implementation of cavity investigation, it is necessary to utilize the appropriate instrument in considering the material of the object and the depth in the material.

Generally, the impulse radar method is suitable for surveying cavities that occur on the under apron. However, it is necessary to monitor changes in the detectable depth and resolution, depending on the soil material to be inspected, groundwater level, or type and thickness of the apron pavement. The EM radar method can be used to determine the presence and location of cavities but cannot easily determine the thickness (depth) of a cavity; this method also is not useful for underwater cavity inspection. It is therefore necessary to know the position of the groundwater when investigating the lower part of an apron.

Table-5.4.1 Types of EM radar methods used in cavity inspections

| Methods | | Characteristics |
|---|---|---|
| Impulse radar | For underground cavities | • General underground radar equipment<br>• Used in cavity searches under roads |
| | For cavities behind concrete | • Can detect cavities at the back of reinforced concrete |
| Continuous wave radar | | • Survey depth is approximately 5 times that measured with ordinary equipment. |
| Chirp radar | | • Survey depth is approximately 2 times that measured with ordinary equipment. |

Table-5.4.2 Approximate guide for determining the relationship between the frequency and survey depth of EM radar methods[10)]

| Target | Frequency used | Survey depth (m) |
|---|---|---|
| Underground piping | 300 to 500 MHz | 0.5 to 2 |
| | 80 to 120 MHz | 2 to 10 |
| Cavities under road | 500 to 700 MHz | Just underneath the pavement surface |
| | 200 to 500 MHz | 0.5 to 3 |
| Cavities in bedrock | 500 MHz | 1 to 2 |
| | 300 MHz | 2 to 5 |
| | 80 MHz | 5 to 10 |
| Rebar in concrete | 1000 MHz | 0.05 to 0.3 |
| | 900 MHz | 0.1 to 0.5 |
| Thickness of pavement | 1000 MHz | 0.05 to 0.3 |
| | 900 MHz | 0.1 to 0.5 |

2) Using an inspection hole

This method involves drilling an inspection hole in the pavement in advance to directly evaluate the presence and progression of cavities[11)]. This method can be used at different sites, as it enables the direct and quantitative determination of the presence and progression of cavities. Furthermore, this method requires no advanced or specialized knowledge, can be used to identify cavities in daily inspections, and can be used on both newly paved roads and existing pavement. When an inspection hole is drilled through the caisson superstructure, it indicates any washout of fill sand associated with damage to caisson sidewalls.

# Chapter 5 Site Investigation for Steel Materials and Corrosion Protection Systems

## 5.1 Outline

| |
|---|
| In site investigation of steel materials constituting steel structures of port and harbor facilities and their corrosion protection systems, it is necessary to choose adequate methods based on the condition of the target structures, required information and accuracy, and the causes of deformation. |

<Commentary>

The steel structures of port and harbor facilities are exposed to marine environments and are therefore under severely corrosive conditions compared with onshore steel structures. This chapter is mainly relevant to the steel structures of port and harbor facilities (e.g., quaywalls, open-type wharfs, revetments) that use steel sheet piles, steel pipe sheet piles, and steel pipe piles. This chapter may also be applied with modifications to other steel structures in port and harbors and underwater when carefully considering and assessing their conditions.

This chapter details the following standard site investigation methods:

① Site investigation of electric corrosion protection using a cathodic protection system with galvanic anodes

② Site investigation of protective coating system

③ Plate thickness measurement of steel materials

## 5.2 Site Investigation of Cathodic-Protection System

(1) Site investigation of cathodic protection systems with galvanic anodes generally assesses following items:

①Electric potential of steel materials

② Installation status and consumption of anodes

(2) In addition to (1), examinations to understand chronological trends in corrosion protection effects should be carried out if necessary.

<Commentary>

(1)

A site investigation of a cathodic protection system with galvanic anodes is generally carried out to ① measure the potential of the steel materials and ②determine the installation status and consumption of anodes.

Measuring the potential of steel structures can indicate the current corrosion state of a structure. If the potential of steel submerged in seawater and measured by an Ag/AgCl[sw] electrode is less than -800 mV (corrosion protection management potential), the corrosion of the structure is under control. However, if the electric potential of steel is greater than the corrosion control management potential, the corrosion is out of control. As abnormalities such as exhaustion or anode drops occur, it is also necessary to examine the installation or consumption of the anode.

① Potential of steel materials

The potential of steel materials can typically be measured with a high resistance voltmeter, reference electrode and a potential measurement apparatus installed at the target structure of corrosion protection. In general, a DC voltmeter with an internal resistance of 1 MΩ/V or greater can be used as a high resistance voltmeter, and an Ag/AgCl[sw] electrode can be used as a reference electrode. However, if a reference electrode is used in a location such as on the seabed, where it is difficult to replace reference electrodes, and the same electrode is therefore continuously used for a long period, it is necessary to use a zinc electrode, whose composition maintains a stable and intrinsic potential. A long-term (approximately 10 years) onsite experiment has confirmed that a zinc electrode possesses sufficient durability in a severe environment with large waves or sand movement.

The potential of corrosion protection target structures in seawater is measured at 1meter intervals in the depth direction of the structure, as shown in Figure-5.5.1. The same measurement points can be used each time. It is important to confirm the transition of the corrosion protection status with changes in potential. For potential measurements, the positive terminal of the high resistance voltmeter is connected to the potential measurement apparatus through a lead wire, while the negative terminal is connected to the reference electrode. For connection jigs, instruments, such as alligator clips, that have low contact resistance are generally used. It is also necessary to attach a weight to the reference electrode in advance so that the measurement position does not change due to conditions such as tides. Potential measurement apparatuses (Photo-5.5.1) are installed every 20 to 50 meters in the extending direction of the corrosion protection target structure. The potential is generally measured at the points where potential measurement apparatuses are installed and at the midway points.

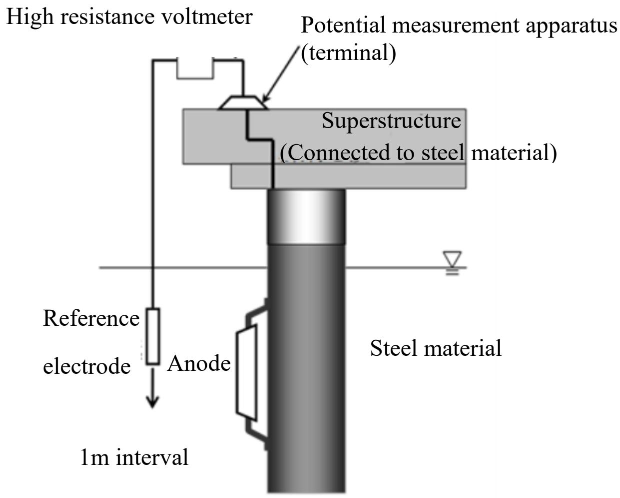



Figure-5.5.1 Potential measurement method

Photo-5.5.1 Potential measurement apparatus (terminal)

② <u>Examination of anodes</u>

Visual inspection of the anodes' installation status, the assessment of their consumption, and the measurement of the electric current generated at the anodes is necessary.

<u>1) Visual inspection of installation status of anodes</u>

Visual inspection is performed to confirm the number of installed anodes and that the status of the installed anodes is identical as that at the time of construction. If necessary, photos can be taken with an underwater camera.

2) Examination of consumption

By measuring the consumption of the anodes, the remaining life of the anodes and the density of protective current of the whole target structure can be determined. To measure consumption, 3 to 5% of the total number of installed anodes are randomly selected from arbitrary positions, and either a diver measures the forms and dimensions of the anodes, or the anodes are pulled up, and their weight is measured on land.

3) Examination of generated current

By measuring the electric current generated at the anodes, the operation status of the cathodic protection device can be confirmed, and the approximate remaining life of the anodes can be estimated. The current generated at an anode is generally measured by the voltage drop method, which measures shunt voltage. For these measurements, the apparatus used to measure the generated current is required to be mounted on the anode in advance.

(2)

The corrosion protection effects of steel structures at ports and harbors may be confirmed using test pieces or through an environmental survey, in addition to (1). The confirmation achieved using test pieces not only confirms the corrosion status of the surfaces of steel materials but also can quantitatively indicate the corrosion protection effects based on the weight reduction caused by corrosion.

When using test pieces, a pair of test pieces (one energized test piece and one non-energized test piece) is mounted at each depth of the target structure when the cathodic protection system is installed. Test pieces are mounted at both ends and in the middle section of the facility. For the depth direction, test pieces are normally mounted around the surface, in the middle, and around the sea bottom.

After certain amount of time has passed, the extraneous material is removed, and the test pieces are cleaned. Then, the surface condition is visually inspected, and the weight is measured. The weight reduction by corrosion, calculated from the mass reduction of test pieces, is used to calculate the corrosion rate and the corrosion protection efficiency of the target structure. The corrosion rate and corrosion protection efficiency are calculated from the test piece data using the following formulas:

Corrosion rate = corrosion weight reduction / test piece surface area / test period / test piece density (5.5.1)

Corrosion protection efficiency = (weight reduction of non-protected test piece – weight reduction of protected test piece) / weight reduction of non-protected test piece (5.5.2)

## 5.3 Site Investigation of Protective Coating System

(1) Site investigation of protective coating system is mainly performed visually. If harmful deformation is observed, another specific examination is required to be performed to identify details.

(2) Site investigation of protective coating system is required to be performed depending on type of coating material.

<Commentary>

(1)

The main objective of inspection and examination of the protective coating is to visually identify deformation in the coating materials that might have occurred due to aging or the impact of driftwood and vessels. This protection ensures that no abnormal condition exists. If any harmful deformation is observed, it is necessary to perform another specific examination to precisely identify the specific conditions and cause(s) of deformation and then take appropriate measures.

Visual inspection of the protective coating is performed for the entire area of the target facility. It is recommended that all the steel materials be examined. If this is not possible, the most typically affected portions of the structure should be examined. Inspection and examination records should be consulted, and the portions of the structure in which abnormal conditions were observed during previous inspection should be added to the current inspection areas. Photos should be taken of these portions and deformations.

While examining the protective coating, defects, such as insufficient base material adjustment during construction and insufficient fastening of bolts/nuts, are often observed within one year of completion of construction

Examination to identify the precise conditions of any damage or deterioration should be performed in the splashing zone, tidal zone, and areas under the sea to which protective coating has been applied. In general, adhered organisms and objects below tidal zones should be removed before examining a pile at each inspection point or a concave sheet-pile and convex sheet-pile at each inspection point.

(2)

Deformation of the protective coating can take different forms, depending on the coating material. Visual inspections should focus on the following deformations based on the type of coating material:

① Coating: blistering, cracking, and separation of coating; signs of rusting on coated steel material

② Organic coating: separation, blistering and cracking of coating material

③ Petrolatum coating: missing protective cover, corrosion and loosening of bolts or nuts

④ Mortar coating: [Non-protective cover type] falling, cracks and separation of mortar
[Protective cover type] falling, crack, deformation and separation of protective cover, corrosion and loosening of bolts and nuts

⑤ Metal coating: corrosion, rusting, falling, crack, damage, abrasion, and flaws of the steel material

Below, inspection and examination methods and precautions for each type of coating material are specified.

① Painting

Deterioration of the paint film can take the form of blistering, cracking, separation of the paint film and rusting of steel material under the paint film. If deterioration of the coating reaches the surface of the steel material, running rust will appear. Inspection and examination of the coating is mainly performed in detail visually, focusing on rust, blistering, cracking, and separation of the paint film. During visual inspection, a hammer sounding with a plastic hammer should be performed to determine if fragments of paint film with reduced adhesion remain on the steel material.

Several methods are available to identify the degrees of rust, blistering, cracking, and spalling. For example, these phenomena can be scored using standard pictures corresponding to the size and development density in several steps, or they can be quantified with an area ratio.

The area ratios of rust, blistering and spalling are visually estimated, using the criteria for the rust area ratio as a reference. The rust area is the area of the rusted surface of the steel material. The rust area does not include the area of the coating surface covered with running rust.

② Organic coating

Organic coating has a paint film thicker than that of an ordinary painting and has good durability. The items that are inspected and examined are essentially identical to those for ordinary painting, and a similar visual inspection is performed.

③ Petrolatum coating

Petrolatum coating consists of an anticorrosion petrolatum material on the surface of the steel material and a protective cover. The visual inspection mainly focuses on the protective cover. During the examination performed twenty years after the construction of the Hazaki observation open-type wharf (the Hazaki Oceanographical Research Station)[12) ] , no corrosion was found in the steel sheet piles where the protective covers on the inner petrolatum material were intact, and no cavity existed under the covers. Thus, for petrolatum coating in general, the deformation of the protective cover and any cavities beneath it should be inspected.

Inspection of the protective cover should focus on whether there is cracking and deformation of the cover and corrosion and loosening of the fastening bolts or nuts. Inspections of the cavity should be performed by a sound examination using a plastic hammer or other suitable means. In the case that pieces of particular band or stiffening plates have been applied to the joints of protective cover, and if there are any elements such as cracking or deformation, appropriate surveys should be required.

If the sound examination reveals internal cavities containing moving seawater, the protective cover should be removed, and any corrosion of the steel material should be examined.

④ Inorganic coating (mortar coating)

Mortar coating may or may not have a protective cover.

For mortar coating without a protective cover, deformation, such as cracks in the coating material or missing portions, should be visually inspected. If the coating material has deteriorated, cracks and/or a loss of a portion may be observed, and “rust strain” may exude from the corroded steel material at the end portion.

For mortar coating with a protective cover, the inner material is generally considered sound if the protective cover is intact, as in the case of petrolatum coating. Thus, crack examination on the cover should be performed. If there is a cavity between the protective cover and the mortar, and if seawater is flowing into this cavity, the cover has lost its protective function. In this case, sound examination should be performed to determine if there are any cavities. If a cavity is detected, the protective cover should be removed, and inspection should be performed as if it were a mortar coating without a protective cover.

The inspection and examination of mortar coatings should mainly be performed visually. The core of the material may be sampled to measure the chloride ion concentration as required because the concentration of chloride ions infiltrating the mortar material often provides valid information.

The inspection and examination of reinforced concrete coating should be analogously performed. It is desirable to also examine the reinforced concrete to detect any corrosion of the reinforcing bars.

⑤ Metal coating

In general, anticorrosive metals are used for metal coatings. Therefore, if the coating material is undamaged, the base material (steel) remains sound. However, once the coating is damaged, bimetallic corrosion occurs between the steel material and the coating metal. Such corrosion may develop considerably in a brief period. The examination should be carried out carefully to identify even minor damage. If the cathodic protection method applied in seawater is working correctly, bimetallic corrosion is prevented from occurring in the tidal zone. It is also necessary to evaluate the anticorrosive effect of the cathodic protection method during the inspection and examination of metal coatings.

## 5.4 Measurement of Steel Plate Thickness

### 5.4.1 General

(1) Steel plate thickness should be measured to determine whether steel material is sound when non corrosion protection is applied, when existing corrosion protection works insufficiently, or to identify corrosion rate of the steel material and/or predict progress of deterioration due to corrosion.

(2) Most suitable method should be utilized to measure plate thickness, considering measuring position, measurement location, and conditions of measurement surface.

<Commentary>

Measurements of the steel plate thickness are performed to quantitatively ascertain the corrosion conditions of a steel structure. For this kind of measurement, appropriate examination locations, measuring positions and measurement points should be chosen depending on the purpose of the examination. Additionally, local corrosion should be measured as necessary.

In general, an ultrasonic thickness meter is used to determine the steel plate thickness. This apparatus uses ultrasonic pulses. Pulses emitted by a probe placed on the steel material are reflected by the bottom of the steel material and returned to the probe. This apparatus utilizes the principle that the duration between emission and return is proportional to the transmission distance of the ultrasonic wave. Separate dedicated probes are used above and below sea level. An ultrasonic thickness meter capable of measurements both in the air and underwater using different probes is typically used. It is necessary to calibrate the ultrasonic thickness meter in advance. To obtain accurate thickness measurements, a reference steel plate whose thickness is known and nearly identical to that of the target steel material should be used.

Using an ultrasonic thickness meter, three rounds of each measurement are performed at the specified measurement points. The average of the resulting values is used as the definitive measured value. If an abnormal value is obtained, measures, including remeasurements, should be considered.

Photo-5.5.2 Plate thickness measurement using an ultrasonic thickness meter

All operators of the plate thickness measurement devices should be briefed in advance on specific procedures, including the application of a probe to the surface of the steel material. It is desirable to take photos of the steel surfaces at the plate thickness measurement points while performing the measurements.

The ultrasonic thickness meter has the advantage of yielding accurate results in a simple way. Nonetheless, it is necessary to remove deteriorated areas of the coating material and organism adhesion in advance to expose the surface of the target steel material. This preparatory work requires manpower and takes a long time. The debris from the removal work is required to be disposed of elsewhere.

5.4.2 Selection of examination points and measuring positions

(1) Examination points should be selected by focusing on the portions whose plate thickness has been considerably reduced, based on corrosion protection inspection and examination results and visual inspection results for steel material.

(2) Measuring positions should be selected by considering functions of corrosion protection, corrosion condition of steel material, and distribution of stresses to portions and members of structures.

<Commentary>

(1)

The examination points are a group of measuring positions projected on a plane of a normal line of the structure. These points indicate the general conditions of corrosion. When performance assessment is performed for a facility, these points are used to evaluate the entire facility. Therefore, appropriate examination points should be selected. Based on the results of visual inspection of the structure, the conditions of opening and pitting corrosion, the conditions of corrosion (range of rust), the age of the facility, and the initial steel plate thickness should be considered, and considerably corroded portions requiring measures should be primarily selected.

If visual inspection suggests a nearly uniform distribution of corroded points along a long section of the normal line, the examination points may be selected for such sections using the following methods:

- Corrosion conditions ①: The pitting corrosions or a continuous group of orange-colored rust points are observed over a wide range from the mean low water level to the L.W.L. If the facility is at least five years old, one examination point should be selected approximately every twenty meters (20 m) along the normal line.

- Corrosion conditions ②: Orange-colored rust points are partially observed from the mean low water level to the L.W.L. If the facility is at least ten years old, one examination point should be selected approximately every fifty meters (50 m) along the normal line.

- Corrosion conditions ③: For conditions other than ① and ②, for example, if no or very few orange-colored rust points are observed in the range from the mean low water level to the L.W.L., one examination point should be selected approximately every hundred meters (100 m) along the normal line.

Photo-5.5.3 Corrosion conditions ①

Photo-5.5.4 Corrosion conditions ①

Photo-5.5.5 Corrosion conditions ②

Photo-5.5.6 Corrosion conditions ③

For corrosion conditions ② and ③, the distances between the examination points are wider than those for corrosion condition ① because the possibility of the presence of serious corrosion requiring immediate measures is lower in corrosion conditions ② or ③ than in corrosion conditions ①. Thus, the economic efficiency of the examination is considered in choosing among these options. Accordingly, if the steel plate thickness measurements suggest more severe corrosion requiring measures than was suggested by visual inspection, additional examination points should be selected to achieve a frequency of one examination point every twenty meters (20 m) along the normal line, as in the case of corrosion condition ①. Moreover, it is desirable to select at least two examination points for every facility. To determine the corrosion condition (①, ②, or ③), visual inspection should be performed. Photos 5.5.3 to 5.5.6 can be used as a reference. When the condition is unclear, the more serious corrosion condition should be selected.

When the performance of a substructure of an open-type wharf is evaluated, the plate thicknesses of all piles along a row perpendicular to the normal line should be measured at every examination point so that each pile can be evaluated depending on the corrosion conditions. For an open-type wharf, therefore, a group of piles should be evaluated along one row perpendicular to the normal line at each examination point.

(2)

The measuring positions are the group of points representing the positions of the steel plate thickness examination points in the vertical direction. These points are selected to examine the distribution of the corroded spots of the portions and members of a structure in the vertical direction. The measuring positions should be selected by considering the functions of the corrosion protection after the corrosion conditions of the steel material are identified by visual inspection to ascertain the type of corrosion (e.g., concentrated corrosion). Moreover, it is desirable to select points that may correspond to the sites of structural problems (e.g. the points where the maximum stress is generated).

The portions where serious corrosion may occur are generally located around the H.W.L. and the zone from the mean low water level to the L.W.L. In most cases, coating protection is applied to portions above the H.W.L., while coating protection and cathodic protection method are applied to the zone from the mean low water level to the L.W.L. Thus, the measuring positions should be selected depending on the specific conditions of deformation. The upper portions of piles of a sheet-pile structure are subject to less stress, whereas the upper portions of a piled pier are subject to greater stress. Therefore, the steel plate thickness should be measured in the latter structure. Even in the case of a sheet piles structure, if a hole is produced in the sheet-pile due to corrosion, the back-filling material will flow out. Therefore, the steel plate thickness should be measured.

Figure-5.5.2 shows the standard measuring positions for piles and sheet piles. Four measuring points are indicated for the following reasons.

Point “a” of a pile is located at the highest portion and is subject to high stresses and the most serious corrosion. Points “b” and “c” are subject to not only relatively high stresses but also concentrated corrosion. The results of a stress analysis for a structure largely depend on the section’s stiffness around these points. The maximum amount of corrosion should be determined as accurately as possible. Thus, positions that are expected to be most affected by corrosion should be selected as Points “b” and “c”, considering the corrosion conditions along the zone from the mean low water level to the L.W.L. If the tidal level difference or the range of serious corrosion is large, it is desirable to increase the number of measuring positions. If the tidal level difference is small, only one measuring position around this section is required to be selected. The position “L.W.L.–2 m” is acceptable as Point “d” in seawater, as the corrosion rate does not vary around this position below sea level even in the case of concentrated corrosion. Thus, this position will not significantly affect the results of a stress analysis.

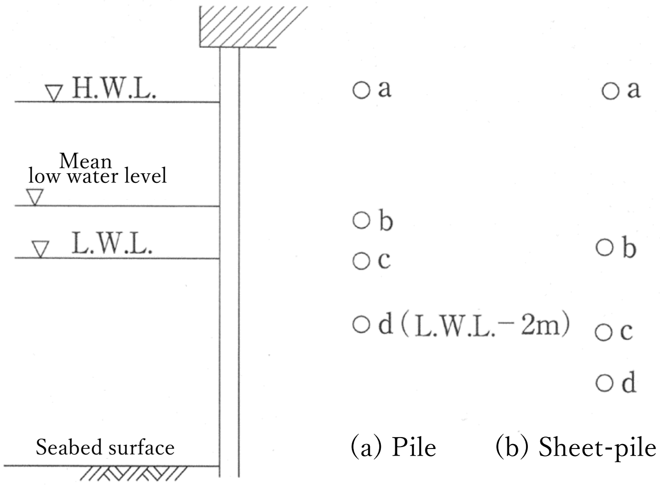



Figure-5.5.2 Standard measuring positions

In the case of a sheet-pile, the stresses around the H.W.L. and the zone from the mean low water level (M.L.W.L) to the L.W.L are relatively low. However, if a hole is produced with the development of corrosion, the back-filling material will start to flow out. Therefore, the measurement points should be located around this zone. A position that is expected to be most affected by corrosion should be selected as Point “b”, according to visual inspection of the zone from the M.L.W.L to the L.W.L. As the maximum stresses are generated in seawater, two points should be selected in seawater to identify the maximum amount of corrosion. For sheet-pile structures, measuring positions should be selected around the zone where the maximum design bending moment is produced. A vertical distance of 0.5 meters (0.5 m) to 1.0 meter (1.0 m) should be secured between points.

5.4.3 Selection of plate thickness measurement points

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| Plate thickness measurement points should be selected by considering deterioration conditions of corrosion control and shape of steel material. |

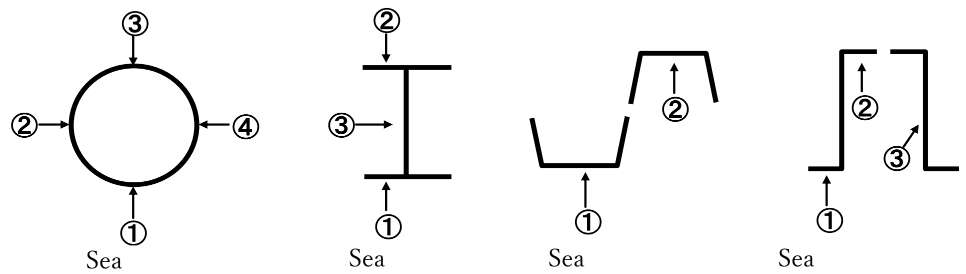
<Commentary>

The plate thickness measurement points indicate the points at which the thickness of the steel material is to be measured. The measurements of thickness correspond to the actual section shapes of the steel materials at the measuring position. Figure-5.5.3 shows the standard thickness measurement points for differently shaped steel materials.

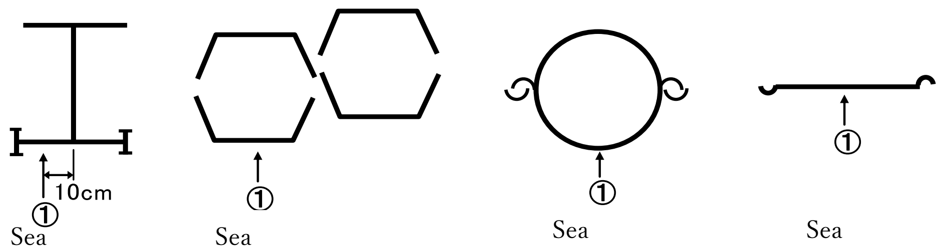
Organism adhesion and objects located in the 100-mm square should be removed with a tool, such as a hammer or scraper, and the exposed steel material surface should be further scraped with a wire brush or a grindstone to clear the surface of the steel material.

At each plate thickness measurement point, the probe of the thickness meter should be placed at five or three points (see Figure-5.5.4) to measure the steel plate thickness. The average of the five or three measurements should be adopted as the definitive measured value.

If the steel material has a hole, its location (the hole's center point) should be selected as one of the thickness measurement points, and the value "0" should be assigned to the thickness of the steel at this point. If the coating protection has partially deteriorated, the measurement points should be located in these portions. For steel pipe sheet piles, joints should be excluded from the selection of measurement points.

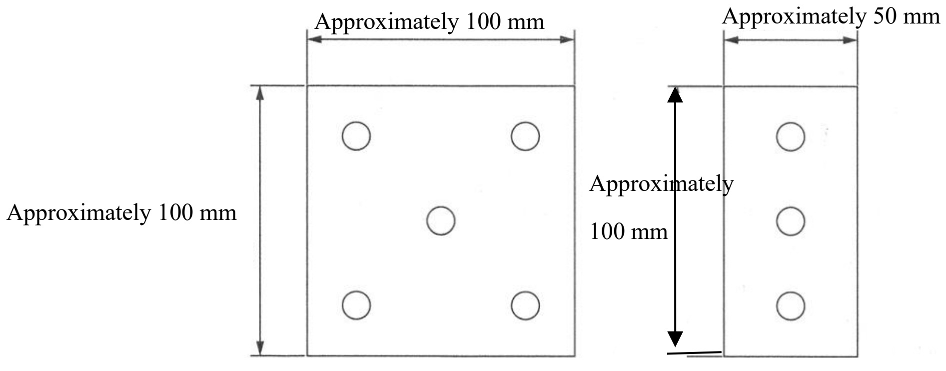



(a) Steel pipe pile
(b) H-section steel-pile
(c) U-section steel sheet-pile
(d) Z-section steel sheet-pile

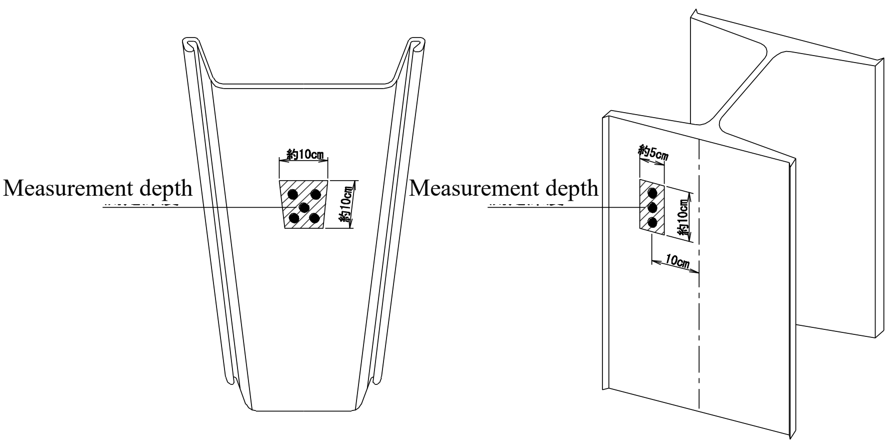



(e) H-section steel sheet-pile
(f) Combined steel sheet-pile
(g) Steel pipe sheet-pile
(h) Linear-section steel sheet-pile

Figure-5.5.3 Standard thickness measurement points




(a) Normal (b) Box sheet-pile




▨: Approximate zone where steel material surface is exposed

●: Points to which the probe is applied (three rounds of measurement at each point)

Figure-5.5.4 Points at which the thickness meter probe is placed

5.4.4 Measurement of local corrosion

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|---|
| If local corrosion is observed, its depth should be measured as needed. |

<Commentary>

The surface of corroded steel may have flat areas of uniformly developed corrosion and uneven areas with many scattered corrosion points (pitting corrosion) of different sizes. To enhance the accuracy of the performance assessment of steel materials, it is crucial to examine the conditions of the local corrosion areas and measure the depth of the corroded portions.

