1. General

1-1. Scope of Application

This Design Casebook covers general design methods for various types of projects, including new constructions, renovations, upgrades, and maintenance of seaport facilities. It incorporates the latest TCVNs, which employ a performance-based design approach. The primary method of performance verification used in this casebook is limit states design. In certain calculation scenarios where appropriate justifications are provided, the allowable stress design method may be employed.

Major types introduced in the Design Casebook include:

- ✓ Part 2: Open-type Wharves on Piles
- ✓ Part 3: Sheet-pile Quaywall
- ✓ Part 4: Caisson-type Gravity Quaywall
- ✓ Part 5: Platform and Dolphin
- ✓ Part 6: Sloping Breakwater
- ✓ Part 7: Caisson-type Gravity Breakwater
- ✓ Part 8: Deep Mixing Method
- ✓ Part 9: Prefabricated Vertical Drain

NOTE 1: Two methods according to limit states are simultaneously presented in TCVN 11820: the method of partial factors designs following BS 6349/Eurocode, and the method of load and resistance factors designs following OCDI 2020.
NOTE 2: Consultant may use one of the two methods mentioned above or others but <u>shall not use a mixture of both methods in one project</u>.
NOTE 3: This casebook mainly introduces the method according to OCDI 2020 in TCVN 11820.

1-2. Reference Standards

The casebook complies with the following standards. TCVN compliant equations, tables, figures and their respective applicable TCVN parts are provided in the Technical Notes. Equations, tables, and figures that are not yet included in the TCVN and therefore refer to other standards are presented in the Technical Notes as "Reference."

(1) TCVN

- ✓ TCVN 11820-1: 2025, General Principles
- ✓ TCVN 11820-2: 2025, Loads and Actions
- ✓ TCVN 11820-3: 2019, Materials
- ✓ TCVN 11820-4-1: 2020, Foundations
- ✓ TCVN 11820-4-2: 2020, Soil Improvement
- ✓ TCVN 11820-5: 2021, Wharves
- ✓ TCVN 11820-6: 2023, Breakwater
- ✓ TCVN 11820-11: 2025, Concrete and Reinforced Concrete Structures
- ✓ TCVN 7888: 2014, Pretensioned Spun Concrete Piles
- ✓ TCVN 9152: 2012, Hydraulic Structure– Designing Process for Retaining Walls
- ✓ TCVN 9346: 2012, Concrete and reinforced concrete structures - Requirement of

protection from corrosion in marine environment
- ✓ TCVN 9386-1: 2012, Design of Structures for Earthquake Resistances
- ✓ TCVN 10304: 2024, Design of Pile Foundations
- ✓ TCCS 02: 2017, Breakwater - Design Requirement

(2) Others
- ✓ OCDI 2020: Technical Standards and Commentaries for Port and Harbour Facilities in Japan
- ✓ JSCE Guideline: 2012, Standard Specification for Concrete Structures, Design
- ✓ Cement Deep Mixing Association in Japan: 2022, CDM Manual
- ✓ PIANC MarCom WG 33: 2002, Guidelines for The Design of Fender Systems
- ✓ ASCE 61-14: 2014, Seismic Design of Piers and Wharves

1-3. Adherence to International Standards

The performance-based design approach, grounded in the WTO-TBT Agreement, is an international standard. Since Vietnam's accession to the WTO in 2007, this approach is required to be included in the national standard, TCVN. Section 2.4 in the TBT relates to international standardization, while section 2.8 relates to the performance-based approach.

> Section 2.4
> Where technical regulations are required and relevant international standards exist or their completion is imminent, Members shall use them, or the relevant parts of them, as a basis for their technical regulations….
> Section 2.8
> Wherever appropriate, Members shall specify technical regulations based on product requirements <u>in terms of performance rather than design or descriptive characteristics</u>.

Source: TBT Agreement

In terms of international standardization, ISO 2394 is widely acknowledged as the international standard. This standard employs the limit state design method and mandates setting appropriate reliability levels for each limit state to ensure safety. In essence, it requires a quantitative evaluation of safety. To adhere to this standard, it is essential to develop national design standards that quantitatively assess safety using a reliability design method based on probability.

> ISO 2394
> Structures and structural elements shall be designed, constructed and maintained in such a way that they are suited for their use during the design working life and in an economic way. In particular they shall, with appropriate degrees of reliability, fulfill the following requirements:
> - they shall perform adequately under all expected actions (serviceability limit state requirement);
> - they shall withstand extreme and/or frequently repeated actions occurring during their construction and anticipated use (ultimate limit state requirement);

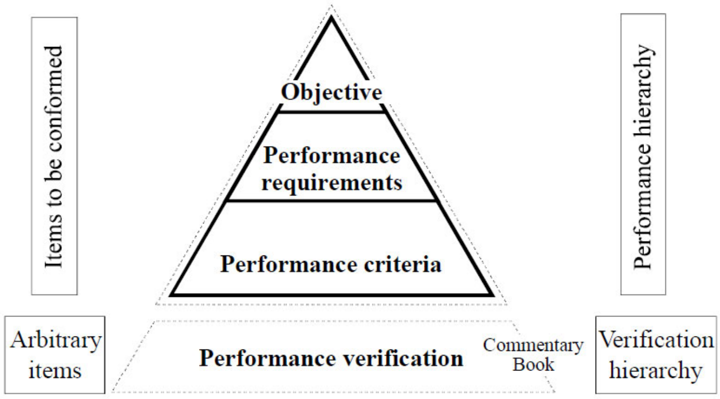
Source: ISO 2394

2. Performance-Based Design Approach

Figure 2.1 shows the hierarchy structure of performance and verification of a basic framework of the performance-based design of seaport facilities. In the figure, the "objective" is the reason why the facility concerned is needed, "performance requirements" is the performance of the facilities needed to achieve the objective plainly explained from the viewpoint of accountability, and the "performance criteria" are the technical explanation of a set of rules needed to verify the performance requirements. "Performance verification" is the process of confirming that performance criteria are met.

OCDI 2020 is introducing "objectives (purpose)", "performance requirements" and "performance criteria" for typical seaport facilities. The Ministerial Ordinance specifies "objectives (purpose)" and "performance requirements" of facilities according to the hierarchy shown in Figure 2.1. The Public Notice specifying requirements conforming to the Ministerial Ordinance specifies "performance criteria". If there is no Ministerial Ordinance and/or Public Notice in Vietnam yet, Consultant may need to propose them in consultation with the clients / investors and obtain approval before the project begins.

TCVN 11820 Part 1: 2025, Hinh. 2



Source: TCVN 11820-1-2025

Figure 2.1- Positioning of Performance Hierarchy and Performance Verification

Performance verification is a part of the design work and verifies whether the performance criteria are met. No specific method is mandated for conducting the verification. It is essentially left to the Consultant's discretion to select the appropriate method for performance verification, as well as to specify the acceptable safety margins and deformation limits, etc.

3. Objective (Purpose) of Seaport Project

The objective (purpose) of a project is the reason why related facilities are necessary, and it becomes the basis of the performance requirements of the related facilities. The purpose of a project is the minimum role that related projects should play from the perspective of the public interest. The example of the "Objective (Purpose)" in OCDI 2020 is referenced in Chapter 8 "Example of Performance-Based Design".

4. Performance Requirement

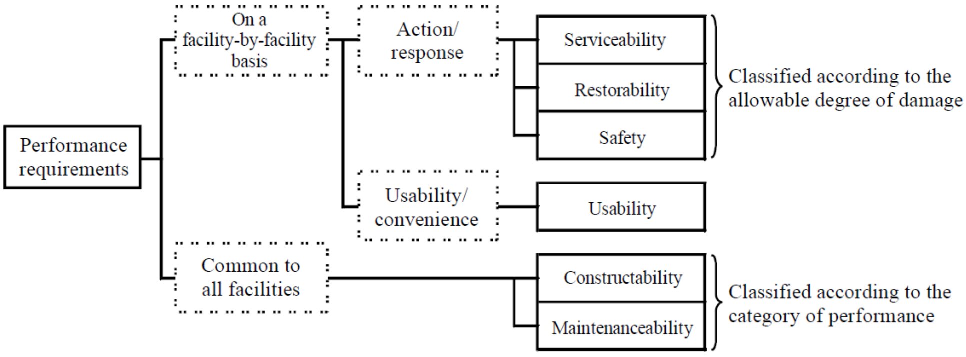
4-1. Positioning of Performance Requirements

Performance Requirements" means the necessary performance that the relevant facility must have to achieve its objectives and are the basis of the performance criteria of the related facility, taking into account their importance and the surrounding circumstances. The example of the "Performance Requirement" in OCDI 2020 is referenced in Chapter 8 "Example of Performance-Based Design".

4-2. Classification of Performance Requirements

Figure 4.1 shows the classification of performance requirements. The performance requirements are broadly divided into performance requirements specified for each facility (4-3 and 4-4) below, and performance requirements common to all facilities (4-5) below. Performance requirements specified by facilities are classified into performance related to the structural response of the facilities (serviceability, restorability, safety) and performance related to structural specifications (usability). Performance requirements common to all facilities are classified into constructability, maintainability, etc.

TCVN 11820 Part 1: 2025, Hinh 3



Source: TCVN 11820-1-2025

Figure 4.1- Classification of Performance Requirements

4-3. Serviceability, Restorability and Safety

Performance for the structural response of a facility is classified into: (1) serviceability, (2) restorability and (3) safety according to the allowable degree of damage and is defined as follows. The order of the allowable degree of damage is:
(3) safety > (2) restorability > (1) serviceability.

(1) Serviceability

The capability to use facilities without issues occurring. No damage occurs from the expected actions or damage remains at a level in which the required functions can be quickly and fully restored with only minor repairs.

(2) Restorability

The capability to continuously use facilities by making repairs within a technically possible and economically feasible range. Damage resulting from the expected actions remains at a level at which the required functions can be restored with minor repairs in a short period of time.

(3) Safety

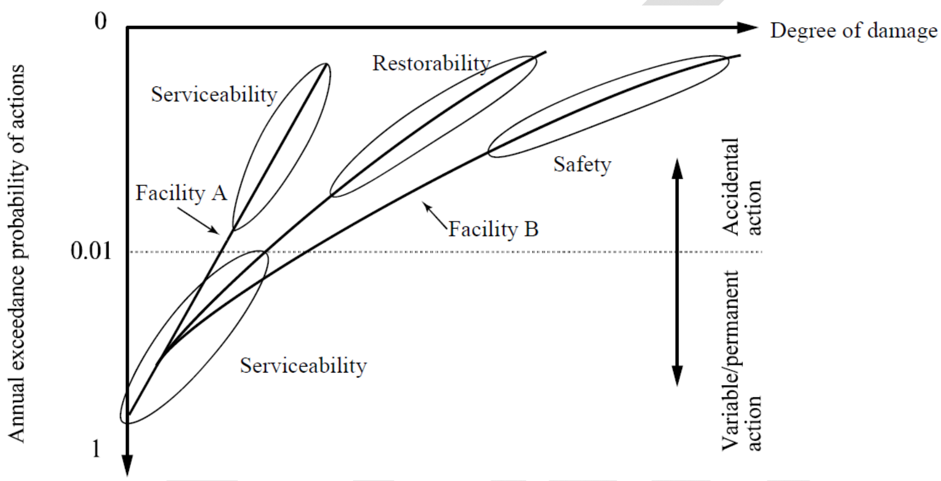
The capability to ensure the safety of human lives, etc. Damage resulting from the expected actions does not become fatal to the facilities and remains at a level that does not put the safety of human lives in jeopardy, etc. even if a certain level of damage occurs.

The basic principles of performance requirements related to structural responses for facilities are as follows.

1) For permanent and variable actions (with an annual exceedance probability of about 0.01 or more), the basic requirement is serviceability. It can be assumed that ensuring serviceability also ensures restorability and safety against permanent and variable actions.

2) For accidental actions (with an annual exceedance probability of about 0.01 or less), performance either of serviceability, restorability or safety may be selected according to the expected functions and significance of the facilities. Except for high earthquake-resistance facilities and facilities prepared for accidental incidents, performance against accidental actions is essentially not required. It does not, however, deny the necessity of verification against accidental actions judged by the persons or organizations responsible for performance verification among facility owners, etc.

In the above, the threshold of 0.01 for the annual exceedance probability discriminating against permanent actions and variable actions from accidental actions is determined just for convenience and serves as a guide when the design service life is in the standard range (approximately 50 years).



TCVN 11820 Part 1: 2025, Hinh 4

Source: TCVN 11820-1-2025

Figure 4.2- Conceptual Diagram of the Relationship Between Design Situations and Performance Requirements

Figure 4.2 shows the performance requirements concerning the structural response of facilities to different scenarios. The vertical axis represents the annual exceedance probability of actions, showing how frequently certain loads might surpass threshold levels within a year. The horizontal axis measures the degree of damage inflicted on facilities by these actions.

The curve in the diagram sets the acceptable performance standards for facilities under different scenarios. Facilities must be engineered to avoid severe damage from actions, whether variable or permanent, that have a high likelihood of occurrence as substantial damage in these scenarios is considered unacceptable.

Conversely, complete prevention of any damage from low-probability accidental actions is economically infeasible. Therefore, a small degree of damage under such circumstances is permissible. For example:

- ✓ Facility A is designed to maintain operational capability for critical functions, such as transporting emergency supplies immediately after a significant earthquake. This facility's design limits damage from accidental actions to minor levels, thus ensuring continued serviceability.
- ✓ Facility B focuses on maintaining minimal essential functions in the event of accidental actions. It allows for a greater degree of damage but is engineered to avoid catastrophic failures, thereby ensuring overall safety.

