Part I General

Chapter 1 General Rules

1.1 Scope of Application

This book is a translated version of the major parts of *the Technical Standards and Commentaries for Port and Harbour Facilities in Japan*, which are referred to as "the Technical Standards" hereinafter.

The Technical Standards are applied to the construction, improvement and maintenance of the port and harbor facilities in Japan. **Fig. 1.1.1** shows the statutory structure of the Technical Standards for Port and Harbour Facilities in Japan set forth by the Port and Harbour Law, which is composed of the *Ministerial Ordinance* and the *Public Notice* and was enacted in July 2007, supplemented with *Commentaries*.

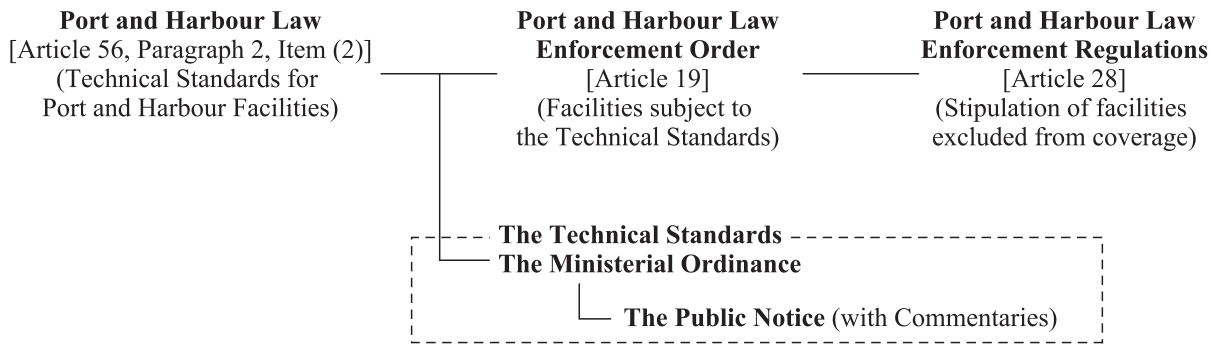

Fig. 1.1.1. Statutory Structure of the Technical Standards for Port and Harbour Facilities

Commentaries mainly provide engineers with explanation on the background to and the basis for the *Public Notice*. In addition, **Technical Notes** are added at many subsections for provision of further explanation and detailed information. They are intended to assist engineers in designing facilities, by presenting explanation of the investigation methods and/or related standards, specific examples of structures, and other related materials.

1.2 Definition of Terms

The terms defined hereinafter include those defined in Article 1 of the Ministerial Ordinance and those defined in Article 1 of the Public Notice. The other terms are those used in the present Technical Standards.

Accidental actions
means the actions which can be expected to have a low possibility of occurrence during the design working life and which have a large effect on the facilities concerned, including tsunamis, Level 2 earthquake ground motion, waves of extremely rare event, collision by ships and fire.

Accidental situation
means the situation in which the dominating actions are accidental actions, among the states in which one action, or combination of two or more actions such as accidental actions and permanent actions are considered in the performance criteria and the performance verification.

Accidental waves
means the waves which have an extremely low possibility of attacking during the design working life of the facilities concerned, among waves expected to attack at the location where the facilities are to be installed, although which will have a major impact on the objective facilities in the event of an attack.

Annual exceedence probability
means the probability that an expected or greater action will occur one or more times in one year.

Cargo handling facilities
means the facilities provided for the use in port cargo handling, including stationary cargo handling equipment, rail-mounted cargo handling equipment, cargo handling areas and sheds.

Characteristic value
means the values representing the respective characteristics of the strengths of the materials comprising structures and the forces acting on the structures, corresponding to certain probability conditions, by considering the deviations of these items.

Constructability
means the performance which enables construction while securing safety in construction work within an appropriate construction period using suitable and reliable methods.

Design value
means the value obtained by multiplying the characteristic value of a design parameter by the partial factor.

Design situation
means the combination of actions considered in the verification.

Design working life
means the period during which facilities satisfy the performance requirements which were set in the design of the facilities.

Encounter probability
means the probability that the action greater than the action in a certain return period will occur at least once during the lifetime of the facilities.

Expected total cost
means the total amount of the initial construction cost of facilities and the expected recovery cost of disasters expected to occur during a certain period.

Facilities against accidental incident
means the facilities in which there is a danger of serious impact on life, property, or socioeconomic activity accompanying damage of the objective facilities.
Facilities against accidental incident include breakwaters, revetments, seawalls, water gates, quaywalls, buoys, floating piers, levees, and locks and water gates constructed behind densely populated areas, and in addition, facilities which handle hazardous cargoes, port transportation facilities used by the general public and vehicles, and tunnels and bridges for trunk port traffic needs.

Facilities for ship service
means the facilities provided for the use of ships, including water supply facilities, fueling facilities, and coal supply facilities for ships, ship repair facilities and ship storage facilities.

Fatigue limit state
means the state in which failure similar to that in the ultimate limit state occurs due to repeated loads acting during the lifetime of the structure.

Ground motion propagation effects
means the effect on ground motion of the propagation path from the source to the seismic bedrock of the point concerned.

High earthquake-resistance facilities
means the port and harbour facilities which contribute to the recovery and reconstruction of the port and the surrounding area when damage occurs due to a large-scale earthquake.
High earthquake-resistance facilities include quaywalls, piers, and lighter's wharfs which contribute to the transport of the emergency supplies and the trunk line cargoes, and greenbelts, and plazas, which function as the counter disaster bases (bases contributing to the recovery and reconstruction of the port and surrounding area).

Level 1 earthquake ground motion
means the ground motion with a high probability of occurring during the design working life of the facilities, based on the relationship between the return period of ground motion and the design working life of the objective facilities, among ground motions expected to occur at the location where the facilities are to be installed.

Level 2 earthquake ground motion
means the ground motion having an intensity of the maximum scale, among ground motions expected to occur at the location where the facilities are to be installed.

Life cycle cost
means the total amount of the initial construction cost of facilities and the expected recovery cost of disasters expected during the design working life.

Limit state design
means the design method to verify the limit state which is defined as state when a load acts on a structure and some inconvenience on the functions or the safety of the structure occurs. The states subject to the examination are the ultimate limit state, serviceability limit state, and fatigue limit state.

Limit state function
means the function showing the relationship between the variable resistance of the structure and the variable force acting on the structure.
The limit state function provides the limit state of the structures, and is mainly used in calculating the probability of failure of the structures.

Maintenanceability
means the performance which is capable of continuously securing the required performance necessary in facilities by implementing repairs and maintenance, within the range of technically possible and economically appropriate against the deterioration and the damage of the facilities due to the use of the facilities and expected actions.

Maintenance level
means the level of maintenance control set for each member comprising the facilities, considering changes over time in the members comprising the facilities, the ease of inspection and diagnosis, and maintenance work, and the importance of the facilities, in accordance with the maintenance control plan for the facilities as a whole.

Mooring facilities
means the facilities where ships moor for cargo handling and passenger embarkation/disembarkation including quaywalls, mooring buoys, mooring piles, piers, floating piers, lighter's wharfs and slipways.

Partial factor
means the factor when using the method to verify the performance of facilities by confirming that the design value of resistance R_d exceeds the design value of the effect of actions S_d, upon defining that the design value for that factor is the value obtained by multiplying the characteristic value of a factor by a certain coefficient.

Performance criteria
means the criteria which concretely describe performance requirements so that performance verification is possible.

Performance requirements
means the performance which facilities must possess in order to achieve their purpose.

Performance verification
means the act of confirming that facilities satisfy the performance criteria.

Permanent actions
means the actions which are expected to act on facilities continuously through the design working life, including self weight, earth pressure, and environmental actions.