If any local corrosion (more than 3 mm deep) is observed, casts of these corroded portions should be taken, or their depths should be measured with a depth gauge to determine the current minimum steel thickness. Additionally, the corrosion shapes should be recorded. If several local corroded portions are observed, it is desirable to choose the five largest corroded portions and measure the depths of corrosion in these areas (see Figure-5.5.5).

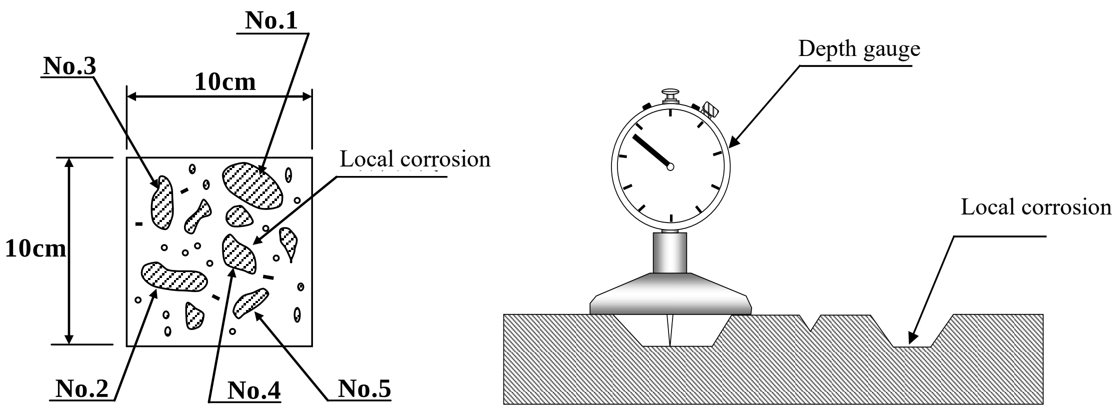


Figure-5.5.5 Example of local corrosion measurements with a depth gauge

# Chapter 6 Examination of Concrete

## 6.1 Outline

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|---|
| Examinations of port and harbor concrete structures are required to use methods that are suited to conditions of target structures, required data and their accuracy, and causes of deformation. |

<Commentary>

Port and harbor concrete structures are exposed to more severe meteorological and oceanographic conditions than ordinary land structures. Port and harbor concrete structures are seriously affected by the physical and chemical actions of seawater, and materials steadily deteriorate over time. Chloride ions in particular penetrate the concrete, corroding the reinforcing bars. Consequently, various forms of deterioration, including cracks, delamination, and spalling of cover concrete, can occur, resulting in so-called chloride-induced corrosion. Many cases of alkali-silica reaction (ASR) caused by supplies of water and alkali in seawater in addition to the cement have been reported in certain regions.

Table-5.6.1 lists common inspection/examination methods for concrete structures.

Table-5.6.1 Common inspection/examination methods for concrete structures

| Inspection/Examination Item | | Methods |
|---|---|---|
| Concrete strength | | Compressive strength test using core, rebound hammer sounding, impact elastic wave method |
| Crack in concrete | | Visual inspection, ultrasonic method, impact elastic wave method, infrared method, acoustic emission (AE) method |
| Depth of crack in concrete | | Ultrasonic method, core sampling |
| Crack width in concrete | | Crack scale method, contact gauge method |
| Spalling of concrete from internal cavity | | Hammer sounding, ultrasonic method, impact elastic wave method, infrared method, electromagnetic wave radar method, X-ray transmission method |
| Conditions of corroded reinforcing bars | | Measurement of half-cell potential |
| Rate of corrosion of reinforcing bars | | Measurement of polarization resistance |
| Corrosive environment for reinforcing bars | | Measurement of electrical resistivity (specific resistance) of concrete |
| Analysis of concrete | Chloride-induced corrosion and Carbonation | Measurement of chloride ion concentration, measurement of carbonation depth |
| | Alkali-silica reaction (ASR) | Polarization microscope, scanning electron microscopy (SEM), powder X-ray diffraction |
| | | Alkali-silica reactivity test |

## 6.2 Concrete Strength

| Most suitable method should be employed to examine strength of concrete. |
| --- |

<Commentary>

Concrete strength can be estimated or identified mainly by the following examination methods:

① Rebound hammer sounding

② Compressive test of sampled cores

<u>① Rebound hammer sounding</u>

This method estimates the compressive strength (rebound number) of concrete based on the extent of rebounding. A weight is impacted against the concrete surface using a spring or natural gravity to determine the rebound number of the concrete. This simple method is commonly applied in various fields because it can be applied in a non-destructive way. Basically, the rebound numbers are modified based on the user manual supplied by the manufacturer to obtain the reference value. This reference value is used to estimate the concrete's compressive strength from the conversion formula. Any finishing layer or additional coating on the surface of the concrete should be removed in advance to expose the concrete. Any uneven area on the surface and organism adhesion or objects should be removed, and the surface should be polished with a suitable tool (e.g., grindstone) before starting the operation.

Note that when using the rebound number, the test hammer strength can differ from the compressive strength of the standard cylindrical specimen made of the test piece's concrete by ±50% or more in certain cases. The rebound number can be affected by various factors, including the humidity of the concrete surface, the type of aggregate used and the type of test hammer. Hence, it is desirable, if possible, to sample the cores and compare the rebound number with the actual strength to verify the accuracy of the estimated results. This method is highly effective for comparing the strengths of various portions of concrete in the same structure that is constructed of the same concrete and for evaluating the uniformity of the concrete.

<u>② Compressive test of sampled cores</u>

If satisfactory data are not obtained from the a forementioned non-destructive test, or if more accurate data are required, damaging small portions of the structure will be unavoidable. A commonly used, partially damaging method is a load test of the sampled cores. This test will provide not only the compressive strength of the concrete but also the measured values of the tensile strength and the elastic coefficient.

Before sampling the cores, an electromagnetic wave radar method or electromagnetic induction method should be applied to survey the reinforcing bars in the concrete to avoid cutting the reinforcing bars while sampling. Cores should preferably not be sampled at construction joints, at portions that were in contact with formwork or at damaged portions containing cracks and honeycombs, but the cores should be sampled at locations away from the reinforcing bars. After core sampling, the resulting holes are required to be repaired with an appropriate material, such as shrinkage-compensated mortar. In general, the cores to be subjected to a compressive strength test are required to have a diameter more than three times the maximum size of the coarse aggregate. The height-to-diameter ratio of the core should preferably be between 1.90 and 2.10.

## 6.3 Cracks, Spalling, and Internal Cavities

(1) Cracks, spalling, and internal cavities in concrete are required to be inspected and examined by methods that are suited for purpose, depending on the existing defects and required data and their accuracy.

(2) Essential aspect of inspection and examination of cracks, delamination and internal cavities in concrete is visual inspection of concrete surfaces.

(3) If deemed necessary after results of visual inspection is obtained, another specific inspection and examination using technical apparatuses should be performed based on the defects to be identified and the required accuracy of inspection and examination.

<Commentary>

(1)

Many types of inspection or examination methods can be applied to cracks, spalling, and internal cavities in concrete. The methods that are suitable for the purpose should be chosen depending on the defects to be identified and the required accuracy of inspection and examination.

(2)

If material deterioration develops in a concrete structure, deformation often becomes visible on its surfaces. A concrete structure damaged by chloride-induced corrosion often shows cracks on its surface, resulting from the corrosion of reinforcing bars. Rust fluid from the cracks discolors the concrete surface. If the corrosion progresses, the covering concrete will become cracked and delaminated from the main portion of the structure, exposing the reinforcing bars, and causing further corrosion to the bars. Thus, visual inspection of concrete surfaces is important for the early detection of chloride-induced corrosion. The typical symptoms of deterioration due to alkali-silica reaction (ASR) are cracks, discoloration, and exudation of gel. In general, the first step of inspection or examination is visual inspection of the concrete surfaces. If the inspector cannot access the concrete surfaces, tools such as binoculars are effective.

For the spalling of concrete cover, in particular, combining a visual inspection with a hammer sounding is effective. To perform a hammer sounding, the concrete surfaces are impacted by a hammer. Based on the observed hammering sound and the impact of the hammer, the inspector estimates the locations of the concrete delamination and determines the presence of deterioration.

If any defects on the concrete surface are observed during visual inspection, and if they are to be quantitatively evaluated, it is desirable to use a simple tool, such as a scale, to determine the range of the defects. To measure crack widths, a crack scale is generally used because it is simple to operate. In general, the widest place of each crack is measured.

Below is a list of examination categories and specific phenomena to note during the observation of concrete surface conditions:

① Discoloration and stains
・Exudation of corrosion products
・Exudation of white gel from concrete
・Efflorescence
・Discoloration of concrete
② Cracks in concrete
・Orientations and patterns of cracks
・Number of cracks
・Width and length of representative crack
・Exudation of corrosion products from cracks
③ Delamination of concrete fragments
・Delamination of concrete fragments, number and range of locations of delamination
・Exposure and/or corrosion of reinforcing bars due to delamination, number and range of locations of exposure and/or corrosion
④ Spalling of concrete fragments
・Number and range of locations of spalled fragments
・Exposure, corrosion and/or fracture of reinforcing bars due to spalling, number and range of locations of exposure, corrosion and/or fracture

(3)
Non-destructive tests are highly effective when the internal conditions of the concrete are required to be identified or when more detailed data are required for estimating the deterioration mechanism and determining the degree of deterioration. For the inspection and examination using non-destructive testing apparatuses, the most suitable methods and apparatuses should be selected after establishing the purpose of inspection or examination, the scope of application and the required estimation accuracy. Table-5.6.2 shows common non-destructive test methods for cracks, spalling, and internal cavities in concrete. The elastic wave method refers to a broad category of methods for obtaining data on the internal zones of concrete by measuring the properties of elastic waves being propagated through the concrete. Included in this category are the ultrasonic wave method, the impact elastic wave method, and the acoustic emission (AE) method. The electromagnetic wave method also refers to a broad category of methods utilizing electromagnetic waves transmitted through or reflected onto the concrete mass. Included in this category are the electromagnetic wave radar method, the infrared method and the X-ray transmission method, and these methods are chosen depending on the type of electromagnetic wave.[8)]

Table-5.6.2 Types of non-destructive test methods for concrete

| Condition to be Evaluated | Type of Non-destructive Test Method | Overarching Category |
|---|---|---|
| Cracks | Ultrasonic method<br>Acoustic emission (AE) method | Elastic wave method |
| | Infrared method<br>X-ray transmission | Electromagnetic wave method |
| Delamination/Internal Cavities | Ultrasonic method<br>Impact elastic wave method<br>Hammering method | Elastic wave method |
| | Infrared method<br>Electromagnetic wave radar method<br>X-ray transmission method | Electromagnetic wave method |

Below are examples of methods that are applicable to the inspection/examination of locations and areas of cracks, delamination, and spalling in port and harbor concrete structures.

・Image analysis of cracks with a digital camera

Images taken with a digital camera are subjected to image processing to analyze the patterns (e.g., axial directions and honeycomb shape), the positions and the density (total extension of cracks/measured area) of the cracks. In many cases, the causes of cracks can be estimated from the identified crack patterns. The density or digitalization of cracks in concrete helps identify the nature of their development.

・Direct measurement of widths and lengths of cracks

A crack scale, contact gauge and pi-shape displacement transducer are tools that can directly measure the width of a crack. A crack scale is placed on the crack, and the figure corresponding to the crack is visually read. With a contact gauge, the length between two points is read on the gauge to determine the distance between the gauge points on both sides of the crack. With a pi-shape displacement transducer, the change in electric resistance on the gauge during loading is used to determine the change in crack width. To measure the crack length, a gauge is placed along the crack, and the length figure is read from the gauge.

Whichever method is chosen, measuring changes in crack width over time helps ascertain the future development of the crack.

・Measurement of the depth and width of a crack by core sampling

The depth and width of a crack observed on a concrete surface can be measured after sampling the core in the range containing the crack. If cracks have developed from the concrete surface into a deep zone, as in the case of concrete affected by an alkali-silica reaction (ASR), a core extending to a certain depth should be sampled.

・Image analysis of delamination using a digital camera or thermography

High definition digital images are captured and modified to produce a synthetic image, based on which delamination is identified. The digital image method can be used to collect data from locations where they cannot be collected by visual inspection without approaching them. This method allows for the use of telephoto lenses that enable efficient operations without the need for scaffolding.

The infrared method (thermography) is a non-contact method for ascertaining the positions of delamination from the distribution of surface temperatures. This method is based on the principle that any delamination, cavity or crack in concrete transmits heat differently than the structurally sound portions of the same concrete. Whereas the non-contact method enables a wide range to be observed, the measurement results are affected by stains on the concrete surface, leakage of water and the degree of solar insolation. Additionally, the probe depth limit of this method is 30 to 50 mm.

## 6.4 Chloride Ion Concentration in Concrete

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|---|
| Most suitable method to determine concentration of chloride ions in concrete should be adopted. |

<Commentary>

Examining the chloride ion concentration in concrete is important for grading the deterioration level of a concrete structure due to chloride-induced corrosion and predicting the progression of deterioration.

This method measures the concentration of chloride ions in concrete with a potentiometric titrator or ion-exchange chromatography using concrete cores sampled and concrete fragments chipped from the concrete structure or concrete powder obtained from the drill hole.

The term "total chloride ions" designates all free chloride ions in a pore solution of hardened concrete, i.e., the chloride ions bound in the hydration product of cement.

The concentration of chloride ions in concrete is generally measured at reinforcing bars (covering depth) and at several points along the line from the concrete surface to the depth.

The chloride ion concentration at these positions serves as an index for determining whether reinforcement corrosion has started. In general, reinforcing bars in concrete are in a highly alkaline environment (pH≥12), which inhibits corrosion. This environment is the result of the minute oxide layer that forms on the reinforcing bars. When chloride ions enter the concrete and exceed a specified concentration (chloride threshold value) at the position of reinforcement zone, the reinforcing bars undergo depassivation, and corrosion starts to develop even though the pH of the concrete remains high. Technical Standards for Port and Harbor Facilities in Japan adopt 2.0 $kg/m^3$ as the lowest chloride threshold value based on survey results in Japan. This value is an example for Japan, and should be set appropriately in consideration of the environment of the target country and the situation of the target structure. Measuring chloride ion concentration at different depths under the concrete surface yields the apparent diffusion coefficient for chloride ions in the concrete, which can be utilized for predicting the future penetration of chloride ions.

When cores are sampled to determine the concentration of chloride ions in the concrete, attention should be paid to the maximum size of the coarse aggregate. Cores should preferably have a diameter at least three times the maximum size of the coarse aggregate. It is also important to record the sampling positions and identify the exposed side of the concrete. After sampling, the cores should be sealed and stored in plastic bags to prevent the chloride ions from leaking out in the presence of humidity.

Concrete pieces may be cut from the core using a dry concrete cutter to measure the chloride ion concentration at different depths under the concrete surface. This process prevents leaching of chloride ions from the concrete that may be caused by using water. Therefore, it is desirable to cut concrete pieces that are 10 to 20 mm thick, as the presence of coarse aggregates in a small piece of concrete is liable to greatly affect the measurement results. Then, these concrete pieces containing aggregates are pulverized into pieces not exceeding 0.15 mm in size and used as samples for the analysis.

To measure the total chloride ion concentration, nitric acid is added to the samples to dissolve the chloride ions bound in the hydration product of cement. The samples are then boiled to extract the chloride ions. The solution including the insoluble particulate is filtered, and the chloride ion concentration contained in the filtrate is measured by potentiometric titration.

## 6.5 Corrosion of Reinforcing Bars

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|---|
| Suitable method for examining reinforcing bars in concrete for corrosion should be adopted based on required data and their accuracy. |

<Commentary>

The corrosion of reinforcing bars will not only damage the aesthetic appearance of the concrete structure with cracks and rust stains but also considerably affect its structural performance. For port and harbor concrete structures constructed in a more severe corrosive environment compared with ordinary land structures, identifying the development of corrosion of the reinforcing bars, and predicting the progression of deterioration are critical for maintaining and repairing the structures.

The methods of inspection/examination of reinforcing bars in concrete can be categorized as follows:

① Estimating the corrosion of reinforcing bars using a non-destructive test

② Observing the corrosion of reinforcing bars by local destruction of the mass

<u>① Estimating corrosion of reinforcing bars using a non-destructive test</u>

Non-destructive tests for the corrosion of reinforcing bars are generally based on electrochemical principles. These methods utilizing the corrosion of reinforcing bars as an electrochemical reaction allow the corrosion activity and the corrosion rate of reinforcing bars in concrete to be estimated. The main measurement items are the half-cell potential and polarization resistance. In addition, the electrical resistivity of concrete is considered an effective measurement item, as it considerably affects the development of corrosion of reinforcing bars in concrete.

A common issue with electrochemical methods is that the water content in the target concrete is liable to affect the results. If the concrete surface is completely dry or completely immersed in water, it is impossible to estimate corrosion conditions using an electrochemical method. Additionally, if epoxy resin-coated bars are used as internal reinforcement, an electrochemical method cannot be used.

To monitor the corrosion conditions of reinforcing bars over a long period, embedded sensors can be used in concrete. Various embedded sensors have been developed, such as sensors for measuring the half-cell potential or polarization resistance of reinforcing bars and sensors for measuring the electric current generated by macro cell corrosion.

<u>・Half-cell potential</u>

The half-cell potential is measured to estimate the possibility of corrosion in the reinforcing bars. The positive (+) terminal is connected to the reinforcing bar, and the negative (–) terminal is connected to the reference electrode. Then, the reference electrode is placed in contact with the concrete surface using a wet sponge at the point immediately above the reinforcing bar. In most cases, the reinforcing bar is connected to the positive (+) terminal after a portion of the bar has been tapped off (see Figure-5.6.1).

In general, if the half-cell potential is more negative than the criteria, corrosion has likely developed to a considerable extent in the reinforcing bar, whereas if it is more positive than the criteria, there is likely no or little corrosion. Table-5.6.3 shows examples of criteria for assessing the presence of corrosion in a reinforcing bar using measured values of half-cell potential. Notably, these criteria are not applicable without modifying port and harbor concrete structures. In such cases, the results of the assessment do not correspond to the actual corrosion conditions. These criteria should be applied very carefully after a review. It is difficult to define universal criteria for assessing the half-cell potential, since to a considerable extent, it depends on various environmental conditions, such as moisture in concrete, the chloride ion concentration, and the atmospheric temperature.

Thus, in general, half-cell potentials should be measured across the entire surfaces of the portions or members of the structure, and the distribution of half-cell potentials should be got. An effective method is to use operational tools to inspect visual factors. For example, a drawing of equipotential lines (contour mapping composed of equipotential points linked with lines) can be performed using the measured values of half-cell potentials in the examined area. Thus, the locations of the portions or members of the structure where the possible presence of corrosion is high can be visually estimated (Figure-5.6.2). If a part of the reinforcing bar is exposed, and the corrosion conditions are evaluated at points where the possibility of corrosion is suspected to be high based on the equipotential lines, the accuracy of the evaluation of corrosion of the reinforcing bars in a wide area will increase.

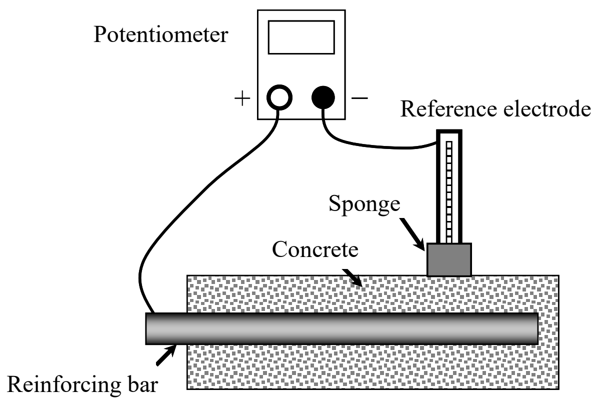


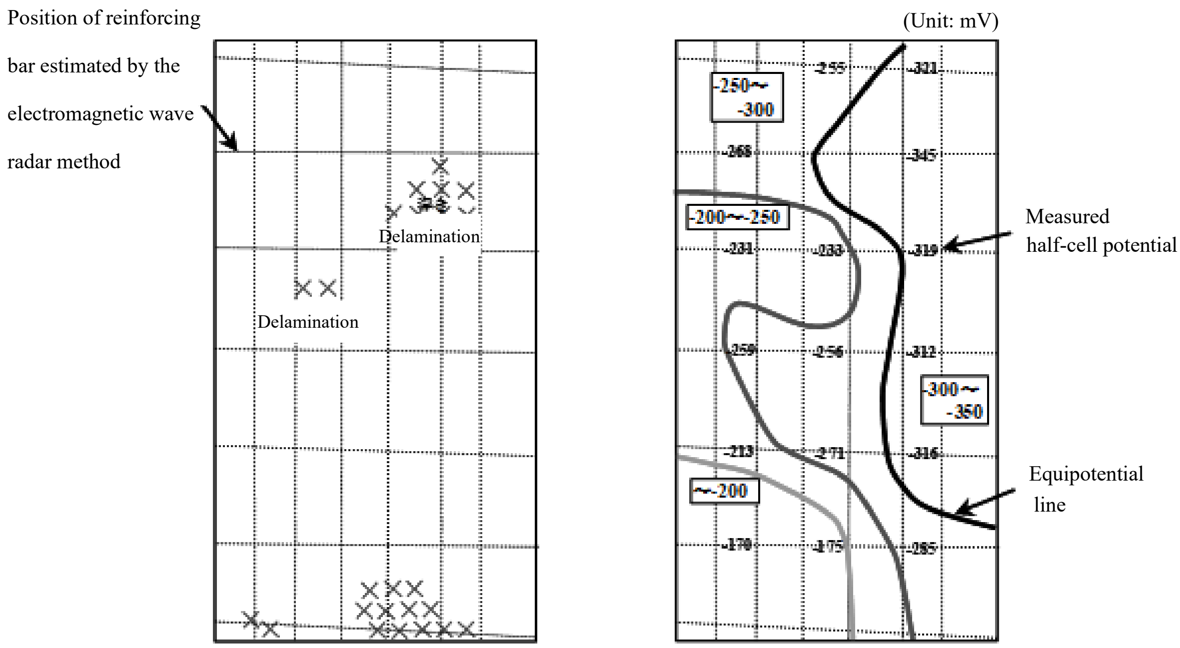

Figure-5.6.1 Measurement of half-cell potential

Table-5.6.3 Criteria for assessing corrosion in a reinforcing bar using measured half-cell potentials (examples)

| Half-cell Potential *E*<br>When a saturated copper sulfate electrode is used[*1] | Half-cell Potential *E*<br>When saturated silver chloride electrode is used [*2] | Possibility of Corrosion |
|---|---|---|
| $-200\ \mathrm{mV} < E$ | $-80\ \mathrm{mV} < E$ | No presence of corrosion with a probability of 90% or greater |
| $-350\ \mathrm{mV} < E \leq -200\ \mathrm{mV}$ | $-230\ \mathrm{mV} < E \leq -80\ \mathrm{mV}$ | Uncertain |
| $E \leq -350\ \mathrm{mV}$ | $E \leq -230\ \mathrm{mV}$ | Presence of corrosion with a probability of 90% or greater |

[*1] ASTM C 876: Standard Test Method for Half-cell Potentials of Uncoated Reinforcing in Concrete

[*2] Converted from the half-cell potential value using a 25°C saturated copper sulfate electrode




Defects on bottom of beam and positions on the reinforcing bar

Measurement results of half-cell potentials

*Note: Measured values using a saturated silver chloride electrode are shown.

Figure-5.6.2 Measured half-cell potentials in an RC beam of a pier superstructure

<u>・Polarization resistance</u>

To measure polarization resistance is a method to know the corrosion rate of a reinforcing bar. A part of the reinforcing bar in the concrete is exposed to secure electric conduction, and the sensor is placed in contact with the concrete surface at the point immediately above the bar. Various methods can be used for this measurement. A portable apparatus utilizing AC impedance can also be used.

For a polarization resistance measurement, the electric current that is generated when a steel material’s potential is slightly polarized from its half-cell potential (the potential is forcibly shifted) is measured. The polarization resistance is calculated using the following equation:

$$R_p = \Delta E / \Delta i \qquad (5.6.1)$$

where $R_p$: polarization resistance [$\Omega$ cm$^2$]

$\Delta E$: amount of polarization [V]

$\Delta i$: current generated [A/cm$^2$]

The corrosion current (corrosion rate) is calculated using the following equation:

$$I_{corr} = K / R_p \qquad (5.6.2)$$

where $I_{corr}$: corrosion current [A/cm$^2$]

$K$: constant determined depending on type of steel material and environmental conditions, generally, 0.026 V

$R_p$: polarization resistance [$\Omega$ cm$^2$]

Table-5.6.4 shows examples of the criteria for assessing corrosion rates of reinforcing bars using measured values of polarization resistance. These criteria can be used for reference purposes.

Table-5.6.4 Criteria for assessing the corrosion rate using polarization resistances [13)]

| Polarization Resistance $R_p$ [k$\Omega$ cm$^2$] | Corrosion Current Density $I_{corr}$ [$\mu$A/cm$^2$] | Measured Corrosion Rate |
|---|---|---|
| $R_p \geq 130$ - 260 | $I_{corr} < 0.1$ - 0.2 | Passive (no corrosion) |
| $52 \leq R_p \leq 130$ | $0.2 \leq I_{corr} \leq 0.5$ | Low or medium corrosion rate |
| $26 \leq R_p \leq 52$ | $0.5 \leq I_{corr} \leq 1$ | Medium or high corrosion rate |
| $R_p < 26$ | $I_{corr} > 1$ | Very high corrosion rate |

The polarization resistance method is used to estimate the corrosion rates. If the polarization resistance is successively measured, the extent of corrosion of a reinforcing bar can be estimated as an integral of time.

・Electrical resistivity of concrete (specific resistance)

The corrosion of a reinforcing bar in an internally dry concrete (with higher electrical resistivity) develops more slowly than that in an internally less dry (moist) concrete (with lower electrical resistivity). As there is a certain correlation between the water content and electrical resistivity of concrete, the measured values of electrical resistivity will, to a certain extent, indicate the corrosion activity rate of a reinforcing bar[14)]. Various methods can be used to measure the electrical resistivity, such as utilizing AC impedance to measure electrical resistivity and polarization resistance simultaneously and measuring electrical resistivity using four electrodes.

② Observing the corrosion of reinforcing bars by local destruction

If satisfactory data cannot be obtained from the non-destructive test or if more accurate data are required, it is often effective to destroy local portions of the structure. If the structure is locally destroyed, the degree of corrosion of the reinforcing bars in concrete can directly be identified with the following procedure.

・Examination of the corrosion of a reinforcing bar

A part of the concrete is removed to expose the reinforcing bar, and the conditions of the bar are visually inspected. An important inspection item is the presence of pitting corrosion because if pitting corrosion is present, both the overall section of the reinforcing bar and the bearing capabilities of the portions and members are considerably reduced. Thus, the structure is in a dangerous condition.

In addition to visual inspection, if possible, the actual remaining diameter of the reinforcing bar should be measured with a caliper. When quantitative corrosion data are obtained, the corrosion rate up to the present can be estimated. Such data are beneficial for estimating the remaining bearing capabilities of the portions and members of the structure.

# Chapter 7 Monitoring with Sensors and Other Equipment for Structures

## 7.1 Outline

| |
|---|
| When performing an objective, continuous observation of state of deformations that could be generated in a structure and of their impact on structure, monitoring method, such as sensors, should be selected based on factors such as type of deformation, investigated items, and accuracy required. |

<Commentary>

To ascertain the soundness of a facility throughout its service life, it is very important to ensure its long lifetime based on an optimum maintenance plan, which also helps prevent accidents or disasters. Reliance on conventional techniques, such as visual inspection and hammer sounding, to verify the soundness of a facility by the inspection and diagnosis requires considerable time and effort and is therefore inefficient. Continuous monitoring of the generation of a deformation and its grade by applying the latest technologies can facilitate a preventive approach to maintenance and repair. Monitoring methods may be roughly classified into two groups, i.e. continuous, in which sensors and other equipment are placed on the structures, and periodical, in which monitoring is carried out with a mobile unit (e.g. vehicles) equipped with sensors and similar equipment.