4-4. Usability

Usability is specified as performance requirements for structural specifications, etc. "Usability" means the capability that facilities shall have from the standpoint of the service and convenience of the facilities. Specifically, it means that the facilities are appropriately arranged, that the structural specifications (length, width, water depth, crest elevation, clearance limits, etc.) and harbor calmness, etc., satisfy the required values, and that they have the required ancillary facilities as appropriate.

4-5. Constructability and Maintainability

(1) Constructability

"Constructability" means the capability to perform construction by utilizing reliable and appropriate methods and ensuring safety of the works for a reasonable construction period. Constructability can be considered satisfied by complying with the construction outlined in Chapter 8 "Example of Performance-Based Design".

(2) Maintainability

"Maintainability" means the capability to continuously ensure the required performance for the facilities by repairing and reinforcing, etc., the deterioration and damage of facilities due to use and expected actions within a technically possible and economically feasible range. Maintainability can be considered satisfied by complying with the maintenance outlined in Chapter 8 "Example of Performance-Based Design".

4-6. Concrete Design

In Figure 4.1-, the performance requirements related to concrete design covered by TCVN Part 11 include "serviceability," "restorability," and "safety." However, since "restorability" is difficult to quantify, Part 11 primarily addresses "serviceability" and "safety," but also covers "durability," which specifies changes in performance over time.

5. Performance Criteria

Performance criteria are the specifications of verifications needed to satisfy performance requirements from a technical viewpoint. Meeting the performance criteria given here is hence considered as meeting the performance requirements. In constructing, improving, or maintaining a facility with a special structural type, or in assuming special design situation, performance criteria shall be properly specified by taking account of the performance criteria for similar structural types and the surrounding of the facilities concerned.

Examples of the "Performance Criteria" in OCDI 2020 are referenced in Chapter 8 "Example of Performance-Based Design".

6. Performance Verification

(1) Selection of Performance Verification Methods

Performance verification involves confirming that specific performance criteria are met. Even in Japan, there are no regulations in Ministerial Ordinances or Public Notices on how to perform this verification. Therefore, Consultants conducting performance verification must select and apply reliable methods.

(2) Types of Performance Verification Methods

Performance verification methods for structural responses to actions can be classified as follows and may be implemented individually or in combination to verify performance. Design Casebook Part 2 through Part 9 outline standard performance verification methods for different structural types based on design situations. However, Consultants can also apply non-standard performance verification methods at their own discretion and responsibility.

Whichever performance verification method is adopted, it shall be applied with careful consideration of the reliability of the entire design method. This assessment should include evaluations based on past examples of disasters, construction experiences, and similar historical data.

1) Reliability-Based Design Method

The reliability-based design method precisely defines the limit states of performance required for target structures and quantitatively verifies the likelihood of exceeding these limits, generally referred to as "Failure Probability," using probability theory techniques. This method categorizes into three design levels based on the verification approach for failure probability. The highest level, Level 3, evaluates using the structure's failure probability P_f. Level 2 employs a reliability index β, and the simplest, Level 1, utilizes partial factors.

Table 1.2- Three Levels of the Reliability-Based Design Method OCDI 2020 Part I, Chapter 1, Table 3.9.1

Design Level	Performance Verification Equation	Evaluation Parameter
Level 3 reliability-based design method	$P_{fr} \geq P_f$	Failure Probability
Level 2 reliability-based design method	$\beta_T \leq \beta$	Reliability Index
Level 1 reliability-based design method	$R_d \geq S_d$	Design value

Source: OCDI 2020

In performance verification through reliability design methods, it is crucial to accurately evaluate the uncertainty associated with various design parameters such as actions and strengths, design models, and other factors related to the performance of the facilities. Additionally, it is essential to appropriately set the target safety level, which includes target failure probabilities or reliability indices.

For performance verification using the Level 1 reliability-based design method (partial factors method), it is necessary to accurately assess the uncertainty of design parameters, design models, and other relevant factors. It is also important to correctly set the partial factors that reflect the target failure probability or reliability indices.

A lack of understanding regarding the uncertainty of design parameters and models for the facilities to be designed can compromise the appropriateness of using a performance verification method based on the reliability-based design method. In situations where these uncertainties are not adequately addressed, it is advisable to consider alternative performance verification methods as outlined below.

2) Methods Based on Numerical Analysis

Methods based on numerical analysis, such as the Finite Element Method (FEM) and Finite Difference Method (FDM), calculate response values (stress, deformation, etc.) for target structures subjected to various actions. These methods quantitatively ensure that the response values do not exceed the defined limit states (stress, deformation, etc.) where the performance requirements of the target structure are not met.

In performance verification using numerical analysis methods, it is essential to assess the reasonableness and applicability of the method from various perspectives. These include comparisons to exact analytical solutions, historical behaviors of actual structures, and the reproducibility of test results. Such evaluations are crucial to judiciously determining the reliability of the method concerned.

3) Model Test Methods or In-Situ Test Methods

The model test method evaluates crucial aspects of structural design such as response values to actions, load characteristics, and destruction forms of the target structure. This is achieved through experiments using a reduced model, which may include hydraulic model experiments, centrifugal load model experiments, shaking table model experiments, etc. These experiments verify the performance requirements for the target structures.

In contrast, in-situ test methods verify performance using a full-scale model of the facility being designed, rather than a reduced model.

When utilizing either model test methods or in-situ test methods for performance verification, it is essential to carefully evaluate the performance of the facilities concerned. This evaluation must take into account the differences in response between the models and actual structures, as well as the preconditions, applicable limits, and the accuracy of the experiments or tests conducted.

4) Method Based on Past Experiences

Methods based on past experiences, such as the safety factor method and allowable stress method, are well-established with numerous historical applications.

However, unlike the reliability-based design method described earlier, methods based on past experiences do not provide a quantitative evaluation of the likelihood of exceeding the limit state. It is also important to note that the frequent use of these methods does not necessarily guarantee their reliability.

7. Supplementary Explanation

7-1. Design Service Life of Seaport Project

The design service life of a seaport project, or any of its construction components, is established based on the classification of construction, sustainability, and fire safety standards applicable to the project or its components. To estimate the design service life of each project or component within a seaport project, it is useful to refer to the methodologies used in international standards for similar assessments.

When planning for a long design service life, several factors need careful consideration:

- ✓ The structural load may increase over time.
- ✓ It is important to choose materials with a longer lifespan that also match the project's duration.
- ✓ A maintenance program aligned with the design service life specifications is essential.

The determination of the design service life for a seaport project involves a collaborative decision-making process between the Investor and the Consultant.

7-2. Annual Exceedance Probability

(1) Annual Exceedance Probability and Return Period

"Annual Exceedance Probability" means the probability that an event of an assumed magnitude or higher occurs once or more in a year. "Return period" means a mean time interval (expressed in years) between events occurring at a certain level of magnitude or higher and expressed in the inverse number of an annual exceedance probability.

(2) Encounter Probability

"Encounter Probability" means the probability that the facilities concerned encounter an event that is larger than the corresponding event within a certain return period during its design service life. The encounter probability can be obtained using the Equation (7.1).

$$E_1 = 1 - (1 - 1/T_1)^{L_1} \quad (7.1)$$

TCVN 11820 Part 1: 2025, Equation (1)

Where:

E_1 : encounter probability
T_1 : return period (year)
L_1 : design service life (year)

7-3. Classification of Actions

Actions are classified into 1) permanent actions, 2) variable actions and 3) accidental actions mainly according to the size of time variations and the social risks that need to be addressed. Table 7.1 shows examples of classified dominating actions to be considered in the performance verification of seaport facilities.

(1) Permanent Actions

Actions assumed to apply continuously throughout the design service life of a structure. The time variation of the action is less than the average value or tends to increase or decrease monotonically and steadily within the design service life until the variation reaches a certain limiting value.

(2) Variable Actions

The characteristic values are given probabilistically, and the variations within the design service are multidirectional and cannot be ignored compared to the average value.

(3) Accidental Actions

Actions that are difficult to predict probabilistically or actions whose annual probabilities of exceedance are smaller than those of variable actions, but whose characteristic values are extremely large that they cannot be considered socially negligible.

In the performance verification of seaport facilities, it is essential to appropriately consider the actions on the facility. The return period of the actions considered should be set appropriately, taking into account the characteristics of each action, the importance of the structure, and the design service life, among other factors.

Table 7.1- Classification of Dominating Actions

TCVN 11820 Part 1: 2025, Bang 1

	Action	Required Performance
Permanent actions	Self-weight, earth pressure, environmental actions such as temperature stress, corrosion, freezing and thawing, etc.	Serviceability
Variable actions	Waves, wind, water level (tide level), surcharge of cargo or vehicles, action due to ship berthing/traction,	Serviceability

	level 1 earthquake ground motion, etc.	
Accidental actions	Collision with a ship or other object except when berthing, fire, tsunami, level 2 earthquake ground motion, accidental waves, etc.	Serviceability, Restorability, Safety

Source: Modified from TCVN 11820-1-2025

(4) Level 1 Earthquake

Level 1 earthquake motions that are supposed to occur with a high possibility of occurrence during the design working life of facilities when considering the relationship between the return period of the earthquake motion and the design service life of the facilities. In OCDI 2020, PIANC guideline, etc., the standard return period for Level 1 earthquake motion is 75 years, but Vietnam has a history of designing for earthquake motion with a return period of 500 years in accordance with TCVN 9386-1:2012. This can be understood as a safe approach until earthquake data is accumulated and analyzed in the future. Therefore, adjustments to earthquake motion and related factors will have to be carried out within the responsibility of each consultant.

(5) Level 2 Earthquake

In OCDI 2020, level 2 earthquake ground motion means the strongest earthquake ground motions that are supposed to occur at the place where the facilities are constructed.

In setting Level 2 earthquake ground motions, scenario earthquakes shall be selected from the following six types of earthquakes, taking into account the peak amplitude, frequency content and duration of resultant ground motions and their potential effects on structures. The selection of the scenario earthquakes shall be based on a comprehensive evaluation of the survey results by government agencies, and of regional disaster prevention plans.

i) Recurrence of past earthquakes that caused huge damage
ii) Earthquakes caused by active faults
iii) Other earthquakes expected from seismological and/or geological point of view
iv) Scenario earthquakes hypothesized by government agencies
v) Scenario earthquakes hypothesized by local governments
vi) M6.5 direct earthquake

As reference, in PIANC guideline, if the design working life is 50 years, the return period for Level 2 earthquake is 475 years.

In regions of low seismicity, Level 1 might be relatively small and of minor engineering significance. In this case, only Level 2 is used along with an appropriately specified criteria. Here, it is assumed that satisfactory performance for Level 2 will implicitly ensure required performance under the anticipated Level 1 motion. It may be noted that this single level approach is somewhat similar to conventional design practice; it differs only in that a structure is designed in accordance with the designated acceptable level of damage.

7-4. Dominating Actions and Secondary Actions

The passage discusses how to manage the combination of dominating and secondary actions in engineering designs, emphasizing the application of Turkstra's rule. This rule is suitable when the chance of simultaneous occurrence of such actions is low, suggesting the use of characteristic values for secondary actions that are more likely to occur. However, in scenarios where actions are highly correlated, such as in offshore wind power facilities with both wave and wind actions, Turkstra's rule may be inapplicable due to the risk of simultaneous occurrence, potentially leading to under or overdesigning. Instead, it is recommended to adjust the characteristic values to best match the most probable conditions, using specific referenced methods to achieve an optimal and safe design.

7-5. Design Situation

When conducting performance verification, it is essential to classify "Design Situations" based on the nature of the dominating actions. These are categorized as follows:

- ✓ Permanent Design Situation: Dominated by permanent actions, which are consistent and continuous throughout the lifecycle of the structure.
- ✓ Variable Design Situation: Dominated by variable actions, which can change over time due to environmental factors or operational conditions.
- ✓ Accidental Design Situation: Dominated by accidental actions, which are unexpected and can significantly action the structure, often considered in safety assessments and risk management.

This classification helps in tailoring the assessment approach to address the most critical actions on the structure's performance and safety.

7-6. Setting of Actions

(1) Setting of Actions

In the performance verification, it is critical to consider the designed life and the specific performance requirements. It is also essential to accurately set the magnitude of actions and other factors that the facility will encounter. This setting must comprehensively account for various conditions, including natural environmental factors. Additionally, as required, consideration should be given to actions during the design service life that are influenced by factors such as estuarine hydraulics, littoral drift, ground settlement, ground liquefaction, and other environmental actions.

(2) Setting of Combination of Actions

A "combination of actions" refers to the types and amounts of actions that are simultaneously considered during performance verification. When setting this combination, it is essential to account for the design service life of the facility and its performance requirements adequately. Additionally, the interplay between dominating and subordinate actions must be carefully considered.

For instances of combinations of dominating and subordinate actions as assumed in the performance criteria, reference is made to the specific cases detailed in Chapter 2 “Fundamental Items in Design”. When determining the combination of actions, it is permissible to assume that subordinate actions, which have a relatively high annual exceedance probability and occur frequently within the design service life, are less critical if the likelihood of their simultaneous occurrence with dominating actions is low.

7-7. Materials

(1) Selection of Materials

The selection of materials needs to properly take account of their quality and durability. Major materials include steel products, concrete, bituminous materials, stone, wood, various metallic materials, plastics, rubber, coating materials, injectable materials, landfill materials (including wastes), and recyclable resource materials (slag, coal ash, crushed concrete, dredged soil, asphalt concrete modules, etc.).