Permanent situation
means the situation in which the dominating actions are permanent actions, among the states in which one or multiple permanent actions, or combination of permanent actions and variable actions are considered in the performance criteria and the performance verification.

Port transportation facilities
means the facilities provided for the use in transportation necessary for the use of ports and harbours, including roads, parking lots, bridges, railroads, rail tracks, canals and heliports.

Protective facilities for harbor
means the facilities which protect waterways and basins such as breakwaters, sediment control groins, seawalls, training jetties, water gates, locks, revetments, banks, groins and parapet walls, and shore facilities such as facilities on water area, mooring facilities and cargo handling facilities.

Random variable
means the variable which is characterized by the fact that the value of the variable changes probabilistically, as in action forces such as waves, winds, and the resistance force of facilities to those forces.

Reliability-based design method
means the method of quantitatively evaluating the probability of failure expected in failure mode(s) when the limit state to be verified is clearly defined and the failure mode(s) for that state are identified.

Reliability index
means the index showing the safety of a structure until failure with a certain failure probability; expressed by the ratio of the average value to the standard deviation of the limit state function.

Restorability
means that the facilities can recover their required functions within a short period of time by repairs in a range which is technically possible and economically appropriate.

Return period
means the average time interval (years) from the time when an action of a certain magnitude or larger occurs until that action next occurs again.

Safety
means the performance capable of securing the safety of human life; in the event of a certain degree of damage corresponding to the expected actions, the degree of damage shall not be fatal for the facilities, and shall be limited to a range which does not have a serious impact on securing the safety of human life.

Sensitivity factor
means the index showing the degree of influence of respective design parameters on the total performance of facilities.

Serviceability
means the performance which enables use without inconvenience from the viewpoint of use; in the case in which damage does not occur due to the expected action, or limited to a range in which the degree of damage is such that the facilities can recover their required functions quickly with very minor repairs.

Serviceability limit state
means the state in which comparatively minor inconvenience such as excessive cracking occurs due to actions that frequently occur during the lifetime of a structure.

Site effects
means the effects of the earthquake motion to the deposit layers on the seismic bedrock.

Source effects of earthquake
means the effect of the rupture process of the source fault on the ground motion.

Storage facilities
means the facilities provided for the use in the storage of cargoes being handled in ports, including warehouses, open storage yards, timber ponds, coal storage yards, yards for hazardous cargo and oil storage facilities.

System failure probability
means the probability of failure of the facilities as a whole system caused by a combination of individual failure modes which occur under uncertain factors.

System reliability
means the reliability of the total system against failure in cases where there are multiple failure modes . The reliability of the total system will differ depending on whether the failure mode is a series system or a parallel system.

Target safety level
means the level which is the target for defining facilities as being in a safe state in the reliability-based design method.

Ultimate limit state
means the state in which failure occurs in a structure due to the maximum load.

Variable actions
means the actions due to winds, waves, water pressure, water currents, and ship berthing force and tractive force, and actions such as Level 1 earthquake ground motion, and surcharges which show changes over time during the design working life that are not negligible in comparison with their average values and are not unidirectional and the characteristic values of these actions being given probabilistically.

Variable situation
means the situation in which the dominating actions are variable actions among the states in which one or multiple variable actions, or combination of permanent actions and variable actions are considered in the performance criteria and the performance verification.

Variable waves
means the waves with a high possibility of attacking during the design working life of the facilities concerned, among waves expected as attacking at the location where the facilities are to be installed.

Waterways and basins
means the water areas where ships navigate or anchor, such as navigation channels, basins, and small craft basins.

1.3 Performance-based Design

1.3.1 Performance-based Design Systems

Fig. 1.3.1 shows a basic framework of the performance-based design of port facilities.[5] References 1), 2), 3), and 4) are considered as higher-level standards in this system. In the figure, the "objective" is the reason why the facility concerned is needed, the "performance requirements" is the performance of the facilities needed to achieve the objective plainly explained from the viewpoint of accountability, and the performance criteria is the technical explanation of a set of rules needed to verify the performance requirements. According to this hierarchy consisting of the objective, the performance requirements, and the performance criteria, the "ministerial ordinance to set technical standards for port facilities" (hereafter referred to as "ministerial ordinance") corresponding to the higher-level criteria specifies the objectives and the performance requirements of facilities, and the "public notice to set the details of technical standards for port facilities (hereafter referred to as "public notice")" that defines the requirements conforming to the ministerial ordinance specifies the performance criteria.

The performance verification is an act to verify that the performance criteria are satisfied. No particular method is mondatory for it. Actual performance verification methods, allowable failure probabilities, allowable deformation limits, etc. are left to the discretion of the designers of the facilities concerned. This document is therefore positioned as a reference for the designers to correctly understand the standards stipulated based on the performance criteria. This document illustrates the standard performance verification methods, allowable failure probabilities, and the standard ways of thinking about deformation limit values with examples. This document does not, however, intend to discourage the development and introduction of new technologies. If the designers set performance criteria for the performance verification of the facilities concerned other than those specified by the notifications and can prove that the performance requirements are met, they may assume that the facilities concerned conform to the criteria.

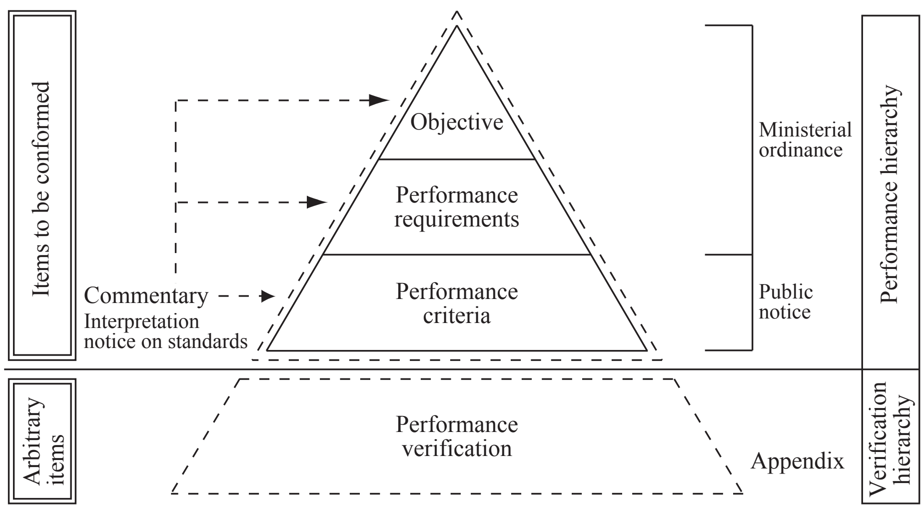

Fig. 1.3.1 Positioning of Performance Hierarchy and Performance Verification

1.3.2 Classification of Performance Requirements

For the sake of convenience, the performance requirements specified by ministerial ordinances of the technical standards is classified according to the range of applicable facilities, the category of performance, and the allowable degree of damage. The range of applicable facilities means whether the performance requirements is on a facility-by-facility basis or common to all facilities. The category of performance means whether the performance requirements are on structural responses to action or on the requirements for usability of facilities and enhancement of convenience.

Refer to **Fig. 1.3.2** for the classification of performance requirements.