Moreover, the objects of monitoring may be divided into two groups, i.e. the monitoring of a structure itself in terms of deformation, cracks, corrosion, and other damage, and the monitoring of external forces that impact a structure (e.g. wave force, earthquake).

**References of Part5**


1) Geospatial Information Authority of Japan: Manual for Public Survey by using UAV, 2016 (amendment 2017)

2) Geospatial Information Authority of Japan: Manual for Multiple GNSS Measure, 2015

3) Muneo YOSHIE, Toshinari TANAKA, Hiroshi TAKAHASHI: A Study about Digital Photogrammetry System of Simplified Inspection Sanction for Seashore Protective Facility, 57th Outline of Annual Academic Lecture by Japan Society of Civil Engineering, PP59-60, 2002

4) Japan Marine Surveys Association: Manual for Engineering of Marine Surveys -Bathymetry-, 2017

5) Japan Marine Surveys Association: Rule book relating to Hydrography Surveys, 2014

6) Specialist Center of Port and Airport Engineering: Construction Work at Port and Harbor for Beginner and Intermediate level (Amendment), 2011

7) Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism: Manual of Bathymetry by Multibeam (Dredging Version), 2017

8) Japan Concrete Institute: Diagnosis Technology for Concrete 18 (Basic), 2018

9) Shigeharu YAMADA, Toshimune IMAI: Inspection of Howling by Underground Multichannel Rader for Reinforced Concrete, Applicability to Maintain, Engineering for Concrete, Vol. 56, No.1, pp69-72, 2018

10) Japan Geotechnical Consultants Association: Applicability of Geophysical Survey in the field of Disaster Prevention and Maintenance, Series of Geotechnical Survey Engineering (New Market Creation: the field of Disaster Prevention and Maintenance), Aug. 2007

11) Atsushi FUJII, Toru SATO, Kenji SAKATA, Toru YAMAJI, Ema KATO: Technical Note on Strategic Maintenance of Port and Harbor Facilities 〜Evaluation of Inspection and Repair Techniques〜, TECHNICAL NOTE of National Institute for Land and Infrastructure Management, No. 933, 2016.9.

12）T.Yamaji, Y.Akira and M.Abe:：Studies on the Estimation of Durability of Protective Coating Methods for Steel Pipe Pile based on the Long Term Marine Exposure Test for 30 years, NACE East Asia & Pacific Area Conference 2019

13) CEB Working Party V/4.1: Strategies for Testing and Assessment of Concrete Structures Affected by Reinforcement Corrosion (draft4) BBRI-CST-WTCB, 1997

14 Japan Society of Civil Engineering: Specification of Concrete (for Maintenance), 2013

# Part 6 Predicting Deformation Progression

## Chapter 1 General

### 1.1 Scope of Application

| |
|---|
| This part is relevant to predicting progression of deformation of port and harbor facilities. |

<Commentary>

This part specifies the prediction of the progression of the deterioration of parts or members of steel and concrete structures and the deformation of port and harbor facilities.

There are a wide variety of port and harbor facilities, and performance requirements vary greatly. For this reason, it is valuable to predict the progression of deterioration on a per facility part or member basis. As the performance grade of a structural member is judged according to the deterioration of parts and members, it is necessary to evaluate the state of the deterioration of those parts and members and to predict its progression.

Specifically, for steel structures, the targeted forms of deterioration are the corrosion of steel, the consumption of anodes in cathodic protection, and the deterioration of protective coatings. For concrete structures, the targets are deteriorated by chloride-induced corrosion and by alkali-silica reaction (ASR).

### 1.2 Purpose

| |
|---|
| (1) Proper maintenance of port and harbor facilities requires accurate prediction of deterioration of the whole facility or of its part/members.<br>(2) Deterioration must be predicted by presuming deterioration mechanism corresponding to target part/member or structure and by using suitable model. |

<Commentary>

Port and harbor facilities can be roughly divided into two types: steel structures and concrete structures. This part specifies the prediction methods for both types of structures. Note, “Manuals for corrosion protection and the repair of steel structures in ports” can be refereed for details on steel structures and “Manuals for repair of concrete structures in ports.” is the same on concrete structures.

In predicting the deterioration of steel and concrete structures and other structures in ports, the deterioration mechanism may sometimes be unknown. Furthermore, even when the deterioration mechanism is known, modeling the mechanism might be difficult. In addition, even when the deterioration mechanism is known, evaluation can often be challenging because the degree of deterioration progression varies within the same structure. One suitable method for addressing these situations is the use of a stochastic model known as a “Markov chain model” to predict, for example, the time shift in the distribution of visual inspection results (a, b, c, and d) within a visually inspected target structure[1]. Markov chain model can be applied to predict not only the temporal progression of material deterioration but also the generation and development of deformation.

Chapter 2 Predicting Deterioration of Steel Structures

## 2.1 Outline

> This chapter specifies prediction of deterioration of steel structures with corrosion protection methods, specifically, cathodic protection (cathodic protection by galvanic anodes) and protective coating. This chapter also specifies prediction of deterioration of structures without corrosion protection.

<Commentary>

Deterioration of a steel structure varies greatly depending on the corrosion protection method, so predictions should be made according to the corrosion protection method used.

## 2.2 Predicting Deterioration of Cathodic protection

> (1) For a steel material with cathodic protection, future consumption rate of anode is predicted based on calculations using actual measurements of anode consumption.
> (2) Thickness of steel materials with cathodic protection should be set appropriately based on predictions of protective effect.

<Commentary>

(1)

Measuring the amount of anode consumption enables the prediction of future consumption and the remaining service life of a cathodic protection system. Figure-6.2.1 shows an example of test results of the amount of anode consumption. Each dotted line connects the point in the upper left corner (point presuming the remaining anode ratio as 1 at the point of zero elapsed years) and the minimum value of anode consumption amount measured in each inspection target block. In this case, the design service life of the anode is ten years, but the anode is predicted to still function after ten years and to be completely depleted in another four to eight years.

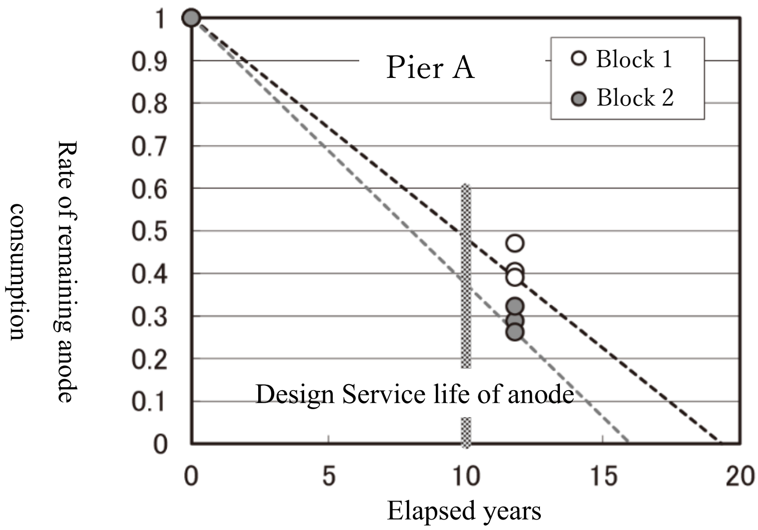



Figure-6.2.1 Test results of the amount of anode consumption

Figure-6.2.2 illustrates the effect of the anode replacement time on the protection current. If the anode is replaced before it is completely consumed, it is possible to reduce consumption of the protection current during anodic exchange because the electrocoating (electrodeposits) formed on the surface of the steel material remains. Conversely, if the anode is replaced after it has been completely consumed, because the electrocoating is lost, an additional protection current is necessary to form an electrocoating. Thus, it is preferable to replace the anode before it is completely consumed.

As with the corrosion rate of steel materials, factors affecting the anode consumption rate include the dissolved oxygen in seawater, seawater electric resistivity, and seawater flow speed. If these influential factors vary greatly during the service life, also the consumption rate varies in proportion to the factors' change.

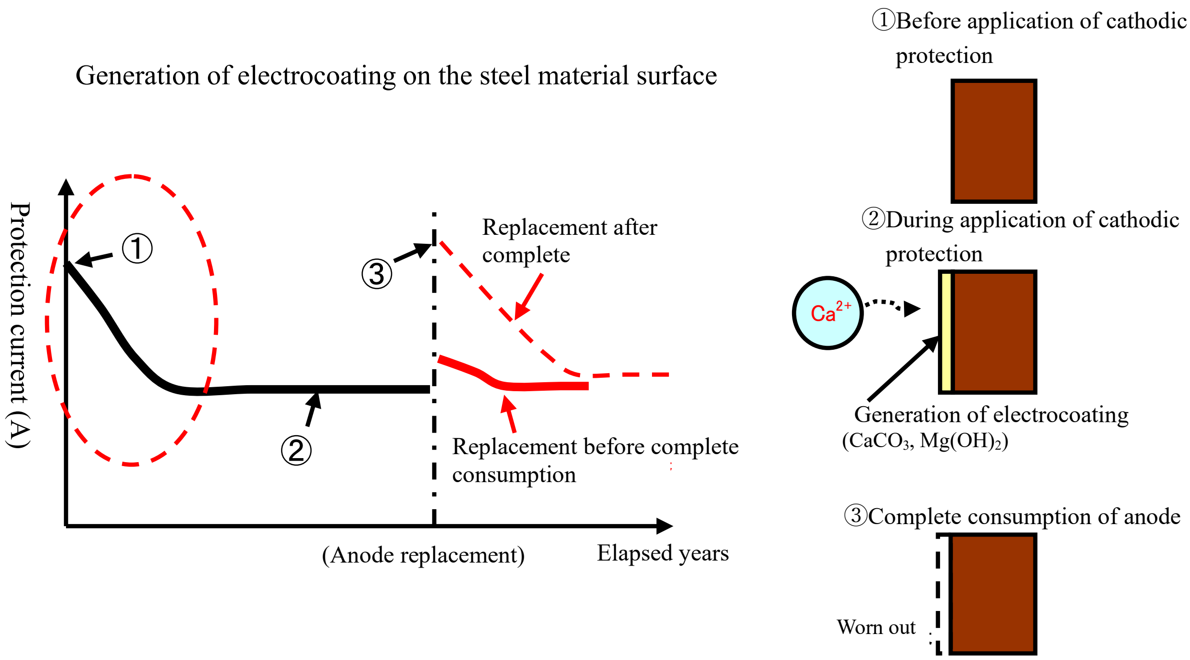



Figure-6.2.2 Effect of anode replacement time on protection current (image)

(2)

Generally, in Japan, cathodic protection is designed to have a corrosion protection efficiency of 90%. Thus, even when cathodic protection is applied, corrosion is assumed to progress at a rate that is 10% of the corrosion rate under conditions without corrosion protection (0.2 mm/year × 0.1 = 0.02 mm/year; thickness reduction of 1 mm in 50 years). If the protection has remained until anode renewal and is designed to continue, it is possible to set an appropriate value by considering the actual corrosion protection effect of cathodic protection in the target environment.

## 2.3 Predicting Deterioration of Protective coating

| |
|---|
| For steel materials with protective coating, progression of deterioration should be predicted by considering characteristics of each coating method and establishing appropriate model. If selecting appropriate model is difficult, then deterioration progression can be predicted based on the deterioration level of the parts and members. |

<Commentary>

The deterioration mechanism of protective coating differs greatly depending on the coating material and application method. In addition, most mechanisms by which protective coating inhibit the progression of deterioration remain unclear, and it is often difficult to establish an appropriate deterioration model. Therefore, currently, the most feasible approach is to predict the progression of deterioration based on the deterioration level of the parts and members (a, b, c, d) and by employing a Markov chain model.

## 2.4 Predicting the Deterioration of Steel Materials without Corrosion Protection

| |
|---|
| For steel materials without corrosion protection, progression of deterioration should be predicted based on steel material corrosion rate. |

<Commentary>

For a steel material without corrosion protection, the corrosion rate should be calculated by measuring the steel material's thickness to determine the thickness reduction and dividing this value by the number of elapsed years. Using this corrosion rate makes it possible to predict the remaining thickness, but factors such as dissolved oxygen in seawater, seawater electric resistivity, and seawater flow speed greatly affect the corrosion rate of steel material corrosion. If these influential factors vary greatly during the service life or are anticipated to do so, it is crucial to consider changes in the corrosion rate. For steel materials without corrosion protection, it is necessary to determine the current corrosion rate from thickness measurements and then predict the progression of future corrosion. These results may be used as necessary to evaluate the residual strength of steel structures.

# Chapter 3 Predicting Deterioration of Concrete Structures

## 3.1 Outline

(1) Deterioration of concrete structures should be predicted by presuming deterioration mechanism corresponding to target part/member or structure and by using appropriate model.

(2) In principle, deterioration mechanism should be estimated based on external factors affecting deterioration and the characteristics of deformation that can be obtained from inspection results of structure.

<Commentary>

Table-6.3.1 summarizes the relationship among the deterioration mechanism, deterioration factors, deterioration phenomena, and deterioration index that are covered in this document. As port facilities are located in a marine environment, most of their deterioration mechanisms are considered to arise from chloride-induced corrosion, whereby chloride ions act as the key deterioration factor. Because the alkali-silica reaction (ASR) depends on the rock type of the aggregate, the possibility of the occurrence of an ASR depends on regional geology. As the environment around the structure greatly affects the progression of chloride-induced corrosion and the ASR, the deterioration mechanism must be estimated by considering the environmental conditions.

Neutralization, which is a common deterioration phenomenon, progresses very slowly in port structures compared to that of onshore structures because port structures are exposed to a wet environment [2].

The deformation observed during inspection may include those not caused by deterioration (thermal cracks, shrinkage cracks) and damage caused by a sudden external force. The deformation must be considered distinct from those caused by the deterioration listed in Table-6.3.1.

Table−6.3.1 Relationship of deterioration mechanism and factors, indexes, and phenomena[3]

| Deterioration mechanism | Deterioration factor | Deterioration phenomenon | Deterioration index |
|---|---|---|---|
| Chloride-induced corrosion | Chloride ion | Chloride-induced corrosion is a type of deterioration in which rebar corrosion in the concrete is initiated by chloride ions, causing cracking or delamination of the concrete cover and sectional area reduction of rebars. | Chloride ion concentration<br>Rebar corrosion |
| Alkali-silica reaction (ASR) | Reactive aggregate | ASR is a phenomenon of deterioration in which the aggregate containing reactive silica minerals reacts with alkaline solution in the concrete, causing excessive expansion and cracking of the concrete. | Cracking (amount of expansion) |

## 3.2 Predicting Deterioration of Concrete Structures from Chloride-Induced Corrosion

### 3.2.1 General

(1) Chloride-ion penetration and progression of reinforcing bar corrosion should be predicted to estimate deterioration of concrete structures caused by chloride-induced corrosion.

(2) In principle, deterioration should be predicted based on the results of inspection/investigation.

<Commentary>

(1)

In chloride-induced corrosion, the reinforcing bars in concrete start corroding due to the presence of chloride ions. The expansion of the corrosion product causes cracks and spalling of the concrete, and the cross-sectional area of the reinforcing bars decreases, reducing the structure's performance. Therefore, to predict when the corrosion of a reinforcing bar will begin, it is necessary to predict the penetration of chloride ions. Predicting the progression of reinforcing bar corrosion requires knowing the reinforcing bar corrosion rate. The corrosion rate after the initiation of reinforcing bar corrosion mainly depends on the availability of water and oxygen, which are required for the corrosion reaction. Therefore, the corrosion rate varies depending on the environment in which the structure is located and on the quality of the concrete. The corrosion rate must be appropriately established by considering these influences. If the onset and rate of the reinforcing bar corrosion can be predicted in this manner, it becomes possible to predict decreases in the reinforcing bar cross-sectional area. This prediction, in turn makes it possible to predict the degradation in the structural performance of the reinforced concrete members.

(2)

Regarding the parameters required for predicting chloride ion penetration, it is preferable to use the results of chloride ion concentration from a core sampled from the actual structure. Based on the results of inspections and tests using electrochemical and other methods, it is possible to estimate the corrosion rate of the reinforcing bars, which is required to predict the progression of the corrosion.

3.2.2 Predicting chloride ion penetration in concrete

(1) Penetration of chloride ions in concrete can be predicted using Fick's second law of diffusion.

(2) Penetration of chloride ions in concrete should be predicted by considering quality of concrete and influence of surrounding environment on structure.

<Commentary>

(1)

As the movement of chloride ions in concrete can be considered a diffusion phenomenon, it is acceptable to use equation (6.3.1), or Fick's second law of diffusion, which is solved by using appropriate boundary conditions. The equation (6.3.2) is widely known and is a solution to (6.3.1) that assumes the chloride ion concentration on the concrete surface is constant regardless of service life. Note that $D_{ap}$ in (6.3.2) is set as the "apparent diffusion coefficient" because $C$ ($x$, $t$) represents the total concentration of chloride ions per unit volume of concrete, not in the liquid phase that is defined in (6.3.1). If the concentration of initially contaminated chloride ions $C_i$ is unknown, it is acceptable to substitute the chloride ion concentration of a specimen sampled from a location that is considered to be unaffected by chloride ion penetration.

$$\frac{\partial C}{\partial t} = D_c \left( \frac{\partial^2 C}{\partial x^2} \right) \qquad (6.3.1)$$

Here, $C$: chloride ion concentration in liquid phase (in solution); $D_c$: apparent chloride ion diffusion coefficient; $x$: distance from concrete surface; and $t$: time.

$$+ \qquad C(x,t) = C_0 \left( 1 - erf\left( \frac{0.1\,x}{2\sqrt{D_{ap}t}} \right) \right) \quad C_i \qquad (6.3.2)$$

Here, $C$ ($x$, $t$): chloride ion concentration (kg/m$^3$) at a depth $x$ (mm) from the concrete surface at elapsed time t (years); $C_0$: chloride ion concentration at the concrete surface (kg/m$^3$); $D_{ap}$: apparent diffusion coefficient of chloride ions (cm$^2$/year); $C_i$: concentration of initially contaminated chloride ions; and *erf*: error function.

(2)

If the equation (6.3.2) is used for prediction, the apparent diffusion coefficient $D_{ap}$ depends heavily on the quality of the concrete. Specifically, the apparent diffusion coefficient is greatly affected by the water-cement ratio *W/C* and cement type. In addition, the chloride ion concentration at the concrete surface $C_0$ depends greatly on the exposure environment (e.g. tidal zone, splash zone).

There are three feasible methods for setting these parameters ($C_0$, and $D_{ap}$), as follows, which explains later. Note that iii) applies only to $D_{ap}$.

i) Using inspection results for the target structure

ii) Using inspection results for a similar environment and structure and existing study records

iii) Using diffusion coefficients in concrete obtained from accelerated tests

i) Using inspection results from the target structure

If the inspection/test results of the chloride ion concentration distribution have been obtained, $C_0$ and $D_{ap}$ can be determined by conducting regression analysis of the chloride ion concentration profile according to (6.3.2).

When calculating the apparent diffusion coefficient of chloride ions using the chloride ion concentration distribution in the sampled concrete core, given the reliability of regression analysis, it is preferable to use values at five or more locations at different depths from the concrete surface. If neutralization has occurred on the concrete surface layer, since chloride ions in the concrete have moved to and concentrated at the neutralization front, the chloride ion concentration at the concrete surface layer should be excluded from calculation in such cases[4)]. Figure-6.3.1 shows an example of a chloride ion concentration profile and the result of regression analysis when the concrete surface layer is neutralized.

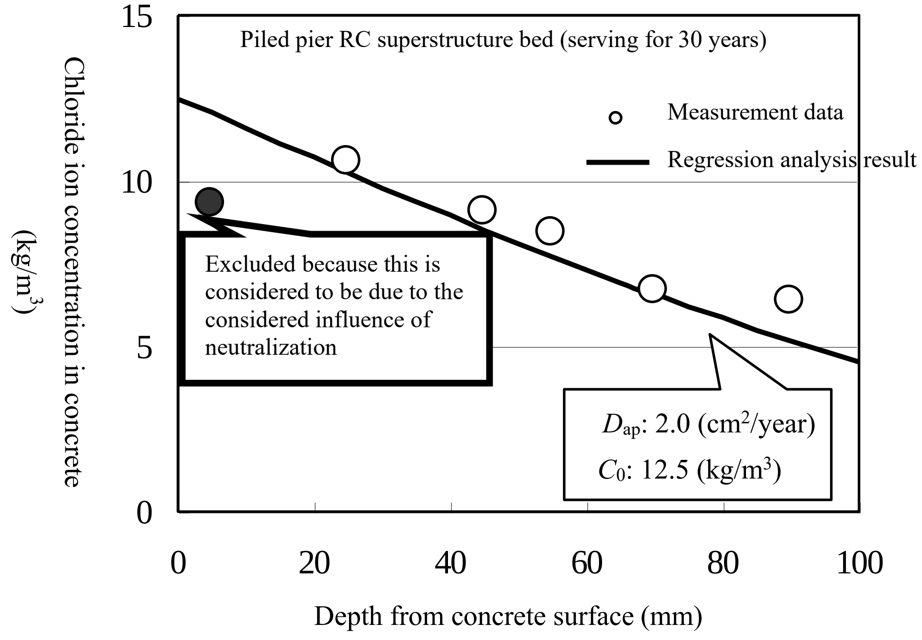



Figure-6.3.1 Chloride ion concentration profile in concrete whose surface layer is neutralized, and the result of regression analysis

ii) Using inspection results from a similar environment and structure and existing study records

If no inspection/investigation results exist, $C_0$ and $D_{ap}$ can be obtained by the following method.

(1) Apparent diffusion coefficient $D_{ap}$

It is also possible to obtain the diffusion coefficient design value $D_d$ from the water-cement ratio $W/C$ using the following formula. Note that it is acceptable to regard $D_d = D_{ap}$. If there is no cracking on the structure or if the number of cracks is small, the second term on the right side in (6.3.3) can be neglected.

$$D_d = \gamma_c D_k + \lambda \left( \frac{w}{\ell} \right) D_0 \qquad (6.3.3)$$

Here, $\gamma_c$: material factor of concrete. Generally, this value can be set to 1.0.

$D_k$: characteristic value of chloride ion diffusion coefficient in concrete (cm$^2$/year)

$\lambda$: factor expressing the influence of existing cracks on the diffusion coefficient. Generally, this factor can be set to 1.5.

$D_0$: constant expressing the influence of cracks on the movement of chloride ions in concrete. This constant can generally be set to 400 cm$^2$/y.

$w/\ell$ : ratio of crack width to crack interval ($w/\ell = (\sigma_{se}/E_s + \varepsilon'_{csd})$)

$\sigma_{se}$: increase in the stress of the reinforcing bar (N/mm$^2$)

$E_s$: Young's modulus of reinforcing bar (N/mm$^2$)

$\varepsilon'_{csd}$: constant for considering an increase in crack width due to concrete shrinkage, creep, and other factors

If the actual concrete that is used is known, the characteristic value of the chloride ion diffusion coefficient in concrete $D_k$ used in (6.3.3) can be obtained from an experiment[5)] using a specimen produced from the concrete. In other cases, it is possible to obtain the value by assigning $W/C$ to (6.3.4) and (6.3.5). In this case, however, the estimated accuracy of $D_k$ is not high.

・When using normal Portland cement ($0.35 < W/C < 0.55$)

$$\log_{10} D_k = 3.4 (W/C) - 1.9 \qquad (6.3.4)$$

・When using blast-furnace slag cement or silica fume ($0.40 < W/C < 0.55$)

$$\log_{10} D_k = 2.5 (W/C) - 1.8 \qquad (6.3.5)$$

(2) Chloride ion concentration *of* concrete surface $C_0$

According to TSCPHF, it is acceptable to obtain $C_0$ by using the following formula. Note that this formula was determined based on the result of an investigation of piled pier bridge superstructures[6)].

$$C_0 = -6.0\,x + 15.1 \qquad (6.3.6)$$

Here, $x$: distance between H.W.L. and the concrete surface (m). However, the application range of $x$ must be approximately $0 \leq x \leq 2$, and the $C_0$ value must not fall below 6.0 kg/m$^3$.

iii) Using diffusion coefficients in concrete obtained from accelerated tests

An electrical migration test is a method to estimate the diffusion coefficient of chloride ions in concrete. With this method, even when chloride ions have not penetrated through a sampled concrete core, it is nevertheless possible to estimate the diffusion coefficient of chloride ions in the concrete. The electrical migration test measures the ease with which chloride ion migrate through porous concrete by using the electric potential gradient as the driving force of chloride ion movement. The coefficient representing this ease of movement is called effective diffusion coefficient. The effective diffusion coefficient differs from the apparent diffusion coefficient mentioned earlier, which is used for all the chloride ions in the concrete. Therefore, the effective diffusion coefficient estimated with the electrical migration test must be converted into apparent diffusion coefficient in concrete.

3.2.3 Predicting progression of reinforcing bar corrosion in concrete

(1) Progression of reinforcing bar corrosion in concrete should be predicted by properly considering quality of concrete and influence of surrounding environment.
(2) In principle, time at which corrosion of reinforcing bars in concrete should be determined, based on chloride ion concentration in reinforcing bars.
(3) To predict progression of corrosion up to generation of cracks in concrete, it is necessary to set rate of reinforcing bar corrosion and amount of reinforcing bar corrosion generated by the cracking.
(4) To predict the progression of corrosion after corrosion cracks have appeared in concrete, it is necessary to set rate of reinforcing bar corrosion after generation of cracks.

<Commentary>

(1)

The corrosion of reinforcing bars requires oxygen and water. In port concrete structures, as water is usually abundant, the availability of oxygen influences the corrosion rate of reinforcing bars. The speed of oxygen movement through concrete greatly depends on the moisture content of concrete; the more moisture, the slower the oxygen migrates through the concrete. Therefore, when a concrete structure is exposed to a submerged zone, as the amount of oxygen available at the concrete surface is small, and the speed of oxygen migration in the concrete is low, the amount of oxygen supplied to the reinforcing bars in the concrete substantially decreases. Consequently, little corrosion occurs. However, even when a concrete structure is submerged, if a serious crack develops on the concrete, intense corrosion may occur in the crack[7)]. On the other hand, in an environment such as a splash zone, there is abundant seawater, and the structure is always exposed to the atmosphere where oxygen is supplied. This condition produces a severe environment for reinforcing bars in concrete, making it difficult to resist corrosion. As explained, in predicting the progression of corrosion, it is necessary to consider the environment surrounding the structure in question.

Figure-6.3.2 shows a simple model of the progression of corrosion of a reinforcing bar in concrete. Corrosion occurs at a certain point, after which the reinforcing bars corrode, expand and form cracks. Then, the corrosion rate further increases, accelerating the progression of corrosion.

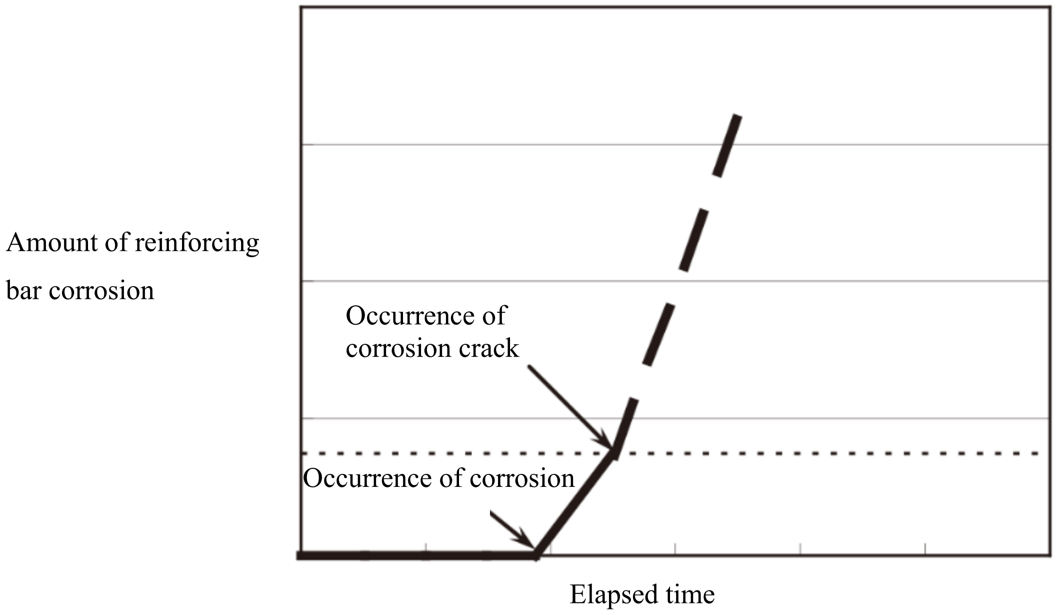



Figure-6.3.2 Variation in the extent of corrosion over time

(2)

The chloride ion threshold value for corrosion $C_{lim}$ is generally recognized to be approximately 1.2 to 2.4 kg/m$^3$. Technical Standards for Port and Harbor Facilities in Japan adopt a value of 2.0 kg/m$^3$ based on survey results. In an environment such as a submerged zone, in which cavities in the concrete are saturated with water, the amount of oxygen necessary for corrosion reactions is insufficient. Therefore, there is little corrosion of reinforcing bars, despite a high concentration of chloride ions.