(2) Physical Properties of Materials

"Physical Properties of Materials" means material properties such as strength, weight per unit volume, friction coefficient and others. The physical properties of materials need to be set properly based on the available standards or quality data obtained using other reliable tests. The setting of the physical properties of materials and cross-sectional specifications requires proper consideration of material degradation and others due to environmental actions.

7-8. Characteristic Values

"Characteristic values" means values indicating characteristics of actions or materials quantitatively considered in design. When setting the characteristic values of the design factor, please refer to Chapter 9, TCVN11820 Part 3 and OCDI 2020.

This casebook utilizes characteristic values classified as below:

- ✓ Various standard values (e.g. yield strength of steel materials)
- ✓ Expected values (design waves, level 1 earthquake motion, etc.)
- ✓ Corrected mean values to be set by taking account of variation in survey data and statistical errors of estimates of mean values (shear strength of ground, etc.)
- ✓ Standard setting utilized as in the past (weight per unit volume of plain concrete, design berthing velocity, etc.)
- ✓ Values calculated with empiric of theoretical equations (wave force equations, etc.)

7-9. Performance Verification Equation

Performance verification using the partial factor method in this casebook can be conducted by utilizing Equations (7.2), (7.3) and (7.4). The performance verification equation shown below is based on a partial factor method using a load and resistance factor design method.

$$m\left(\gamma_i \frac{S_d}{R_d}\right) \le 1.0 \qquad (7.2)$$

$$S_d = f(\gamma_{S1}S_{1k}, \cdots, \gamma_{Sn}S_{nk}) = f(\gamma_{S1}S_{1k}(x_{1k}\cdots x_{pk}), \cdots, \gamma_{Sn}S_{nk}(x_{1k}\cdots x_{pk})) \qquad (7.3)$$

$$R_d = g(\gamma_{R1}R_{1k}, \cdots, \gamma_{Rn}R_{nk}) = g(\gamma_{R1}R_{1k}(x_{1k}\cdots x_{pk}), \cdots, \gamma_{Rn}R_{nk}(x_{1k}\cdots x_{pk})) \qquad (7.4)$$

TCVN 11820 Part 1: 2025, Equation (5), (6), (7)

Where:

S_d	:	design value of response value
R_d	:	design value of limit value
γ_i	:	factor to take account of the significance of the structure, social impact when the limit state is so on (structural factor). Unless otherwise specified, γ_i =1.0 and is not shown in this casebook.
m	:	adjustment factor
S_{jk}	:	characteristic value of action effect j (j=1..n)
γ_{sj}	:	partial factor to multiply to the characteristic value S_{jk} of action effect j
S_j ()	:	equation to calculate the characteristic value S_{jk} of action effect j

R_{jk} : characteristic value of resistance(strength) j (j=1..m)
γ_{Rj} : partial factor to multiply to the characteristic value R_{jk} of resistance (strength) j
R_j () : equation to calculate the characteristic value R_{jk} of resistance (strength) j
x_{jk} : characteristic value of design factor x_j (j=1..p)

Performance verification using the partial factor method in this casebook is a method to verify the performance of structures by confirming the ratio of design value of the response value (stress, cross-sectional force, total action value, displacement, etc.) which occurs due to actions made to the structure and design value of the limit value (yield strength, cross-sectional strength, total resistance value, allowable displacement, etc.) based on the resistance (strength) of the structure (hereinafter called "Ratio of Strength against Action" multiplied by the structure factor and the adjustment factor is 1.0 or less, as shown in the above equation.

(3) Partial Factor

The partial factor in this casebook is the value calculated using a statistical analysis or reliable method as a factor to multiply the characteristic value of action effect or resistance (including characteristic value of design factor) to ensure the target performance of the objective structures. A partial factor calculated with statistical analysis means a factor calculated with calibration using a reliability analysis. Unless otherwise specified, the partial factor concerned shows that is has been calculated with a statistical analysis if the values of partial factors (γ_{sj}, γ_{Rj}) in Equations (7.3) and (7.4) are not 1.0 in this casebook. In this case, while no adjustment factor shown in (4) below is necessary in principle, performance verification may be carried out using the adjustment factor of 1.0 for the sake of convenience based on Equation (7.4).

(4) Adjustment Factor

"Methods Based on Past Experiences" (well-proven methods with many examples of past applications, such as the safety factor method, allowable stress method used as in the past) may also be deemed as a reliable method. In this case, verification may be carried out using an adjustment factor by setting all partial factors to 1.0 for the sake of convenience in order to clearly indicate that it differs from verification using a partial factor calculated with statistical analysis. The adjustment factor is a factor for adjustment to have an equivalent structural cross-section to the safety level specified in "Methods Based on Past Experiences" and corresponds to the allowable safety factor of an existing safety factor method or allowable stress method.

7-10. Relationship to Feasibility Studies

(1) Positioning of Feasibility Studies

Feasibility Study assesses the objective (purpose) by providing a systematic and objective evaluation of the project's potential success. It assesses various aspects such as economic viability, environmental impact, market demand, and technical solutions, ensuring that the project aligns with public interest and is realistically achievable and sustainably beneficial.

(2) Performance-based Design Process

Performance-based design is the process of defining and detailing the necessary performance to meet specific project requirements. It starts with identifying the "purpose," specifies the "performance requirements," sets "performance criteria," and ultimately checks through "performance verification" to ensure the design meets these requirements.

(3) Relationship

1) Foundation Setting

Information obtained from the feasibility study (project viability, cost estimates, timelines, risk assessments) serves as critical foundations for the performance-based design process. The results of the feasibility analysis influence the setting of performance requirements and particularly help shape the technical requirements and cost constraints of the project.

2) Iterative Relationship

As the performance-based design progresses, new challenges or needs for improvement may emerge. In such cases, it might be necessary to update the feasibility study or conduct new investigations. Insights gained at each stage of performance design may prompt a re-evaluation of the project's feasibility.

8. Example of Performance-Based Design

8-1. General

Items to be generally considered in design facilities are listed below. Structural cross-sections used materials and other items thought to be most appropriate as a whole are determined by properly setting and taking into consideration these conditions so that the performance requirements for the target facilities are continually met throughout the design service life. These items should carefully be set as they influence each other.

Table 8.1 shows a list of general design conditions necessary for the design of typical port facilities (breakwaters, revetments and mooring facilities).

- ✓ Purpose of Installation of Facilities
- ✓ Design service life
- ✓ Performance Requirements
- ✓ Performance Criteria
- ✓ Performance Verification Method
- ✓ Planning Conditions
- ✓ Usage Conditions
- ✓ Natural Environmental Conditions
- ✓ Material Conditions
- ✓ Construction Conditions
- ✓ Maintenance Conditions
- ✓ Consideration of Events Exceeding Design Conditions
- ✓ Consideration of Environment
- ✓ Economic Efficiency

8-2. Purpose of Installation of Facilities

OCDI 2020 outlines the purpose of each type of facility as follows:

Protective Facilities for Harbors

The purpose of protective facilities for harbors includes ensuring harbor calmness, maintaining water depths, preventing beach erosion, controlling the rise of water levels in the areas using protective facilities during storm surges, diminishing invading waves by tsunamis and protecting harbor facilities and hinterland from waves, storm surges,

OCDI 2020 Part III, Chapter 4, 1 General

and tsunamis. In the deliberation of the measures against tsunamis and storm surges for harbors, it is necessary to appropriately set the targets of protecting harbors according to the magnitude and occurrence frequency of tsunamis and storm surges, after considering sufficiently their impacts on human lives, property and socioeconomic activities.
Recently, there has been demand for water intimate amenity functions enabling people to enjoy the proximity to the marine environment and play with water. In general, many protective facilities for harbors are provided with additional facilities to fulfill some of these functions. Accordingly, the performance verification shall consider the usability enabling each protective facility for harbors to fulfill these purposes.

Mooring Facilities
The purpose of installing mooring facilities is to ensure the safety and smoothness of the mooring and landing operation of ships, the embarkation and disembarkation of passengers, and the loading and unloading of cargo.

OCDI 2020 Part III, Chapter 5, 1 General

8-3. Design Service Life

(1) Consideration

The design service life of port facilities is "the period to be properly set in the design stage of facilities as the period during which the facilities concerned continue to meet their performance requirements." This design service life is generally set using comprehensive judgement by considering the purpose of installation and significance of the facilities concerned, usage conditions such as the relationship with the surrounding usage conditions (e.g., other facilities), and how the length of the set design service life affects the selection of materials considering the setting of actions and environmental actions, construction cost and other factors. The service life is judged in the design stage to be able to surely maintain the functions and performance required during the facility's design service life if the originally set maintenance policy is complied with. It is desirable to properly set the design service life by considering the various types defined below.

✓ Physical working period

Physical working period refers to the number of years after which facilities will not be able to maintain the required performance because of actions such as corrosion and weathering to members and materials composing the facilities.

✓ Functional working period

Functional working period refers to the number of years after which facilities will not be used because of issues regarding their function such as insufficient water depth at basins due to increases in ship size.

✓ Economical working period

Economical working period refers to the number of years after which the facilities concerned will lose out economically to other facilities unless improvements are made.

✓ Working period from the viewpoint of social programs

This refers to the number of years after which new plans will replace originally targeted functions, or other functions will be demanded.

Table 8.1- List of General Design Conditions Necessary for the Design of Typical Port Facilities (Breakwaters, Revetments and Mooring Facilities)

TCVN 11820 Part 1: 2025, Bang 2

	Protective facilities for harbor		Mooring facility	Remarks
	Breakwaters	Revetments		
Planning conditions				
(1) Purpose of facilities	○	○	○	
(2) Performance requirements	○	○	○	
Usage conditions				
(1) Performance criteria	○	○	○	
(2) Project process	○	○	○	
(3) Design service life	○	○	○	
(4) Extension of planning	○	○	○	
(5) Planning crown height	○	○	○	
(6) Planning depth, design water depth	○	○	○	
(7) Datum level	○	○	○	T.P., A.P., Y.P., etc.
(8) Width and gradient of the apron	−	−	○	
(9) Design ship	−	−	○	
(10) Berthing condition of the design ship	−	−	○	
(11) Tractive force	−	−	○	
(12) Dead weight	△	○	○	Cargo handling equipment
(13) Other	△	△	△	Amenity-oriented functions, consideration for safe navigation of small crafts, etc.
Natural environmental conditions				
(1) Tide level conditions	○	○	○	Abnormal tide level
(2) Residual water level conditions	−	○	○	
(3) Wave conditions	○	○	△	
(4) Ground conditions	○	○	○	
(5) Earthquake conditions	○	○	○	
(6) Tsunami conditions	△	△	△	
(7) Other	△	△	△	Wind, air temperature, flow of sea water, snowfall, mist, etc.
Material conditions				
(1) Used materials	○	○	○	New materials, new members, procurement conditions (carry-in route, supply quantity), reuse of members, etc.
(2) Corrosion control conditions, corrosion rate	○	○	○	
(3) Other	△	△	△	Friction coefficient, etc.
Construction conditions, etc.				
(1) Coordinate	○	○	○	
(2) Construction conditions	○	○	○	Structure fabrication conditions, constraints from neighboring facilities (navigation channels, mooring facilities, airports, bridges, overhead wires, submarine cables, etc.), hazardous cargo, etc.
(3) Other	○	○	○	Construction period, construction working rate, construction method, working ship machines, construction accuracy, etc.
Maintenance conditions				
(1) Inspection and diagnosis plans	○	○	○	Inspection facilities, measurement instruments, etc.
(2) Other	△	△	△	Usage conditions
Consideration for environment				
(1) Consideration for environment	△	△	△	Structures for cohabitation with living things Consideration for water quality, landscape, sediment, air quality, etc.
Consideration for improvement design				
(1) Purpose of improvement	○	○	○	Change of use, change of performance, extension of the working life, etc.

Source: TCVN 11820-1-2025

(2) Examples of Design Service Life

Examples of design service life are shown in Table 8.2 to Table 8.4.

Table 8.2- National Classification of Design Working Life (ISO 2394: 1998)

ISO 2394: 1998 TCVN 11820 Part 1: 2025, Appendix B

Type	Design life (years)	Construction type
1	1 to 5	Temporary works (for construction; import and export of materials...)
2	25	Some structures in the project can be replaced or repaired (such as beams, face plates, bridge abutments, bridge bearings...)
3	50	Building; Public works and other structures…
4	≥100	Permanent works (Monuments; special important structures; Large-scale bridges...)