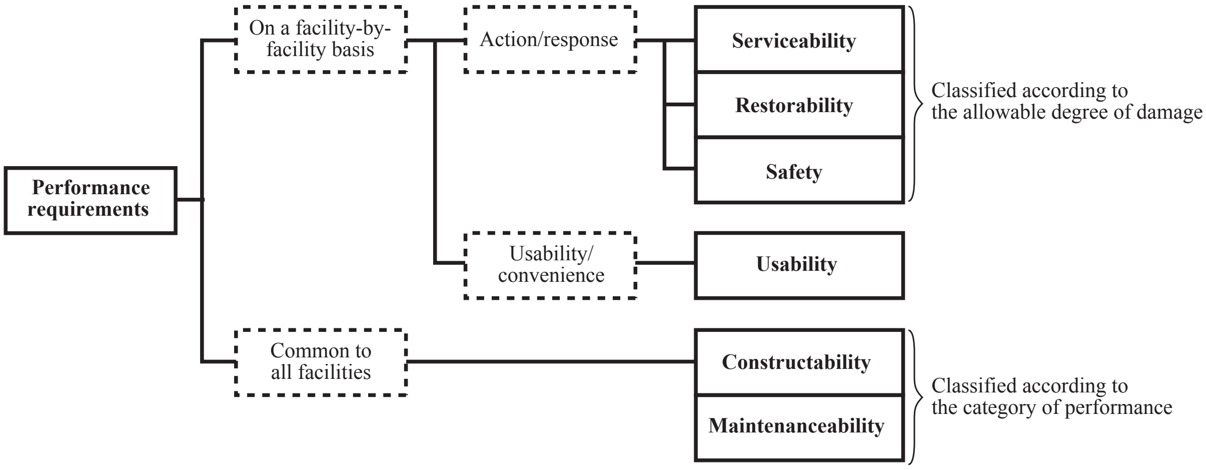

Fig. 1.3.2 Classification of Performance Requirements

1.3.3 Performance Requirements

Performance requirements are the performance required for facilities to achieve their objectives. It includes performance on the structural responses and structural dimensions, constructability, maintenanceability, etc. of the facilities. Performance on structural responses of a facility is classified into three categories according to the allowable degree of damage: (1) serviceability, (2) restorability, and (3) safety.

These categories are arranged in order of the allowable degree of damage: (3) safety > (2) restorability > (1) serviceability. **Fig. 1.3.3** shows the performance requirements for structural responses of port facilities.[5] In the figure, the vertical and horizontal axes show the annual exceedence probability of action and the degree of damage, respectively. The curve in the figure shows the performance of facilities. Except permanent actions, the characteristic values of actions are generally determined depending on their annual occurrence probabilities. Different amounts of action cause different degrees of damage to facilities. Damage to facilities caused by variable or permanent actions with a relatively high annual exceedence probability is not acceptable. Since protecting facilities from damage by accidental actions with a very low annual exceedence probability is economically unreasonable, a small amount of damage to facilities caused by accidental actions is acceptable. The following summarize the basic concepts on performance requirements for port facilities:

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

(2) As for accidental actions (with an annual exceedence probability of about 0.01 or less), satisfaction of performance either of serviceability, restorability, or safety taking account of the expected functions and significance of facilities. Except in the cases where facilities are high seismic resistance structure and where damage to facilities affects a significant influence on human life, property, or social and economic activities, performance against accidental actions is basically not required. It does not, however, deny the necessity of verification against accidental actions conducted by the persons responsible for performance verification in facility owners.

The threshold value of 0.01 used in the above Items (1) and (2) is just for the sake of convenience and unrestrictive. It is only a guide for the cases where design working life falls within a standard range.

For example, when designing a facility having a function of transporting emergency supply materials immediately after a big earthquake, it is required to set its degree of damage caused by accidental actions small as shown by the facility A in **Fig. 1.3.3** (ensuring serviceability). When designing a facility having a minimum function against accidental actions, it is necessary to set an allowable degree of damage at a relatively large value and make sure that the facility does not suffer fatal damage (ensuring safety).

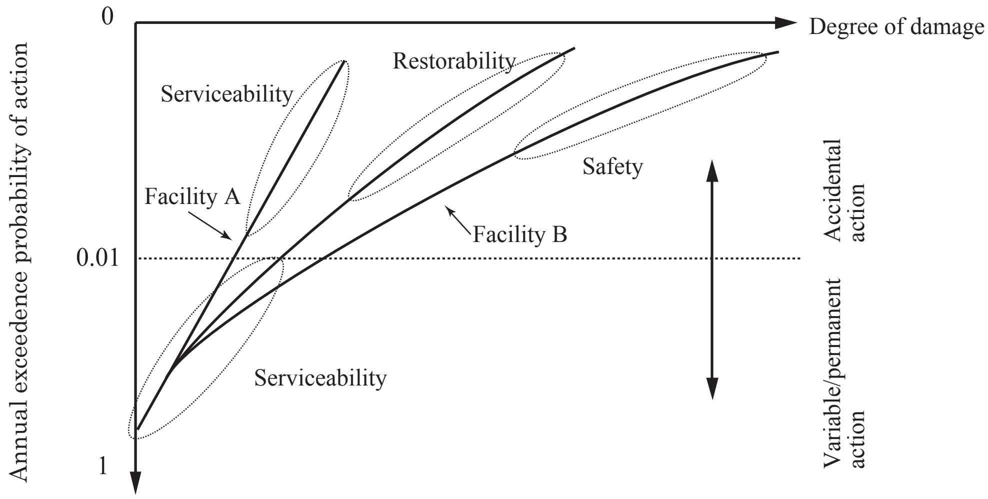

Fig. 1.3.3 Conceptual Diagram of the Relation Between Design situations and Required Performance

Performance requirements for structural responses of the subject facilities of technical standards given in ministerial ordinances specify, based on the above concepts, the minimum requirements for individual facilities to have from the view point of public welfare. Responsible persons for the construction, improvement, and maintenance of the subject facilities of technical standards can therefore set as necessary performance levels higher than these criteria as the performance requirements for the facilities, taking account of their surrounding situations and required functions. Requirements for crest heights, harbour calmness, and ancillary facilities are also given as performance requirements for structural dimensions from the viewpoints of the usability and convenience of facilities. Ministerial ordinances specify performance requirements for structural responses and structural factors on a facility-by-facility basis. However, the following performance requirements for constructability and maintenanceability are factors common to all facilities:

- Constructability: performance required for constructing facilities. Refer to **Part I, Chapter 2, Section 2 Construction of Facilities Subject to the Technical Standards.**
- Maintenanceability: performance required for maintaining facilities. Refer to **Part I, Chapter 2, Section 3 Maintenance of Facilities Subject to the Technical Standards.**

1.3.4 Actions

Actions are classified into three categories mainly according to time history in their amounts and their social risks to be addressed: permanent, variable, and accidental actions. **Table 1.3.1** shows examples of dominating actions to be considered in the performance verification of port facilities.

Performance verification shall properly take account of the effects of actions on the facility concerned. The return periods of actions taken into consideration in performance verification shall be appropriately set based on the characteristics of individual actions, the significance of structures, and the design working life of the facility. It should be noted that the return period means the average interval between the occurrence of actions of a certain amount or more and is different from the design working life. For example, the probability that an action with a return period of 50 years (annual exceedence probability: 1/50 = 0.02) occurs during a design working life of 50 years is $1-(1-0.02)^{50} = 0.64$ if the past history of actions does not affect the annual probability of exceedence. Actions with a return period either longer or shorter than the design working life also have a certain probability of occurence in the design working life. When the structure of the facilities under construction is different from the one expected at the time of completion, it is necessary to take account of differences in the effects of actions on the structure during construction.

Table 1.3.1 Classification of Dominating Actions

Category	Action
Permanent action	Self weight, earth pressure, environmental actions such as temperature stress, corrosion, freezing and thawing, etc.
Variable action	Waves, winds, water level (tide level), surcharge of cargo or vehicle, action due to ship berthing/tracting, Level 1 earthquake ground motion, etc.
Accidental action	Collision with a ship or other object except when berthing, fire, tsunami, Level 2 earthquake ground motion, accidental waves, etc.