It is necessary to properly set $C_{lim}$ by considering not only whether the environment is covered or exposed but also the importance and designed service life of the structure. In inspections or tests, if the relationship between the chloride ion concentration and state of corrosion of the reinforcing bar are known, and if it is possible to set $C_{lim}$, then that value can be used. The state of corrosion in the bar can be evaluated by locally chipping the concrete.

By assigning $C_{lim}$ in the manner explained above, covering, $C_0$, and $D_{ap}$ in (6.3.2), it is possible to obtain the start time of corrosion $t_{lim}$ in the reinforcing bar. Note that in "the verification of reinforcing bars corrosion due to penetration of chloride ions" in TSCPHF, policy is to ensure that the start time of corrosion $t_{lim}$ in the reinforcing bar exceeds the designed service life.

(3)

Regarding chloride-induced corrosion of reinforcing bars before the generation of cracks in covered concrete, it is often difficult to set the corrosion rate because the influencing factors are complicated, and in many cases, corrosion progresses locally and intensively. The following methods for setting the corrosion rate are currently available.

<u>(1) Using inspection/test results</u>

This method involves measuring the corrosion rate of the reinforcing bar through inspections or tests. The obtained value is used to predict future corrosion. Measurement methods include the polarization resistance method, which allows non-destructive measurement, and the method of evaluating the actual state of corrosion by locally chipping the concrete.

(2) Using existing test results or various models

It is possible to set the corrosion rate using existing test results.

As the reinforcing bar corrosion progresses and the reinforcing bars expand, cracks occur in the concrete. The following formula can be used as a reference for calculating the "amount of reinforcing bar corrosion that generates cracking".

$$W_{cr} \fallingdotseq 10\,(c／d) \qquad (6.3.7)$$

Here, $W_{cr}$: corrosion limit of crack generation (mg/cm$^2$), $c$: cover (cm), and $d$: reinforcing bar diameter (cm).

The period from the onset of reinforcing bar corrosion $t_{lim}$ to the time when corrosion cracking appears in the concrete ($\Delta t_{cr}$) is obtained by dividing the amount of corrosion that generates corrosion cracking by the corrosion rate set here. In other words, $t_{lim} + \Delta t_{cr}$ is the period from the start of service to the generation of reinforcing bar corrosion cracks (refer to Figure-6.3.2).

(4)

By setting the corrosion rate to reflect the point after the generation of corrosion cracks in concrete, it becomes possible to predict the decrease in the cross-sectional area of the reinforcing bar. In turn, degradation in the structural performance of the reinforcing bar concrete members can be predicted with respect to the reinforcing bar corrosion. However, there is insufficient knowledge to determine the corrosion rate after the generation of corrosion cracks in concrete because the corrosion rate increases sharply once corrosion cracks appear, and also there is few studies and investigation case about this phenomenon.

# Chapter 4 Predicting Progression of Deformations Using a Markov Chain Model

## 4.1 Outline

(1) When deterioration mechanism is unknown, or modeling mechanism is difficult to make even deterioration mechanism is known, though it is possible to stochastically predict future deformation in deterioration condition of a structure by a Markov chain model.

(2) Even when deterioration mechanism is known, prediction by a Markov chain model is possible. This method is effective when deterioration condition varies in same structure and evaluating degree of deterioration is difficult.

<Commentary>

In predicting the deterioration of various structures, the deterioration mechanism may be unknown. At times, the deterioration mechanism may be known, but modeling is difficult. Furthermore, there are cases in which the deterioration condition varies within the target structure, making it necessary to obtain values for prediction from as wide an area as possible in the target structure. In such cases, predicting and assessing the deterioration in the whole structure is difficult.

A stochastic model known as a Markov chain model is statistical method by which the probability of a given object transitioning in a certain manner from one state to the next state is determined stochastically by employing the concepts of "state" and "transition"[8]. Using the results of periodic inspection and diagnosis (a, b, c, d) to determine the deterioration level in the target structure, setting the transition probability of the deterioration level as transition probability $p_x$, and expressing the transition of this deterioration level as shown in Figure-6.4.1, it becomes possible to predict the progression of deterioration. The mechanism underlying deterioration is briefly described below.

When a certain period of time has elapsed, a part/member with a given deterioration level transitions to the next deterioration level with transition probability $p_x$ or remains at the same deterioration level with remaining probability (1- $p_x$).The transition of the deterioration level occurs at all deterioration level simultaneously, and the deterioration level at the final stage ("a" in this explanation) does not progress further but finally remains at that point. According to this model, the state transition repeats whenever a certain period elapses, and the degree of deterioration gradually progresses. This process of deterioration can be expressed by (6.4.1), assuming the deterioration level of all the parts/members in their initial state is "d".

$$\begin{pmatrix} d \\ c \\ b \\ a \end{pmatrix} = \begin{pmatrix} 1-p_x & 0 & 0 & 0 \\ p_x & 1-p_x & 0 & 0 \\ 0 & p_x & 1-p_x & 0 \\ 0 & 0 & p_x & 1 \end{pmatrix}^t \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad (6.4.1)$$

Here, $p_x$ is the transition probability, $t$ is the elapsed time, and ($d$, $c$, $b$, $a$) are percentages that reflect the deterioration level. Transition probability $p_x$ is an index indicating the speed of deterioration and it can be treated as a fixed value when using the deterioration level explained in Chapter 4.

This section explains the basic characteristics of a Markov chain model. Figure-6.4.2 shows the transition of the percentage of the deterioration level over time. Note that as time passes, the ratio of deterioration level “d” decreases, while the ratios of deterioration level “c”, “b” and “a” increase.

Figure-6.4.3 shows the influence of transition probability $p_x$ on the rate of deterioration. When the elapsed time is the same, as the transition probability increases, the peak of the degree of deterioration shifts from deterioration degree “d” to “c”. This consequence reveals that the transition probability reflects the deterioration rate.

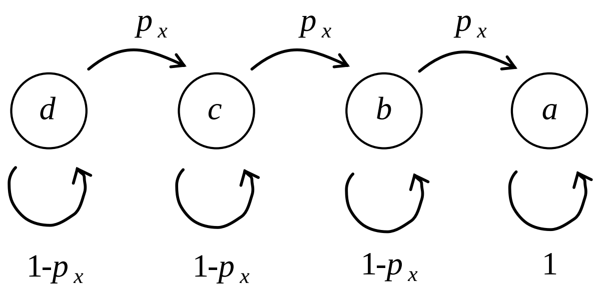



Figure-6.4.1 Markov chain transition of general regular inspection and diagnosis results (a, b, c, and d)

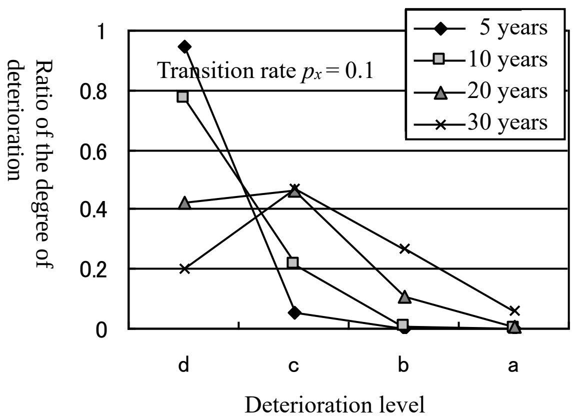



Figure-6.4.2 Changes in the ratio of the deterioration level over time

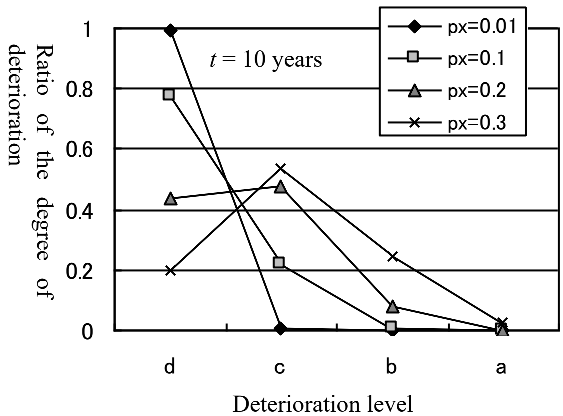



Figure-6.4.3 Impact of transition rate $p_x$ on changes in the ratio of deterioration level

## 4.2 Applying a Markov Chain Model

(1) When distribution of deterioration level in same structure and elapsed years are known, it is possible to predict progression of deterioration by a Markov chain model.
(2) When applying a Markov chain model, it is necessary to set correct number of states.

<Commentary>

(1)

When applying a Markov chain model, a certain number of total inspection results must be obtained under the same conditions. However, if deterioration level "d" represents most of the results, caution is necessary because there is a risk of underestimating the transition rate $p_x$ and obtaining an inaccurate prediction by the reason of little deformation and newly built. A Markov chain model can be applied not only to material deterioration, such as chloride-induced corrosion of reinforcing bars, which progresses over time, but also to the occurrence and development of deformation. In addition, although this section only describes the application of a Markov chain model to grade deterioration level (a, b, c, and d), this model can also be applied analogously to judge performance grade (A, B, C, and D).

(2)

The equation (6.4.1) shows a single state as a state in a Markov chain model that corresponds to a single deterioration degree. In certain cases, however, the measured value and the calculated value do not sufficiently match. In such cases, increasing the number of the state in the Markov chain model that corresponds to a single deterioration level may result in a moderate match between the measured and calculated values.

**References of Part6**

1) Kenichi KOMURE, Hidenori HAMADA, Hiroshi YOKOTA, Toru YAMAJI: Development of A Model on Deterioration Progress for RC Deck of Open Type Wharf, Report of the Port and Airport Research Institute, Vol.4, 2004.

2) Tsutomu FUKUTE, Kunio YAMAMOTO, Hidenori HAMADA: Study on the Durability of Concrete Mixed with Sea Water, Report of the Port and Harbour Research Institute, Vol.29, 1990.

3) Japan Society of Civil Engineering: Specification of Concrete (for Maintenance), 2013

4) Concrete Committee, Japan Society of Civil Engineering: Standard of Japan Society of Civil Engineering "Measuring Method of Chloride Ion Distribution in Concrete of Existing Constructure (design) Formulation (JSCE-G578-2003), Research Papers by JSCE, No.767, v-64, pp.17-25, Aug. 2004

5) Japan Society of Civil Engineering: Enactment of Chloride Ion in Concrete Diffusion Factor Test Method, and Testing Method of Desired Standardization, Concrete Engineering Series No.55, 2003.

6) Toru YAMAJI, Hiroshi YOKOTA, Shoji NAKANO, Hidenori HAMADA: Study on the verification of steel corrosion in port reinforced concrete structure based on site survey and long term exposure test, Research Papers E by Japan Society of Civil Engineering, Vol.64, No.2, pp.335-347, 2008.

7) Hidenori HAMADA, Hiroshi YOKOTA, Shoji NAKANO, Ema KATO: The Impact on Material Performance by Cracks Occurring on Cover Concrete, Japan Concrete Institute Vol43, N0.5, pp139-143, 2005.5.

8) Hidenori MORIMURA, Yukio TAKAHASHI: Markov Anal**ysis, JUSE Press, Ltd,** OR Library 18, 1989

# Part 7 Types and Selection of Countermeasures

## Chapter 1 General

### 1.1 Scope of Application

| |
|---|
| This part is relevant to countermeasures for maintenance and repair taken based on results of comprehensive assessment of steel structures and concrete structures that constitute port and harbor facilities. |

<Commentary>

This part describes the standard types of countermeasures and the methods for their selection based on the comprehensive assessment of the steel structures and concrete structures that constitute port and harbor facilities. The countermeasures include general repairs and reinforcement, follow-up observation, either restriction or suspension of the facility utilization, and a variety of countermeasures. The appropriate methods are required to be selected based on various criteria, including the state of deterioration of the structures, the importance of facilities, and economic efficiency. Table-7.1.1 shows examples of typical countermeasures. countermeasures also include taking actions such as restricting or suspending the facility utilization and prohibiting entry based on the facility utilization in question or of the surrounding facilities.

Table-7.1.1 Examples of typical countermeasures

| Type of countermeasure | Description |
|---|---|
| Follow-up observation | Countermeasure that is taken while continuing to inspect the same items at the same frequency |
| Rearrangement of inspection and diagnosis plan | Countermeasure for which the inspected items or inspection frequency is changed |
| Repair | Countermeasure for restoring performance and durability to the initial levels or for improving durability beyond the initial level |
| Reinforcement | Countermeasure for improving performance beyond the initial level |
| Upgrade | Countermeasure taken when upgrading facilities is more reasonable than repair or reinforcement |
| Removal | Countermeasure taken when facilities are no longer required |

One of the countermeasures is to decide to perform the regular periodic inspection and diagnosis without performing repairs, the require reason is when preventing progression of structural deterioration is clear. In this case, however, the necessity of changing the items to be inspected or the inspection frequency is required to be determined based on the results of recently conducted the regular periodic inspection and diagnosis.

This part mainly describes the repair and reinforcement of steel structures and concrete structures that constitute port and harbor facilities. Ancillary facilities (e.g., fenders, curbing) are not described in this part. When determining the methods of repair and reinforcement or the scope of countermeasures to be taken, an additional investigation is required to be conducted if the information from the regular periodic inspection and diagnosis results is insufficient.

In addition, in the case of cavity at the rear of quaywall, appropriate action is required to be taken based on the cause. If the cavity is caused by pitting (attributable to corrosion) in a steel sheet pile, filling the hole could be an essential countermeasure. On the other hand, in cases of the breakage of sand invasion prevention sheets and others incidents where the cause of the cavity cannot be identified, taking an essential countermeasure is difficult. In such cases, cavity is possible to be filled with urethane, mortar, or other material, but these fills are only emergency countermeasures, and caution is necessary.

# Chapter 2 Countermeasures for Steel Structures

## 2.1 Outline

(1) If performance of steel structures has degraded, and it has been determined that repair or reinforcement is required to be performed, a method that satisfies required performance should be selected.

(2) If selecting countermeasures based on a performance evaluation is difficult, countermeasures are also possible to be selected based on level of structural deterioration.

(3) If corrosion protection is in place for steel materials, appropriate repairs is required to be performed by considering characteristics of various corrosion protection methods and state of deterioration.

(4) If corrosion protection has yet to be implemented for steel materials, appropriate corrosion protection is required to be selected, and repair or reinforcement is required to be considered by considering corrosive environment category and current corrosion state.

<Commentary>

(1) and (2)

Generally, if corrosion protection has been applied to a steel structure and is providing the desired effect, the performance of the steel structure is expected to be maintained. When applying corrosion protection methods, an evaluation of the quantitative performance of cathodic protection is easy to perform, which makes it relatively straightforward to determine the need for countermeasures (upgrading the anode) and to allocate time for implementing the countermeasures. However, for protective coating, it is often difficult to select countermeasures based on a quantitative assessment and to allocate time for implementing them. In such cases, structure's deterioration level can be used to select countermeasures and allocate time for implementing them.

(3)

The corrosion protection methods covered in this item are cathodic protection (cathodic protection by galvanic anodes) and protective coating. Appropriate repairs are required to be performed by considering the characteristics of each corrosion protection method and the state of structural deterioration. For details, see "Corrosion Protection and Repair Manual for Port and Harbor Steel Structures[1)]" and "Manual for Corrosion Protection and Repair of Port Steel Structures (2009)"[2)].

(4)

If corrosion protection is not in place, appropriate corrosion protection is required to be selected, and reinforcement of insufficient steel wall thickness is required to be considered by considering the corrosive environment category and the current corrosion state. For details, see "Corrosion Protection and Repair Manual for Port and Harbuor Steel Structures" [1)] and "Manual for Corrosion Protection and Repair of Port Steel Structures (2009)"[2)].

## 2.2 Repairs for Cathodic protection

(1) If cathodic protection is not being maintained, appropriate countermeasures for are required to be taken.
(2) An anode approaching end of its service life should be replaced before it is completely consumed.

<Commentary>

(1)

If normal corrosion protection has not been maintained for a long time due to the consumption of the anode or other reasons, the remaining wall thickness of the steel materials is required to be measured. Then, whether the steel materials retain the required performance is required to be confirmed. After confirming this fact, a new anode is required to be promptly installed. In addition, if anode has been consumed more rapidly than its designed service life, the cause is required to be investigated, and countermeasures, such as changing the design density of the protection current, is required to be taken. An example of a diagnostic flow is described in reference[3)].

(2)

If an anode that has completely been consumed is replaced, the electro coating (electrodeposition) will have been lost, so a protection current is required for this coating to form. In addition, if the non-corrosion protection LED state persists for a long period (2 to 3 years or longer), part of the protection current is consumed as the reduction current of the rust generated on the surface of the steel. For this reason, the initial density of the protective current is required to be expected to be 1.1 to 1.2 times higher than otherwise predicted by considering the ratio of the required protection current to the reduction current and the anode's service life[4)].

On the other hand, when the anode is replaced before it has been completely consumed, the electro coating on the steel material surface will remain, which allows the protection current consumed at the time of anode replacement to be reduced. For this reason, the anode should be replaced before it has been completely consumed.

## 2.3 Repairs for Protective coating

Protective coating repairs is required to be appropriately performed according to the type, characteristics, and deterioration state of the coating material.

<Commentary>

The method for repairing protective coating should be determined by considering the state of deterioration of the parts to be repaired, the recoatability of the coating materials, and various other criteria. List of repairing methods for each type of protective coating method is shown in Table-7.2.1. In many cases, partial repairs are generally performed by the same methods used for the current protective coating. However, depending on the type of protective coating, repairs using the same material or method may be difficult or inappropriate due to the state of degradation or the extent or environment of the surface preparation. For paint or organic material coatings, the repair method is required to be determined by considering factors including the part to be repaired, the state of degradation, the extent of surface preparation, and the recoatability.

For full repairs (reconstruction of coating), the repair method is required to be determined by considering factors such as the history of the coating, the on-site conditions, the durability of coating materials (expected service life), and service life of facility for the future.

Table-7.2.1 List of repairing methods for each type of corrosion protection method[3)]

| Method | | Outline of corrosion protection method | Applicable repair method |
|---|---|---|---|
| Coating | | Method for preventing corrosion by coating the surface of a steel product with a coating material of resin and pigment with additive and solvent added to form a coated film on it. Generally, a newly manufactured product is coated at a factory. This method is very versatile, as it can be applied irrespective of shape of the steel product to be protected. | Coating<br>Underwater curing type coating*<br>Super thick film coating<br>Petrolatum coating* |
| Super thick film coating | | Method of coating the surface of a steel product with a liquid coating material. Coating is executed at factory. Coating with a thickness of 1 to 3 mm can be provided. | |
| Underwater curing type coating | | Method of coating steel products on site with materials that can be applied under water (mainly, underwater curing type epoxy resin coating material). Coating with a thickness of 1 to 5 mm is provided. This method is often used for preventing the corrosion of existing underwater steel structures and facilitates a partial repair. | |
| Heavy duty plastic coating | Polyethylene coating | Executed at a factory. Coating with a thickness of 2 to 3 mm is provided. Polyethylene is a resin with excellent endurance, chemical resistance and seawater resistance. In addition, mixing it with carbon black has improved its weather resistance. Since it has a high impact resistance and a strong adhesive force, it resists damage and is easy to handle. | Stick method<br>Patch method<br>Petrolatum coating*<br>Underwater curing type coating* |
| | Urethane elastomer coating | Executed at a factory. Coating with a thickness of 2 to 3 mm is provided. Urethane elastomer refers to elastic urethane resin, which is two-liquid mixed curing type coating material. It provides a hard coating with a good low-temperature drying performance and elasticity, particularly | Polyurethane method for repair<br>Underwater curing type coating*<br>Petrolatum coating* |

| | | |
|---|---|---|
| | excelling in wear resistance. | |
| Corrosion resisting metal coating | Method for preventing corrosion by applying metal excelling in corrosion resistance, to the surface of a steel member. There are seawater resisting stainless steel coating, sheet titanium clad steel coating, etc. and they are executed at a factory. It provides high mechanical strength and it is superior to impact resistance and wear resistance. On the other hand, the initial investment on this method tends to be relatively large. | Patch applying method<br>Overlay welding method<br>Petrolatum coating |
| Mortar coating | Protective cover which also serves as a formwork is set on the surface of a steel product, and the space between the protective cover and the steel material is filled with mortar. The alkalinity of the mortar reduces the corrosion of the steel product, and the protective cover protects the mortar. | Repair of a protective cover<br>- Underwater curing type coating<br>- Installation of a cover for repair*<br>Mortar coating*<br>Underwater curing type coating*<br>Petrolatum coating* |
| Petrolatum coating | Method for coating the surface of steel product on site with a petrolatum type corrosion preventive material which is a kind of petroleum wax. A protective cover is attached to protect the corrosion protective material against external forces such as large waves and driftage impacts and increase the corrosion protective effect by sticking fast the corrosion protective material to the steel product. | Petrolatum coating<br>Underwater curing type coating<br>Mortar coating |

No mark: For partial repair

*: Including overall repair

## 2.4 Repair and Reinforcement for Uncoating

(1) After ascertaining corrosive environment category and corrosion state of steel structures and evaluating their current performance, countermeasures that allow required performance to be maintained for specified time period is required to be appropriately applied in combination.

(2) When implementing only one corrosion protection method, the method should be selected by following same policy as that for designing a new structure.

(3) If required performance cannot be maintained with only a corrosion protection method, reinforcement is required to be performed to restore mechanical performance.

<Commentary>

(1)

If the remaining steel thickness has been reduced due to the progression of corrosion, and it is predicted that the specified performance will be unable to be maintained in near future, appropriate corrosion protection is required to be applied. If the required performance is not already being retained, reinforcement to ensure improved performance is required to be promptly performed, followed by appropriate corrosion protection.

Note that a performance evaluation of the steel structures should be performed by comparing the cross-sectional strength calculated from the steel thickness and the sectional force calculated from the action. In addition, it is necessary to clarify the performance of the steel materials after performing countermeasures and to confirm that the performance is satisfactory for the design service life.

(2)

Protective coating (cathodic protection, coating) should be selected by following the same policy as that for designing a new structure, taking into account factors such as the corrosive environment category and the design service life.

(3)

General reinforcement for restoring mechanical performance is implemented by covering the degraded section to allow the repaired section to resist external forces with a single material and method or with another material and method used in combination with the steel materials at the repaired section, thus ensuring the desired performance and transmitting sufficient stress between each steel material. The following are the two typical methods applied for this purpose:

(1) Method using reinforced concrete

This method wraps the reinforced concrete around the existing steel materials. The reinforced concrete is required to be securely fixed to the sound sections of the existing steel materials using studs and other parts.

In addition, due to the existence of reinforcing bars inside the concrete, changes in performance due to aging are required to be considered, and performance through to the end of the service life is required to be confirmed.

(2) Method using steel plates

This method joins a steel plate to the surface of an existing steel material with fillet welding. The steel plate is required to be securely fixed to a sound section (generally, at least 5 mm thick) on the existing steel material. A slit part is usually provided to secure the fixation length.

In addition, since the steel base and welded part are exposed at the area where the steel plate has been welded, corrosion may occur at an early stage, so the necessary corrosion protection are required to be planned.

## Chapter 3 Countermeasures for Concrete Structures

### 3.1 Outline

(1) When performance of a concrete structure has degraded, and it has been determined that repairs or strengthening is required to be performed, a method that ensures required performance should be selected as countermeasure for repair.

(2) If selecting countermeasures based on a performance evaluation is difficult, countermeasures are also possible to be selected based on deterioration level.

<Commentary>

(1)

For concrete structures, countermeasures (repairs or strengthening) are required to be selected to address each deterioration factor. This approach applies mainly to chloride-induced corrosion. For details, see "Standard Specifications for Concrete Structures (Maintenance)"[5].

Concrete structures may have cracks that are not attributable to the chloride-induced corrosion or ASR at an early stage after initial usage. The main reasons for such cracks include loads or plastic shrinkage due to the hardening of concrete or drying. In addition, concrete structures may have defects because of construction failures, such as honeycombs and cold joints. When faults such as cracks are left untreated, deterioration factors (e.g., chloride ions, water) are likely to infiltrate the concrete, which may accelerate the progression of the deterioration due to chloride-induced corrosion or ASR. Therefore, this chapter also briefly explains countermeasures that should be taken as preventive measures for defects, such as cracks.

For details, see "Practical Guidelines for Investigation, Repair and Strengthening of Cracked Concrete Structures [6]".

(2)

In many cases it is difficult to select countermeasures based on a quantitative evaluation of performance. If this is the case, countermeasures need to be selected based on the structure's deterioration level. Note, however, that in this case, materials and methods are required to be selected based on the deterioration mechanism.

## 3.2 Repair and Strengthening of Structures with Chloride-Induced Corrosion

> Methods and materials of repair and strengthening of a structure with chloride-induced corrosion are required to be selected by considering the performance degradation due to chloride-induced corrosion so that the desired effect can be obtained.

<Commentary>

Deterioration from chloride-induced corrosion tends to rapidly progress at a certain stage. It is therefore recommended to perform preventive maintenance before deterioration becomes apparent. When repair or reinforcement is conducted, it is necessary to clarify the expected results of the countermeasure and to clarify requirements for the methods or materials necessary to achieve these results. It is recommended to incorporate the physicochemical properties of the materials to be used into a structural equation or deterioration prediction equation, evaluate the expected results, and then perform the appropriate action.

The superstructure (RC or PC) of an open-type wharf is a representative example of a part that deteriorates from chloride-induced corrosion. See “Manual for Repair of Port Concrete Structures[7]” for details.

Some typical repair or strengthening methods used to address structural deterioration due to chloride-induced corrosion are shown in Table-7.3.1. This table may be used as a reference. When the degree of deterioration varies greatly by location in a single structure, it is necessary to appropriately combine repair methods which are distinct for around areas rather than to use an individual method for each member.

Table-7.3.1 Standard repair methods (chloride-induced corrosion)[2]

| Example of method | Expected results |
|---|---|
| (Surface coating)* | Reduction in source of rebar corrosion factors |
| Surface coating, cathodic protection | Control of rebar corrosion progress |
| Surface coating, cathodic protection, patch repair | Removal of rebar corrosion factors, control of corrosion progress |
| FRP adhesion, patch repair, thickness enhancement | Improvement of load carrying capacity |

* Conducted as a preventive maintenance measure

1) Surface coating

The main purpose is to cover the concrete surface with various materials (mainly resin or polymer cement materials) to control the penetration of deteriorating factors (such as chloride ions or oxygen) from the outside.

The general procedure includes the removal of dirt from the concrete surface by, for example, sand blasting, application of primer (pretreatment), surface adjustment with paste if any surface unevenness remains, and application of a main coat (intermediate coat) and finish coat (surface coat) (see Figure-7.3.1). The surface covering also includes panel type covering materials such as embedded forms. This type of covering is provided by resin that is left in place as a protective material.

When selecting the surface covering materials, the following conditions may be used as a reference:

Conditions for selecting a surface coating material[8)] (partly omitted)

(1) When applied as a surface coating, the material should prevent the penetration of chloride ions into the concrete or the patch repair material.

(2) When cracks occur in the coating material, the material is required to be strong and flexible to stick these cracks to maintain the resistance against a penetration of chloride ion.

(3) The material is required to exhibit sufficient adhesion to the base material (existing concrete or patch repair material) of the coating material. When coating surfaces, the material should be applied separately to the wet surface (surface water content of 10% or greater) and the dry surface (surface water content of less than 10%), using the surface water content ratio as the reference, and the material for each surface is required to be different. The performance of the material applied to the wet surface should be equivalent to that applied to the dry surface, except the capability of following cracks.