Source: ISO 2394-1998, TCVN 11820-1-2025

Table 8.3- Design Service Life and Return Periods of Variable Actions for Typical Facilities (OCDI 2020)

OCDI 2020, Part 1, Chapter 2, Table 2.3.3

Case example	Design working life	Return period of main variable actions
Breakwater	50 years	- Level 1 earthquake ground motion: 75 years - Design wave: 50 years
Tsunami Breakwater	100 years	- Level 1 earthquake ground motion: 150 years - Design wave: 100 years
Mooring facility	50 years	- Level 1 earthquake ground motion: 75 years
Immersed tunnel	100 years	- Level 1 earthquake ground motion: 150 years
Bridge	100 years	- Level 1 earthquake ground motion: 150 years

Source: OCDI 2020

Table 8.4- Indicative Design Working Life Categories for Marine Work (BS 6349-1-1: 2013)

BS 6349-1-1: 2013, Table 1 TCVN 11820 Part 1: 2025, Appendix B

Design life level	Indicates design life (years)	Examples
1	10	Temporary structures*
2	10 to 25	Structural components designed to be replaceable in a structure or building have a longer design service life.
3	15 to 30	Specialized structures for non-renewable natural resources, petrochemical or similar industrial or commercial applications (e.g. piled docks, moorings and docking piers, Ro-Ro bridges) .
4	50	Common port infrastructure for industrial and commercial ports includes reclamation, shore protection, breakwaters, and wharf walls.
5	100	Common port infrastructure includes breakwaters for ports with important economic or national strategic value. Regional flood protection infrastructure or shore correction infrastructure.
* Các kết cấu hay bộ phận kết cấu có thể tháo dỡ với quan điểm sử dụng lại cần xem xét như không phải là công trình tạm.		
* Structures or structural parts that can be dismantled with a view to reuse should be considered as not temporary works.		

Source: BS 6349-1-1-2013, TCVN 11820-1-2025

(3) Setting the Action Characteristic Value and Design Service Life

When the design service life is set to be much longer than the standard period, greater action is usually adopted as a characteristic value by setting a return period necessary for calculating an action characteristic value longer than the standard (the annual exceedance probability becomes smaller). In this case, an action return period is often set so that the probability of encountering (encounter probability) an action greater than a set action becomes the same as that of the standard design during the design service life of the facilities.

On the other hand, it is undesirable from the viewpoint of the public interest to set a design service life significantly shorter than the standard life, and correspondingly, an action return period shorter than the standard period (annual exceedance probability becomes greater), in addition to adopting a smaller action as a characteristic value and should be avoided. For example, when breakwater or mooring facilities that support logistics at a port collapse in a minor earthquake with less than level 1 earthquake ground motion or small wave force with less than the standard return period, the logistics at the entire port will decline significantly and the economic activities around the port will be largely affected even if the collapsed facilities are just a part of the entire port.

8-4. Performance Requirements and Performance Criteria

(1) Setting Performance Requirements and Performance Criteria

In the performance design system, it is crucial to establish clear performance requirements. This involves defining performance criteria indices which are used to conduct specific verifications based on the set performance requirements, including their limit values and the methods for verifying these indices.

The process starts by determining the required level of function and performance for target facilities under various scenarios. This includes estimating the operational lifespan of the facilities, the types, sizes, and combinations of actions they will encounter, and the frequency of these actions during that period. It is also essential to assess the potential impact of any damage to the facilities on the surrounding environment and how much this impact should be mitigated.

To ensure that the performance requirements are met, the appropriate indices and their limit values must be established, along with selecting suitable verification methods. Moreover, even during the construction phase, it is necessary to evaluate how these elements should be assessed. This evaluation should consider maintaining a balance between economic efficiency, environmental protection, and aesthetic integration into the landscape, all within the constraints of the construction timeline leading up to the start of operational life.

(2) Design focused on "Performance"

This casebook details the setting of actions under standard design conditions, outlines performance criteria, introduces standard performance verification methods, and sets limit values specifically for port structures in Japan. However, the essence of performance design extends beyond this, emphasizing a comprehensive assessment as highlighted in section (1).

In other words, it is always required to check the following items as example: 1) whether assumed design situations in past are really sufficient, 2) whether an index of the performance criteria is really appropriate, and 3) whether a more appropriate method, such as switching from the safety factor method to the reliability-based design method, can be introduced so that the limit state is confirmed when verifying indices. In particular, the aforementioned careful research will be necessary when introducing new construction methods, structural types, materials and so on because no existing standards or manuals can be followed. The framework of performance design also has a role in preventing oversights because an action that causes no issues with previous structural types can have a substantial impact on a new structural type in unexpected ways.

In regard to performance requirements, it is desirable to confirm if new performance needs to be added or set according to the purpose of the facilities concerned, social situation or other factors in the design stage. For example, as part of efforts toward creating a sustainable society, it is also possible to introduce a framework to set performance requirements to suppress the impact on the environment in construction work and to quantitatively verify the amount of CO_2 emission as performance criteria.

8-5. Examples of Performance Requirements and Performance Criteria

OCDI 2020 outlines the performance requirements and performance criteria of each type of facility as follows:

(1) Common Items for Breakwaters (Example)

1) Performance Requirement

a) The performance requirements for breakwaters shall be as prescribed in the following items depending on the structure type for the purpose of securing safe navigation, anchorage and mooring of ships, ensuring smooth cargo handling, and preventing damage to buildings, structures, and other facilities in the port by maintaining the calmness in the harbor water area. OCDI 2020 Part III, Chapter 3, p. 920

- ✓ Breakwater shall satisfy the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism so as to enable the reduction of the height of waves intruding into the harbor.
- ✓ Damage to breakwaters, etc. due to self-weight, variable waves, Level 1 earthquake ground motion, etc. shall not impair the functions of the breakwaters and not adversely affect the continuous use of the breakwaters.

b) In addition to the provisions of the preceding paragraph, the performance requirements for the breakwaters in the following items shall be specified respectively in those items:

- ✓ Performance requirements for breakwaters which are required to protect the hinterland of the breakwaters from storm surges or design tsunamis" shall be such that the breakwaters satisfy the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism so as to enable the appropriate reduction of the rise in water level and flow velocity due to storm surges or design tsunamis in the harbour.
- ✓ Performance requirements for breakwaters for the purpose of environmental conservation" shall be such that the breakwaters satisfy the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism so as to contribute to conservation of the environment of ports without impairing the original functions of the breakwaters.
- ✓ Performance requirements for breakwaters to be utilized by an unspecified large number of people" shall be such that the breakwaters satisfy the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism so as to

ensure the safety of the users of the breakwaters.

- ✓ Performance requirements for breakwaters in the place where there is a risk of serious impact on human lives, property, or socioeconomic activity if they are stricken by disaster" shall be such that damage to breakwaters, etc. due to design tsunamis, accidental waves, Level 2 earthquake ground motions, etc. does not have a serious impact on the structural stability of the breakwaters in consideration of the structure type even in cases where functions of the breakwaters are impaired. Provided, however, that in cases where performance requirements for the breakwaters which are required to protect the hinterland of the breakwaters from design tsunamis, the damage due to design tsunamis, Level 2 earthquake ground motion, etc. shall not adversely affect restoration through minor repair works of the functions of the breakwaters.

c) In addition to the provisions of the preceding two paragraphs, the performance requirements for breakwaters in the place where there is a risk of serious impact on human lives, property, or socioeconomic activity, shall be such that a serious impact on the structural stability of the breakwaters caused by damage, etc. due to the actions of the tsunamis, etc. even in cases where tsunami with intensity exceeding the design tsunami occurs at the place where the breakwaters are located, shall be delayed as much as possible in consideration of the structure type.

2) Performance Criteria

OCDI 2020 Part III, Chapter 3, pp. 920-921

a) The performance criteria common to breakwaters shall be as prescribed respectively in the following items:

- ✓ Breakwaters shall be located appropriately so as to satisfy the harbor calmness indicated in the following frame and shall have the dimensions which enable the transmitted wave height to be equal to or less than the allowable level.

> Basins which are provided for use in the anchorage or mooring of ships in front of quay walls, mooring piles, piers and floating piers shall in principle secure harbor calmness, enabling the working rate of cargo handling operation at equal to or greater than 97.5% in terms of time throughout the year. Provided, however, that this rate shall not be applied to basins where the mode of utilization of mooring facilities or the water areas in front of them are regarded as special.

- ✓ Breakwaters having wave-absorbing structures shall have the dimensions which enable full performance of the required wave-absorbing function.

b) In addition to the provisions of the preceding paragraph, the performance criteria for the breakwaters specified in the following items shall be as prescribed respectively in those items:

- ✓ Performance criteria for breakwaters which are required to protect the hinterland from storm surges" shall be such that the breakwaters are located appropriately so as to reduce the rise of water level and flow velocity in the harbor due to storm surges and have the dimensions necessary for functions of breakwaters.
- ✓ Performance criteria for breakwaters required to protect the hinterland from

design tsunamis" shall be such that the breakwaters are located appropriately so as to reduce the rise of water level and flow velocity in the harbor due to design tsunamis and have the dimensions necessary for functions of breakwaters.

- ✓ Performance criteria for breakwaters for the purpose of environmental conservation" shall be such that the breakwaters shall have the necessary dimensions so that they can contribute to conservation of the environment of ports without impairing their original functions in consideration of the environmental conditions, etc. to which the facilities are subjected.
- ✓ Performance criteria for breakwaters utilized by an unspecified large number of people" shall be such that breakwaters have the dimensions necessary to secure the safety of users in consideration of the environmental conditions, usage conditions, etc. to which the facilities are subjected.
- ✓ Performance criteria for breakwaters in the place where there is a risk of serious impact on human lives, property, or socioeconomic activity by the damage to the breakwaters" shall be such that the degree of damage under the accidental situation, in which the dominating actions are design tsunamis, accidental waves, or Level 2 earthquake ground motions, is equal to or less than the threshold level in consideration of the performance requirements.

3) Interpretation of the Performance Criteria

a) Performance Criteria Common to Breakwaters

OCDI 2020 Part III, Chapter 3, pp. 921-924

- ✓ Breakwaters shall have serviceability as their common performance requirement. The term "serviceability" refers to that the harbor calmness in the ports is secured.
- ✓ The dimensions for securing harbor calmness shall indicate a structure including shape and crown height that affects the transmitted wave height or transmission ratio of waves. In setting the crown height in the performance verifications of breakwaters, appropriate consideration shall be given to the effect of ground settlement.
- ✓ The allowable transmitted wave height is the limit value of the wave height of waves transmitted from outside the harbor to inside the harbor over the breakwaters. Provided, however, that the index of the limit value in the performance verifications is not limited to the transmitted wave height but also includes cases in which the wave transmission ratio is used.
- ✓ In the performance verifications of breakwaters, the allowable transmitted wave height or wave transmission ratio shall be set appropriately to secure harbor calmness. Furthermore, the allowable transmitted wave height or wave transmission ratio shall generally be calculated considering the type of structure and crown height of the breakwater.

b) Performance Criteria for Specific Breakwaters

- ✓ Storm surge protection breakwaters
- ✓ Tsunami protection breakwaters
- ✓ Symbiosis breakwaters
- ✓ Amenity-oriented breakwaters
- ✓ Breakwaters of facilities prepared for accidental incidents

Please refer to OCDI 2020 for the interpretation of performance criteria for these five special breakwaters.

(2) Gravity Type Breakwater and Sloping Breakwater (Example)

1) Performance Criteria

a) The performance criteria for gravity-type breakwaters are prescribed respectively in the following items:

- ✓ Under the permanent state, in which the dominating action is self-weight, the risk of slip failure of ground shall be equal to or less than the threshold level.
- ✓ Under the variable situation, in which the dominating actions are variable waves and Level 1 earthquake ground motion, the risk of failures due to the sliding and overturning of breakwater body and the insufficient bearing capacity of the foundation ground shall be equal to or less than the threshold level.

OCDI 2020 Part III, Chapter 3, p. 930

2) Interpretation of the Performance Criteria

- ✓ The required performance of gravity-type breakwaters under the permanent action situation in which the dominant action is self-weight and the variable action situation in which the dominant actions are variable waves and Level 1 earthquake ground motions shall focus on usability. The performance verification items and standard indexes to determine the limit values with respect to the actions shall be those shown in Table 8.5, except those for sloping breakwaters, which are separately shown in Table 8.6.

OCDI 2020 Part III, Chapter 3, pp. 930-931

Table 8.5- Performance Verification Items and Standard Indexes to Determine the Limit Values of Gravity-type Breakwaters (Except Sloping Breakwaters)

OCDI 2020 Part III, Chapter 3, Attached Table 10-3

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Permanent	Self-weight	Water pressure	Circular slip failure of the ground	Action-resistance ratio with respect to circular slip failure
	Variable	Variable waves, [Level 1 earthquake ground motion]	Self-weight, Water pressure	Sliding and overturning of the breakwater body, bearing capacity of the foundation ground	Action-resistance ratios with respect to sliding, overturning and bearing capacity

NOTE: [ ] indicates the alternative dominant action to be studied as design situations.

Source: Modified from OCDI 2020

- ✓ In addition to the above, gravity-type breakwaters shall be subjected to the requirements and commentaries on Performance Criteria of Armor Stones and Blocks as needed.
- ✓ In addition to the above, breakwaters with wave-dissipating structures (breakwaters covered with wave dissipating blocks, upright wave-absorbing block breakwaters,

wave-absorbing caisson breakwaters, etc.) shall be subjected to the requirements on the Serviceability with Respect to Wave-Dissipating Function.