1.3.5 Design Situation

When conducting performance verification, a design situation, which means a combination of actions taken into account in the verification shall be defined. They are classified into three categories: permanent, variable (where variable actions are dominating actions), and accidental (where accidental actions are dominating actions) situations.

Actions are generally divided into dominating and non-dominating actions. In the cases where the possibility of simultaneous occurrence of dominating and non-dominating actions is low, the characteristic values of the non-dominating actions are likely to be those frequently occurring in a design working life with a relatively high annual exceedence probability. It is unreasonable to set all characteristic values of actions with a low possibility of simultaneous occurrence at values with a low annual exceedence probability and to combine them. The general principle on the combination of such actions is called the Turkstra's rule.

In conducting performance verification of port facilities, a design situation may have a number of situations in which dominating actions are different from each other. This document hence uses an expression "--- situation with respect to --- (dominating action)" to distinguish dominating actions. For example, if dominating actions are variable waves, " variable situation in respect of waves" is written.

References

1) ISO 2394 : General principles on reliability for structures, 1998
2) Ministry of Land, Infrastructures and Transport: Basics related to Civil Engineering and Architecture Design, Oct. 2002
3) Japan Society of Civil Engineering: Comprehensive design code (draft)-Principle and guide line for the preparation of structural design based on performance design concept-, Mar. 2003
4) Japan Association for Earthquake Engineering: design principle for foundation structures based on performance design concept, Mar. 2006
5) Nagao, T and F. Kawana: performance prescription of the design method for port and harbour facilities, 60th Annual Meeting of JSCE, 2005

1.4 Performance Criteria

Public Notice

Fundamentals of Performance Criteria

Article 2

The performance criteria for the facilities subject to the Technical Standards as specified in this Public Notice can be used as the requirements for verification of the performance requirements. The same applies to the performance criteria not specified in this Public Notice but proved to satisfy the performance requirements of the facilities subject to the Technical Standards.

[Technical Note]

Performance criteria are the technical regulations needed to verify performance requirements. Meeting the performance criteria given here is hence considered as meeting performance requirements. Public notices specify performance criteria on only general facilities of dominating structural types. In constructing, improving, or maintaining other structural types of the subject facilities of technical standards, or in assuming specific design situations, therefore, performance criteria shall be properly specified taking account of performance criteria for similar structural types and the surrounding situations of the facilities concerned.

Performance criteria given in public notices specify, according to performance requirements, the performance required for facilities to have from the viewpoint of public welfare. Responsible persons for constructing, improving, or maintaining the subject facilities of technical standards can hence set higher-level codes than those given in public notices. In such cases, however, the setting should be appropriately made based on a proper approach such as life cycle cost minimization.

1.5 Performance Verification

Public Notice

Fundamentals of Performance Verification

Article 3

1 Performance verification of the facilities subject to the Technical Standards shall be conducted using a method which can take account of the actions to the facilities, requirements for services, and the uncertainty of the performance of the facilities concerned or other methods having high reliability.

2 The performance verification of the facilities subject to the Technical Standards shall be made in principle by executing the subsequent items taking into consideration the situations in which the facilities concerned will encounter during the design working life:

(1) Appropriately select the actions in consideration of the environmental conditions surrounding the facilities concerned and others.

(2) Appropriately select the combination of the actions in consideration of the possible simultaneous occurrence of dominant and non-dominant actions.

(3) Select the materials of the facilities concerned in consideration of their characteristics and the environmental influences on them, and appropriately specify their physical properties.

[Commentary]

(1) Fundamentals of Performance Verification

① Methods capable of taking account of actions, requirements for services, and the uncertainty of the performance of the facilities concerned

The methods capable of taking account of requirements for services and the uncertainty of the facility performance concerned are the performance verification methods capable of properly taking account of the uncertainty of the performance of the facilities concerned such as the uncertainty of actions and strengths caused by the uncertainty inherent to various design parameters such as natural conditions, material characteristics, and analysis methods. Reliability-based design methods shall be generally used.

The performance verification using a reliability design method needs to properly evaluate actions, and the uncertainty inherent to various design parameters relating to the performance of the facilities concerned and properly set target failure probabilities or reliability indices.

The performance verification using the level 1 reliability-based design method (partial factors method) needs to properly evaluate the uncertainty of design parameters and set the partial factors reflecting target reliability indices.

② Other reliable methods

Other reliable methods are in principle performance verification methods to specifically and quantitatively evaluate the performance of the facilities concerned. They generally include numerical analysis methods, model test methods, and in situ test methods. If these methods are inappropriate to use, however, methods to indirectly evaluate the performance of the facilities concerned based on past experiences taking account of various conditions such as natural conditions can be interpreted as one of the other reliable methods.

③ Corrosion of steel products

The performance verification of the subject facilities of technical standards shall be carried out properly taking account of the corrosion of steel products according to various conditions such as natural conditions. Since the steel products used for the subject facilities of technical standards are generally installed in highly corrosive environments, anticorrosion measures shall be taken using anticorrosion methods such as cathodic protection methods, coating methods, etc.

(1) Performance Verification Methods and Performance Criteria

Performance verification is an act to verify that performance criteria are satisfied. Ministerial ordinances and public notices do not define specifications for verification. Designers conducting performance verification shall take responsibility for using reliable methods. **Table 1.3.2** summarizes currently available verification methods on structural responses to actions recommended for individual design situations. Reliability-based design methods are in principle applied to the performance verification for permanent and variable situations, and numerical analysis methods are used for accidental situation. If the methods shown in **Table 1.3.2** cannot be used due to insufficient technical knowledge, methods based on past experiences may be used. When using the verification methods shown above, note the following:

① Reliability-based design methods
The performance verification using a reliability-based design method needs to properly evaluate actions, strengths, and the uncertainty inherent to various design parameters relating to the performance of the facilities concerned and properly set target failure probabilities or reliability indices. The performance verification using the level 1 reliability-based design method (partial factor method) needs to properly evaluate the uncertainty of design parameters and set the partial factors reflecting target reliability indices.

② Numerical analysis methods
The performance verification using a numerical analysis method needs to study the applicability of the method concerned from the viewpoints of the behaviors of actual structures in the past and the reproducibility of test results and carefully judge the reliability of the method concerned.

③ Model test methods or in-situ test methods
The performance verification using a model test method or a in-situ test method needs to carefully evaluate the performance of the facilities concerned taking account of differences in response between models and actual structures and of the accuracy of tests and tests.

④ Methods based on past experiences
When performance verification using a method based on past experiences is unavoidable, it should be noted that the number of actual applications does not necessarily mean high reliability.

Table 1.3.2 Performance verification methods recommended for individual Design situations

Design situation	Dominating action	Performance verification method
Permanent situation Variable situation	Self weight, earth pressure, winds, waves, water pressure, action due to ship berthing/tracting, surcharge	Reliability-based design method (partial factor method and others)
		Model test method, or in-situ test method
	Level 1 earthquake ground motion	Reliability-based design method (partial factor method and others)
		Numerical analysis method (nonlinear seismic response analysis taking account of dynamic interaction between the ground and the structure)
		Model test method
Accidental situation	Collision with a ship, tsunami, Level 2 earthquake ground motion, accidental waves, fire	Numerical analysis method (method capable of specifically evaluating the amount of deformation or degree of damage)
		Model test method or in-situ test method

Taking account of the conformity of technical standards to international standards and the accountability of designers, this document adopts the following methods: for the permanent and variable situations, a reliability-based design method capable of quantitatively evaluating the stability of facilities; for the accidental situation, a numerical analysis method capable of specifically evaluating the amount of deformation and the degree of damage caused by actions.