The surface coating should be applied before any deterioration starts as preventive maintenance. When using the surface coating method, it is necessary to evaluate the chloride ion concentration at the rebar position at the time of application. It is also necessary to periodically inspect the status of the deterioration of the surface coating material.

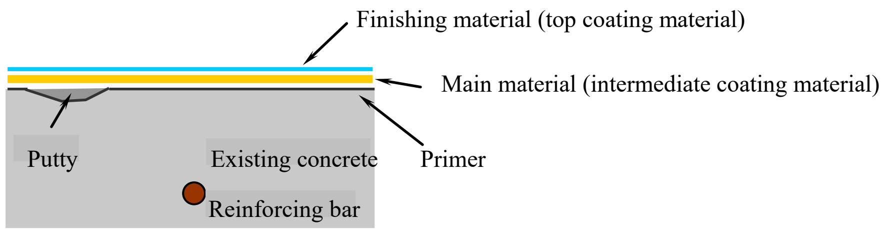



Figure-7.3.1 Example of Surface coating

2) Patch repair

The patch repair method may be applied when a large amount of chloride ions is contained in the concrete around the rebar position or when the rebar corrosion has progressed. The portion of the concrete in which a large amount of chloride ions is contained should be removed, and this part should be filled with the patch repair material (often cement mortar or polymer cement mortar) (see Figure-7.3.2). This material is often used jointly with the surface coating to prevent the penetration of chloride ions into the newly applied patch repair material. When a beam member is the target of repair, embedded forms are possible to be used as the surface coating material[9].

The general repair procedure involves chipping the concrete to the back of the rebars suffering ongoing corrosion to remove the rebar rust, performing an anti-rust treatment of the rebars, applying the primer (pretreatment) to the existing concrete area and repairing the section with the patch repair material. When the sectional area of the rebars rust removed is insufficient to satisfy the required structural performance, it is necessary to increase the number of rebars by installing splice bars. The type of material and the method of placement differ considerably when the target of patch repair has a large area versus when it has a small area. The repair material is generally filled using a trowel when the section being repaired is small. When the section being repaired is large, the material is filled by mortar filling or spraying.

A wide variety of materials and methods used for patch repair have been commercialized to date.

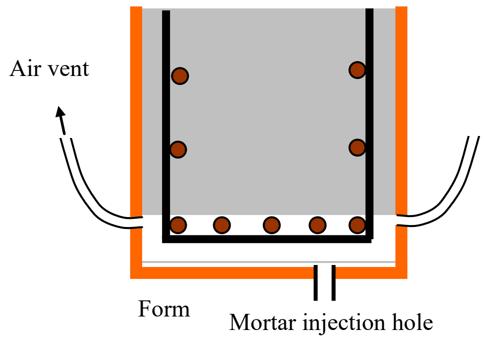



Figure-7.3.2　Example of patch repair

（Cement mortar）

Basic Policy for the Design of Patch Repair Materials[8] (partly omitted)

(1) For places where the patch repair method is applied, the basic procedure should be to ensure the full removal of the concrete to the back of the rebars. However, it is essential to fully understand the dead and live loads of the structure and to ensure safety in advance.

(2) When the residual sectional area of rebars is reduced, compensating the reduction with splice bars should be the basic solution.

(3) Care is required to be taken to ensure that the rebar covering thickness of the repaired part is equal to what is indicated in the design.

Conditions for selecting the patch repair materials[8]

(1) The material is required to have sufficient strength and density.

(2) The material is required not to crack from dry shrinkage or the heat of hydration.

(3) The material is required to demonstrate excellent adhesion with the existing concrete and

ensure good workability.

(4) The material is required to have sufficient durability against seawater.

(5) The chloride ion diffusion coefficient is recommended to be minimized.

When the concrete near the patch repair material contains a large amount of chloride ions, corrosion can intensively progress at the boundary between the patch repair material and the existing concrete (i.e., macrocell corrosion), as shown in Figure-7.3.3. To avoid this situation, it is advisable to remove as much of the affected concrete as possible.

The patch repair material can also show signs of deterioration, such as cracking or spalling, after completion of the patch repair work. To avoid this issue, it is necessary to periodically check the status of the deterioration of the patch repair material, as in the case of surface covering material.

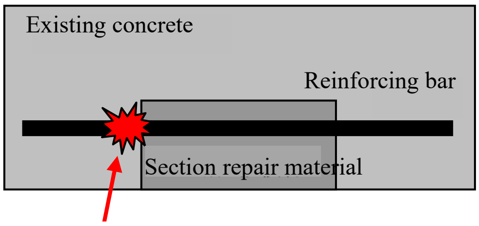



Figure-7.3.3 Macrocell corrosion at the boundary of patch repair material (Image)

3) Cathodic protection

This method controls the corrosion reaction by providing electrons to the rebars in the concrete. There are two main kinds of methods:

1) an electrode is attached to the concrete surface to let an electric current flow (anode), and direct current (approximately 10 to 30 mA/m$^2$) is sent from an external power source;

2) a metal that dissolves more easily than iron is attached to the concrete surface as an anode (sometimes called a sacrificial anode), which then supplies electrons.

For method 1), the anode used may be planar, linear, or pointed in shape. For method 2), the anode used is generally planar in shape. Examples of anodes used in both methods are shown in Figure-7.3.4. These types of cathodic protection can be applied when the concrete near the reinforcement contains a large amount of chloride ions. It is necessary to select the appropriate cathodic protection method (the means of providing an electric current or the shape of the anode) based on factors such as the environmental conditions, cost, and the design lifetime of the cathodic protection materials or equipment.

For selecting methods of cathodic protection, the following documents can be consulted.

・Recommendations for the design and construction of a electrochemical corrosion protection Method[10].

The standard procedure for cathodic protection is shown below. When the concrete surface is seriously deteriorated, it should be patch repaired first, and at the same time, the anode material should be placed on the surface. On the other hand, when little deterioration has occurred, patch repair is unnecessary, but the anode can be placed on the concrete surface.

The most important task after applying cathodic protection is to periodically check if the current is flowing properly. A typical method for this check it is to ensure that the potential of the reinforcement is transferred to the positive side at over 100 mV (depolarization) within 24 hours after electricity is stopped. This depolarization status can be affected by the wet condition of the concrete. When a member is located near a tidal zone, the speed of depolarization can be delayed[11].

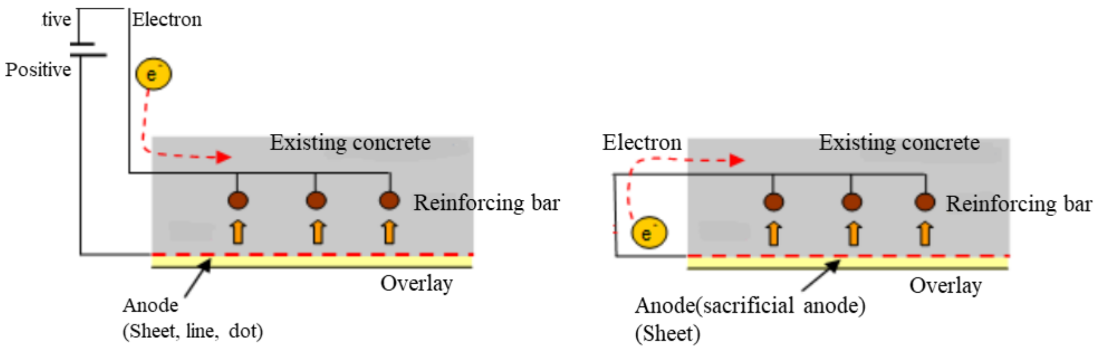



Figure-7.3.4 Example of cathodic protection

Table-7.3.2 Examples of preventive maintenance repair of cracks

| Example of method | | Outline |
|---|---|---|
| Only cracks are repaired | Crack covering | A coating film is applied over minute cracks. |
| | Injection | A resin- or cement-based material is injected into cracks. |
| | Filling | The concrete along a crack is removed in a U shape approximately 10 mm wide, and the repair material is filled into the groove. This method is used when relatively wide cracks are present, and the rebars are not yet corroded. |
| Cracks and other defects are repaired | Surface covering | The surface of a concrete structure is covered with resin or polymer cement material. This method is discussed in Section 3.2 of this chapter. |
| | Electrodeposition | This method is usually applied to an underwater structure. When a direct current is carried from a temporary anode set underwater to rebars in the concrete, $Ca^{2+}$ and $Mg^{2+}$ in the electrolyte (seawater) are precipitated as electrodeposits inside the cracks or on the concrete surface. |

Table-7.3.2.

The following documents can be used as a reference when selecting a method for repairing cracks.

・CDIT: Manual for Repair of Port Concrete Structures[7)]

・JCI: Practical Guidelines for the Investigation, Repair and Strengthening of Cracked Concrete Structures [6)]

When the structure comprises plain concrete, and no problem occurs even if chloride ions penetrate the concrete, it is less necessary to repair the cracks. It is also less necessary to repair reinforced concrete structures when the cracks in those structures are not yet sufficiently developed to penetrate the concrete, the cracks are very small in width (less than 0.2 to 0.3 mm), or the supply of seawater to the concrete surface is very low.

**References of Part7**


1) The Oversea Coastal area Development Institute, Coastal Development Institute of Technology: Corrosion Protection and Repair Manual for Port and Harbour Steel Structures, 1998

2) Coastal Development Institute of Technology: Manual for Corrosion Protection and Repair of Port Steel Structures, 2009

3) Ema KATO, Nozomu SOMEYA, Yuichiro KAWABATA, Hiroto TADO, Toru YAMAJI, Nobuhito NAKATANI: Practical Approach to Preventive Maintenance of Port Steel Structure, Technical note of the port and airport research institute, No.1336, 2017.9.

4) Coastal Development Institute of Technology: Manual for Corrosion Protection and Repair of Port Steel Structures, p81, 2009

5) Japan Society of Civil Engineering: Standard Specifications for Concrete Structures (Maintenance), 2001

6) Japan Concrete Institute: Practical Guidelines for the Investigation, Repair and Strengthening of Cracked Concrete Structures, 2013

7) Coastal Development Institute of Technology: Manual for Repair of Port Concrete Structures, 2018

8) Tokyo Port Terminal Corporation: Manual of Inspection and Repair for Deterioration for Wharf, pp.43-49, June 2004

9) Japan Society of Civil Engineering: Surface Protection Construction Method Guideline of Design Construction (Draft), Concrete Library No.107, 2001

10) Japan Society of Civil Engineering: Recommendations for the design and construction of a electrochemical corrosion protection Method, Concrete Library No.107, 2001

11) Tetsuji KIMURA, Shoji NAKANO, Toru YAMAJI, Yoshikazu AKIRA, Hidenori HAMADA, Ryousuke TAKAHASHI: Study about Depolarization Behavior of Electric Protection around RC Wharf at Tidal Zone, 62nd Outline of Annual Academic Lecture by Japan Society of Civil Engineering, Fifth Section, pp.1019-1020, Sept. 2007

# Part 8 Recording

## Chapter 1 General

### 1.1 General

To perform appropriate maintenance and repair of port and harbor facilities, it is necessary to record and preserve results of following: design, construction, initial inspection and diagnosis, daily inspection and diagnosis, periodic inspection and diagnosis, extraordinary inspection and diagnosis, comprehensive evaluation, deterioration prediction, measures, and other tasks.

## Chapter 2 Items and Methods

### 2.1 Outline

It is necessary to record contents and results of performance evaluations related to maintenance required to maintain port and harbor facilities.

### 2.2 Items to be Recorded

(1) Items to be recorded include the following:

facility structural types, structural outlines, typical cross sections, floor plans and front views, construction history, criteria applied to design and construction, service life, environmental and other conditions, utilization status, material properties, plan and result of inspection and diagnosis, deterioration prediction results, photographs, names of persons responsible for maintenance and repair, and names of inspectors.

(2) For facilities for which measures have been taken, following should be recorded:

methods of measures described in design documents and construction process records, name of the persons responsible for the design, construction work, and supervision of construction work.

### 2.3 Recording Methods

Records for maintenance and repair need to be preserved in a certain form, considering future maintenance of facilities, and more those records should be exact and objective.

## Chapter 3 Preservation

### 3.1 Method and Period of Preservation

Records for maintenance and repair need to be preserved appropriate and effective method for period during which facility is in service, so that records can be utilized in future, considering maintenance of facilities for the future.

Appendix A

# Attachment Format

# for Inspection and Diagnosis

Regular periodic inspection and diagnosis

Attachment　Format for inspection and diagnosis

## Inspection items and deterioration judgement criteria: Waterways and basins

| Facility | Inspection category | inspection items | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|
| Waterways and basins | I | Water depth | Hearing from person involved or simple bathymetric survey using a simple depth sounder | a | □It is seemed that there are some parts not meeting the specified water depth. |
| | | | | b | ――― |
| | | | | c | ――― |
| | | | | d | □Specified water depth is secured. |
| | I | Status of waterways or mooring basin | Visual inspection | a | □There are floating obstacles. |
| | | | | b | ――― |
| | | | | c | ――― |
| | | | | d | □No deformations are found |

## Inspection items and deterioration judgement criteria: Caisson breakwater

| Facility | Inspection category | inspection items | | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|---|
| Caisson breakwater | I | Displacement | | Visual inspection (incl. measurements using a tape measure or other instruments. Idential wording hereafter)<br>・ Horizontal displacement | a | ☐Caissons are detached partially from the mound. |
| | | | | | b | ☐There is a gap equivalent to the width of sidewall (40–50 cm) between the caissons. |
| | | | | | c | ☐There is a small gap. |
| | | | | | d | ☐No deformations are found |
| | | Caisson | Deterioration and damages of concrete | Visual inspection<br>・ Cracking, spalling, and damage<br>・ Exposure of steel bars<br>・ Signs of deterioration, etc. | a | ☐There are holes, cracks and losses allowing outflow of filling.<br>☐Steel bars are exposed over a wide area. |
| | | | | | b | ☐There are cracks about 3 mm wide in several directions. |
| | | | | | c | ☐There are cracks about 3 mm wide in a single direction.<br>☐Steel bars are partially exposed. |
| | | | | | d | ☐No deformations are found |
| | II | Subsidence | | Visual inspection<br>・ (joint gap), difference in level | a | ☐There is significant subsidence (about 1 m-deep). |
| | | | | | b | ☐There is uneven settlement about dozens cm deep between caissons. |
| | | | | | c | ☐ There is uneven settlement about a few cm deep between caissons. |
| | | | | | d | ☐No deformations are found |
| | | Superstructure | Deterioration and damages of concrete | Visual inspection<br>・ Cracking, spalling and damage<br>・ Signs of deterioration, etc. | a | ☐There are deficiencies which influence on the function of breakwater. |
| | | | | | b | ☐There are cracks 1 cm wide or more.<br>☐There are slight damages. |
| | | | | | c | ☐There are cracks less than 1 cm wide. |
| | | | | | d | ☐No deformations are found |
| | | Wavedissipating block | Displacement, scattering,settlement subsidence | Visual inspection<br>・ Deformation of crown, slope and top of slope of the wavedissipating structure<br>・Displacement and scattering of the wave-dissipating blocks | a | ☐The section area of the wave-dissipating structure of a unit inspection segment is lost more than the thickness of one layer of the block by erosion. |
| | | | | | b | ☐The section area of the wave-dissipating structure of a unit inspection segment is lost by erosion(less than the thickness of one layer of the block). |
| | | | | | c | ☐Wave-dissipating blocks are moved in part (scattered, settled) |
| | | | | | d | ☐No deformations are found |
| | | | Damages, deficiencies | Visual inspection<br>・Damage and crack of the wave-dissipating block<br>・ Number of chipped blocks | a | ☐25% of blocks are chipped. |
| | | | | | b | ☐Deformations are evaluated as the middle degree a through c. |
| | | | | | c | ☐There are several blocks chipped or partially deteriorated. |
| | | | | | d | ☐No deformations are found |

## Inspection items and deterioration judgement criteria: Revetment, levee 1/2

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Seawall, revetment, levee | I | Displacement of the whole structure | | Visual inspection (incl. measurement using scales and measures.hereinafter the same applies.)<br>・Displacement | a | □There are gaps 20 cm or more from the adjacent span.<br>□There are deformations of face line that influence on the function of seawall, revetment and levee. |
| | | | | | b | □There are gaps 10 to 20 cm from the adjacent span.<br>□There is deformation on the face line. |
| | | | | | c | □In other cases than the above, there are gaps less than 10 cm from the adjacent span. |
| | | | | | d | □No deformations are found |
| | | Settlement of the whole structure | | Visual inspection<br>・Settlement of the levee body | a | □There is significant subsidence (about 1 m deep) . |
| | | | | | b | □There is an uneven settlement about dozens cm from the adjacent span. |
| | | | | | c | □There is an uneven settlement about centimeters from the adjacent span. |
| | | | | | d | □No deformations are found |
| | | Main works (gravitytype)<br>(In the case of reinforced concrete) | Deterioration and damages of concrete | Visual inspection<br>・ Cracking, spalling, and damage<br>・ Signs of deterioration, etc. | a | □There are holes, cracks and losses allowing outflow of filling.<br>□Steel bars are exposed over a wide area. |
| | | | | | b | □There are cracks about 3 mm wide in several directions. |
| | | | | | c | □There are cracks about 3 mm wide in a single direction.<br>□Steel bars are partially exposed. |
| | | | | | d | □No deformations are found |
| | | Rear part of the revetment and levee or the levee itself | Cavity, outflow | Visual inspection (of places where there is a settlement, cavity, or gap at the joint)<br>・Status of the rear ground of the levee<br>・Gap and misalignment of the joints | a | □There is outflow of the filling from the rear part of the revetment or levee, or from inside the levee body.<br>□There are cavities the ground bearing the rear part of the revetment or levee, as well as in the ground of the levee body itself. |
| | | | | | b | □There are significant gaps or openning at the joints of the levee. |
| | | | | | c | □There are slight gaps or openning at the joints of the levee. |
| | | | | | d | □No deformations are found |
| | | Parapet wall | Deterioration and damages of concrete<br>(In the case of reinforced concrete) | Visual inspection<br>・ Cracking, spalling, damages<br>・ Corrosion of reinforcing bars<br>・ Signs of deterioration, etc. | a | □There are damages which influence on the function of the parapet wall. |
| | | | | | b | □There are cracks about 3 mm wide in several directions.<br>□Steel bars are exposed over a wide area. |
| | | | | | c | □There are cracks about 3 mm wide in several directions.<br>□Steel bars are partially exposed. |
| | | | | | d | □No deformations are found |
| | | | Deterioration and damages of concrete<br>(In the case of plain concrete) | Visual inspection<br>・ Cracking and damage<br>・ Signs of deterioration, etc. | a | □There are signs of flow-out of soil from penetrating crack.<br>□The damage is 10 % or more in area to the surface of the component. |
| | | | | | b | □The damage is less than 10% in area to the surface of the component. |
| | | | | | c | □There are penetrating cracks but no sign of outflow of soil.<br>□There is non-penetrating crack 1 cm wide or more. |
| | | | | | d | □No deformations are found |
| | | Steel sheet pile, etc. | Corrosion, cracks and damages of steel | Visual inspection<br>・Presence of holes<br>・Scratches on the surface | a | □There are holes, deformations and significant damages due to corrosion. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | □No holes and deformations due to corrosion. |

Attachment　Format for inspection and diagnosis

## Inspection items and deterioration judgement criteria: Revetment, levee 2/2

| Facility | Inspection category | inspection items | | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|---|
| Seawall, revetment, levee | Ⅱ | Main structure (gravity type) | Deterioration and damages of concrete | | Visual inspection<br>・Cracks and damage<br>・ Signs of deterioration, etc. | a | ☐There are deficiencies which influence on function of the structure. |
| | | | | | | b | ☐There are cracks 1 cm wide or more.<br>☐There are slight damages. |
| | | | | | | c | ☐There are cracks less than 1 cm wide. |
| | | | | | | d | ☐No deformations are found |
| | | Steel sheet pile, etc. | Anticorrosive coating | Paint | Visual inspection<br>・Rust and blistering<br>・Spalling of coating | a | ☐There are rust and blistering in a wide area.<br>☐There are spalling and cracks of coating caused by rust in a wide area.<br>☐The ratio of defect area is 10% or more. |
| | | | | | | b | ☐There are large rusts or blisterings everywhere.<br>☐There is spalling of coating caused by rust in a wide area.<br>☐The ratio of defect area is 0.3% or more and less than 10%. |
| | | | | | | c | ☐There are rust and blistering in some area.<br>☐Spalling and cracks of paint are dotted with.<br>☐The ratio of deformation area is 0.03% or more and less than 0.3%. |
| | | | | | | d | ☐There isn't much deformation and paint looks free from damaged.<br>☐The ratio of deformation area is less than 0.03%. |
| | | | | Heavy-duty anticorrosive coating | Visual inspection<br>・Deterioration of coating | a | ☐The heavy duty anticorrosive protective coating is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration reaches the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Super-thick film coating | Visual inspection<br>・Deterioration of coating | a | ☐The super-thick film coating is significantly deteriorated, with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Corrosionresistant metal coating | Visual inspection<br>・Deterioration of coating | a | ☐There is significant deterioration in the corrosion-resistant metal coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Underwater hardening coating | Visual inspection<br>・Deterioration of coating | a | ☐There is a significant deterioration in the underwater hardening coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Petrolatum coating | Visual inspection<br>・Protection cover sheet<br>・Bolts, nuts | a | ☐Protection cover sheets are detached and the petrolatum coating is exposed or detached, and there is rusting on the steel surface. |
| | | | | | | b | ☐There are cracks in the protection cover sheet or the cover plate.<br>☐There are loosened bolts, nuts, or etc. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐There are slight cracks on the surface of the protection cover sheet.<br>☐There are loosened bolts, nuts or band materials.<br>☐The coating is partially peeled off on the edge seal. |
| | | | | | | d | ☐No deformations are found |
| | | | | Mortar coating | Visual inspection<br>・Protection cover sheet<br>・Deterioration and damages of mortar | a | ☐Protection cover sheets are detached in a wide area.<br>☐There is rust fluid on the mortar surface.<br>☐The mortar is failed and rust appears on the steel surface.<br>☐(When the protection cover or mortar layer is removed,) there is reduction of steel thickness. |
| | | | | | | b | ☐Cracks are observed in the protection cover sheets or mounting materials and the protection cover sheets are partially detached.<br>☐There is slight rust fluid but there is no streaming.<br>☐(When the protection cover is removed,) there are numerous cracks in the mortar and rust fluid. |
| | | | | | | c | ☐The protection covers are discolored or whitened.<br>☐Cracks are observed on the surface but the area is less than 1%.<br>☐The mounting members such as bolts and nuts of the protection cover are loosened. |
| | | | | | | d | ☐No deformations are found |
| | | | Cathodic protection | | Measurement of electrical potential (corrosion control electorical potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride-800mV<br>・Saturated copper sulfate-800mV | a | ☐The corrosion control electorical potential is not maintained. |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | ☐The corrosion control electorical potential is maintained. |
| | | | Displacement, scattering,settlement | | Visual inspection<br>・ Deformation of crown, slope and top of slope of the wavedissipating structure<br>・Displacement and scattering | a | ☐The section area of the wave-dissipating structure of a unit inspection segment is reduced more than the length of one layer of the block by erosion. |
| | | | | | | b | ☐The section area of the wave-dissipating structure of a unit inspection segment is reduced by erosion (less than the length of one layer of the block) |
| | | | | | | c | ☐Wave-dissipating blocks are moved in part (scattered, settled) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Wavedissipating work | | of the wave-dissipating blocks | d | ☐No deformations are found |
| | | | Damages, deficiencies | Visual inspection<br>・Damages and cracks of the wave-dissipating blocks<br>・ Number of chipped blocks | a | ☐25% of blocks are chipped. |
| | | | | | b | ☐Deformations evaluate in the middle degrees a through c. |
| | | | | | c | ☐There are several blocks chipped or partially deteriorated. |
| | | | | | d | ☐No deformations are found |

## Inspection items and deterioration judgement criteria: Revetment, levee

【Items for inspection and diagnosis not necessary to be covered totally when the status may be grasped by daily inspection】

| Facility | Inspection category | inspection items | | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|---|
| Seawall, revetment, levee | Ⅲ | Drainage equipment | Breaks of drainage equipment, deformation and corrosion of gratings | Visual inspection (incl. measurement using scales and measures. hereinafter the same applies.)<br>・ Clogging of ditches<br>・ Breaks, deformations<br>・ Corrosion of gratings | a | ☐Breaks and damages are observed on drain ditches or drain pits.<br>☐The drain ditch or drain pit is clogged with soil.<br>☐Gratings are lost.<br>☐Gratings are deformed and corroded significantly and unusable. |
| | | | | | b | ――― |
| | | | | | c | ☐Gratings are deformed or corroded. |
| | | | | | d | ☐No deformations are found |
| | | Front apron | Cracks and damages of front apron | Visual inspection<br>・Cracks and damages | a | ☐The function of the apron is lost due to their cracks and damages. |
| | | | | | b | ――― |
| | | | | | c | ☐There are cracks in the apron. |
| | | | | | d | ☐No deformations are found |

Attachment Format for inspection and diagnosis

## Inspection items and deterioration judgement criteria：Caisson-type quaywall

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Caisson-type quaywall | Ⅰ | Face line of the wharf | Lateral displacements,irregularities | Visual inspection<br>・Displacement | a | ☐There is a gap 20 cm or more between the caissons |
| | | | | | b | ☐There is a gap 10 to 20 cm between the caissons. |
| | | | | | c | ☐Other than the above, there is a gap less than 10 cm between the caissons. |
| | | | | | d | ☐No deformations are found |
| | | Apron | Subsidence, collapse | Visual inspection | a | ☐Soil behind the caissons outflow.<br>☐There is a collapse at the apron behind the caissons.<br>☐The traffic of vehicles or pedestrians is hampered significantly. |
| | | | | | b | ☐There is a subsidence (uneven settlement) 3 cm or more at the apron.<br>☐There is a subsidence (uneven settlement) 30 cm or more between the apron and the rear ground.<br>☐There are obvious opennings or gaps in the joints of caissons (incl. superstructure.) |
| | | | | | c | ☐There is a subsidence (uneven settlement) less than 3 cm at the apron.<br>☐There is a subsidence (uneven settlement) less than 30 cm between the apron and the rear ground.<br>☐There are gaps or slight opennings at the joints of caissons (incl. superstructure.) |
| | | | | | d | ☐No deformations are found |
| | | Caisson | Deterioration, damages on the side walls | Visual inspection<br>・ Cracking, spalling, damages<br>・ Exposure of steel bars<br>・ Signs of deterioration, etc. | a | ☐There are holes, cracks and damage allowing outflow of filling.<br>☐Steel bars are exposed over a wide area. |
| | | | | | b | ☐There are cracks about 3 mm wide in several directions. |
| | | | | | c | ☐There are cracks about 3 mm wide in a single direction.<br>☐Steel bars are partially exposed. |
| | | | | | d | ☐No deformations are found |
| | Ⅱ | Apron (normal state) | Deterioration, damages of concrete or asphalt | Visual inspection<br>・ Cracks, damages of concrete or asphalt | a | ☐The cracking degree of concrete pavement is $2m/m^2$ or more.<br>☐The cracking ratio of asphalt pavement is 30% or more.<br>☐There are cracks and damages impeding the traffic of vehicles or pedestrians. |
| | | | | | b | ☐The cracking degree of concrete pavement is 0.5 to 2 $m/m^2$ .<br>☐The cracking ratio of asphalt pavement is 20 to 30% . |
| | | | | | c | ☐There are slight cracks. |
| | | | | | d | ☐No deformations are found |
| | | Apron (When the use of container terminal is severely restricted) | Uneven settlement, rutting,cracking of pavement | Visual inspection<br>uneven settlement, rutting | a | ☐There are subsidence, collapses, rutting and cracks which are dangerous for traffic of vehicles.<br>☐There is an uneven settlement 15 mm or more.<br>☐There is a rutting 10 mm or more.<br>☐There are cracks 3 mm wide or more. |
| | | | | | b | ☐There is an uneven settlement 10 to 15 mm.<br>☐There are cracks less than 3 mm wide. |
| | | | | | c | ☐There is an uneven settlement less than 10 mm.<br>☐There is a rutting less than 10 mm.<br>☐There are slight cracks. |
| | | | | | d | ☐No deformations are found |
| | | Superstructure (for reinforced concrete) | Deterioration, damages of concrete | Visual inspection<br>・Cracking, spalling and damage<br>・Corrosion of steel bars<br>・Signs of deterioration, etc. | a | ☐There are damages influence on the function of the quaywall. |
| | | | | | b | ☐There are cracks 3 mm wide or more.<br>☐Steel bars are exposed over a wide area. |
| | | | | | c | ☐There are cracks less than 3 mm wide.<br>☐Steel bars are partially exposed. |
| | | | | | d | ☐No deformations are found |
| | | Superstructure (for nonreinforced concrete) | Deterioration, damages of concrete | Visual inspection<br>・Cracking and damage<br>・Signs of deterioration, etc. | a | ☐There are damages influence on the function of the quaywall. |
| | | | | | b | ☐There are cracks 1 cm wide or more.<br>☐There are slight damages. |
| | | | | | c | ☐There are cracks less than 1 cm wide. |
| | | | | | d | ☐No deformations are found |