Table 8.6- Performance Verification Items and Standard Indexes to Determine the Limit Values of Sloping Breakwaters

OCDI 2020 Part III, Chapter 3, Attached Table 10-4

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Permanent	Self-weight	Water pressure	Circular slip failure of the ground	Action-resistance ratio with respect to circular slip failure
	Variable	Variable waves	Self-weight, Water pressure	Sliding and overturning of the superstructure	Action-resistance ratios with respect to sliding and overturning
				Bearing capacity of the foundation ground	Action-resistance ratios with respect to bearing capacity
		Level 1 earthquake ground motion	Self-weight, Water pressure	Bearing capacity of the foundation ground	Action-resistance ratios with respect to bearing capacity

Source: Modified from OCDI 2020

(3) Common Items for Wharves (Example)

1) Performance Requirement

OCDI 2020 Part III, Chapter 5, p. 1072

a) The performance requirements for quaywalls shall be as prescribed respectively in the following items in consideration of the structural type:

- ✓ The performance requirements shall be such that the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism in Japan are satisfied so as to enable the safe and smooth mooring of ships, embarkation and disembarkation of people, and handling of cargoes.
- ✓ Damage to the quaywall, etc. due to the action of self-weight, earth pressure, Level 1 earthquake ground motion, berthing and traction by ships, surcharge loads, etc. shall not impair the functions of the quaywalls and shall not adversely affect the continuous use of the quaywall.

b) In addition to the provisions of the previous paragraph, the performance requirements for quaywalls provided in the following items shall be as prescribed respectively in those items:

- ✓ "Performance requirements for quaywalls to protect environment" shall be such that quaywalls shall satisfy the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism so as to contribute to conservation of the environment of ports and harbors without impairing the original functions of the quaywalls.
- ✓ "Performance requirements for quaywalls classified as high earthquake-resistance facilities" shall be such that damage due to the action of Level 2 earthquake

ground motions, etc. shall not affect the restoration through minor repair works of functions required for the quaywalls in the aftermath of the occurrence of Level 2 earthquake ground motion. Provided, however, that for the performance requirements for the quaywall which requires further improvements in earthquake-resistant performance due to environmental conditions, social conditions, etc. to which the quaywalls are subjected, damage due to Level 2 earthquake ground motions, etc. shall not impair the functions required for the quaywalls in the aftermath of the occurrence of Level 2 earthquake ground motion, and shall not adversely affect the continuous uses of the quaywalls.

2) Performance Criteria

OCDI 2020 Part III, Chapter 5, p. 1072

a) The performance criteria common to quaywalls shall be as prescribed respectively in the following items:

- ✓ Quaywalls shall have water depth and length necessary for accommodating the design ships in consideration of their dimensions.
- ✓ Quaywalls shall have a crown height that considers the range of tidal levels, the dimensions of the design ship, and the usage conditions of the facilities.
- ✓ Quaywalls shall have ancillary equipment as necessary in consideration of the usage conditions.

b) In addition to the provisions of the preceding paragraph, the performance criteria for quaywalls specified in the following items shall be as prescribed respectively in those items:

- ✓ "Performance criteria for quaywalls for the purpose of environmental conservation" shall be such that quaywalls have the dimensions necessary to contribute to conservation of environments of ports and harbors in consideration of the environmental conditions, etc. to which the quaywalls are subjected, without impairing the original functions of the quaywalls.
- ✓ "Performance criteria for quaywalls classified as high earthquake-resistance facilities" shall be such that the degree of damage under the accidental situation, in which dominating action is Level 2 earthquake ground motion, shall be equal to or less than the threshold level in consideration of the performance requirements.

3) Interpretation of the Performance Criteria on Environmental Conservation

OCDI 2020 Part III, Chapter 5, pp. 1073-1077

- ✓ Quaywalls for protecting the environment are classified as green quaywalls to which the subsequent items shall be applied, in addition to the provisions for quaywalls.
- ✓ The performance requirement for green quaywalls shall focus on serviceability. The term "protective capability" refers to the performance of quaywalls in protecting port environments for organisms, ecosystems, and others without impairing their essential functions.
- ✓ The dimensions of quaywalls for protecting environments shall indicate the structure, cross-sectional dimensions, and ancillary facilities. When setting the structure and cross-sectional dimensions in the performance verifications of quaywalls to protect environments and installing ancillary facilities, appropriate

consideration shall be given to factors that affect the objective to protect port environments for organisms and ecosystems without impairing the essential functions of the quaywalls.

4) Interpretation of the Performance Criteria on High Earthquake-resistance Facilities

a) The following classification are used as standards in provisions stipulating the appropriate performance of high earthquake-resistance facilities corresponding to the functions necessary after the action of Level 2 earthquake ground motions and the allowable period for restoration of demonstrate those functions.

- ✓ Specially designated (emergency supply transport):
  Facilities that can be used by ships and perform embarkation/disembarkation of persons, cargo handling of emergency supplies, etc., immediately after the action of Level 2 earthquake ground motions.
- ✓ Specially designated (trunk line cargo transport):
  Facilities that can be used by ships and perform cargo handling of trunk line cargos within a short period after the action of Level 2 earthquake ground motions.
- ✓ Standard (emergency supply transport):
  Facilities that can be used by ships and perform the embarkation/disembarkation of persons, cargo handling of emergency supplies, etc., within a certain period after the action of Level 2 earthquake ground motions.

The performance requirements and the contents of the design situation are set for the respective facilities according to this classification. Refer to Table 8.7 for the details of the classification of high-earthquake-resistance facilities.

Table 8.7- Classification of High-Earthquake-Resistance Facilities

OCDI 2020 Part III, Chapter 5, Table 1-5-1

	High earthquake-resistance facility		
	Specially designated		Standard
	Emergency supply transport	Trunk line cargo transport	Emergency supply transport
Functions required after the actions of Level 2 earthquake ground motions	Facilities need to maintain structural stability after earthquakes so that they can promptly be used for the mooring and landing operation of ships, the embarkation and disembarkation of passengers, and the loading and unloading of cargoes, including emergency relief supplies.	Facilities need to maintain structural stability after earthquakes so that they can promptly (in a short period of time) be used for the mooring and landing of ships and the loading and unloading of trunk line cargoes.	Facilities need to maintain structural stability after earthquakes so that they can be used for the loading and unloading of emergency relief supplies after a lapse of a certain period (approximately 1 week).
	Functions required after earthquakes (Primary functions are not required)	Primary functions	Functions required after earthquakes (Primary functions are not required)
Required performance	Usability*)	Restorability	Restorability*)
Allowable degree of restoration	Minor repairs	Minor repairs	A certain level of repairs
Limit values of the deformation	Residual horizontal deformation is 30 to 100 cm and residual inclination angles is 3°,	The responses of the structural members of cranes is within the elastic	Residual horizontal deformation is approximately 100 cm or more

	respectively.	limits	

NOTE*): The required performance is for the functions to be fulfilled after earthquakes (to transport emergency relief supplies) and not for the primary functions of respective facilities.

Source: Modified from OCDI 2020

b) The performance requirements for high earthquake-resistance facilities under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action are stipulated in the subsequent items corresponding to the classifications of high earthquake-resistance facilities:

- ✓ The performance requirement for high earthquake-resistance facilities (specially designated (emergency supply transport)) shall focus on serviceability. Serviceability refers to the limited performance requirements for the functions of facilities deemed necessary for transporting emergency supplies after earthquakes and is independent of the serviceability required for normal cargo handling work in facilities.
- ✓ The performance requirement for high earthquake-resistance facilities (specially designated (trunk line cargo transport)) shall focus on restorability.
- ✓ The performance requirement for high earthquake-resistance facilities (standard (emergency supply transport)) shall focus on restorability.

c) Table 8.8 shows the verification items and standard indexes to determine the limit values that are common to quaywalls classified as high earthquake-resistance facilities under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action. “Damage” has been adopted as the verification item in Table 8.8 from the viewpoint of comprehensiveness and by considering the fact that verification items will differ depending on the structural type. Furthermore, the indexes for determining limit value shall be appropriately set for performance verification. It may also be noted that setting in connection with “OCDI 2020 p.554, Structural Members Comprising the Facilities Subject to the Technical Standard” may also be applied, when necessary, in addition to the code.

Table 8.8- Verification Items and Standard Indexes to Determining the Limit Values that are Common to Quaywalls Classified as High Earthquake -resistance Facilities

OCDI 2020 Part III, Chapter 5, Attached Table 11-1

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Restorability, Serviceability	Accidental	Level 2 earthquake ground motion	Self-weight, earth pressure, water pressure, surcharge	Damage	-

NOTE: “serviceability” refers to the “necessary function after earthquake (emergency supply transport).”
“restorability” refers to the “essential function” or “necessary function after earthquake (emergency supply transport”

Source: Modified from OCDI 2020

d) Table 8.9 shows the verification items and standard indexes to determine the limit values for gravity-type quaywalls classified as high earthquake-resistance facilities under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action. The standard indexes for determining limit value for the face line deformation quantity of a quaywall in the table can be set with reference to the descriptions in subsequent items corresponding to the classification of high earthquake-resistance facilities.

Table 8.9- Verification Items and Standard Indexes to Determining the Limit Values for Gravity-type Quaywalls Classified as High Earthquake -resistance Facilities

OCDI 2020 Part III, Chapter 5, Attached Table 11-2

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Restorability, Serviceability	Accidental	Level 2 earthquake ground motion	Self-weight, earth pressure, water pressure, surcharge	Deformation of the face line of the quaywall	Limit of residual deformation

NOTE: "serviceability" refers to the "necessary function after earthquake (emergency supply transport)."
"restorability" refers to the "essential function" or "necessary function after earthquake (emergency supply transport"

Source: Modified from OCDI 2020

- ✓ High earthquake-resistance facilities (specially designated (emergency supply transport))

  The limit of deformation of high earthquake-resistance facilities (specially designated (emergency supply transport)) shall be the deformation of a degree such that the berthing of ships for the marine transport of emergency supplies, evacuees, construction machinery for removing obstructions, etc., is possible and shall be set appropriately. In general, the residual horizontal displacement of the quaywall can be used as the index of deformation.
- ✓ High earthquake-resistance facilities (specially designated truck line supply transport)

  The limit of deformation of high earthquake-resistance facilities (specially designated (truck line cargo transport)) shall be the deformation of a degree such that truck line cargo transport can be performed after slight restoration, within the permissible displacement set in line with the characteristics of the cargo handling equipment, or similar and shall be set appropriately. In general, the residual horizontal displacement of the quaywall, residual inclination angle of the wall, and relative displacement of the rail span can be used as indexes of deformation. In case of quaywalls using cargo handling equipment for truck line cargo transport, appropriate consideration shall be given to the form, type, and characteristics of the cargo handling equipment when setting limit values.
- ✓ High earthquake-resistance facilities (standard (emergency supply transport)

  The limit of deformation of high earthquake-resistance facilities (standard (emergency supply transport)) shall be the deformation of a degree such that cargo handling of emergency supplies can be performed after emergency restoration within a given period of time and shall be set appropriately. In general, the residual horizontal displacement of the quaywall can be used as the index of deformation.

e) Table 8.10 shows the verification items and standard indexes to determine the limit values for sheet pile quaywalls classified as high earthquake-resistance facilities (specially designated (emergency supply transport) and specially designated (trunk line supply transport)) under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action. The structural types of anchorages are broadly classified as vertical pile anchorage, coupled-pile anchorage, sheet pile anchorage, and concrete wall anchorage. In the performance verification of anchorages, appropriate verification items shall be set corresponding to the structural type. The standard indexes for determining the limit values for the face line deformation quantity in the table shall be equivalent to the performance criteria of gravity-type quaywalls classified as high earthquake-resistance facilities (specially designated (emergency supply transport) and specially designated (trunk line supply transport)).

Table 8.10- Verification Items and Standard Indexes to Determining the Limit Values for Sheet Pile Quaywalls Classified as High Earthquake -resistance Facilities (Specially Designated Emergency Supply Transport and Truck Line Supply Transport) with respect to the Accidental Situation

OCDI 2020 Part III, Chapter 5, Attached Table 11-3

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Restorability, Serviceability	Accidental	Level 2 earthquake ground motion	Self-weight, earth pressure, water pressure, surcharge	Deformation of the face line of the quaywall	Limit of residual deformation
				Yielding of sheet piles	Design yield stress
				Rupture of the tie member	Design rupture strength
				Damage to anchorage *1)	Limit curvature
				Axial force acting on anchorage *2)	Action-resistance ratio with respect to the bearing force of anchorage (pushing and pulling)
				Stability of the anchorage *3)	Design ultimate capacity of the section
				Cross-sectional failure of the superstructure	Design ultimate capacity of the section

*1) The structural types of anchorage are limited to cases of vertical pile anchorage, couple-pile anchorage, and sheet pile anchorage.

*2) The structural types of anchorage are limited to the case of coupled-pile anchorage.

*3) The structural types of anchorage are limited to the case of concrete wall anchorage.

NOTE: "serviceability" refers to the "necessary function after earthquake (emergency supply transport)" and indicates the required capacity for specially designated for specially designated (emergency supply transport) "restorability" refers to the "essential function" and indicates the required capacity for specially designated (trunk line cargo transport).

Source: Modified from OCDI 2020

f) Table 8.11 shows the verification items and standard indexes for determining the limit values for sheet pile quaywalls classified as high earthquake-resistance facilities (standard (emergency supply transport)) under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action. The standard indexes for determining the limit values for the face line deformation quantity in the table shall be equivalent to the performance criteria of gravity-type quaywalls classified as high earthquake-resistance facilities (standard (emergency supply transport)).

Table 8.11- Verification Items and Standard Indexes to Determining the Limit Values for Sheet Pile Quaywalls Classified as High Earthquake -resistance Facilities (Standard Emergency Supply Transport) with respect to the Accidental Situation

OCDI 2020 Part III, Chapter 5, Attached Table 11-4

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Restorability	Accidental	Level 2 earthquake ground motion	Self-weight, earth pressure, water pressure, surcharge	Deformation of the face line of the quaywall	Limit of residual deformation
				Damage to sheet pile	Limit curvature
				Rupture of the tie member	Design rupture strength
				Damage to anchorage *1)	Limit curvature
				Axial force acting on anchorage *2)	Action-resistance ratio with respect to the bearing force of anchorage (pushing and pulling)
				Stability of the anchorage *3)	Design ultimate capacity of the section
				Cross-sectional failure of the superstructure	Design ultimate capacity of the section

*1) The types of anchorage are limited to cases of vertical pile anchorage, couple-pile anchorage, and sheet pile anchorage.