A typical breakwater with a design working life of about 50 years, for example, needs to have usability against waves with a 50 year return period. Verify the usability by checking that the probability of failure against the sliding, overturning and foundation failure of the breakwater is not higher than the allowable value. Setting this allowable failure probability at a value as low as about 1% shall be considered to ensure the serviceability.

In performance verification for the accidental situation, properly assume actions that have a low possibility of occurrence in the area concerned but are unignorable to ensure social safety based on disaster cases and scenarios, use a numerical analysis method to evaluate the responses of the facility concerned to the actions, and judge if the degree of damage falls within a permissible range. Persons responsible for performance verification shall properly set a permissible range of deformation depending on the functions required for the facility after suffering damage from the actions concerned.

Other performance verification methods shall include the methods that persons in charge of

Table 1.3.3 Expected Performance Verification Methods for Each Facility or Structure Type, and for Each Design situation and Verification Item (1/4)

Facility or structure type	Design situation	Verification item	Assumed performance verification method						Facilities that can follow this performance verification method
			Reliability design method		Numerical analysis method (dynamic analysis method)	Methods based on specifications of previous design methods (formal partial factor methods)	Methods based on similar structure types or other standards	Methods based on empirical determinations	
			Level 1 reliability design methods (partial factor methods)	Level 3 reliability design methods (methods that consider probabilistic deformation)					
Composite breakwater	Permanent situation related to self weight	Ground slip failure	○						Upright breakwater, gravity type special breakwater, sediment control groin, groin, training jetty, etc.
	Variable situation associated with waves	Sliding or overturning of the upright portion, bearing capacity of the foundation ground	○	○ Sliding					
	Variable situation associated with level 1 earthquake ground motion	Sliding or overturning of the upright portion, bearing capacity of the foundation ground			○	○			
	Accidental situation	Deformation/damage			○ Level 2 earthquake ground motion	○ Tsunami, etc.			
	–	Crown height, harbor calmness, etc.						○	
Sloping breakwater	Permanent situation associated with self weight	Ground slip failure				○			Rubble revetment, etc.
	Variable situation associated with waves	Sliding or overturning of the superstructure, failure of the ground, etc.				○			
	Variable situation associated with level 1 earthquake ground motion	Sliding or overturning of the superstructure, failure of the ground, etc.			○	○			
	Accidental situation	Sliding or overturning of the superstructure, failure of the ground, etc.			○ Level 2 earthquake ground motion	○ Tsunami, etc.			
	–	Crown height, harbor calmness, etc.						○	
Pile type breakwater	Overall					○			
Breakwater with wide footing on soft ground	Overall					○			
Revetment	Overall						○ See mooring facilities, etc.		Breakwater, parapet, seawall, etc.
Lock	Overall					○			Water gate, etc.

* Expected verifications are shown by ○. As much as possible, this table shows all the verification items for the expected performance verification methods of this document, but does not rule out verification by other appropriate methods. This table does not include determination of liquefaction or study of precipitation, so a separate study is required.

Table 1.3.3 Expected Performance Verification Methods for Each Facility or Structure Type, and for Each Design situation and Verification Item (2/4)

Facility or structure type	Design situation	Verification item	Assumed performance verification method: Reliability design method: Level 1 reliability design methods (partial factor methods)	Level 3 reliability design methods (methods that consider probabilistic deformation)	Numerical analysis method (dynamic analysis method)	Methods based on specifications of previous design methods (formal partial factor methods)	Methods based on similar structure types or other standards	Methods based on empirical determinations	Facilities that can follow this performance verification method
Gravity type quaywall	Permanent situation associated with self weight	Ground slip failure	○						Placement type cellular-bulkhead quaywall (however, not including verification of sheer deformation, the main bodies of the cells, arcs, and joints), gravity type revetment, etc.
	Permanent situation associated with earth pressure	Sliding or overturning of the wall, bearing capacity of the foundation ground	○						
	Variable situation associated with level 1 earthquake ground motion	Sliding or overturning of the wall, bearing capacity of the foundation ground			○	○			
	Variable situation associated with level 2 earthquake ground motion	Deformation			○				
	---	Dimensions of the base, ancillary facilities, etc.						○	
Sheet Piled quaywall	Permanent situation associated with self weight	Ground slip failure	○						Sheet piled revetment, etc.
	Permanent situation associated with earth pressure	Stress of sheet pile and tie rods	○						
	Permanent situation associated with earth pressure	Stress of waling				○			
	Variable situation associated with level 1 earthquake ground motion	Stress of sheet pile, tie rods, and waling			○	○			
	Variable situation associated with ship action	Stress of tie rods and waling				○			
	Overall	Anchorage work (anchorage wharves, coupled pile anchorage, anchorage sheet pile, concrete wall anchorage)				○			
	Accidental situation associated with level 2 earthquake ground motion	Deformation/cross-sectional strength of sheet pile, tie rods, and anchorage work			○				
	---	Dimensions of the base, ancillary facilities, etc.						○	
Cantilevered sheet pile type quay wall	Overall					○			Sheet piled revetment, etc.

* Expected verifications are shown by ○. As much as possible, this table shows all the verification items for the expected performance verification methods of this document, but does not rule out verification by other appropriate methods. This table does not include determination of liquefaction or study of precipitation, so a separate study is required.

Table 1.3.3 Expected Performance Verification Methods for Each Facility or Structure Type, and for Each Design situation and Verification Item (3/4)

Facility or structure Type	Design situation	Verification item	Assumed performance verification method						Facilities that can follow this performance verification method
			Reliability design method		Numerical analysis method (dynamic analysis method)	Methods based on specifications of previous design methods (formal partial factor methods)	Methods based on similar structure types or other standards	Methods based on empirical determinations	
			Level 1 reliability design methods (partial factor methods)	Level 3 reliability design methods (methods that consider probabilistic deformation)					
Double sheet piled quaywall	All					○			
Embedded Type Cellular-Bulkhead Quaywall	Permanent situation associated with earth pressure	Sheer deformation cell crown deformation				○			Placement type cellular-bulkhead quaywall, cell type revetment, steel cell type dolphin, etc.
	Permanent situation associated with earth pressure	Sliding of the wall, bearing capacity of the foundation ground				○			
	Permanent situation associated with earth pressure	Stress of the main bodies of the cells and arcs	○						
	Permanent situation associated with self weight	Ground slip failure	○						
	Variable situation associated with level 1 earthquake ground motion	Sliding of the wall, bearing capacity of the foundation ground, cell crown deformation			○	○			
	Accidental situation associated with level 2 earthquake ground motion	Deformation			○				
	---	Dimensions of the base, ancillary facilities, etc.						○	
Quaywall with relieving platform	Overall					○			
Floating pier	Variable situation associated with wave or ship action	Verification of the floating body					○		Floating breakwater, etc.
	Overall	Verification of the mooring					○		
	---	Dimensions and ancillary facilities						○	
Mooring buoy	Variable associated with ship action	Verification of the anchoring chain of floating body, ground chain, sinker chain, mooring anchor, etc.				○			
	---	Dimensions, etc.						○	

* Expected verifications are shown by ○. As much as possible, this table shows all the verification items for the expected performance verification methods of this document, but does not rule out verification by other appropriate methods. This table does not include determination of liquefaction or study of precipitation, so a separate study is required.