## Inspection items and deterioration judgement criteria：Sheet pile type quaywall 1/2

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Sheet pile type quaywall | Ⅰ | Face line of the wharf | Lateral displacements, irregularities | Visual inspection<br>・Displacement, settlement | a | □There is a gap 20 cm or more between the adjacent superstructure.<br>□There is an irregular queywall face line which degrades the structure's performance. |
| | | | | | b | □There is an irregular queywall face line.<br>□There is a gap 10 to 20 cm between the adjacent superstructure. |
| | | | | | c | □Other than the above, there is a gap less than 10 cm between the adjacent superstructure. |
| | | | | | d | □No deformations are found |
| | | Apron | Subsidence, collapse | Visual inspection | a | □Soil behind the main structure outflows<br>□There is a collapse at the apron behind the main structure.<br>□There are significant deformation and cracks for vehicles and pedestrians. |
| | | | | | b | □There is a sign of outflow of soil behind the main structure.<br>□There is subsidence 3 cm or more between the apron and the main structure.<br>□There is subsidence 30 cm or more between the apron and the rear ground. |
| | | | | | c | □There is subsidence less than 3 cm at the apron.<br>□There is subsidence less than 30 cm between the apron and the rear ground. |
| | | | | | d | □No deformations are found |
| | | Steel sheet type pile, etc. | Corrosion, cracks and damages of steel | Visual inspection<br>・Presence of holes<br>・Scratches on the surface | a | □There are holes, deformations and significant damages due to corrosion. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | □No hole and deformation due to corrosion. |
| | Ⅱ | Apron (normal state) | Deterioration, damages of concrete or asphalt | Visual inspection<br>・Cracks, damages of concrete or asphalt | a | □The cracking degree of concrete pavement is $2m/m^2$ or more.<br>□The cracking ratio of asphalt pavement is 30% or more.<br>□There are cracks and damages impeding the traffic of vehicles or pedestrians. |
| | | | | | b | □The cracking degree of concrete pavement is 0.5 to 2 $m/m^2$.<br>□The cracking ratio of asphalt pavement is 20 to 30%. |
| | | | | | c | □There are slight cracks. |
| | | | | | d | □No deformations are found |
| | | Apron (When the use of container terminal is severely restricted) | Uneven settlement, rutting,cracking of pavement | Visual inspection<br>Uneven settlement, rutting | a | □There are dangerous uneven settlement, subsidence, rutting and cracks for vehicles.<br>□There is uneven settlement 15 mm or more.<br>□There is a rutting 10 mm or more.<br>□There are cracks 3 mm wide or more each. |
| | | | | | b | □There is uneven settlement 10 to 15 mm.<br>□There are cracks less than 3 mm wide. |
| | | | | | c | □There is uneven settlement less than 10 mm.<br>□There is a rutting less than 10 mm.<br>□There are slight cracks. |
| | | | | | d | □No deformations are found |
| | | Superstructure | Deterioration and damages of concrete | Visual inspection<br>・Cracks, spalling, damages<br>・Corrosion of reinforcing bars<br>・Signs of deterioration, etc. | a | □There are damages influence on the function of the quaywall. |
| | | | | | b | □There are cracks 3 mm wide or more.<br>□Steel bars are exposed over a wide area. |
| | | | | | c | □There are cracks less than 3 mm wide.<br>□Steel bars are partially exposed. |
| | | | | | d | □No deformations are found |

## Inspection items and deterioration judgement criteria：Sheet pile type quaywall 2/2

| Facility | Inspection category | inspection items | | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|---|
| Sheet pile type quaywall | Ⅱ | Steel sheet pile, etc. | Anticorrosive coating | Paint | Visual inspection<br>・Rust and blistering<br>・spalling of paint | a | ☐There are rust and blistering in a wide area.<br>☐There are spalling and cracks of paint caused by rust in a wide area.<br>☐The ratio of defect area is 10% or more. |
| | | | | | | b | ☐There is large rust or blistering.<br>☐There are spalling of paint caused by rust in a wide area.<br>☐The ratio of defect area is 0.3% or more and less than 10%. |
| | | | | | | c | ☐There are rust and blistering in some area.<br>☐The paint is spalling in parts and cracks are dotted.<br>☐The ratio of defect area is 0.03% or more and less than 0.3%. |
| | | | | | | d | ☐There isn't much deformation and paint looks free from damaged<br>☐The ratio of defect area is less than 0.03%. |
| | | | | Heavy-duty anticorrosive coating | Visual inspection<br>・Deterioration of coating | a | ☐The heavy-duty anticorrosive coating is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration reaches the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Super-thick film coating | Visual inspection<br>・Deterioration of coating | a | ☐The super-thick film coating is significantly deteriorated, with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Corrosionresistant metal coating | Visual inspection<br>・Deterioration of coating | a | ☐There is a significant damage in the corrosion-resistant metal coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Underwater hardening coating | Visual inspection<br>・Deterioration of coating | a | ☐The corrosion-resistant metal coating is significantly deteriorated and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Petrolatum coating | Visual inspection<br>・Protection cover sheet<br>・Bolts, nuts | a | ☐Protection cover sheets are detached and the petrolatum coating is exposed or detached, and there is rust on the steel surface. |
| | | | | | | b | ☐There are cracks in the protection cover sheet or the cover plate.<br>☐There is corrosion on bolts, nuts, or band material. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐There are slight cracks on the surface of the protection cover sheet.<br>☐There are loosened bolts, nuts or etc.<br>☐The edge seal is partially peeled off. |
| | | | | | | d | ☐No deformations are found |
| | | | | Mortar coating | Visual inspection<br>・Protection cover sheet<br>・Deterioration and damages of mortar | a | ☐Protection cover sheets are detached in a wide area.<br>☐There is rust fluid on the mortar surface.<br>☐The mortar is detached and rust generates on the steel surface.<br>☐(When the protection cover or mortar layer is removed,) there is reduction of steel thickness. |
| | | | | | | b | ☐There are cracks of the protection cover or mounting member, and the protection cover is partially detached.<br>☐There is slight rust fluid but rust fluid is not streaming.<br>☐(When the protection cover is removed,) there are many cracks in the mortar and rust fluid. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐There are cracks on the surface but the area is less than 1%.<br>☐The mounting members of the protection cover sheets including bolts and nuts are loosened. |
| | | | | | | d | ☐No deformations are found |
| | | | Cathodic protection | | Measurement of electrical potential (corrosion control electoric potential per electrode)<br>・Saturated calomel-800mV<br>・ Seawater silver chloride-800mV<br>・Saturated copper sulfate-850mV | a | ☐The corrosion control electoric potential is not maintained. |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | ☐The corrosion control electoric potential is maintained. |

## Inspection items and deterioration judgement criteria: Pile supported Open type wharf 1/3

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Open type wharf | I | Pier face line | Lateral displacements irregularities | Visual inspection<br>・Displacement, settlement | a | ☐There is a gap 20 cm or more between the structure and the adjacent superstructure. |
| | | | | | b | ☐There is a gap 10 to 20 cm between the structure and the adjacent superstructure. |
| | | | | | c | ☐In other cases than the above, there is a gap less than 10 cm between the structure and the adjacent superstructure. |
| | | | | | d | ☐No deformations are found |
| | | Apron | Subsidence, collapse | Visual inspection | a | ☐Behind the earth retaining, soil outflows.<br>☐There is a collapse at the apron behind the earth retaining.<br>☐There are significant hinderance for vehicles and pedestrains. |
| | | | | | b | ☐There are significant openings or gaps at the joints of the earth retaining.<br>☐There is an uneven settlement 3 cm or more on the apron.<br>☐There is an uneven settlement 30 cm or more between the apron and the rear ground. |
| | | | | | c | ☐There are slight openings or gaps at the joints of the earth retaining.<br>☐There is an uneven settlement less than 3 cm on the apron.<br>☐There is an uneven settlement less than 30 cm between the apron and the rear ground. |
| | | | | | d | ☐No deformations are found |
| | | Superstructure (underneath surface) (In the case of prestressed concrete) | Deterioration and damages of concrete | Visual inspection<br>・Presence of cracks<br>・Presence of rust fluid | a | ☐There are cracks.<br>☐There is rust frluid. |
| | | | | | b | ☐ーーー |
| | | | | | c | ☐ーーー |
| | | | | | d | ☐No deformations are found |
| | | Steel pipe pile | Corrosion, cracks and damages of steel | Visual inspection<br>・Presence of holes<br>・Scratches on the surface | a | ☐There are holes, deformations and significant damages due to corrosion. |
| | | | | | b | ☐ーーー |
| | | | | | c | ☐ーーー |
| | | | | | d | ☐No holes and deformations due to corrosion. |
| | | Earth retaining part | | Visual inspection (to be done adequately for the type of earth retaining) | a<br>b<br>c<br>d | According to the structural type of earth retaining, the inspection form for caisson-type quaywall or for sheet pile type quaywall wall is used adequately. |
| | II | Apron (normal state) | Deterioration, damages of concrete or asphalt | Visual inspection<br>・Cracks, damages of concrete or asphalt | a | ☐The cracking degree of concrete pavement is $2m/m^2$ or more.<br>☐The cracking ratio of asphalt pavement is 30% or more.<br>☐There are cracks and damages impeding the traffic of vehicles or pedestrians. |
| | | | | | b | ☐The cracking degree of concrete pavement is 0.5 to $2\ m/m^2$ .<br>☐The cracking ratio of asphalt pavement is 20 to 30% . |
| | | | | | c | ☐There are slight cracks. |
| | | | | | d | ☐No deformations are found |
| | | Apron (When the use of container terminal is severely restricted) | Uneven settlement, rutting, cracking of pavement | Visual inspection<br>uneven settlement, irregularities, rutting | a | ☐There are uneven settlement, rutting and cracks, which are dangerous for traffic of vehicles.<br>☐There is an uneven settlement 15 mm or more.<br>☐There is a rutting 10 mm or more.<br>☐There are cracks 3 mm wide or more. |
| | | | | | b | ☐There is an uneven settlement 10 to 15 mm.<br>☐There are cracks less than 3 mm wide. |
| | | | | | c | ☐There is an uneven settlement less than 10 mm.<br>☐There is a rutting less than 10 mm.<br>☐There are slight cracks. |
| | | | | | d | ☐No deformations are found |

## Inspection items and deterioration judgement criteria: Open type wharf 2/3

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Open type wharf | Ⅱ | Super−structure (underneath surface) (In the case of reinforced concrete) | Deterioration and damages of concrete | Visual inspection<br>・Direction of cracks<br>・Number, length and width of cracks<br>・Spalling of covering<br>・Presence of rust fluid<br>・Corrosion status of steel bars | a | Slab：<br>☐There are mesh cracks covering 50% or more of the surface.<br>☐There are some detachment of covering depth.<br>☐There is rust fluid in a wide area.<br>Beam, haunch：<br>☐There are cracks 3 mm wide or more in the axial direction of steel bars.<br>☐There are some detachment of covering depth.<br>☐There are rust fluid in a wide area. |
| | | | | | b | Slab：<br>☐There are mesh cracks covering less than 50% of the surface.<br>☐There are rust fluid partially.<br>Beam, haunch：<br>☐There are cracks less than 3 mm wide in the axial direction of steel bars.<br>☐Rust fluid forms partially. |
| | | | | | c | Slab：<br>☐There are cracks in a single direction, or precipitation of gel in band or line.<br>☐There is rust fluid partially.<br>Beam, haunch：<br>☐There is only cracks perpendicular to axial direction.<br>☐Rust fluid are dotted partially. |
| | | | | | d | ☐No deformations are found |
| | | Super−structure (upper and side part) | Deterioration and damages of concrete | Visual inspection<br>・Cracking, spalling, damages<br>・Corrosion of steel bars<br>・Signs of deterioration, etc. | a | ☐There are damages which may degrade the function of the quaywall. |
| | | | | | b | ☐There are cracks 3 mm wide or more.<br>☐Steel bars are exposed in a wide area. |
| | | | | | c | ☐There are cracks less than 3 mm wide.<br>☐Steel bars are partially exposed. |
| | | | | | d | ☐No deformations are found |

Inspection items and deterioration judgement criteria: Pile supported Open type wharf 3/3

| Facility | Inspection category | inspection items | | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|---|
| Open type wharf | Ⅱ | Steel pipe pile | Anticorrosive coating | Paint | Visual inspection<br>・Rust and blistering<br>・Spalling of coating | a | □There are rust and blistering in a wide area.<br>□There are spalling and cracks of coating caused by rust in a wide area.<br>□The ratio of defect area is 10% or more. |
| | | | | | | b | □There are large rust or blistering.<br>□There are spalling of coating caused by rust in a wide area.<br>□The ratio of defect area is 0.3% or more and less than 10%. |
| | | | | | | c | □There are rust and blistering in some area.<br>□Spalling of painting and cracks are dotted.<br>□The ratio of defect area is 0.03% or more and less than 0.3%. |
| | | | | | | d | □There isn't much deformation and paint looks free from damaged<br>□The ratio of defect area is less than 0.03%. |
| | | | | Heavy-duty anticorrosive coating | Visual inspection<br>・Deterioration of coating | a | □The heavy-duty anticorrosive coating is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | □Partially the coating deterioration reaches the steel, and the steel components are corroded. |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel |
| | | | | | | d | □No deformations are found |
| | | | | Super-thick film coating | Visual inspection<br>・Deterioration of coating | a | □The super-thick film coating is significantly deteriorated, with noticeable corrosion of steel. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found |
| | | | | Corrosion-resistant metal coating | Visual inspection<br>・Deterioration of coating | a | □There is a significant deterioration in the underwater hardening coating and the steel is corroded. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found |
| | | | | Underwater hardening coating | Visual inspection<br>・Deterioration of coating | a | □There is a significant deterioration in the underwater hardening coating and the steel is corroded. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found |
| | | | | Petrolatum coating | Visual inspection<br>・Protection cover sheet<br>・Bolts, nuts | a | □Protection cover sheets are detached, the petrolatum coating is exposed or detached, and there is rust on the steel surface. |
| | | | | | | b | □There are cracks in the protection cover sheet or the cover plate.<br>□Corrosion is observed on bolts, nuts or band materials. |
| | | | | | | c | □The protection cover sheets are discolored or whitened.<br>□There are slight cracks on the surface of the protection cover sheet.<br>□There are loosened bolts, nuts or band materials.<br>□There is partial spalling on the edge seal. |
| | | | | | | d | □No deformations are found |
| | | | | Mortar coating | Visual inspection<br>・Protection cover sheet<br>・Deterioration and damages of mortar | a | □Protection cover sheets are detached in a wide area.<br>□There is rust fluid on the mortar surface.<br>□The mortar is detached and rust appers on the steel surface.<br>□(When the covering material or mortar layer is removed,) there is reduction of steel thickness. |
| | | | | | | b | □There are cracks in the protection cover sheets or mounting members, and the protection cover sheets are partially detached.<br>□There is slight rust fluid but rust fluid is not streaming.<br>□(When the covering material is removed,) there are many cracks in the mortar and rust fluid. |
| | | | | | | c | □The protection cover sheets are discolored or whitened.<br>□There are cracks on the surface but the area is less than 1%.<br>□The mounting members of the protection cover sheets including bolts, nuts and others are loosened. |
| | | | | | | d | □No deformations are found |
| | | | Cathodic protection | | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・ Seawater silver chloride-800mV | a | □The corrosion control electorical potential is not maintained. |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | □The corrosion control electorical potential is maintained. |
| | | Access bridge | Damages and painting of main structure | | Visual inspection<br>・Damages, cracks<br>・Painting<br>・Displacement | a | □There are significant hinderance for vehicles and pedestrains. |
| | | | | | | b | □There are damages. |
| | | | | | | c | □There are slight damages. |
| | | | | | | d | □No deformations are found |

Format for detailed regular inspection and diagnosis (inspection items and deterioration judgement criteria: Floating pier 1/2)

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Floating pier | I | Exterior of the pontoon | (For steel materials) Corrosion, cracks and damages of steel | Visual inspection<br>･Presence of holes<br>･Scratches on the surface | a | ☐There are holes, deformation or significant damages due to corrosion. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | ☐No holes and deformations due to corrosion. |
| | | | (For reinforced concrete) Deterioration and damages of concrete | Visual inspection<br>・ Direction of cracks<br>・ Number, length and width of cracks<br>・ Spalling of covering<br>・ Presence of rust fluid<br>・ Corrosion of steel bars | a | ☐There are cracks 3 mm wide or more along steel bars.<br>☐There is detachment of covering depth.<br>☐Rust fluid appears in a wide area.<br>☐There is a danger of subsiding area caused by perforated crack. |
| | | | | | b | ☐There are cracks less than 3 mm wide along steel bars.<br>☐Rust fluid partially appears. |
| | | | | | c | ☐There are slight cracks.<br>☐There is rust fluid partially. |
| | | | | | d | ☐No deformations are found |
| | | | (For prestressed concrete) Deterioration and damages of concrete | Visual inspection<br>･Presence of cracks<br>･Presence of rust fluid | a | ☐There are cracks.<br>☐There is rust fluid. |
| | | | | | b | ☐――― |
| | | | | | c | ☐――― |
| | | | | | d | ☐No deformations are found |
| | | Interior of the pontoon | Cracks, damages of the main structure | Visual inspection<br>･Water leaks | a | ☐There is Flood due to cracks, fissures or damages. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | ☐No deformations are found |
| | | Roller | Deterioration and damages of roller | Abnormal noise | a | ☐Abnormal noise occurs from the roller. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | ☐No abnormal noise occurs from the roller. |
| | | Mooring pile, mooring chain | Abrasion, painting, corrosion | Visual inspection<br>･Status of mooring pile, breaks of mooring chains | a | ☐There are deformation, significant abrasion or holes of mooring piles.<br>☐There is a significant abrasion of mooring piles. |
| | | | | | b | ☐There is slight abrasion or opening corrosion.<br>☐There are cracks or spallings in the coating material of mooring chains in the whole area. |
| | | | | | c | ☐There are slight damages in the coating material of mooring chains. |
| | | | | | d | ☐No deformations are found |
| | | Connecting bridge, access bridge | Safety, damages, corrosion | Visual inspection<br>･Safety for traffic<br>･Presence of rust, damages<br>･Paint | a | ☐The connecting bridge is not stable impeding traffic to the pontoon. |
| | | | | | b | ――― |
| | | | | | c | ☐There are spalling of paint and rust. |
| | | | | | d | ☐There is no spalling of paint or rust, and the connecting bridge is stable. |
| | Ⅱ | Apron | Deterioration, damages of concrete or asphalt | Visual inspection<br>･Cracks, irregularities and uneven settlement of concrete or asphalt | a | ☐The cracking degree of concrete pavement is 2m/m$^2$ or more.<br>☐The cracking ratio of asphalt pavement is 30% or more.<br>☐There are cracks and damages impeding the traffic of vehicles or pedestrians. |
| | | | | | b | ☐The cracking degree of concrete pavement is 0.5 to 2 m/m$^2$ or more.<br>☐The cracking ratio of asphalt pavement is 20 to 30%. |
| | | | | | c | ☐There are slight cracks. |
| | | | | | d | ☐No deformations are found |

Format for detailed regular inspection and diagnosis (inspection items and deterioration judgement criteria: Floating pier 2/2)

| Facility | Inspection category | inspection items | | | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|---|---|
| Floating pier | Ⅱ | Steel members of steel pontoon, mooring piles and chains, connecting bridge, etc. | Anticorrosive coating | Paint | Visual inspection<br>・Rust and blistering<br>・Spalling of coating | a | ☐There are rust and blistering in a wide area.<br>☐There are spalling and cracks of coating caused by rust in a wide area.<br>☐The ratio of defect area is 10% or more. |
| | | | | | | b | ☐There is large rust or blistering.<br>☐There are spalling of coating and rust in a wide area.<br>☐The defect area is 0.3% or more and less than 10%. |
| | | | | | | c | ☐There are rust and blistering in some area.<br>☐The painting is spalling in parts and cracks are dotted.<br>☐The ratio of defect area is 0.03% or more and less than 0.3%. |
| | | | | | | d | ☐There isn't much deformation and paint looks free from damaged<br>☐The ratio of defect area is less than 0.03%. |
| | | | | Heavy-duty anticorrosive coating | Diving inspection<br>・Deterioration of coating | a | ☐The heavy-duty anticorrosive coating is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration reaches the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Super-thick film coating | Diving inspection<br>・Measurement of film thickness,<br>etc. | a | ☐The super-thick film coating is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Corrosionresistant metal coating | Diving inspection<br>・Deterioration of coating | a | ☐There is a significant deterioration in the corrosion-resistant metal coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Underwater hardening coating | Diving inspection<br>・Measurement of film thickness,<br>etc. | a | ☐There is a significant deterioration in the underwater hardening coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found |
| | | | | Petrolatum coating | Diving inspection<br>・Protection cover sheet<br>・Bolts, nuts | a | ☐Protection cover sheets are detached, the petrolatum coating is exposed or detached, and there is rusting on the steel surface. |
| | | | | | | b | ☐There are cracks in the protection cover sheet or the cover plate.<br>☐There is corrosion on bolts, nuts or band materials. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐There are slight cracks on the surface of the protection cover sheet.<br>☐There are loosened bolts, nuts or band materials.<br>☐There is partial spalling on the edge seal. |
| | | | | | | d | ☐No deformations are found |
| | | | | Mortar coating | Diving inspection<br>・Protection cover sheet<br>・Deterioration and damages of mortar | a | ☐Protection cover sheets are detached in a wide area.<br>☐There is rust fluid on the mortar surface.<br>☐The mortar is damage and rust generates on the steel surface.<br>☐(When the covering material or mortar layer is removed,) there is reduction of the thick steel. |
| | | | | | | b | ☐There are cracks in the protection cover sheets or mounting members and the protection cover sheets are partially detached.<br>☐There are slight rust fluid but there is no streaming.<br>☐(When the covering material is removed,) there are many cracks in the mortar and rust fluid. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐There are cracks on the surface but the area is less than 1%.<br>☐The mounting members of the protection cover sheets including bolts, nuts and band materials are loosened. |
| | | | | | | d | ☐No deformations are found |
| | | | Cathodic protection | | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride-800mV<br>・Saturated copper sulfate-850mV | a | ☐The corrosion control electorical potential is not maintained at a desired level. |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | ☐The corrosion control electorical potential is maintained. |

Attachment Format for inspection and diagnosis

Format for general regular inspection and diagnosis (inspection items and deterioration judgement criteria：Mooring buoy)

| Facility | Inspection category | inspection items | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|
| Mooring buoy | I | Damages and deterioration of buoy | Visual inspection | a | □There are damages or deteriorations impeding the performance. |
| | | | | b | ――― |
| | | | | c | ――― |
| | | | | d | □No deformations are found |

## Inspection items and deterioration judgement criteria:  Ancillary facilities

[Items for inspection and diagnosis not necessary to be covered totally when the status may be inspectioned by daily inspection]

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Ancillary facilities | Ⅲ | Mooring post and rings | Deteriorations, damages, spalling of paint, etc. | Visual inspection (incl. measurement using instuments. hereinafter the same applies.)<br>・Damages, deformation | a | ☐The mooring posts and mooring rings are unable to be used by breaks and damages. |
| | | | | | b | ――― |
| | | | | | c | ☐There are damages or deformations of mooring posts, and the coating is spalling. |
| | | | | | d | ☐No deformations are found |
| | | Fender | Damages, breakage of fender, corrosion of fixing brackets, etc. | Visual inspection<br>・Damages of rubber parts<br>・Rust and scratches of fixing brackets | a | ☐Main structure (rubber part): damages or permanent deformation are observed.<br>☐Mounting brackets: There are loosened, detached, bent or cut parts. |
| | | | | | b | ――― |
| | | | | | c | ☐Main structure (rubber part): There is deficiency, crack or chipping.<br>☐Mounting brackets: Rust generates. |
| | | | | | d | ☐No deformations are found |
| | | Lighting equipment | Deterioration and damages of lights, posts or foundation | Visual inspection<br>– Corrosion, cracks damages of steel members<br>– Damages of lights | a | ☐Lights do not work.<br>☐Posts are deformed. |
| | | | | | b | ――― |
| | | | | | c | ☐Paint is spalling and the equipment is partially rusted.<br>☐There are cracks a little in the foundation concrete of posts. |
| | | | | | d | ☐No deformations are found |
| | | Curbing, safety fence | Damages, painting, corrosion of the main structure | Visual inspection<br>・Damages, deformation<br>・Condition of paint<br>・Corrosion | a | ☐There are defects.<br>☐There are damages or deformations impeding the function. |
| | | | | | b | ――― |
| | | | | | c | ☐There are damages, deformation, and corrosion of curbing or spalling of paint. |
| | | | | | d | ☐No deformations are found |
| | | Drainage facility | Breaks of drainage facility, deformation and corrosion of gratings | Visual inspection<br>・Clogging of drain ditch<br>・Breakage, deformation<br>Corrosion of gratings | a | ☐There are breakages of drain ditch or drainage basin.<br>☐There is loss of gratings.<br>☐Deformation and corrosion of gratings are too significant to use. |
| | | | | | b | ――― |
| | | | | | c | ☐Gratings are deformed or corroded. |
| | | | | | d | ☐No deformations are found |
| | | Fence, door, rope | Breakage, corrosion and loosening of rope strands | Visual inspection<br>・Damages, deformation of main structures, spalling of paint<br>・Corrosion of steel members, etc. | a | ☐There are damages and deformations impeding the function. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | ☐No deformations are found |
| | | Signs | Deterioration and damages of sign board, post and foundation | Visual inspection<br>・Corrosion, cracks damages of steel members<br>・Damages of lights | a | ☐The visibility of sign boards is significantly low and there are damages or deformations impeding the function.<br>☐The posts are deformed. |
| | | | | | b | ――― |
| | | | | | c | ☐The paint is spalling or there is rust partially.<br>☐There are slight cracks in foundation concrete of posts. |
| | | | | | d | ☐No deformations are found |
| | | Foundation of cargo handling equipment | Deterioration and damages of concrete | Visual inspection<br>・Cracks, spalling, damages<br>・Corrosion of steel bars<br>・Sign of deterioration, etc. | a | ☐There are cracks 3 mm wide or more in the axial direction of steel bars.<br>☐There are spalling parts of covering depth. |
| | | | | | b | ☐There are cracks less than 3 mm wide in the axial direction of steel bars. |
| | | | | | c | ☐There are cracks perpendicular to the axial direction.<br>☐Rust fluid spots are dotted. |
| | | | | | d | ☐No deformations are found |
| | | | Deterioration, damages and deformation of rail | Visual inspection<br>・Difference in level, smoothness, etc.<br>・Damages, deformation of rail, etc. | a | ☐There are damages or deformations impeding the function. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | ☐No deformations are found |
| | | | Deterioration, damages and corrosion of metal anchorage | Visual inspection<br>・ Damages or deformation of main structure, spalling of paint<br>・ Corrosion of steel members, etc. | a | ☐There are damages or deformations impeding the function. |
| | | | | | b | ――― |
| | | | | | c | ☐There are spalling of paint or rust generates partially. |
| | | | | | d | ☐No deformations are found |
| | | Ladder | Damages, painting, corrosion of the main structure | Visual inspection<br>・Damages, deformation<br>・Painting<br>・Corrosion (for steel) | a | ☐Spalling<br>☐There are significant damages and corrosions that are deemed dangerous to use. |
| | | | | | b | ――― |
| | | | | | c | ☐There are damages, deformation, spalling of paint and rust in the main structure. |
| | | | | | d | ☐No deformations are found |

Appendix B

# Attachment Format

# for Inspection and Diagnosis

Detailed periodic inspection and diagnosis

Attachment  Format for inspection and diagnosis

## Inspection items and deterioration judgement criteria: Waterways and basins

[Items for inspection and diagnosis to be selected depending on the necessity of data collection or prediction of deterioration]

| Facility | Inspection category | inspection items | Inspection method | Deterioration judgement criteria |
|---|---|---|---|---|
| Waterways and basins | I | Water depth | Bathymetric survey | Record the data on water depth to be filed as bathymetric images. |