*2) The structural types of anchorage are limited to the case of coupled-pile anchorage.

*3) The structural types of anchorage are limited to the case of concrete wall anchorage.

NOTE: “restorability” refers to the “essential function” after earthquake (emergency supply transport)

Source: Modified from OCDI 2020

g) The verification items and standard indexes for determining the limit values for cantilevered sheet pile quaywalls classified as high earthquake-resistance facilities under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action shall be equivalent to the provisions for sheet pile quaywalls classified as high earthquake-resistance facilities with the exception of the verification items for tie rods and anchorages.

h) The verification items and standard indexes for determining the limit values for double sheet pile quaywalls classified as high earthquake-resistance facilities under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action shall be equivalent to the provisions for sheet pile quaywalls classified as high earthquake-resistance facilities.

i) The verification items and standard indexes for determining the limit values for quaywalls with relieving platforms classified as high earthquake-resistance facilities under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action shall be equivalent to the provisions for gravity-type quaywalls and sheet pile quaywalls classified as high earthquake-resistance facilities corresponding to the structural characteristics of respective members.

j) The verification items and standard indexes for determining the limit values for cellular-bulkhead quaywalls classified as high earthquake-resistance facilities under the accidental situation with respect to Level 2 earthquake ground motions as the dominant action shall be equivalent to the provisions for gravity-type quaywalls classified as high earthquake-resistance facilities.

(4) Gravity Type Quaywall (Example)

1) Performance Criteria

The performance criteria for gravity-type quaywalls shall be as prescribed respectively in the following items:

- ✓ The risk of sliding failure of the ground under the permanent state, in which the dominating action is self-weight, shall be equal to or less than the threshold level.
- ✓ The risk of failure due to the sliding or overturning of the quaywall body and the insufficient bearing capacity of the foundation ground under the permanent state, in which the dominating action is earth pressure, and under the variable situation, in which the dominating action is Level 1 earthquake ground motion, shall be equal to or less than the threshold level.

OCDI 2020 Part III, Chapter 5, p. 1084

2) Interpretation of the Performance Criteria

The required performance of gravity-type quaywalls under the permanent state in which the dominant actions are self-weight and earth pressure, and under the variable state in which the dominant actions are Level 1 earthquake ground motions shall focus on serviceability. Table 8.12 shows the performance verification items and standard indexes for determining limit values with respect to the actions.

Table 8.12- Performance Verification Items and Standard Indexes to Determine the Limit Values under the Respective Design Situations of Gravity-type Quaywalls except Accidental Situations

OCDI 2020 Part III, Chapter 5, Attached Table 11-5

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Permanent	Self-weight	Water pressure, surcharges	Circular slip failure of the ground	Action-resistance ratio with respect to circular slip failure

		Earth pressure	Self-weight, water pressure, surcharges	Sliding, overturning of the quaywall, bearing capacity of the foundation ground	Action–resistance ratios with respect to sliding, overturning, and bearing capacity
	Variable	Level 1 earthquake ground motion	Self-weight, earth pressure, water pressure, surcharges	Sliding, overturning of the quaywall, bearing capacity of the foundation ground	Action–resistance ratios with respect to sliding, overturning, and bearing capacity

Source: Modified from OCDI 2020

(5) Sheet Pile Quaywall (Example)

1) Performance Criteria

OCDI 2020 Part III, Chapter 5, p. 1108

a) The performance criteria for sheet pile quaywalls shall be as prescribed respectively in the following items:

- ✓ Sheet piles shall have the embedment length necessary for the structural stability and shall contain the degree of risk indicating that the stresses in the sheet piles may exceed the yield stress at the level equal to or less than the threshold level under the permanent situation, in which the dominating action is earth pressure, and under the variable situation, in which the dominating action is Level 1 earthquake ground motion.
- ✓ The following criteria shall be satisfied under the permanent situation, in which the dominating action is earth pressure, and under the variable situation, in which the dominating actions are Level 1 earthquake ground motion and traction by ships:
  - For anchored structures, the anchorage shall be located appropriately in consideration of the structural type, and the risk of losing the structural stability shall be equal to or less than the threshold level.
  - For structures with ties and waling, the risk that the stresses in the ties and waling may exceed the yield stress shall be equal to or less than the threshold level.
  - For structures with superstructures, the risk of impairing the integrity of the members of the superstructure shall be equal to or less than the threshold level.
- ✓ For structures with superstructures, the risk of impairing the integrity of the members of the superstructure shall be equal to or less than the threshold level under the variable situation, in which the dominating action is ship berthing.
- ✓ Under the permanent situation, in which the dominating action is self-weight, the risk of occurrence of slip failure in the ground below the bottom end of the sheet pile shall be equal to or less than the threshold level.

b) In addition to the provisions in the preceding paragraph, the performance criteria for cantilevered sheet piles shall indicate that the risk in which the amount of deformation of the top of the pile may exceed the allowable limit of deformation is equal to or less than the threshold level under the permanent situation, in which the dominant action is earth pressure, and under the variable situation, in which the dominant actions are Level 1 earthquake ground motion, ship berthing, and traction by ships.

c) In addition to the provisions in the paragraph a), the performance criteria for double sheet pile structures shall be as prescribed respectively in the following items:

- ✓ The risk of occurrence of sliding of the structural body shall be equal to or less than the threshold level under the permanent situation, in which the dominating action is earth pressure, and under the variable situation, in which the dominating action is Level 1 earthquake ground motion.
- ✓ The risk that the deformation of the top of the front or rear sheet pile may exceed the allowable limit of deformation shall be equal to or less than the threshold level under the permanent situation, in which the dominating action is earth pressure, and under the variable situation, in which the dominating action is Level 1 earthquake ground motion.
- ✓ The risk of losing the stability due to the shear deformation of the structural body shall be equal to or less than the threshold level under the permanent situation, in which the dominating action is earth pressure.

2) Interpretation of the Performance Criteria on Sheet Pile Quaywalls

The required performance of sheet pile quaywalls under a permanent state in which the dominant action is earth pressure and a variable state in which the dominant actions are Level 1 earthquake ground motions shall be serviceability. The performance verification items and standard indexes for determining the limit values with respect to the actions shall be shown in Table 8.13 provided that those having structures comprising anchorages, those having structures comprising ties and waling, and those having copings shall comply with the provisions in 3), 4), and 5), below respectively.

OCDI 2020 Part III, Chapter 5, pp. 1109-1112

Table 8.13- Performance Verification Items and Standard Indexes to Determine the Limit Values under the Respective Design Situations of Sheet Pile Quaywalls

OCDI 2020 Part III, Chapter 5, Attached Table 11-6

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Permanent	Earth pressure	Water pressure, surcharges	Necessary embedded length	Embedded length required for structural stability
				Yielding of the sheet pile	Design yield stress of sheet pile
	Variable	Level 1 earthquake ground motion	Earth pressure, water pressure, surcharges	Necessary embedded length	Embedded length required for structural stability
				Yielding of the sheet pile	Design yield stress of sheet pile

Source: Modified from OCDI 2020

3) Interpretation of the Performance Criteria on Anchorages

For the permanent state in which the dominant action is earth pressure and the variable state in which the dominant actions are Level 1 earthquake ground motions and traction by ships, the performance verification items and standard indexes for determining the limit values with respect to anchorages shall be those shown in Table 8.14.

Table 8.14- Performance Verification Items and Standard Indexes to Determine the Limit Values with respect to Anchorages under the Respective Design Situations of Sheet Pile Quaywalls

OCDI 2020 Part III, Chapter 5, Attached Table 11-7

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Permanent	Earth pressure	Water pressure, surcharges	Necessary embedded length	Embedded length required for structural stability
				Yielding of the anchorage 1)	Design yield stress
				Axial force on the anchorage 2)	Action–resistance ratio with respect to the bearing force of an anchorage (press force and pullout force)
				Stability of the anchor wall 3)	Design cross-section resistance Passive earth pressure on the front face of anchor plate
	Variable	Level 1 earthquake ground motion [traction force of ships]	Earth pressure, water pressure, surcharges	Necessary embedded length	Embedded length required for structural stability
				Yielding of the anchorage *1)	Design yield stress
				Axial force on the anchorage *2)	Action–resistance ratio with respect to the bearing force of an anchorage (press force and pullout force)
				Stability of the anchor wall *3)	Design cross-section resistance Passive earth pressure on the front face of anchor plate

NOTE: [ ] indicates an alternative dominant action to be studied as design situations

*1) Only when the structural type of the anchorage is a vertical pile anchor, a coupled-pile anchor, or sheet pile anchor.

*2) Only when the structural type of the anchorage is a coupled-pile anchor.

*3) Only when the structural type of the anchorage is a slab anchor.

Source: Modified from OCDI 2020

4) Interpretation of the Performance Criteria on Ties and Wales

For the permanent state in which the dominant action is earth pressure and the variable state in which the dominant actions are Level 1 earthquake ground motions and traction by ships, the performance verification items and the standard indexes for determining the limit values with respect to ties and waling shall be those shown in Table 8.15.

Table 8.15- Performance Verification Items and Standard Indexes to Determine the Limit Values with respect to Ties and Waling under the Respective Design Situations of Sheet Pile Quaywalls

OCDI 2020 Part III, Chapter 5, Attached Table 11-8

Performance	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Permanent	Earth pressure	Water pressure, surcharges	Yielding of the tie	Design yield stress
				Yielding of the waling	
	Variable	Level 1 earthquake ground motion [traction force of ships]	Earth pressure, water pressure, surcharges	Yielding of the tie	
				Yielding of the waling	

NOTE: [ ] indicates an alternative dominant action to be studied as design situations

Source: Modified from OCDI 2020

5) Interpretation of the Performance Criteria on Coping

For the permanent state in which the dominant action is earth pressure and the variable state in which the dominant actions are Level 1 earthquake ground motions and traction by ships, the performance verification items and standard indexes for determining the limit values with respect to the copings of sheet pile quaywalls shall be those shown in Table 8.16.

Table 8.16- Performance Verification Items and Standard Indexes to Determine the Limit Values with respect to Ties and Waling under the Respective Design Situations of Sheet Pile Quaywalls

OCDI 2020 Part III, Chapter 5, Attached Table 11-9

Performance	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Permanent	Earth pressure	Surcharges	Cross-section stress of the coping	Bending compression stress
	Variable	Level 1 earthquake ground motion [traction force of ships] [berthing force of ships]	Earth pressure, surcharges	Failure of the cross section of the coping	Design cross-section resistance

NOTE: [ ] indicates an alternative dominant action to be studied as design situations

Source: Modified from OCDI 2020

6) Interpretation of the Performance Criteria on Circular Slip Failure

For the permanent situation in which the dominant action is the self-weight of sheet pile quaywalls, the performance verification items and standard indexes to determine the limit values of sheet pile quaywalls shall be those shown in Table 8.17.

Table 8.17- Performance Verification Items and Standard Indexes to Determine the Limit Values under the Permanent Situation in which the Dominant Action Is the Self-weight of Sheet Pile Quaywalls

OCDI 2020 Part III, Chapter 5, Attached Table 11-10

Performance	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Permanent	Self-weight	Water pressure, surcharges	Circular slip failure of the ground	Action-resistance ratio with respect to circular slip

Source: Modified from OCDI 2020

7) Interpretation of the Performance Criteria on Joints

In the cases of using sheet piles with special joints or large-scale joints, the performance verification items and standard indexes to determine the limit values with respect to the stress on the joints shall be appropriately set as needed.

(6) Piled Piers (Example)

1) Performance Requirement

OCDI 2020 Part III, Chapter 5, p. 1243

a) The performance requirements for piled piers shall be as prescribed respectively in the following items in consideration of the structural type:

- ✓ The requirements specified by the Minister of Land, Infrastructure, Transport and Tourism in Japan shall be satisfied so as to enable the safe and smooth berthing of ships, embarkation and disembarkation of people, and handling of cargo.
- ✓ Damage to the piled pier due to self-weight, earth pressure, Level 1 earthquake ground motions, berthing and traction by ships, surcharge load, etc. shall not impair the functions of the piers and shall not adversely affect its continuous use.

b) In addition to the provisions of the previous paragraph, the performance requirements for piled piers listed in the following items shall be as prescribed respectively in those items:

- ✓ "Performance requirements for piled piers for the purpose of environmental conservation" means that piled piers shall satisfy the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism so as to contribute to conservation of the environment of ports and harbors without impairing the original functions of the piled piers.
- ✓ "Performance requirements for piled piers classified as high earthquake-resistance facilities" means that damage to piled piers, etc. due to Level 2 earthquake ground motions, etc. shall not affect the restoration through minor repair works of functions required for the quaywalls in the aftermath of the occurrence of Level 2 earthquake ground motion. Provided, however, that for the performance requirements for the piled piers which requires further improvements in earthquake-resistant performance due to environmental conditions, social conditions, etc. to which the piled piers are subjected, damage due to Level 2 earthquake ground motions, etc. shall not impair the functions necessary for the quaywalls in the aftermath of the occurrence of Level 2

earthquake ground motion, and shall not adversely affect the continuous uses of the piled piers.