Table 1.3.3 Expected Performance Verification Methods for Each Facility or Structure Type, and for Each Design situation and Verification Item (4/4)

Facility or structure type	Design situation	Verification item	Assumed performance verification method						Facilities that can follow this performance verification method
			Reliability Design Method		Numerical analysis method (dynamic analysis method)	Methods based on specifications of previous design methods (formal partial factor methods)	Methods based on similar structure types or other standards	Methods based on empirical determinations	
			Level 1 reliability design methods (partial factor methods)	Level 3 reliability design methods (methods that consider probabilistic deformation)					
Open-type wharf on vertical piles	Variable situation associated with ship action, level 1 seismic action, or loading	Verification of pile axial strength				○			Open-type wharf on coupled piles, strut type pier, jacket type piled pier, detached piled pier, pile type dolphin
	Variable situation associated with ship action or loading	Pile stress	○						
	Variable situation associated with level 1 earthquake ground motion	Pile stress	○		○				
	Accidental situation associated with level 2 earthquake ground motion	Deformation/damage			○				
	Overall	Verification of earth- retaining section					○ See mooring facilities, etc.		
	---	Dimensions of the base, ancillary facilities, etc.						○	
Shallow draft wharf	Overall						○ See mooring facilities, etc.		
Mooring posts and mooring rings	Variable situation associated with ship action	Stability of members and structures				○			
	---	Installation location, spacing, etc.						○	
Fenders	Variable situation associated with ship action	Berthing energy				○			
	---	Arrangement, etc.						○	
Aprons	Variable situation associated with loading	Verification of pavement soundness				○			
	---	Size, width, slope, etc.						○	

* Expected verifications are shown by ○. As much as possible, this table shows all the verification items for the expected performance verification methods of this document, but does not rule out verification by other appropriate methods. This table does not include determination of liquefaction or study of precipitation, so a separate study is required.

performance verification can freely select. Methods of performance verification other than those listed in **Table 1.3.2** may be used for the performance verification of the subject facilities of technical standards. The persons in charge may also adopt new verification methods. The methods capable of specifically evaluating the performance of the facility concerned, such as those to probabilistic evaluation of indices like a total amount of deformation incurred during the design working life and the life cycle cost, are especially recommendable from the viewpoint of the reasonable performance verification. There may be a method, for example, to verify the performance of the facility concerned taking account of actions corresponding to various return periods as much as possible.

A typical example is the method to use a total amount of deformation incurred during the design working life and the life cycle cost as verification indices and their probabilistic control. From the viewpoint of the reasonable performance verification, such a method should be recommended because it can specifically evaluate the performance of the facility concerned. **Table 1.3.2** has no intention to exclude these methods.

The above reliability-based design methods and numerical analysis approaches have not been established as the performance verification methods for all types of port facilities. They are inapplicable to some facilities. It is therefore necessary to select appropriate performance verification methods for such facilities, taking account of the methods based on the setting used in conventional design methods (methods based on the conventional allowable safety factor method and the allowable stress design method). The methods based on the setting used in conventional design methods are those that use a verification equation in the form of partial factors with no essential change from conventional design methods to allow the latest knowledge and findings to be immediately reflected on performance verification. **Table 1.3.3** shows the performance verification methods assumed in this document corresponding to facility-wise and structure type-wise performance criteria given in public notices. The verification of the variable situation of the cusing the seismic coefficient method needs to calculate seismic coefficients for verification. This document describes the methods of calculating seismic coefficients for verification with the examples of composite breakwaters, gravity-type quaywalls, sheet pile quaywalls with vertical-pile anchorage, sheet pile quaywalls with coupled-pile anchorage, open type wharves on vertical-piles, and the ground improved by the deep mixing method or the sand compaction pile (SCP) method. As exemplified in **Table 1.3.4**, the methods of calculating seismic coefficients for verification used for the above types of facilities can also be applied to the other types, taking account of their structural characteristics. It should be noted that the performance verification methods shown in this document are only examples and it has no intention to restrict the use of other verification methods.

(2) Actions

The performance verification of a subject facility of technical standards needs to take account of its design working life and the performance requirements, and properly set the amounts of actions. The setting of actions needs to take account of various conditions like natural conditions, and as necessary, actions during design working life affected by estuarine hydraulics, littoral drift, ground settlement, ground liquefaction, and environmental actions. For further details on the setting of actions, refer to the regulations and corresponding commentaries in Article 5 to Article 20 of the Public notice of the Technical Standards.

(3) Combination of Actions

The combination of actions means the types and amounts of actions simultaneously considered in performance verification. The setting of the combination of actions needs to properly take account of the design working life of the facility concerned, its performance requirements, etc. For the combination of dominating and non-dominating actions assumed in the performance criteria specified in the public notices of the technical standards, refer to the tables shown in the commentaries of individual facilities.

In setting the combination of actions, non-dominating actions can be assumed to have an amount with a relatively large annual exceedence probability and occur frequently in the design working life, if the possibility of the simultaneous occurrence of dominating and non-dominating actions is low.

(4) Selection of Materials

Selection of materials needs to properly take account of their quality and durability. Materials used for the subject facilities of technical standards include steel products, concrete, bituminous materials, stone, wood, other metallic materials, plastics, rubber, coating materials, landfill materials (including wastes), recycled materials (slag, coal ash, concrete mass, dredged soil, asphalt concrete mass, shells, etc.). Materials conforming to the Japanese Industrial Standards can be assumed to have quality needed to meet the performance requirements of the subject facilities of technical standards.

(5) Characteristic Values of Materials

Characteristic values of materials mean material properties such as strength, weight per unit volume, friction coefficient, etc. Designers need to properly set the characteristic values of materials based on JIS specification values or other reliable quality data. The setting of the physical characteristics of materials and cross sectional dimensions needs proper consideration of material degradation due to environmental actions.

Table 1.3.4 Method of Calculating the Seismic Coefficient for Verification, for Each Facility or Structure Type

Facilities for which the method of calculating the seismic coefficient for verification is specified		Seismic coefficient for verification	Facilities to which the method of calculating the seismic coefficient for verification can be applied
Composite breakwater (caisson type)		Seismic coefficient for verification considering deformation	Composite breakwater (block, cellular block), upright breakwater, sloping breakwater, breakwater armored with wave-dissipating blocks, gravity type special breakwater, caisson type dolphin (not affected by earth pressure), cell type dolphin (not affected by earth pressure)
Breakwater with wide footing on soft ground		Operating seismic coefficient (= maximum acceleration / gravitational acceleration)	–
Gravity type quaywall (caisson type)		Seismic coefficient for verification considering deformation	Gravity type quaywall (l-shaped block, block, cellular block), upright wave-dissipating type quaywall, embedded type cellular-bulkhead quaywall, placement type cellular-bulkhead quaywall, quaywalls with relieving platforms, caisson type dolphin (affected by earth pressure), cell type dolphin (affected by earth pressure), gravity type revetment, embedded type cellular-bulkhead revetment, placement type cellular-bulkhead revetment, rubble type revetment
Sheet piled quaywall	Vertical pile anchorage	Seismic coefficient for verification considering deformation	Sheet piled quaywall (sheet pile anchorage type, concrete wall anchorage type), free standing sheet piled quaywall, sheet piled quaywall with raking pile anchorages, double sheet piled quaywall
	Coupled pile anchorage	Seismic coefficient for verification considering deformation	–
Open-type wharf on vertical piles	Pier	Seismic coefficient for verification using the response spectrum	Open-type wharf on coupled raking piles, jacket type piled pier, strutted type pier, detached piled pier, pile type dolphin, pile type breakwater, quaywalls with sheet pile walls with supporting raking piles to the front, mooring pile
	Earth-retaining section	Seismic coefficient for verification considering deformation	–
Improved subsoil	Deep mixing method	Seismic coefficient for verification considering deformation	–
	SCP method	Seismic coefficient for verification considering deformation	–

* With regard to sediment control groins, training jetties, groins, coastal dikes, parapets, seawalls, locks, water gates, shallow draft wharves, and slipways, it is possible to consider the structure type and the facility's response characteristics during seismic movements when applying the above methods of calculating the seismic coefficient for verification.