## Inspection items and deterioration judgement criteria: Caisson breakwater 1/2

[Items for inspection and diagnosis to be selected depending on the necessity of data collection or prediction of deterioration]

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Caisson breakwater | Ⅰ | Caisson | Deterioration and damages of concrete | Diving inspection<br>・Cracking, spalling and damages<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | a | ☐There are damages, opening and cracks allowing outflow of filling.<br>☐Steel bars are exposed over a wide area. |
| | | | | | b | ☐There are cracks about 3 mm wide in several directions. |
| | | | | | c | ☐There are cracks about 3 mm wide in a single direction.<br>☐Steel bars are partially exposed. |
| | | | | | d | ☐No deformations are found. |
| | | Seabed | Scouring, sedimentation | Diving inspection<br>・Uplift of seabed | a | ☐There is a scouring of 1 m deep or more at the front-foot part of slope of rubble mound.<br>☐There is an impact on the mound or the caisson itself due to scouring.<br>☐The scouring prevention mat is lost or squash. |
| | | | | | b | ☐There is a scouring of 0.5 to 1 m deep at the front-foot part of slope of rubble mound.<br>☐About 50% of the scouring prevention mat is damaged. |
| | | | | | c | ☐There is a scouring or sedimentation of less than 0.5 m deep.<br>☐About 10% of the scouring prevention mat is damaged. |
| | | | | | d | ☐No deformations are found. |
| | Ⅱ | Covering | Displacement, scattering, subsidence | Diving inspection<br>・Deformation of slope, top and foot of slope<br>・Scattering and displacement status of blocks and stones | a | ☐There are displacements, material scatterings or subsidence of 5% or more damages. |
| | | | | | b | ☐There are displacements, material scatterings or subsidence of 1 to 5% damages. |
| | | | | | c | ☐There are displacements, material scatterings or subsidence of less than 1% damages. |
| | | | | | d | ☐No deformations are found. |
| | | Foot protection works | Displacement, scattering, subsidence | Diving inspection<br>・Deformation of slope, top and foot of slope<br>・Scattering and displacement status of blocks and stones | a | ☐There is displacement, scattering or subsidence in a wide area of 50% or more of a unit inspection segment. |
| | | | | | b | ☐There is displacement or scattering in an area of 10 to 50% of a unit inspection segment. |
| | | | | | c | ☐There is displacement or scattering in an area of less than 10% of a unit inspection segment. |
| | | | | | d | ☐No deformations are found. |
| | | Wavedissipating structure | Displacement, scattering, subsidence | Diving inspection<br>・ Deformation of crown, slope and top of slope<br>・Displacement and scattering of the wave-dissipating blocks | a | ☐The section area of the wave-dissipating structure of a unit inspection segment is reduced the length of one layer of the block or more. |
| | | | | | b | ☐The section area of the wave-dissipating structure of a unit inspection segment is reduced by erosion (less than the length of one layer of the block). |
| | | | | | c | ☐Wave-dissipating blocks are moved in part (scattered, settled). |
| | | | | | d | ☐No deformations are found. |

## Inspection items and deterioration judgement criteria: Caisson breakwater 2/2

[Items for inspection and diagnosis to be selected depending on the necessity of data collection or prediction of deterioration]

| Facility | Inspection category | inspection items | | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|---|
| Caisson breakwater | I | Breakwater in whole | Displacement amount<br>・Displacement from the face line at the time of completion of the work or displacement from a fixed point<br>Gap of the joints<br>Inclination amount<br>・Inclination of levee body | Measurement of displacement distance, leveling (inclination is obtained from difference of elevation at 4 points of corners on the crown), using a clinometer, etc.<br>Survey on normal line, measurement of gaps of the joints, diving inspection.<br>Determined referring to the measurement results or measured by clinometers. | Record the date of survey and mesurement, and file them to evaluate displacement of the whole levee body, gaps of joints, and inclination. | |
| | | | Subsidence | Leveling | Record the data of survey and file them to evaluate the levee body for settlement. | |
| | | Caisson | Deterioration and damages of concrete | Detailed inspection<br>・Cracking, spalling and damages<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | File in the form of a changes-in-state map of cracks. | |
| | | | Covering depth | Chipping test, etc. | Record actual measurement values or predicted values of covering depth. | |
| | | | Analysis of concrete | ・Compression strength test of concrete<br>・Measurement of chloride ion content<br>(carbonation measurement and chemical analysis, if necessary) | Record the measurement values. | |
| | | | Production of cavities in the caisson | Visual inspection through bored holes, etc. | a | □Cavities are observed (there is an flow-out of sand filling or a outflow potentiality). |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | □No cavities are observed (no outflows of sand filling). |
| | | Seabed | Scouring, sedimentation | Inspection of geometry of the underwater section, bathymetric survey, etc. | Record the data of survey and file them to evaluate the seabed for scouring and soil sedimentation. | |
| | Ⅱ | Super-structure | Deterioration and damages of concrete | Detailed inspection<br>・Cracking and damage<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | File in the form of a changes-in-state map of cracks. | |
| | | Foot protection works | Displacement, scattering, settlement | Inspection of geometry of the underwater section, cross section surveying, etc. | Record the data of survey, and file them to evaluate the foot protection works for displacement, scattering and settlement. | |
| | | Covering | Displacement, scattering, settlement | Inspection of geometry of the underwater section, cross section surveying, etc. | Record the data of survey, and file them to evaluate the covering for displacement, scattering and settlement. | |
| | | Wave-dissipating work | Displacement, scattering, settlement | Inspection of geometry of the underwater section, cross section surveying, etc. | Record the data of survey, and file them to evaluate the wave dissipating block for displacement, scattering and settlement. | |

Inspection items and deterioration judgement criteria: Revetment, levee 1/3

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Seawall, revetment, levee | I | Main structure (gravity type) | Deterioration and damages of concrete | Diving inspection<br>・Cracking, spalling and damage<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | a | ☐There are holes, cracks or defects allowing outflow of filling.<br>☐Steel bars are exposed over a wide area. |
| | | | | | b | ☐There are cracks about 3 mm wide in several directions. |
| | | | | | c | ☐There are cracks about 3 mm wide in a single direction.<br>☐Steel bars are partially exposed. |
| | | | | | d | ☐No deformations are found. |
| | | Steel sheet pile, etc. | Corrosion, cracks and damages of steel | Diving inspection | a | ☐There are holes, deformations and significant damages due to corrosion.<br>☐There is a sign of outflow of filling materials. |
| | | | | | b | ☐There are corrosion holes around the L.W.L.<br>☐Rust generates in the whole area. |
| | | | | | c | ☐Rust generates partially. |
| | | | | | d | ☐No deformations are found. |
| | | Foundation works | Displacement, settlement, damages | Diving inspection<br>・Forward squeezing, inclination, settlement of the structure<br>・Gaps and uneven settlement at joints<br>・Damages of concrete | a | ☐Outflow, breaks or damages of foundation are observed. There is significant displacement or<br>☐There are significant gaps or uneven settlement at the joints. |
| | | | | | b | ☐There are minor displacements or settlements on the foundation works.<br>☐There are slight gaps or subsidence at the joints. |
| | | | | | c | ――― |
| | | | | | d | ☐No deformations are found. |
| | | Rear part of the revetment and levee or the levee itself | sucking, production of cavity | Electromagnetic radar survey<br>Visual inspection through bored holes | a | ☐Sucking is observed or there is a possibility of sucking.<br>☐The sand invasion prevention plate is broken.<br>☐The sand invasion prevention plate is possibly broken. |
| | | | | | b | ☐There are cavities.<br>☐There are significant deterioration, fissures or damages in the joint cover. |
| | | | | | c | ☐There are slight deterioration, fissures or damages in the joint cover. |
| | | | | | d | ☐No outflow occurs (no cavity is observed). |
| | | Seabed | Scouring, sedimentation | Diving inspection<br>・Uplift of seabed | a | ☐There is a scouring of 1 m deep or more at the front-foot part of slope of rubble mound.<br>☐There is an impact on the mound or the levee body itself due to scouring. |
| | | | | | b | ☐There is a scouring of 0.5 to 1 m deep at the front-foot part of slope of rubble mound. |
| | | | | | c | ☐There is a scouring or sedimentation of less than 0.5 m deep. |
| | | | | | d | ☐No deformations are found. |

## Inspection items and deterioration judgement criteria: Revetment, levee 2/3

| Facility | Inspection category | inspection items | | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|---|
| Seawall, revetment, levee | Ⅱ | Steel sheet pile, etc. | Anticorrosive coating | Paint | Diving inspection<br>･Rust and blistering<br>･Spalling of coating | a | ☐Rust and blistering are observed in a wide area.<br>☐Spalling and cracks of coating caused by rust are appeared in a wide area.<br>☐The ratio of defect area is 10% or more. |
| | | | | | | b | ☐There is large rust or blistering.<br>☐Spalling of coating caused by rust are appeared in a wide area.<br>☐The ratio of defect area is 0.3% or more and less than 10%. |
| | | | | | | c | ☐There are rust and blistering in some area.<br>☐The painting is spalling and cracks are dotted.<br>☐The ratio of defect area is 0.03% or more and less than 0.3%. |
| | | | | | | d | ☐There isn't much deformation and paint looks free from damaged<br>☐The ratiio of defect area is less than 0.03%. |
| | | | | Heavy-duty anticorrosive coating | Diving inspection<br>･Deterioration of coating | a | ☐The heavy-duty anticorrosive coat is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration reaches the steel, and the steel components are corroded. |
| | | | | | | c | ☐Many damages of coating are observed but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Super-thick film coating | Diving inspection<br>･Measurement of film thickness,<br>etc. | a | ☐The super-thick film coating is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Corrosionresistant metal coating | Diving inspection<br>･Deterioration of coating | a | ☐There is a significant deterioration in the corrosion-resistant metal coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Underwater hardening coating | Diving inspection<br>･Measurement of film thickness,<br>etc. | a | ☐There is a significant deterioration in the underwater hardening coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Petrolatum coating | Diving inspection<br>･Protection cover sheet<br>･Bolts, nuts | a | ☐Protection cover sheets are detached and the petrolatum coating is exposed or detached, and rust generates on the steel surface. |
| | | | | | | b | ☐There are cracks in the protection cover sheet or the cover plate.<br>☐Corrosion is observed on bolts, nuts, or band material. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐Slight cracks are observed on the surface of the protection cover sheet.<br>☐There are loosened bolts, nuts or band materials.<br>☐Partial spalling is observed on the edge seal. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Mortar coating | Diving inspection<br>･Protection cover<br>･Deterioration and damages of mortar | a | ☐Protection cover sheets are detached in a wide area.<br>☐Rust fluid is observed on the mortar surface.<br>☐The mortar is failed and rust appears on the steel surface.<br>☐(When the protection cover or mortar layer is removed,) there is reduction of steel thickness. |
| | | | | | | b | ☐There are cracks in the protection cover sheets or mounting materials and the protection cover sheets are partially detached.<br>☐Slight rust fluid traces are observed but there is no overflow.<br>☐(When the protection cover is removed,) there are many cracks in the mortar and rust fluid. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐There are cracks on the surface but the area is less than 1%.<br>☐The mounting members of the protection cover sheets including bolts and nuts are loosened. |
| | | | | | | d | ☐No deformations are found. |
| | | | Cathodic corrosion protection (galvanic anode type) | Anode | Diving inspection<br>・Check the actual status (total) | a | ☐The anode is lost or consumed totally.<br>☐There is a defect at anode installation (hung). |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | ☐No damages such as detachment. |
| | | | Cathodic corrosion protection (ICCP) | DC and electrical equipment | Detailed inspection<br>・Discoloring of terminals<br>・Loosening of bolts and n? | a | ☐There are terminals discolored or bolts and nuts loosened. |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | ☐No deformations are found. |

Inspection items and deterioration judgement criteria: Revetment, levee 3/3

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Seawall, revetment, levee | Ⅱ | Covering | Displacement, scattering, subsidence | Diving inspection<br>・Deformation of slope, top and foot of slope<br>・Scattering and displacement status of blocks and stones | a | ☐There are displacements, material scatterings or subsidence of 5% or more damages. |
| | | | | | b | ☐There are displacements, material scatterings or subsidence of 1 to 5% damages. |
| | | | | | c | ☐There are displacements, material scatterings or subsidence of less than 1% damages. |
| | | | | | d | ☐No deformations are found. |
| | | Foot protection works | Displacement, scattering, subsidence | Diving inspection<br>・Deformation of slope, top and foot of slope<br>・Displacement or scattering of foot protection works | a | ☐There is displacement, scattering or subsidence in a wide area of 50% or more of a unit inspection segment. |
| | | | | | b | ☐There is displacement or scattering in an area of 10 to 50% of a unit inspection segment. |
| | | | | | c | ☐There is displacement or scattering in an area of less than 10% of a unit inspection segment. |
| | | | | | d | ☐No deformations are found. |
| | | Wave-dissipating work | Displacement, scattering, settlement | Diving inspection<br>・Deformation of slope, top and foot of slope<br>・Displacement or scattering of Wave-dissipating block | a | ☐The section area of the wave-dissipating structure of a unit inspection segment is reduced the length of one layer of the block or more by erosion. |
| | | | | | b | ☐The section area of the wave-dissipating structure of a unit inspection segment is reduced by erosion (less than the length of one layer of the block) |
| | | | | | c | ☐Wave-dissipating blocks are moved in part (scattered, subsidence) |
| | | | | | d | ☐No deformations are found. |

## Inspection items and deterioration judgement criteria: Revetment, levee
[Items for inspection and diagnosis to be selected depending on the necessity of data collection or prediction of deterioration]

| Facility | Inspection category | inspection items | | | Inspection method | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Seawall, revetment, levee | Ⅰ | Revetment, whole levee | Displacement, inclination | | Measurement of displacement distance Leveling Surveys using clinometers, etc. | Record the data of survey, and file them so that they may be available to evaluate the revetment and whole levee for displacement and inclination. |
| | | | Subsidence | | leveling | Record the data of survey, and file them so that they may be available to evaluate the revetment and whole levee for settlement. |
| | | Main works (gravity type) | Deterioration and damages of concrete（RC） | | Detailed inspection<br>・Cracking, spalling and damages<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | File as the form of a changes-in-state map of cracks. |
| | | | Covering depth | | Chipping test | Record actual measurement values or predicted values of covering depth. |
| | | | Analysis of concrete | | ・Compression strength test of concrete<br>・Measurement of chloride ion content<br>(carbonation measurement and chemical analysis, if necessary) | Record the measurement values. |
| | | | Cavities in the caisson | | Visual inspection through bored holes, etc. | a □There is an outflow of sand filling or a outflow potentiality (Cavities are observed).<br>b ―――<br>c ―――<br>d □No outflow of sand filling (No cavities are observed). |
| | | Outer slope covering<br>・<br>Crown covering<br>・<br>Back slope covering<br>・<br>Parapet | Deterioration and damages of concrete | | Detailed inspection, etc.<br>・Cracks, spalling, damages<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | File as the form of a changes-in-state map of cracks. |
| | | | Corrosion of reinforcing bars | | Natural electrical potential | Record natural electrical potential measurements to be filed in the form of an equipotential contour. |
| | | | Corrosion rate of reinforcing bars | | Measurement of polarization resistance | Record polarization resistance measurements to be filed in the form of an equipotential contour. |
| | | | Analysis of concrete | | ・Compression strength test of concrete<br>・Measurement of chloride ion content<br>(carbonation measurement and chemical analysis, if necessary) | Record the measurement values. |
| | | Steel sheet pile, etc. | Corrosion, cracks and damages of steel | | Detailed inspection | File as the form of a changes-in-state map of corrosion holes. |
| | | | Measurement of thickness | | Ultrasonic thickness gauge | Record the measurement values. |
| | | Seabed | Scouring, sedimentation | | Inspection of geometry of the underwater section, crosssectional survey, etc. | Record the data of survey, and file them to evaluate the foot protection works for displacement, scattering and settlement. |
| | Ⅱ | Steel sheet pile, etc. | Anticorrosive coating | | Detailed inspection<br>・Corrosion and exposure of steel members<br>・Damages of covering materials<br>・Status of protection covers | File as the form of a changes-in-state map of rusting, blistering, cracking and spalling of coating. |
| | | | Cathodic corrosion protection (galvanic anode type) | Electrical potential | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride800mV<br>・Saturated copper sulfate850mV | Record the measured values to be filed in the form of an equipotential contour. |
| | | | | Anode | Measurement of anode erosion (3 to 5% of the whole) | Record the measurement results of consumption of anode and predict the rest of the service life. |
| | | | | | Measurement of anode current<br>・Both sides, central part and significantly worn parts of the equipment | Record the measured amount of current to be used for evaluating the status of the cathodic corrosion protection. |
| | | | | Test pieces | Appearance inspection<br>・Weighing of test pieces | Check the status of test pieces and record the weights to evaluate the status of the cathodic corrosion protection. |
| | | | Cathodic corrosion protection (ICCP) | DC and electrical equipment | Measurement of DC voltage and<br>the current Insulation resistance of rectifier<br>Insulation resistance of circuit | Record the measured values for evaluating the status of the cathodic corrosion protection. |
| | | | | Electrical potential | Measurement of electrical potential | Record the measured values to be filed in the form of an equipotential contour. |
| | | | | Test pieces | Appearance inspection<br>・Weighing of test pieces | Check the status of test pieces and record the weights to evaluate the status of the cathodic corrosion protection. |

Inspection items and deterioration judgement criteria：Caisson-type quaywall 1/2

| Facility | Inspection category | inspection items | | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|---|
| Caisson-type quaywall | Ⅰ | Apron | Sucking, production of cavity | ・Electromagnetic radar survey<br>・Visual inspection through bored holes, etc. | a | □Sucking is observed or there is a possibility of sucking (cavities are observed).<br>□The sand invasion prevention plate is broken.<br>□The sand invasion prevention sheet is possibly broken. |
| | | | | | b | □Cavities are possibly produced.<br>□There are significant deterioration, fissures or damages in the joint cover. |
| | | | | | c | □There are slight deterioration, fissures or damages in the joint cover. |
| | | | | | d | □No sucking occurs (no cavities are observed). |
| | Ⅰ | Caisson | Deterioration, damages of concrete | Diving inspection<br>・Cracking, spalling, damages, losses<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | a | □There are holes, cracks and losses allowing outflow of filling.<br>□Steel bars are exposed over a wide area. |
| | | | | | b | □There are cracks about 3 mm wide in several directions. |
| | | | | | c | □There are cracks about 3 mm wide in a single direction.<br>□Steel bars are partially exposed. |
| | | | | | d | □No deformations are found. |
| | Ⅰ | Seabed | Scouring, sedimentation | Diving inspection<br>・Uplift of seabed<br>・Scouring, sedimentation | a | □There is a scouring of 1 m deep or more in the front part of the quaywall.<br>□There is a impact on the mound or the quaywall itself due to scouring. |
| | | | | | b | □There is a scouring of 0.5 m to 1 m deep is observed in the front part of the quaywall. |
| | | | | | c | □There is a scouring or sedimentation less than 0.5 m deep. |
| | | | | | d | □No deformations are found. |

Inspection items and deterioration judgement criteria：Caisson-type quaywall 2/2
[Items for inspection and diagnosis to be selected depending on the necessity of data collection or prediction of deterioration]

| Facility | Inspection category | inspection items | | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|---|
| Caisson-type quaywall | Ⅰ | Whole caissontype quaywall | Displacement, inclination, subsidence | Survey on reference points<br>Leveling<br>Surveys using clinometer, etc.<br>・Displacement, inclination, subsidence | Record the data of survey and measurement, and file them to evaluate the quaywall for displacement, inclination and settlement. | |
| | | Apron | Subsidence(uneven settlement), inclination | Leveling<br>Surveys using clinometer, etc.<br>・Settlement, inclination | Record the data of survey and measurement, and file them to evaluate the apron for settlement and inclination. | |
| | | Caisson | Deterioration and damages of concrete | Detailed inspection<br>・Cracking, spalling and damages<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | File as the form of a changes-in-state map of cracks. | |
| | | | Covering depth | Chipping test, electromagnetic radar test, etc. | Record actual measurement values or predicted values of covering depth. | |
| | | | Analysis of concrete | ・Compression strength test of concrete<br>・Measurement of chloride ion content<br>(carbonation measurement and chemical analysis, if necessary) | Record the measurement values. | |
| | | | Production of cavities in the caisson | Visual inspection through the electromagnetic radar or bored holes, etc. | a | □There is an outflow of sand filling or an outflow potentiality (Cavities are observed). |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | □No outflow of sand filling (No cavities are observed). |
| | | Seabed | Scouring, sedimentation | Inspection of geometry of the underwater section, crosssectional survey, etc. | Record the data of survey, and file them so that they may be available to evaluate the foot protection works for displacement, scattering and settlement. | |
| | Ⅱ | Apron | Deterioration, damages of concrete or asphalt | Detailed inspection<br>・Cracking, damages, irregularities, etc. | File as the form of a changes-in-state map of cracks. | |
| | | Super-structure | Deterioration and damages of concrete | Detailed inspection<br>・Cracks, spalling, damages<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | Filed as the form of a changes-in-state map of cracks. | |
| | | | Covering depth | Chipping test, electromagnetic radar test, etc. | Record actual measurement values or predicted values of covering depth. | |
| | | | Analysis of concrete | ・Compression strength test of concrete<br>・Measurement of chloride ion content<br>(carbonation measurement and chemical analysis, if necessary) | Record the measurement values. | |

Inspection items and deterioration judgement criteria：Sheet pile quaywall 1/3

| Facility | Inspection category | inspection items | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Sheet pile quaywall | I | Apron | Sucking, production of cavity | ・Electromagnetic radar survey<br>・Visual inspection through bored<br>holes, etc. | a | □Sucking is observed or there is a possibility of sucking (cavities are observed).<br>□The sand invasion prevention plate is broken.<br>□The sand invasion prevention sheet is possibly broken. |
| | | | | | b | □There are cavities probably. |
| | | | | | c | ――― |
| | | | | | d | □No sucking is observed (no cavities are observed). |
| | | Steel sheet pile, etc. | Corrosion, cracks and damages of steel | Diving inspection | a | □There are holes, deformations and significant damages due to corrosion. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | □No holes and deformations due to corrosion. |
| | | Seabed | Scouring, sedimentation | Diving inspection<br>・Uplift of seabed | a | □There is a scouring of 1 m depth or more in the front part of the quaywall.<br>□There is a impact on the mound or the quaywall itself due to scouring. |
| | | | | | b | □There is a scouring of 0.5 m to 1 m depth in the front part of the quaywall. |
| | | | | | c | □There is a scouring or sedimentation less than 0.5 m deep. |
| | | | | | d | □No deformations are found. |

Inspection items and deterioration judgement criteria：Sheet pile quaywall 2/3

| Facility | Inspection category | inspection items | | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|---|
| Sheet pile quaywall | Ⅱ | Steel sheet pile, etc. | Anticorrosive coating | Paint | Diving inspection<br>･Rust and blistering<br>･Spalling of coating | a | ☐Rust and blistering are observed in a wide area.<br>☐There are spalling and cracks caused by rust in a wide area.<br>☐The ratio of defect area is 10% or more. |
| | | | | | | b | ☐There is large rust or blistering.<br>☐Spalling of coating caused by rust appears in a wide area.<br>☐The ratio of defect area is 0.3% or more and less than 10%. |
| | | | | | | c | ☐There are rust and blistering in some area.<br>☐The painting is spalling and cracks are dotted.<br>☐The ratio of defect area is 0.03% or more and less than 0.3%. |
| | | | | | | d | ☐There isn't much deformation and paint looks free from damaged.<br>☐The ratio of defect area is less than 0.03%. |
| | | | | Heavy-duty anticorrosive coating | Diving inspection<br>･Deterioration of coating | a | ☐The heavy-duty anticorrosive coat is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration reaches the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Super-thick film coating | Diving inspection<br>･Measurement of film thickness, etc. | a | ☐The super-thick film coating is significantly deteriorated, with noticeable corrosion of steel. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Corrosionresistant metal coating | Diving inspection<br>･Deterioration of coating | a | ☐There is a significant damage in the corrosion-resistant metal coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Underwater hardening coating | Diving inspection<br>･Measurement of film thickness, etc. | a | ☐There is a significant damage in the underwater hardening coating and the steel is corroded. |
| | | | | | | b | ☐Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | ☐There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Petrolatum coating | Diving inspection<br>･Protection cover<br>･Bolts, nuts | a | ☐Protection cover sheets are detached and the petrolatum coating is exposed or detached, and rusting is observed on the steel surface. |
| | | | | | | b | ☐There are cracks in the protection cover sheet or the cover plate.<br>☐Corrosion is observed on bolts, nuts, or band material. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐Slight cracks are observed on the surface of the protection cover.<br>☐There are loosened bolts, nuts or band materials.<br>☐The edge seal is partially peeled off. |
| | | | | | | d | ☐No deformations are found. |
| | | | | Mortar coating | Diving inspection<br>･Protection cover<br>･Deterioration and damages of mortar | a | ☐Protection cover sheets are detached in a wide area.<br>☐There is rust fluid on the mortar surface.<br>☐The mortar is gone and rust generates on the steel surface.<br>☐ (When the protection cover or mortar layer is removed,) the thickness of steel is observed being reduced. |
| | | | | | | b | ☐Cracks generate in the protection cover sheets or mounting members and the protection covers are partially detached.<br>☐Slight rust fluid is observed but there is no overflow.<br>☐ (When the protection cover is removed,) there are numerous cracks in the mortar and rust fluid. |
| | | | | | | c | ☐The protection cover sheets are discolored or whitened.<br>☐There are cracks on the surface but the area is less than 1%.<br>☐The mounting members of the protection cover sheets including bolts and nuts are loosened. |
| | | | | | | d | ☐No deformations are found. |
| | | | Cathodic corrosion protection (galvanic anode type) | Anode | Diving inspection<br>・Check the actual status (total) | a | ☐The anode is lost or wasted totally.<br>☐ There is a defect anode installation (hung). |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | ☐No abnormality such as damages. |
| | | | Cathodic corrosion protection (ICCP) | DC and electrical equipment | Detailed inspection<br>・Discoloring of terminals<br>・Loosening of bolts and nuts , etc. | a | ☐There are terminals discolored or bolts and nuts loosened. |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | ☐No deformations are found. |

## Inspection items and deterioration judgement criteria：Sheet pile quaywall 3/3

[Items for inspection and diagnosis to be selected depending on the necessity of data collection or prediction of deterioration]

| Facility | Inspection category | inspection items | | | Inspection method | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Sheet pile quaywall | Ⅰ | Whole sheet pile quaywall | Displacement, inclination, settlement | | Measurement of displacement distance, Leveling, Surveys using clinometers, etc. | Record the data of survey and measurement, and file them to evaluate the quaywall for displacement, inclination and settlement. |
| | | Apron | Settlement (subsidence), inclination | | Leveling<br>Inclination measurement | Record the data of survey and measurement, and file them to evaluate the apron for settlement and inclination. |
| | | Steel sheet pile, etc. | Corrosion, cracks and damages of steel | | Detailed inspection | File in the form of a changes-in-state map of corrosion holes. |
| | | | Measurement of thickness | | Ultrasonic thickness gauge | Record the measurement values. |
| | | Seabed | Scouring, sedimentation | | Inspection of geometry of the underwater section, crosssectional survey, etc. | Record the data of survey and file them to evaluate the foot protection works for displacement, scattering and settlement. |
| | Ⅱ | Apron | Deterioration, damages of concrete and asphalt | | Detailed inspection<br>・Cracking, damages, irregularities, etc. | File in the form of a changes-in-state map of cracks. |
| | | Super-structure | Deterioration and damages of concrete | | Detailed inspection<br>・Cracks, spalling, damages<br>・Exposure of steel bars<br>・Signs of deterioration, etc. | File in the form of a changes-in-state map of cracks. |
| | | | Covering depth | | Chipping test, electromagnetic radar test, etc. | Record actual measurement values or predicted values of covering depth. |
| | | | Analysis of concrete | | ・Compression strength test of concrete ・Measurement of chloride ion content (carbonation measurement and chemical analysis, if necessary) | Record the measurement values. |
| | | Steel sheet pile, etc. | Anticorrosive coating | | Detailed inspection<br>・Corrosion and exposure of steel members<br>・Damages of covering materials<br>・Status of protection covers | File in the form of a changes-in-state map of rusting, blistering, cracking and spalling of coating. |
| | | | Cathodic corrosion protection (galvanic anode type) | Electrical potential | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride800mV<br>・Saturated copper sulfate850mV | Record the measured values to be filed in the form of an equipotential contour. |
| | | | | Anode | Measurement of anode erosion (3 to 5% of the whole) | Record the measurement results of consumption of anode and predict the rest of the service life. |
| | | | | | Measurement of anode current<br>・Both sides, central part and significantly worn parts of the equipment | Record the measured amount of current for evaluating the status of the cathodic protection. |
| | | | | Test pieces | Appearance inspection<br>・Weighing of test pieces | Check the status of test pieces and record the weights to evaluate the status of the cathodic corrosion protection. |
| | | | Cathodic corrosion protection (ICCP) | DC and electrical equipment | Measurement of DC voltage and the current Insulation resistance of rectifier Insulation resistance of circuit | Record the measured values to evaluate the status of the cathodic corrosion protection. |
| | | | | Electrical potential | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride800mV<br>・Saturated copper sulfate850mV | Record the measured values to be filed in the form of an equipotential contour. |
| | | | | Test pieces | Appearance inspection<br>・Weighing of test pieces | Check the status of test pieces and record the weights to evaluate the status of the cathodic protection. |