2) Performance Criteria

a) The provisions of performance criteria on Common Items fir Wharves apply mutatis mutandis to the performance criteria of piled piers.

b) In addition to the provisions of the preceding paragraph, the performance criteria of the access bridge of piled piers shall be as prescribed respectively in the following items:

- ✓ The access bridge of piled piers shall satisfy the following criteria:
  - The access bridge of piled piers shall have the dimensions necessary for enabling the safe and smooth loading, unloading, embarkation and disembarkation, etc. in consideration of the usage conditions.
  - The access bridge of piled piers shall not transmit horizontal loads to the superstructure of the piled pier, and shall not fall down even when the piled pier and the earth-retaining part are displaced owing to the actions of earthquakes, etc.
- ✓ The following criteria shall be satisfied in variable situations in which the dominant actions are Level 1 earthquake ground motions, ship berthing and traction by ships, and imposed load:
  - The risk of impairing the integrity of the members of the superstructure shall be equal to or less than the threshold level.
  - The risk that the axial force acting on the piles may exceed the resistance capacity owing to failure of the ground shall be equal to or less than the threshold level.
  - The risk that the stress in the piles may exceed the yield stress shall be equal to or less than the threshold level.
- ✓ The following criteria shall be satisfied under the variable situation in which the dominating action is variable waves:
  - The risk of impairing the stability of the access bridge due to uplift acting on the access bridge shall be equal to or less than the threshold level.
  - The risk of impairing the integrity of the members of the superstructure shall be equal to or less than the threshold level.
  - The risk that the axial force acting on piles may exceed the resistance capacity owing to failure of the ground shall be equal to or less than the threshold level.
- ✓ For the structures with stiffening members, the risk of impairing the integrity of the stiffening members and connection points of the structures under the variable situation, in which the dominating actions are variable waves, Level 1 earthquake ground motions, ship berthing and traction by ships, and surcharge load, shall be equal to or less than the threshold level.

OCDI 2020 Part III, Chapter 5, pp. 1243-1244

3) Interpretation of the Performance Criteria on High Earthquake Resistance Facilities

a) In regard to the interpretation concerning performance requirements and performance criteria of piled piers that are high earthquake-resistance facilities, the interpretation concerning performance requirements and performance criteria of quay walls that are high earthquake-resistance facilities is applied, excluding performance verification items and standard indexes to provide limit values.

OCDI 2020 Part III, Chapter 5, pp. 1244-

b) Verification items and standard indexes to provide limit values of piled piers that are high earthquake-resistance facilities to accidental situations with a dominating action of Level 2 earthquake ground motion shall be in accordance with Table 8.18. 1247

Table 8.18- Performance Verification Items and Standard Indexes to Determine the Limit Values of Piled Piers that are High Earthquake Resistance Facilities

OCDI 2020 Part III, Chapter 5, Attached Table 11-21

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Restorability Serviceability	Accidental	Level 2 earthquake ground motion	Self-weight, surcharges	Deformation of face line	Residual deformation
				Cross-sectional failure of the superstructure	Design cross-sectional resistance
				Damage to piles	Limit curvature
				Axial forces in the piles	Bearing capacity of piles

Source: Modified from OCDI 2020

c) In Table 8.18, the standard index to provide the limit value for the deformation of the face line shall apply to gravity-type mooring quay walls that are high earthquake-resistance facilities.

d) In Table 8.18, the following performance verification shall be carried out concerning damage to piles of piled piers that are high earthquake-resistance facilities in consideration of the types of high earthquake-resistance facilities.

- ✓ Specifically designated (emergency supply transport) and specifically designated (trunk line cargo transport)
  It shall be verified that no pile which reaches the limit curvature at two locations exists in the cross section of the piled pier concerned.
- ✓ Standard (emergency supply transport)
  It shall be verified that at least one pile which reaches the limit curvature at less than two locations on a pile exists among the piles comprising the piled pier concerned. (It shall be verified that all the piles existing in the cross section of the piled pier concerned are not in a state such that the limit curvature at two or more locations is reached on a pile.)

e) The verification items and standard indexes to provide limit values of the high earthquake-resistance facilities of open-type wharves on vertical piles shall be applied for piled piers that are high earthquake-resistance facilities of structures with stiffened members.

4) Interpretation of the Performance Criteria on Main Structure of Piled Piers

a) The performance requirement for piled piers under a variable situation where the dominating actions are Level 1 earthquake ground motions, berthing and traction by ships, surcharges, and variable waves shall be serviceability. Performance verification items and the standard indexes to provide limit values to these actions concerning the superstructure and the piles of piled piers are shown in Tables 8.19 and 8.20.

Table 8.19- Performance Verification Items and Standard Indexes to Determine the Limit Values in Each Design Situation (Excluding Accidental Situations) Concerning Superstructure of Piled Piers

OCDI 2020 Part III, Chapter 5, Attached Table 11-22

Performance requirement	Design state: State	Design state: Dominating action	Design state: Non-dominating action	Verification item	Standard index to determine the limit value
Serviceability	Variable	Berthing and traction by ships	Self-weight, surcharges	Cross-sectional failure of superstructure	Design cross-sectional resistance
		Level 1 earthquake ground motion	Self-weight, surcharges		
		Surcharges (including surcharges during cargo handling)	Self-weight, wind action on cargo handling equipment and ships		
		Surcharges (including surcharges during cargo handling)	Self-weight, wind action on cargo handling equipment and ships	Crack width of superstructure cross-section	Limit value of bending crack width
		Repeated applied surcharges	Self-weight	Fatigue failure of superstructure	Design fatigue strength
		Variable waves	Self-weight	Cross-sectional failure of superstructure	Design cross-sectional resistance

Source: Modified from OCDI 2020

Table 8.20- Performance Verification Items and Standard Indexes to Determine the Limit Values in Each Design Situation (Excluding Accidental Situations) Concerning Piles of Piled Piers

OCDI 2020 Part III, Chapter 5, Attached Table 11-23

Performance requirement	Design state: State	Design state: Dominating action	Design state: Non-dominating action	Verification item	Standard index to determine the limit value
Serviceability	Variable	Berthing and traction by ships	Self-weight, surcharges	Axial forces in piles	Action-resistance ratio concerning bearing capacity of piles
		Level 1 earthquake ground motion	Self-weight, surcharges		
		Surcharges (including surcharges during cargo handling)	Self-weight, wind action on cargo handling equipment and ships		
		Berthing and traction by ships	Self-weight, surcharges	Yielding of piles	Design yield stress of piles

		Level 1 earthquake ground motion	Self-weight, surcharges		
		Surcharges (including surcharges during cargo handling)	Self-weight, wind action on cargo handling equipment and ships		
		Variable waves	Self-weight	Axial forces acting in piles	Action-resistance ratio concerning bearing capacity of piles

Source: Modified from OCDI 2020

b) The performance verification item and standard index to provide the limit value concerning access bridges of piled piers under the variable situation in which the dominant action is variable waves is shown in Table 8.21. In addition to that shown in Table 8.21, performance verification items and standard indexes to provide limit values concerning access bridges of piled piers shall be adequately established as necessary under the variable situation in which the dominant action is surcharges.

Table 8.21- Performance Verification Items and Standard Indexes to Determine the Limit Values in Each Design Situation (Excluding Accidental Situations) Concerning Access Bridges of Piled Piers

OCDI 2020 Part III, Chapter 5, Attached Table 11-24

Performance	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Variable	Variable waves	Self-weight	Uplift force on access bridge	Design cross-sectional resistance

Source: Modified from OCDI 2020

c) Performance verification items and the standard index to provide a limit value concerning piled piers of structures with stiffening members under the variable situation in which the dominating actions are Level 1 earthquake ground motion, berthing and traction by ships, surcharges, and variable waves shall comply with those of piled piers, and are shown in Table 8.22.

Table 8.22- Performance Verification Items and Standard Indexes to Determine the Limit Values in Each Design Situation (Excluding Accidental Situations) Concerning Piled Piers with Stiffening Members

OCDI 2020 Part III, Chapter 5, Table 11-25

Performance requirement	Design state			Verification item	Standard index to determine the limit value
	State	Dominating action	Non-dominating action		
Serviceability	Variable	Berthing and traction by ships	Self-weight, surcharges	Yielding of stiffening members	Design yield stress, design shear force resistance

		[Level 1 earthquake ground motion]	(Self-weight, surcharges)	Failure of connections at joints	Design shear force resistance
		[Surcharges (including surcharges during cargo handling)]	(Self-weight, surcharges, and wind acting on ships)	Pinching shear failure at joints	Design shear force resistance
		Repeated applied surcharges	Self-weight	Fatigue failure of joints	Design fatigue strength
		Variable waves	Self-weight	Failure of connections at joints	Design shear force resistance

NOTE: Items within square brackets [ ] in the column "Dominating action" indicate that the design situation replaces the dominating actions.
Items within parentheses ( ) in the column "Non-dominating action" indicate that this shall be read according to dominating actions.

Source: Modified from OCDI 2020

5) Interpretation of the Performance Criteria on Earth Retaining Sections

The performance criteria and interpretation concerning earth-retaining sections of piled piers shall, in consideration of the structural types, comply with other criteria and their interpretation such as "Performance Criteria of Gravity-type Quay Walls".

6) Interpretation of the Performance Criteria on Symbiosis Piled Piers

a) A piled pier for environmental conservation is called a "symbiosis piled pier". The following are applied together with the criteria for piled piers:
b) The performance requirement for symbiosis piled piers shall be serviceability. Here, serviceability indicates the performance required to contribute to the preservation of the port environment, such as wildlife and the ecosystem, without impairing the original functions of the piled pier concerned.
c) The dimensions of piled piers for environmental conservation include the structure, cross-sectional dimensions, and ancillary facilities. In establishing the structure and cross-sectional dimensions and installing ancillary facilities in the performance verification of piled piers for environmental conservation, contributing to the preservation of the port environment, including wildlife and the ecosystem, without impairing the original functions of the piled piers concerned shall be considered adequately.

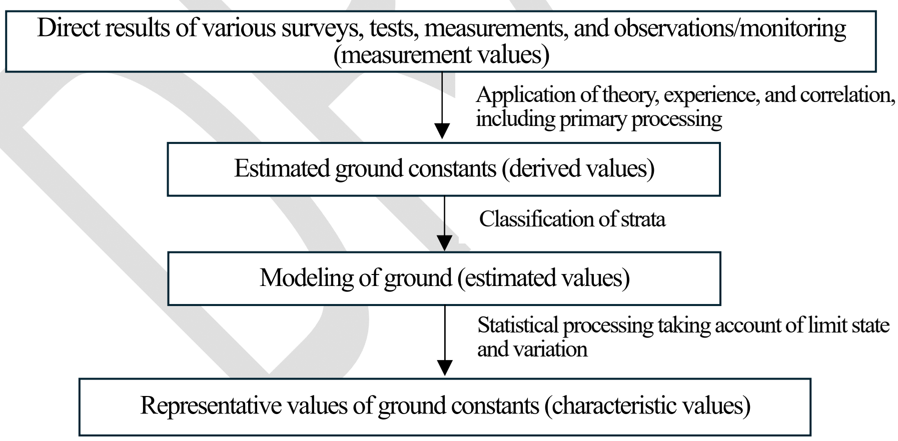
9. Geotechnical Properties as Reference

9-1. Estimation of Geotechnical Properties

(1) General

The design values of geotechnical properties used in performance verification are, in principle, estimated in accordance with the procedure1) shown in Figure 9.1 following the Design Principle for Foundation Structures based on the Performance Design Concept (JGS 4001). However, if there is a rational reason based on the characteristics of the ground investigations and the soil tests, derived values may be used as characteristic values. For example, in the case of measured SPT-N values through the standard penetration test, derived values can be used as characteristic values because there have been proposals of empirical and correlation equations, taking the variations in the measured values into consideration. Also, as with shear wave velocities measured by the geophysical logging, some measured values are obtained from evaluating the complex in-situ conditions and characteristics of the ground, and each measurement location has a different evaluation object. In these cases, derived values may also be used as characteristic values because statistical processing of plural measurement result is inappropriate.

Also, it is difficult to take into account the extent of individual influences of ground investigation or soil test methods on the variations of ground constants in each performance verification case. Thus, assuming that reliability of ground investigation or soil test methods appears in the form of data variations, characteristic values are subjected to corrections according to the variations. This approach simplifies the performance verification method, enabling partial factors (load resistance factors) to be set regardless of ground investigation and soil test methods. It shall be noted that the characteristic value to be set when the number of data is small or data has large variations is slightly different from the essential concept of making the average derived value a characteristic value, as stipulated in JGS 4001.



OCDI 2020 Part II, Chapter 3, Figure 2.1.1

Source: OCDI 2020

Figure 9.1- Examples of the Procedure for Setting the Characteristic Values of Ground Constants

(2) Methods of Estimating Derived Values

As described below, derived values can be obtained from measured ones through either method which: uses measured values directly as derived ones; applies primary processing to measured values; or converts measured values into different engineering quantities.