1.6 Reliability-based Design Method

1.6.1 Outline of Reliability-based Design Method

The reliability-based design method is a method in which the possibility of failure of facilities is evaluated using a technique based on probability theory, and comprises three design levels corresponding to the evaluation method.[1)] Evaluations are performed by the failure probability P_f of the structure at Level 3, highest level, by the reliability index β at level 2, and by a performance verification equation using partial factors, γ at level 1, lowest level as shown in **Table 1.6.1**.

When calculating the failure probability in evaluation by the level 3 reliability-based design method, it is generally necessary to obtain the simultaneous probability density function based on the limit state function, and to perform multiple integrals on the result. However, conducting of standardization of the simultaneous probability density function, and calculation of high order multiple integrals accompany difficulty, so that it is not practical normally. For this reason, techniques such as Monte Carlo Simulation, MCS, etc. are used in numerical calculations of failure probability. Even in such cases, from the viewpoint of reducing the computational load, it is the general practice to apply Variance Reduction Techniques, VRT, etc. rather than the primitive crude Monte Carlo simulation. In the level 2 reliability-based design method, a reliability index which is related to the failure probability is used as an evaluation parameter. The reliability index is calculated based on a method such as First-Order Reliability Method, FORM, or the like. On the other hand, in the level 1 reliability-based design method, verification is performed by calculating design values, which are the products of the characteristic values and partial factors, and then confirming that the design values of resistance R_d are greater than the design values of the effects of actions S_d. Commentaries on the reliability-based design method are available in References 3) and 4) .

Table 1.6.1 Three Levels in Reliability-based Design Method

Design level	Performance verification equation	Evaluation parameter
Level 3	$P_{fT} \geq P_f$	Failure probability
	P_f	
Level 2	$\beta_T \leq \beta$	Reliability index
	β	
Level 1	$R_d \geq S_d$	Design value
	S_d	

Regardless of the method selected, in order to make an accurate quantitative evaluation of the performance of facilities by the reliability-based design method, it is necessary to determine the various indeterminate factors, namely the design parameters which intervene in the performance verification. If this is not achieved, the calculated failure probability or reliability index will have no engineering meaning. Furthermore, in order to achieve design rationalization and construction cost reduction by applying the reliability-based design method, it is necessary to strive for improved accuracy in estimations of the controlling factors with the greatest effect on the design. This is because, in addition to the average values of the design parameters, their standard deviations also affect the failure probability P_f of structures. For this, firstly, it is necessary to designate the controlling factors. For example, evaluation using sensitivity factors is extremely effective as a technique for this. Here, sensitivity factors are indices that express the sensitivity or importance of the various design parameters in the performance of the facilities, as described in detail in **1.6.3 Method of Setting Partial Factors**. Because reliability indices and sensitivity factors are used in calculation of the partial factors in the level 1 reliability-based design method, quantitative evaluation of these values has a large engineering significance.

1.6.2 Level 1 Reliability-based Design Method (Partial Factor Method)

The international standard ISO 2394 "General Principles on Reliability for Structures" and "Basics of Civil Engineering and Architectural Design" (Ministry of Land, Infrastructure, Transport and Tourism) recommend the partial factor method as a standard performance verification method for facilities. Considering conformity to these upper-level standards and simplicity and convenience in practical design work, this document adopts the level 1 reliability-based design method (partial factor method) as the standard performance verification method. However, this does not restrict the use of the level 2 and level 3 reliability-based design methods for performance verification. Rather, because the partial factor method is a simple design method, as described below, adoption of level 2 or level 3 methods for precise control of the possibility of failure is preferable.

The following summarizes the level 1 reliability-based design method as the standard performance verification method.

The level 1 reliability-based design method is a method in which characteristic values are multiplied by partial factors in order to calculate design values, and equation **(1.6.1)** is used to confirm that the design value of resistance R_d is greater than the design value of the effect of actions S_d in order to verify the performance of the facility.

$$Z = R_d - S_d \geq 0 \tag{1.6.1}$$

The design values of the effect of actions S_d and resistance R_d are given by equations **(1.6.2)** and **(1.6.3)**, respectively.

$$S_d = S\left(s_{1_d}, s_{2_d}, s_{3_d}, \cdots\right) \tag{1.6.2}$$

$$R_d = R\left(r_{1_d}, r_{2_d}, r_{3_d}, \cdots\right) \tag{1.6.3}$$

The design values of the individual design parameters necessary in performance verification such as the wave action, the ground motion, material characteristics, etc. are calculated from equations **(1.6.4)** and **(1.6.5).**

$$s_{i_d} = \gamma_{s_i} s_{i_k} \tag{1.6.4}$$

$$r_{j_d} = \gamma_{r_j} r_{j_k} \tag{1.6.5}$$

where

s_{i_d} : design value of design parameter s_i of action effect

γ_s : partial factor of design parameter s_i of action effect

s_{i_k} : characteristic value of design parameter s_i of action effect

r_{jd} : design value of design parameter r_j of resistance

γ_r : partial factor of design parameter r_j of resistance

r_{j_k} : characteristic value of design parameter r_j of resistance

Equations **(1.6.6)** and **(1.6.7)** give the design values of the simplest action effects and resistance, respectively, when $i = j = 1$ (suffixes $i, j = 1$ are omitted). Equation **(1.6.8)** expresses the performance verification equation in that case.

$$S_d = s_d = \gamma_s s_k \tag{1.6.6}$$

$$R_d = r_d = \gamma_r r_k \tag{1.6.7}$$

$$Z = R_d - S_d = \gamma_r r_k - \gamma_s s_k \geq 0 \tag{1.6.8}$$

1.6.3 Methods of Setting Partial Factors

The above **1.6.2** describes the outline of the partial factor method. We describe here the method of setting the partial factors.

In the cases where the stochastic variable X has a normal distribution, the partial factor γ_x used in the level 1 reliability-based design method can be calculated from equation **(1.6.9)** using the reliability index and the sensitivity factor described above.

$$\gamma_X = \left(1 - \alpha_X \beta_{\mathrm{T}} V_X\right) \frac{\mu_X}{X_k} \tag{1.6.9}$$

where

β_{T} : target reliability index

V_X : coefficient of variation of stochastic variable X

μ_X : average value of stochastic variable X

X_k : characteristic value of stochastic variable X

In the cases where the stochastic variable X has a logarithmic normal distribution, the partial factor can be calculated from equation **(1.6.10)**.

$$\gamma_X = \frac{\exp\left(-\alpha_X \beta_T \sqrt{\mathrm{Ln}(1+V_X{}^2)}\right)}{\sqrt{1+V_X{}^2}} \frac{\mu_X}{X_k} \quad (1.6.10)$$

The stochastic variables used in this document have a normal distribution unless otherwise noted.

1.6.4 Setting of Target Safety Level and Target Reliability Index/Partial Factors

In application of reliability-based design methods, how the target safety level is set is a key issue. Methods of setting the target safety level include the following method [1]:

① Method based on accident statistics

② Method based on the average safety level of conventional design criteria (safety factor method, allowable stress method)

③ Method based on comparison with other disaster vulnerabilities

④ Method based on the investment effect necessary for avoiding the risk of human loss

⑤ Method based on the minimization of the life cycle cost

A study [6] of the applicability of these methods to port and harbour facilities revealed the following: Method ① based on accident statistics has difficulty in matching statistics on accidents, which are often caused by human error, with failure probabilities, which are caused by various levels of actions such as waves and earthquakes, whereas method ③ based on comparison with other disaster vulnerabilities and method ④ based on the investment effect necessary for avoiding the risk of human loss do not have high applicability to port and harbour facilities because they were proposed for facilities with a high possibility of direct human loss due to damage to facilities.