Inspection items and deterioration judgement criteria: Pile supported Open type wharf 1/3

| Facility | Inspection category | inspection items | | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|---|
| Pile supported Open type wharf | I | Apron behind the earth retaining part | Sand flow-out and production of cavity | Electromagnetic radar inspection, Drilling visual inspection, etc. | a | □There is sand outflowing. There is a possibility of sand outflowing because of cavity's existance.<br>□The sand preventive plates are damaged.<br>□The sand preventive sheets are likely to be damaged. |
| | | | | | b | □There is a possibility of a cavity.<br>□There are significant deterioration, cracks or damages in the joint cover. |
| | | | | | c | □There are minor deterioration, cracks or damages in the joint cover. |
| | | | | | d | □ There is no sand (no cavities). |
| | | Steel pipe pile | Corrosion, cracks and damages of steel | Diving inspection<br>・Presence of holes<br>・Scratches on the surface | a | □ There are holes, deformations and significant damages due to corrosion. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | □ No hole and deformation due to corrosion. |
| | | Earth retaining part | | Diving inspection, detailed inspection, etc. (to be done adequately for the type of earth retaining) | According to the structural type of earth retaining, the checking form for caisson-type quaywall or for sheet pile quaywall wall is used adequately. | |

## Inspection items and deterioration judgement criteria: Pile supported Open type wharf 2/3

| Facility | Inspection category | inspection items | | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|---|
| Pile supported Open type wharf | Ⅱ | Steel pipe pile | Anticorrosive coating | Paint | Diving inspection<br>･Rust and blistering<br>･Spalling of coating | a | □Rust and blistering are observed in a wide area.<br>□Spalling and cracks of coating caused by rust appear in a wide area.<br>□The ratio of defect area is 10% or more. |
| | | | | | | b | □Major rust or blistering is observed.<br>□Spalling of coating caused by rust is appers in a wide area.<br>□The defect area is 0.3% or more and less than 10%. |
| | | | | | | c | □There are rust and blistering in some area.<br>□Spalling of painting and cracks are dotted.<br>□The ratio of defect area is 0.03% or more and less than 0.3%. |
| | | | | | | d | □There isn't much deformation and coating looks free from damaged.<br>□The ratio of defect area is less than 0.03%. |
| | | | | Heavy-duty anticorrosive coating | Diving inspection<br>･Deterioration of coating | a | □The heavy-duty anticorrosive coat is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | □Partially the coating deterioration reaches the steel, and the steel components are corroded. |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found. |
| | | | | Super-thick film coating | Diving inspection<br>･Measurement of film thickness, etc. | a | □The super-thick film coating is significantly deteriorated, with noticeable corrosion of steel. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found. |
| | | | | Corrosionresistant metal coating | Diving inspection<br>･Deterioration of coating | a | □There a significant deterioration in the corrosion-resistant metal coating is observed and the steel is corroded. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | □Many damages of coating are observed but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found. |
| | | | | Underwater hardening coating | Diving inspection<br>･Measurement of film thickness, etc. | a | □A significant deterioration in the underwater hardening coating is observed and the steel is corroded. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found. |
| | | | | Petrolatum coating | Diving inspection<br>･Protection cover<br>･Bolts, nuts | a | □Protection cover sheets are detached and the petrolatum coating is exposed or detached, and rusting is observed on the steel surface. |
| | | | | | | b | □There are cracks in the protection cover sheet or the cover plate.<br>□Corrosion is observed on bolts, nuts or band materials. |
| | | | | | | c | □The protection cover sheets are discolored or whitened.<br>□Micro cracks are observed on the surface of the protection cover.<br>□There are loosened bolts, nuts or band materials.<br>□Partial spalling is observed on the edge seal. |
| | | | | | | d | □No deformations are found. |
| | | | | Mortar coating | Diving inspection<br>･Protection cover<br>･Deterioration and damages of mortar | a | □Protection cover sheets are detached in a wide area.<br>□Rust fluid is observed on the mortar surface.<br>□The mortar is failed and rust appears on the steel surface.<br>□ (When the covering material or mortar layer is removed,) the thickness of steel is observed being reduced. |
| | | | | | | b | □Cracks are observed in the protection cover sheets or mounting materials and the protection cover sheets are partially detached.<br>□Slight rust fluid is observed but there is no overflow.<br>□ (When the covering material is removed,) numerous cracks in the mortar and rust fluid are observed. |
| | | | | | | c | □The protection cover sheets are discolored or whitened.<br>□ Cracks are observed on the surface but the area is 1% or less.<br>□The mounting materials of the protection cover sheets including bolts, nuts and band materials are loosened. |
| | | | | | | d | □No deformations are found. |
| | | | Cathodic corrosion protection (galvanic anode type) | Anode | Diving inspection<br>•Check the actual status (total) | a | □The anode is lost or wasted totally.<br>□There is a defect in the anode installation (hung). |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | □No abnormality such as damages. |
| | | | Cathodic corriosion protection (ICCP) | DC and electrical equipment | Detailed inspection<br>•Discoloring of terminals<br>•Loosening of bolts and nuts | a | □There are terminals discolored or bolts and nuts loosened. |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | □No deformations are found. |

Inspection items and deterioration judgement criteria: Pile suppirted Open type wharf 3/3
[Items for inspection and diagnosis to be selected depending on the necessity of data collection or prediction of deterioration]

| Facility | Inspection category | inspection items | | | Inspection method | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Pile type | I | Whole pier | Displacement, inclination, settlement | | Measurement of displacement distance<br>Leveling<br>Surveys using clinometers, etc. | Record the data of survey and measurement, and file them to evaluate the quaywall for displacement, inclination and settlement. |
| | | Apron behind the earth retaining part | Settlement (subsidence), inclination | | Leveling<br>Inclination measurement | Record the data of survey and measurement, and file them to evaluate the apron for settlement and inclination. |
| | | Pier superstructure (for presstressed concrete) | Deterioration and damages of concrete | | Detailed inspection<br>・Direction of cracks<br>・Number, length and width of cracks<br>・Spalling of covering<br>・Presence of rust fluid<br>・Corrosion status of steel bars | File in the form of a changes-in-state map of cracks. |
| | | Steel pipe pile | Corrosion, cracks and damages of steel | | Detailed inspection | File in the form of a changes-in-state map of corrosion holes. |
| | | | Measurement of thickness | | Ultrasonic thickness gaug | Record the measurement values. |
| | | Seabed | Scouring, sedimentation | | Inspection of geometry of the underwater section, cross section surveying, etc. | Record the data of survey, and file them to evaluate the foot protection works for displacement, scattering and settlement. |
| | II | Apron behind the earth retaining part | Deterioration, damages of concrete and asphalt | | Detailed inspection<br>・Cracking, damages, irregularities, etc. | File in the form of a changes-in-state map of cracks. |
| | | Pier superstructure (for reinforced concrete) | Deterioration and damages of concrete | | Detailed inspection<br>・Direction of cracks<br>・Number, length and width of cracks<br>・Spalling of covering<br>・Presence of rust fluid<br>・Corrosion status of steel bars | File in the form of a changes-in-state map of cracks. |
| | | | Covering depth | | Chipping test, electromagnetic radar test, etc. | Record actual measurement values or predicted values of covering depth. |
| | | | Corrosion of reinforcing bars | | Natural electrical potential | Record natural electrical potential to be filed in the form of an equipotential contour. |
| | | | Corrosion rate of reinforcing bars | | Measurement of polarization resistance | Record polarization resistance measurements to be filed in the form of an equipotential contour. |
| | | | Analysis of concrete | | ・Compression strength test of concrete<br>・Measurement of chloride ion content (carbonation measurement and chemical analysis, if necessary) | Record the measurement values. |
| | | Steel pipe pile | Anticorrosive coating | | Detailed inspection<br>・Corrosion and exposure of steel members<br>・Damages of covering materials<br>・Status of protection covers | File in the form of a changes-in-state map of rusting, blistering, cracking and Spalling of coating. |
| | | | Cathodic corrosion protection (galvanic anode type) | Electrical potential | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride800mV<br>・Saturated copper sulfate850mV | Record the measured values to be filed in the form of an equipotential contour. |
| | | | | Anode | Measurement of anode erosion (3 to 5% of the whole) | Record the measurement results of consumption of anode and predict the rest of the service life. |
| | | | | | Measurement of anode current<br>・Both sides, central part and significantly worn parts of the equipment | Record the measured amount of current for evaluating the status of the cathodic corrosion protection. |
| | | | | Test pieces | Appearance inspection<br>・Weighing of test pieces | Check the status of test pieces and record the weights to evaluate the status of the cathodic corrosion protection. |
| | | | Cathodic corrosion protection (ICCP) | DC and electrical equipment | Measurement of DC voltage and the current Insulation resistance of rectifier Insulation resistance of circuit | Record the measured values for evaluating the status of the cathodic corrosion protection. |
| | | | | Electrical potential | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride800mV<br>・Saturated copper sulfate850mV | Record the measured values to be filed in the form of an equipotential contour. |
| | | | | Test pieces | Appearance inspection<br>・Weighing of test pieces | Check the status of test pieces and record the weights to evaluate the status of the cathodic protection. |

Inspection items and deterioration judgement criteria: Floating pier 1/3

| Facility | Inspection category | inspection items | | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|---|
| Floating pier | I | Steel members and steel pipe piles | Corrosion, cracks and damages of steel | Diving inspection<br>・Presence of holes<br>・Status of scratches on the surface | a | □There are holes, deformations and significant damages due to corrosion. |
| | | | | | b | ――― |
| | | | | | c | ――― |
| | | | | | d | □No hole and deformation due to corrosion. |
| | | Reinforced concrete members | Deterioration, damages of concrete | Diving inspection<br>・Direction of cracks<br>・Number, length and width of cracks<br>・Spalling of covering<br>・Presence of rust fluid<br>・Corrosion of steel bars | a | □There are cracks 3 mm wide or more along the steel bars.<br>□There is detachment of covering depth.<br>□Fluid rust appears in a wide area. |
| | | | | | b | □There are cracks less than 3 mm wide along the steel bars.<br>□Fluid rust partially appears. |
| | | | | | c | □There are slight cracks.<br>□Rust fluid spots are partially appeared. |
| | | | | | d | □No deformations are found. |

## Inspection items and deterioration judgement criteria: Floating pier 2/3

| Facility | Inspection category | inspection items | | | Inspection method | | Deterioration judgement criteria |
|---|---|---|---|---|---|---|---|
| Floating pier | Ⅱ | Steel members of steel pontoon, mooring piles and chains, connecting bridge, etc. | Anticorrosive coating | Paint | Diving inspection<br>･Rust and blistering<br>･Spalling of coating | a | □Rust and blistering are observed in a wide area.<br>□Spalling and cracks of coating caused by rust appear in a wide area.<br>□The defect area is 10% or more. |
| | | | | | | b | □Major rust or blistering is observed.<br>□Spalling of coating caused by rust appear in a wide area.<br>□The ratio of defect area is 0.3% or more and less than 10%. |
| | | | | | | c | □There are rust and blistering in some area.<br>□The painting is spalling in parts and cracks are dotted.<br>□The defect area is 0.03% or more and less than 0.3%. |
| | | | | | | d | □There isn't much deformation and paint looks free from damaged.<br>□The ratio of defect area is less than 0.03%. |
| | | | | Heavy-duty anticorrosive coating | Diving inspection<br>･Deterioration of coating | a | □The heavy-duty anticorrosive coat is significantly deteriorated with noticeable corrosion of steel. |
| | | | | | | b | □Partially the coating deterioration reaches the steel, and the steel components are corroded. |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found. |
| | | | | Super-thick film coating | Diving inspection<br>･Measurement of film thickness, etc. | a | □The super-thick film coating is significantly deteriorated, with noticeable corrosion of steel. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found. |
| | | | | Corrosionresistant metal coating | Diving inspection<br>･Deterioration of coating | a | □A significant deterioration in the corrosion-resistant metal coating is observed and the steel is corroded. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found. |
| | | | | Underwater hardening coating | Diving inspection<br>･Measurement of film thickness, etc. | a | □A significant deterioration in the underwater hardening coating is observed and the steel is corroded. |
| | | | | | | b | □Partially the coating deterioration involves a corrosion reaching to the steel, and the steel components are corroded. |
| | | | | | | c | □There are many damages of coating but the damage does not reach the steel. |
| | | | | | | d | □No deformations are found. |
| | | | | Petrolatum coating | Diving inspection<br>･Protection cover sheet<br>･Bolts, nuts | a | □Protection covers are detached and the petrolatum coating is exposed or detached, and rusting is observed on the steel surface. |
| | | | | | | b | □There are cracks in the protection cover sheet or the cover plate.<br>□Corrosion is observed on bolts, nuts or band materials. |
| | | | | | | c | □The protection cover sheets are discolored or whitened.<br>□Micro cracks are observed on the surface of the protection cover sheet.<br>□There are loosened bolts, nuts or band materials.<br>□Partial spalling is observed on the edge seal. |
| | | | | | | d | □No deformations are found. |
| | | | | Mortar coating | Diving inspection<br>･Protection cover sheet<br>･Deterioration and damages of mortar | a | □Protection covers are detached in a wide area.<br>□Rust fluid is observed on the mortar surface.<br>□he mortar is failed and rust is produced on the steel surface.<br>□ (When the covering material or mortar layer is removed,) the thickness of steel is observed being reduced. |
| | | | | | | b | □Cracks are observed in the protection cover sheets or mounting materials and the protection cover sheets are partially detached.<br>□Slight rust fluid is observed but there is no overflow.<br>□ (When the covering material is removed,) numerous cracks in the mortar and rust fluid are observed. |
| | | | | | | c | □The protection cover sheets are discolored or whitened.<br>□Cracks are observed on the surface but the area is less than 1%.<br>□The mounting materials of the protection cover sheets including bolts, nuts and band materials are loosened. |
| | | | | | | d | □No deformations are found. |
| | | Steel pontoon, steel materials of mooring piles and chains, connecting bridges, etc. | Cathodic corrosion protection (galvanic anode type) | Anode | Diving inspection<br>・Check the actual status (total) | a | □The anode is lost or consumed totally. (When the anodes are lost, search for them.)<br>□There is a defect in the mounting of anode (hung). |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | □ No abnormality such as damages. |
| | | | Cathodic corrosion protection (ICCP) | DC and electrical equipment | Detailed inspection<br>・Discoloration of terminals<br>・Loosening of bolts, nuts, etc. | a | □There are discoloration, loosened bolts or nuts. |
| | | | | | | b | ――― |
| | | | | | | c | ――― |
| | | | | | | d | □No deformations are found. |

## Inspection items and deterioration judgement criteria: Floating pier 3/3

[Items for inspection and diagnosis to be selected depending on the necessity of data collection or prediction of deterioration]

| Facility | Inspection category | inspection items | | | Inspection method | Deterioration judgement criteria |
|---|---|---|---|---|---|---|
| Floating pier | I | Steel members of steel pontoon, mooring piles and chains, connecting bridge, etc. | Corrosion, cracks and damages of steel | | Detailed inspection | File in the form of a changes-in-state map of corrosion holes. |
| | | | Measurement of thickness | | Ultrasonic thickness gauge | Record the measurement values. |
| | | Reinforced concrete members | Deterioration and damages of concrete | | Detailed inspection<br>・Direction of cracks<br>・Number, length and width of cracks<br>・Spalling of covering<br>・Presence of rust fluid<br>・Corrosion status of steel bars | File in the form of a changes-in-state map of cracks. |
| | | Seabed | Scouring, sedimentation | | Inspection of geometry of the underwater section, cross section surveying, etc. | Record the data of survey, and file them to evaluate the foot protection works for displacement, scattering and settlement. |
| | Ⅱ | Apron | Deterioration, damages of concrete and asphalt | | Detailed inspection<br>・Cracking, damages, irregularities, etc. | File in the form of a changes-in-state map of cracks. |
| | | Steel members of steel pontoon, mooring piles and chains, connecting bridge, etc. | Anticorrosive coating | | Detailed inspection<br>・Corrosion and exposure of steel members<br>・Damages of covering materials<br>・Status of protection covers | File in the form of a changes-in-state map of rusting, blistering, cracking and spalling of coating. |
| | | | Cathodic corrosion protection (galvanic anode type) | Electrical potential | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride800mV<br>・Saturated copper sulfate850mV | Record the measured values to be filed in the form of an equipotential contour. |
| | | | | Anode | Measurement of anode erosion (3 to 5% of the whole) | Record the measurement results of consumption of anode and predict the rest of the service life. |
| | | | | | Measurement of anode current<br>・Both sides, central part and significantly worn parts of the equipment | Record the measured amount of current for evaluating the status of the cathodic corrosion protection. |
| | | | | Test pieces | Appearance inspection<br>・Weighing of test pieces | Check the status of test pieces and record the weights to evaluate the status of the cathodic corrotion protection. |
| | | | Cathodic corrosion protection (ICCP) | DC and electrical equipment | Measurement of DC voltage and the current Insulation resistance of rectifier Insulation resistance of circuit | Record the measured values for evaluating the status of the cathodic protection. |
| | | | | Electrical potential | Measurement of electrical potential (corrosion control potential per electrode)<br>・Saturated calomel-800mV<br>・Seawater silver chloride800mV<br>・Saturated copper sulfate850mV | Record the measured values to be filed in the form of an equipotential contour. |
| | | | | Test pieces | Appearance inspection<br>・Weighing of test pieces | Check the status of test pieces and record the weights to evaluate the status of the cathodic corrosion protection. |

## Format for detailed regular inspection and diagnosis (Check items and deterioration judgement criteria：Mooring buoy)

| Facility | Inspection category | inspection items | Inspection method | Deterioration judgement criteria | |
|---|---|---|---|---|---|
| Mooring buoy | I | Conditions of buoys, main chains, sinkers and mooring anchors, etc. | Diving inspection (When there are plural buoys in the range of a same design water depth, check all buoys). | a | □The main chains, sinkers or mooring anchors are significantly damaged or corroded.<br>□The function of the main chains is lost its efficiency. |
| | | | | b | □Wear and tear is observed on main chains sinkers or mooring anchors. |
| | | | | c | ――― |
| | | | | d | □No deformations are found. |

# Appendix C Examples of Survey Items, Information Obtainable from Survey, and Main Survey Methods

Examples of Survey Items, Information Obtainable from Survey, and Main Survey Methods

| General survey items | Example of information obtainable from survey | Example of main survey methods | Related standards |
|---|---|---|---|
| Overall behavior of structure | • Status of service (load, external force, etc.)<br>• Abnormal noise or vibration<br>• Usability (ride quality, etc.)<br>• Deflection by live load | • Visual check (close or distant)<br>• Method based on feeling one gets while on board a car<br>• Method using loading test | |
| | • Soundness of structure | • Method using elastic waves | NDIS 2421, NDIS 2426 |
| Deformation of appearance | • Presence of initial defects (cracking, honeycombing, cold joints, sand streaks, surface bubbles, etc.)<br>• Presence of concrete discoloration or stains<br>• Presence of cracking or the status of cracking<br>• Presence of scaling or pop out | • Visual check (close or distant) | NDIS 3418 |
| | • Presence of lifting, flaking or peeling | • Tapping method<br>• Hammering method | NDIS 2426-3 |
| | | • Infrared thermography method | |
| | • Presence of steel exposure, corrosion, fracture or deformation<br>• Presence of rust fluid, water leakage, or efflorescence<br>• Presence of gel or wear | • Visual check (close or distant) | |
| | • Surface strain or displacement | • Digital photo measurement<br>• Digital image correlation method<br>• Moire method | NDIS 3418 |
| | • Surface properties | • Surface water absorption test<br>• Surface permeability test | |
| hollowing | ・existence of hollowing | ・hammer sounding<br>・electromagnetic wave radar method<br>・method of drilling inspection holes<br>・method of void inspection holes | |
| Condition of concrete | • Information on materials or mix proportion used | • Method based on documents | |
| | | • Estimation of mix proportion (method using hydrochloric acid dissolution) | (Japan Cement Association F18) |
| | | • Estimation of mix proportion (method using sodium gluconate) | NDIS 3422 |
| | • Condition of water content of concrete | • Electromagnetic radar method<br>• Method using electric resistance | |
| | • Strength (or modulus of elasticity) | • Method using sampled core | JIS A 1108, JIS A 1149 |
| | | • Rebound index method | JIS A 1155, JSCE-G504 |
| | | • Ultrasonic method | NDIS 2426-1 |
| | | • Shock elastic wave method | NDIS 2426-2 |
| | | • Method using BOSS specimens | NDIS 3424 |
| | • Internal strain or changes in strain distribution | • Optical fiber method | JIS A 1154, JSCE-G573 |
| | • Internal cracking or voids | • Fluorescent impregnation method or elastic wave tomography method<br>• X-ray method | |
| | • Degree of intrusion of deterioration factors (depth of carbonation) | • Method using sampled core | JIS A 1152 |
| | | • Method using drilled hole powder sampling | NDIS 3419 |
| | • Degree of intrusion of deterioration factors (depth of chloride ion permeation) | • Core sampling and chemical analysis | JIS A 1154, JSCE-G573 |
| | | • Core sampling or EPMA | JSCE-G574 |

| | | | |
|---|---|---|---|
| Condition of reinforcing bar in concrete, etc. | • Amount of steel<br>• Position, diameter, or covering of steel | • Chipping method | |
| | | • Electromagnetic induction method | NDIS 3430 |
| | | • Electromagnetic radar method | NDIS 3429 |
| | • Condition of PC grout filling | • Ultrasonic method | NDIS 2426-1 |
| | | • Shock elastic wave method | NDIS 2426-2 |
| | | • X-ray tomography method | (NDIS 1401) |
| | • Condition of steel corrosion | • Self-potential method | JSCE-E601 |
| | | • Polarization resistance method | |
| | • Presence of partial loss of sectional area | • X-ray permeation method | (NDIS 1401) |
| | | • Chipping method | (JCI-SC1) |
| | • Rupture of steel | • Magnetic flux leakage method | |
| Condition of steel members (steel structure) | • Condition of cathodic protection | ・Inspections such a visual inspection<br>・Method of potential measurement for steel materials<br>・Method of measuring of the current generated anode | |
| | •Condition of protective coating | ・Inspections such a visual inspection<br>・Inspection depending on types of protective coating | |
| | •Width of steel materials | ・Ultrasonic wave method | |
| Structural details or condition of ancillary equipment, etc. | • Section size of member, covering, anchoring, or condition of joint<br>• Condition of column-beam connection or condition of ancillary equipment | • Method using electromagnetic waves<br>• Direct measurement method | |
| Action | • Weather conditions (atmospheric temperature, humidity, rainfall, amount of insolation, etc.)<br>• Supply of water (condition of weathered area, condition of water supply from the ground, or condition of waterproof layer or drainage equipment)<br>• Supply of salt (amount of airborne salt, influence of seawater, amount of anti-freeze agent spread, etc.)<br>• Loading conditions (condition of vehicles passing)<br>• pH of river water, etc.<br>• Quality of water in sewerage-related facilities<br>• Condition of soil contamination<br>• Condition of occurrence of acid rain or mist | • Direct measurement method<br>• Method based on past records<br>• Method based on data announced by the Meteorological Agency, etc. | |
| Condition of past measures | • Condition of repair or reinforcement<br>• Condition of restriction on service | • Visual check (close or distant)<br>• Method using tests related to repair or reinforcement materials | |

JIS: Japan Industrial Standard; JSCE: Japan Society of Civil Engineers Standard;
NDIS: Non-Destructive Inspection Standard

Standards related to survey

| Inspection method | | Relevant standards | |
|---|---|---|---|
| Visual method | | | |
| | Visual | NDIS 3418 | Visual Testing Method of Concrete Structures |
| Method using non-destructive testing equipment | | | |
| | Rebound index method | JIS A 1155 | Method of measurement for rebound number on surface of concrete |
| | | JSCE-G 504 | Test Method for Test Hammer Strength of Hardened Concrete (draft) |
| | Electromagnetic induction method | NDIS 3430 | Investigation for Locating Rebars in Concrete Structure by Electromagnetic Method |
| | Hammering method, ultrasonic method, impact elastic wave method | NDIS 2426 | Non-destructive Testing of Concrete — Elastic wave method. Part 1: Ultrasonic method; Part 2: Impact elastic wave method; Part 3: Hammering method) |
| | AE method | NDIS 2421 | Acoustic Emission Test Method for Concrete Structures |
| | Electromagnetic radar method | NDIS 3429 | Investigation for Locating Rebars in Concrete Structure by Electromagnetic Radar Method |
| | Infrared thermography method | NDIS 3428 | Test Method for Evaluation of Deformation in Surface Parts of Buildings or Civil Engineering Structures using Infrared Thermography |
| | Self-potential method | JSCE-E 601 | Test Method for Half-cell Potential of Uncoated Rebars in Concrete Structures |
| | Four electrode method | JSCE-K 562 | Test Method for Measuring Resistivity of Patching Repair Materials with Four Electrodes (draft) |
| | X-ray permeation method | (NDIS 1401) | Methods of Radiographic Examination for Concrete Constructions |
| Method requiring destruction | | | |
| | Estimation of mix proportion (hydrochloric acid dissolution) | (Japan Cement Association F18) | "Report on Joint Test related to Mix Proportion Estimation of Hardened Concrete," Concrete Specialty Committee Report F-18, Japan Cement Association |
| | Estimation of mix proportion (sodium gluconate) | NDIS 3422 | Determination of Unit Cement Content in Hardened Concretes by the Sodium Gluconate Method |
| | Chipping method | (JCI-SC1) | Test Method and Standard Related to Corrosion and Corrosion Resistance of Concrete Structures, Japan Concrete Institute (draft), JCI-SC1 "Method for Evaluation of Corrosion of Steels in Concrete" |
| | Method using sampled core | JIS A 1107 | Method of Sampling and Testing for Compressive Strength of Drilled Cores of Concrete |
| | | JIS A 1108 | Method of Test for Compressive Strength of Concrete |
| | | JIS A 1114 | Method of Sampling and Testing for Strength of Sawed Prism of Concrete |
| | | JIS A 1127 | Methods of Test for Dynamic Modulus of Elasticity, Rigidity and Poisson's Ratio of Concrete by Resonance Vibration |
| | | JIS A 1149 | Method of Test for Static Modulus of Elasticity of Concrete |
| | | JIS A 1152 | Method for Measuring Carbonation Depth of Concrete |
| | | JIS A 1154 | Methods of Test for Chloride Ion Content in Hardened Concrete |
| | Core sampling and chemical analysis | JSCE-G 573 | Measurement Method for Distribution of Total Chloride Ion in Concrete Structure (Draft) |
| | | JIS A 1154 | Methods of Test for Chloride Ion Content in Hardened Concrete |
| | | NDIS 3433 | Simplified Test Method for Chloride Ion Content in Hardened Concrete |
| | Core sampling or EPMA | JSCE-G 574 | Test Method for Chemical Element Distribution in Concrete Using EPMA (draft) |
| | Drilled hole powder sampling | NDIS 3419 | Method of Test for Neutralization Depth of Concrete in Structures with Drilling Powder |
| | Method using BOSS specimens | NDIS 3424 | Method of Making and Testing for Compressive Strength of BOSS Specimens |
| Monitoring with sensors | | | |
| | Monitoring | | Report of the Tarui Viaduct Monitoring Evaluation Committee, Japan Society of Civil Engineers |

JIS: Japan Industrial Standard; JSCE: Japan Society of Civil Engineers Standard;
NDIS: Non-Destructive Inspection Standard