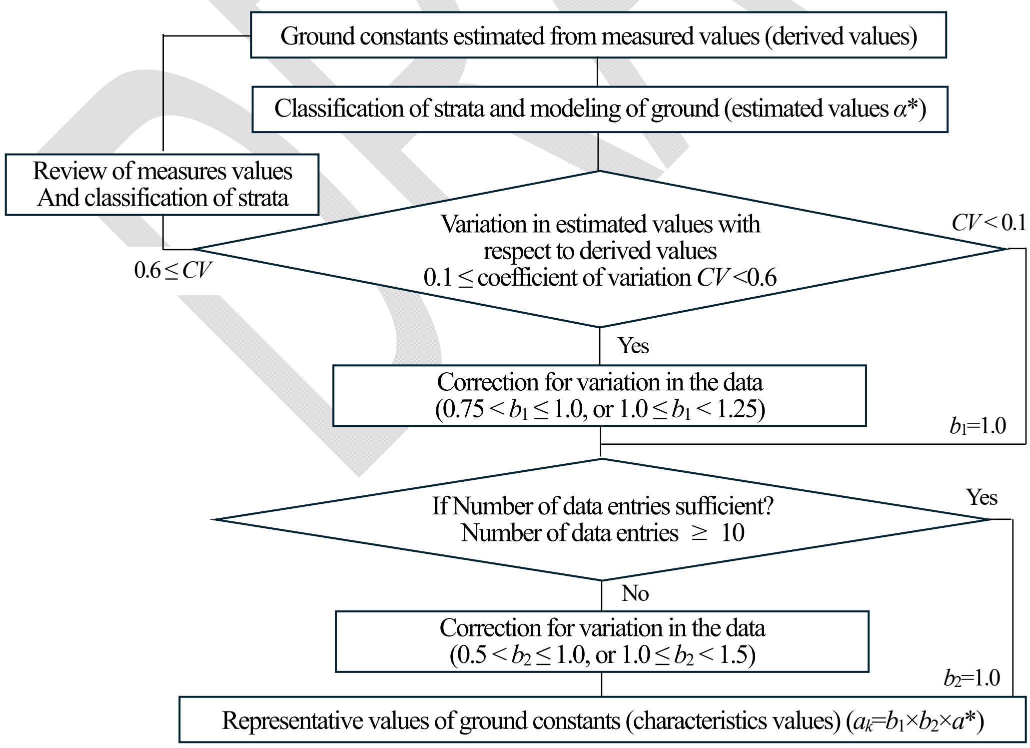
- ✓ The methods which use the measurement values directly as derived ones are, literally, direct ground constant measurements.

- ✓ The methods which apply primary processing to measured values include: area correction in shear tests; correction for the strain rates' effect on shear strength; and simple correction by multiplying measured values by coefficients. The primary processing also includes simple processing of test results such as calculating water contents w, wet density ρ_t, soil particle density ρ_s, and grain sizes; obtaining deformation moduli E from stress-strain relationships; and obtaining consolidation yield stress p_c from the e–log p relationship in compression curves.
- ✓ The methods which convert measured values into different engineering quantities use theoretical or empirical formulas, or obtain fitting parameters, in accordance with theoretical formulas. The methods include: converting SPT-N values into angles of shear resistance ϕ using empirical formulas and obtaining consolidation coefficients c_v by fitting theoretical consolidation curves to settlement-time curves.

(3) Methods of Setting Characteristic Values

1) General

Characteristic values are set generally in accordance with the procedure shown in Figure 9.2. When the number of derived values is large enough to be subjected to statistical processing, and the variations of the derived values are small, characteristic values can be calculated as the averages (expected) values of the derived ones in principle. Given that the number of the data of derived values n is 10 or more, and they have no significant variation with a coefficient of variation of less than 0.1, the statistical processing results of such data are considered to have a certain level of reliability, enabling their average (expected) values to be characteristic values. However, if there is an insufficient number of data on the derived values to carry out statistical processing, and the variation in the derived values is large, it is necessary to set characteristic values by correcting their average values (expected values) through the method shown below.



OCDI 2020 Part II, Chapter 3, Figure 2.1.2

Source: OCDI 2020

Figure 9.2- Example of the Procedure for Setting the Characteristic Values of Ground Constants

2) Correction of the Average (expected) Values of Derived Values

When the number of derived values is limited, or the variation in the derived values is large, the characteristic values shall be set not by simply and automatically obtaining the average (arithmetic average value) of the derived values but by appropriately taking into consideration the estimated error of the statistical average value. In this case, the following method may be used. Because characteristic values have such uncertain factors as errors in the ground investigations and soil tests, estimation errors in the derived values, and inhomogeneity in ground itself, it is desirable to determine characteristic values carefully, with due consideration of the ground investigation conditions (such as the types of survey equipment), soil test conditions (such as the types of test equipment and methods and condition of test specimen), and other soil information, such as stratal organization. The method of correcting the average (expected) of the derived values described here is expected to be applied not only to the values for stability verification of facilities, but also to soil constants in general, including settlement prediction values. The method specified in JGS 4001 is to set the characteristic values in accordance with confidence intervals, assuming that derived values show a normal distribution, if the standard deviation of the population is known, or a t-distribution if the standard deviation is unknown. However, unlike quality indices for factory products, simple statistical processing is difficult when dealing with geotechnical parameters because of errors attributable to ground investigation and soil test methods, estimation errors of derived values, and the distribution and variations in the derived values attributable to the inhomogeneity of ground itself as well as sedimentation conditions.

To obtain geotechnical parameters (the averages, corresponding to characteristic values, with statistical errors incorporated into them) for reliability design, it is necessary to collect a sufficiently large number of test results for statistical processing. Also, to reflect the soil investigation and soil test results in performance verification, it is necessary to model the distribution in the depth direction of the estimated values a^* of the geotechnical parameters (expressed by "a" here), for example: uniform distribution in the depth direction ($a^* = c_1$); linear distribution with estimated values increased in proportion to depth ($a^* = c_1z + c_2$); and quadratic distribution in the depth direction ($a^* = c_1z^2 + c_2z + c_3$). Here c_1, c_2, and c_3 are constants. At least 10 pieces of test data are required when a portion of ground is modeled to a certain depth and the model is subjected to statistical processing. The geotechnical parameters obtained through different soil tests (such as undrained shear strength by triaxial test and unconfined compression tests) have different reliability. Therefore, different partial factors (load resistance factors) shall be set for respective parameters; however, there is no way of knowing the degrees of difference in these partial factors. In contrast, it is well-known that the variation coefficients of these two tests results are significantly different. Based on this, the characteristic values are to be calculated not simply by making the arithmetic averages, but by multiplying the estimated values by the correction coefficients that take into account the variation of the derived values. This method is based on having sufficient test data for statistical processing. Therefore, when there is insufficient test data, it is necessary to further set the characteristic values on the safe side in a manner that multiplies the estimated values by the correction coefficients with respect to insufficient test data. In other words, the characteristic values are calculated either by Equation (9.1) or Equation (9.2). Here, Equation (9.2) is used when it is reasonable to examine the variations of, for example, consolidation yield stress p_c, consolidation coefficients c_v, volume compressibility coefficients m_v, etc. on logarithmic axes.

$$a_k = b_1 b_2 a^* \quad (9.1)$$

$$\log a_k = b_1 b_2 \log a^* = \log a^{*b_1 b_2} \quad (9.2)$$

OCDI 2020 Part II, Chapter 3, Equation (2.1.1) (2.1.2)

Where:

a_k : a representative value of a ground constant (characteristic value)

b_1 : a correction coefficient with respect to the variation in the derived values

b_2 : a correction coefficient with respect to the number of data on derived values

a^* : a model value of the ground constant (estimated value)

A specific correction method (correction coefficient setting method) is described below. When dealing with quantities considered to have balance between action and bearing sides in essence, as is the case with the unit weight of original ground in stability analyses, the correction coefficient values b_1 and b_2 can be set at 1.0.

3) Method of Setting Correction Coefficients with Respect to Derived Value Variations

When examining the variation of test results a with the estimated geotechnical parameters, obtained by modeling the distribution of the test results expressed by a^*, it is convenient to use the standard deviation a/a^*, the normalization of a with a^* (called a coefficient of variation, or CV). Here, this is based on the major premise that a^* is uniformly distributed in a model stratum at its average value or distributed in a manner that enables the least square method to minimize errors. The CVs of the geotechnical parameters, obtained by sampling less disturbed specimens from uniform ground with a thin-walled tube sampler with a fixed piston, and carefully conducting variety of soil tests using the sampled specimens as undisturbed specimens, are 0.1 or less. In other words, test results inevitably vary at this level because even homogeneous ground has a certain amount of inhomogeneity, and even carefully conducted soil tests are subjected to errors. Test results may have larger variations in cases where the ground is inhomogeneous, sampling causes large disturbance in specimens, soil test methods are conducted improperly, or the ground is modeled with inappropriate distribution of values in depth direction. In such cases, characteristic values need to be set on the safe side considering the effects of uncertain factors without applying estimation values a^* directly to the characteristic values.

Therefore, the correction coefficient b_1 with respect to the variations of the derived values are set in accordance with the CVs, defined as the standard deviations SD of (a/a^*). When an object parameter a contributes to the bearing side (advantageous for design such as shear strength) in performance verification, the correction coefficient can be set at about $b_1 = 1 - (CV/2)$. When contributing to the action side (disadvantageous for design such as the unit weight of earth fill and compression indexes), the correction coefficient can be set at about $b_1 = 1 + (CV/2)$. Based on this concept, the values to be used in performance verification are calculated and summarized as shown in Table 9.1. The concept of the correction coefficient b1 is to apply the derived values corresponding to the cumulative probability density of about 70% (called fractal values) to the characteristic values. If the CVs are 0.6 or higher, the test results are unreliable for performance verification. In such a case, the interpretation of test results shall be revised and, if necessary, the ground modeling shall be reexamined. There may be a case of redoing ground investigations

Table 9.1- Values of Correction Coefficients

OCDI 2020 Part II, Chapter 3, Table 2.1.1

Coefficient of variation CV	Correction coefficient b_1	
	When it is necessary to correct the characteristic value to a value smaller than the derived values	When it is necessary to correct the characteristic value to a value larger than the derived values
≥ 0, < 0.1	1.00	1.00
≥ 0.1, < 0.15	0.95	1.05
≥ 0.15, < 0.25	0.90	1.10
≥ 0.25, < 0.4	0.85	1.15
≥ 0.4, < 0.6	0.75	1.25
≥ 0.6	Re-investigate the interpretation of the results or the modeling, or re-do the survey	

Source: OCDI 2020

There are cases of examining the logarithmic distribution of test results when obtaining some geotechnical parameters, such as consolidation yield stress p_c, the consolidation coefficients c_v, and the volume compressibility coefficients m_v. When obtaining the characteristic values of these geotechnical parameters by conducting a large number of soil tests, assuming the object ground is uniform, it is reasonable to examine the variations on logarithmic axes because these geotechnical parameters show logarithmic normal distribution. That is, the *CV* can be expressed by the standard deviations *SD* of $\log a$ / $\log a^*$ with respect to the geotechnical parameter a and, therefore, the values in Table 9.1 can be used directly as the correction coefficient b_1 on the logarithmic axes. In the case of the angles of shear resistance ϕ, the variations of $\tan\phi$, not the variations of ϕ, should be examined by taking their mechanical significance into consideration. However, there is no need to consider *CV* when dealing with the angles of shear resistance of mound materials because the characteristic values to be used for performance verification have already been specified empirically, and the influences of the variations are already incorporated in these values. Here, the *CV* needs to be applied to the characteristic values obtained from statistical processing of reported soil test results. In other words, Table 9.1 does not show the required levels of variations that ground investigation and soil test results need to satisfy, but the values corresponding to the variation levels required when evaluating ground investigation and soil test results.

4) Method of Setting Correction Coefficients with Respect to the Number of Data on Derived Values

In Method of setting correction coefficients with respect to derived value variations, the method is based on the availability of sufficient data to conduct statistical processing. However, if there is insufficient data for statistical processing, the correction coefficients b_2 with respect to the number of data on derived values shall be applied based on the concept that statistical results cannot have a certain degree of reliability unless the number of data is 10 or more. The characteristic values shall be corrected by $b_2 = \{1 \pm (0.5/n)\}$ when there is insufficient data. Here, in the formula of b_2, the negative sign is used to correct the characteristic values of geotechnical parameters used in performance verification if they should be smaller than the derived values, and the positive sign is used to correct the characteristic values if they should be larger than the derived values. For performance verification, there must be two or more data on derived values. However, even in the case where there is only one piece of data on a derived value, the data can still be used for performance verification provided that other parameters (for example SPT-N values or grain size distribution) are available, and the distribution of the derived values can be modeled based on the correlation (limited to generally known correlation) between the derived values and the parameters. In such a case, b_1 and b_2 shall be set at 1 and 1 ± 0.5 respectively.

5) Method of Setting Characteristic Values taking into consideration Modes of the Performance Verification

Soil parameters with respect to consolidation and shear strength are not mutually independent. In performance verification, if these parameters are considered independent, the characteristic values can be obtained by taking the reliability of the respective parameters into consideration. However, the parameters with respect to consolidation need to be closely related to those with respect to shear strength. For example, the stability evaluation needs to consider the effect of consolidation on strength increases. In this case, in the process of obtaining characteristic values from derived values, the respective parameters must be correlated when modeling the distribution of soil test results and obtaining the estimated values. For example, given the relationship of $c_u = m \times \mathrm{OCR} \times \sigma'_{v0}$ derived from the strength increase ratio of $m = c_u/p_c$ and the over consolidation ratio of $\mathrm{OCR} = p_c/\sigma'_{v0}$ where σ'_{v0} is an effective soil overburden pressure, p_c is consolidation yield stress, and c_u is undrained shear strength, the characteristic values are preferably set through the statistical processing of the variations based on the estimated geotechnical parameters consistent with the relationship.

- End -