Taking these viewpoints into consideration, this document generally uses method ② based on calibration to conventional design criteria as the method of setting target safety levels for cases where the probability distributions of parameters are known and verification methods are compatible with failure mechanisms. However, use of method ④ based on the minimization of life cycle cost is not rejected.

When adopting a method using the life cycle cost as the index, the cost arising during the design working life (assumed to be 50 years) is generally defined as the life cycle cost, and the possibility of multiple disasters is considered. Equation **(1.6.11)** shows the expected value of the life cycle cost. It should be noted that this is a narrow definition of life cycle cost.

$$ELC = C_i + \sum_{j=1}^{m} \frac{E_{f_j}}{T} C_f R \quad (1.6.11)$$

$$R = \sum_{k=1}^{T} \frac{1}{(1+i)^{k-1}} \quad (1.6.12)$$

$$E_{f_j} = \nu_j T P_{f_j} \quad (1.6.13)$$

where

ELC : expected value of life cycle cost
C_i : initial construction cost
m : rank number of action of interest
T : design working life (50 years)
E_{f_j} : expected number of damage occurrence caused by action of interest
C_f : cost of recovery after failure
i : social discount rate
P_f : failure probability due to actions of interest
v_j : average annual occurrence rate of action of interest (=1/R)
R : return period of action of interest

Fig. 1.6.1 shows the general concept of this method. Life cycle cost generally shows different trends depending on the side of the minimum value (optimum value). On the right side (dangerous side) of the minimum value, the life cycle cost is sensitive to changes in failure probability, and rapidly increases as the failure probability increases. On the left side (conservative side) of the minimum value, the life cycle cost gradually increases as the failure probability decreases.

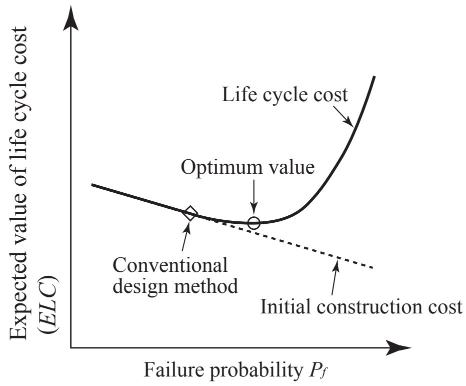

Fig. 1.6.1 Method based on Minimization of Life Cycle Cost

In performance verification of mooring facilities for the permanent situation, the probability distributions of parameters are known and verification methods are compatible with failure mechanisms. Nevertheless, the use of method ② is not necessarily appropriate because multiple failure modes exist in each structural type and there were large differences in the safety levels for each failure mode due to differences in setting in the conventional design methods.[7] Furthermore, the safety levels of the conventional design methods also varied greatly due to the autocorrelation of ground strength, which is affected by the size of the slip arc as in the case of the circular slip failure mode.[8] When using method ⑤, because it is not necessary to consider the action of multiple annual exceedance probabilities in mooring facilities in the permanent situation, the expected total cost expressed by the sum of the initial construction cost and the expected value of failure recovery cost is used as an index, and verification is performed by finding the failure probability for minimizing this index as the optimum value. In this case, the expected total cost is given by equation **(1.6.14)**.

$$ETC = C_i + P_f C_f \tag{1.6.14}$$

where

ETC : expected total cost
C_i : initial construction cost
P_f : failure probability due to action of interest
C_f : cost of recovery after failure

The method of setting partial factors used in this document is based on the following concept.
In the cases where the probability distributions of parameters are known and verification methods are compatible with failure mechanisms, partial factors are generally determined based on calibration to conventional design methods using the allowable safety factor method and similar approaches.

On the other hand, when in performance verification of mooring facilities for the Permanent situation, the probability distributions of parameters are known and the verification methods are compatible with failure mechanisms, but using the partial factors set based on calibration to conventional design methods (allowable safety factor method, allowable stress method, etc.) sometimes leads to the setting of excessively safe and uneconomical cross sections. In such cases, this document recommends the use of partial factors set based on minimization of expected total costs.

In other cases, where the probability distributions of parameters are unknown or verification approaches are not necessarily compatible with failure mechanisms, the setting of target safety levels/partial factors using a probability theory is difficult. Therefore, in such cases, this document determines partial factors stochastically, considering the settings used in conventional design methods (safety factor method, allowable stress method).
Table 1.6.2 summarizes the above-mentioned setting methods by type of facility.

Table 1.6.2 Methods of Setting Target Reliability Indexes/Partial Factors of Major Facilities

Facility	Design situation	Failure mode	Method of setting target reliability index/partial factor
Gravity type breakwater	Permanent situation	Circular slip failure of foundation ground	Method based on minimization of expected total cost
	Variable situation with respect to waves	Sliding of breakwater body Overturning of breakwater body Bearing capacity of the foundation ground	Method based on average safety level of conventional design methods
Gravity type quaywall	Permanent situation	Sliding of wall body Overturning of wall body Bearing capacity of foundation ground Circular slip of foundation ground	Method based on minimization of expected total cost
	Variable situation associated with Level 1 earthquake ground motion	Sliding of wall body Overturning of wall body Bearing capacity of the foundation ground	Method based on setting used in conventional design methods
Sheet piled quaywall	Permanent situation	Embedded length of sheet pile Stress of sheet pile Stress of tie rods Circular slip of foundation ground	Method based on minimization of expected total cost
		Stress of anchorage work (bearing capacity)	Method based on setting used in conventional design methods
	Variable situation associated with Level 1 earthquake ground motion	Embedded length of sheet pile	Method based on setting used in conventional design methods
		Stress of sheet pile Stress of tie member Stress of anchorage work (bearing capacity)	Method based on setting used in conventional design methods
Cellular-bulkhead type quaywall	Permanent situation	Shear deformation Sliding	Method based on setting used in conventional design methods
		Stress of cell shell Stress of arc	Method based on average safety level of conventional design methods
	Variable situation with respect to Level 1 earthquake ground motion	Sliding	Method based on setting used in conventional design methods
Open-type wharf on vertical piles	Variable situation associated with actions caused by ships	Stress of pile (edge yield of pile head)	Method based on minimization of expected total cost
		Bearing capacity of pile	Method based on setting used in conventional design methods
	Variable situation associated with respect to Level 1 earthquake ground motion	Stress of pile (edge yield of pile head)	Method based on average safety level of conventional design methods
		Bearing capacity of pile	Method based on setting used in conventional design methods

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ANNEX 1 Reliability-based Design Method

(1) Level 3 Reliability-based Design Method

In the level 3 reliability-based design method, value of failure probability is assessed directly and cross-sectional dimensions are determined so that failure probability is equal to or lower than an allowable value. Failure probability is calculated by multiple integrals of the joint probability density function of random variables in the failure domain [see equation **(A-1.1)**].

$$P_f = \int \cdots \int_{g(\mathbf{X})<0} f_X(x_1, x_2, \cdots, x_n) dx_1 dx_2, \cdots, dx_n \qquad \text{(A-1.1)}$$

where $x_1, x_2, \ldots x_n$ are stochastic variables, $f_x(x_1, x_2, \ldots x_n)$ is the joint probability density function of the random variables, and $g(\mathbf{X})$ is the limit state function.

The joint probability density function can be expressed by equation **(A-1.2)**, for example, when all random variables are normally distributed.

$$f_{\mathbf{X}}(\mathbf{x}, \mathbf{C}_x) = (2\pi)^{-n/2} |\mathbf{C}_x|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}(\mathbf{x} - \mu_{\mathbf{x}})^T \mathbf{C}_x^{-1} (\mathbf{x} - \mu_{\mathbf{x}})\right] \qquad \text{(A-1.2)}$$

where C_x is the covariance matrix, and μ is the average value.

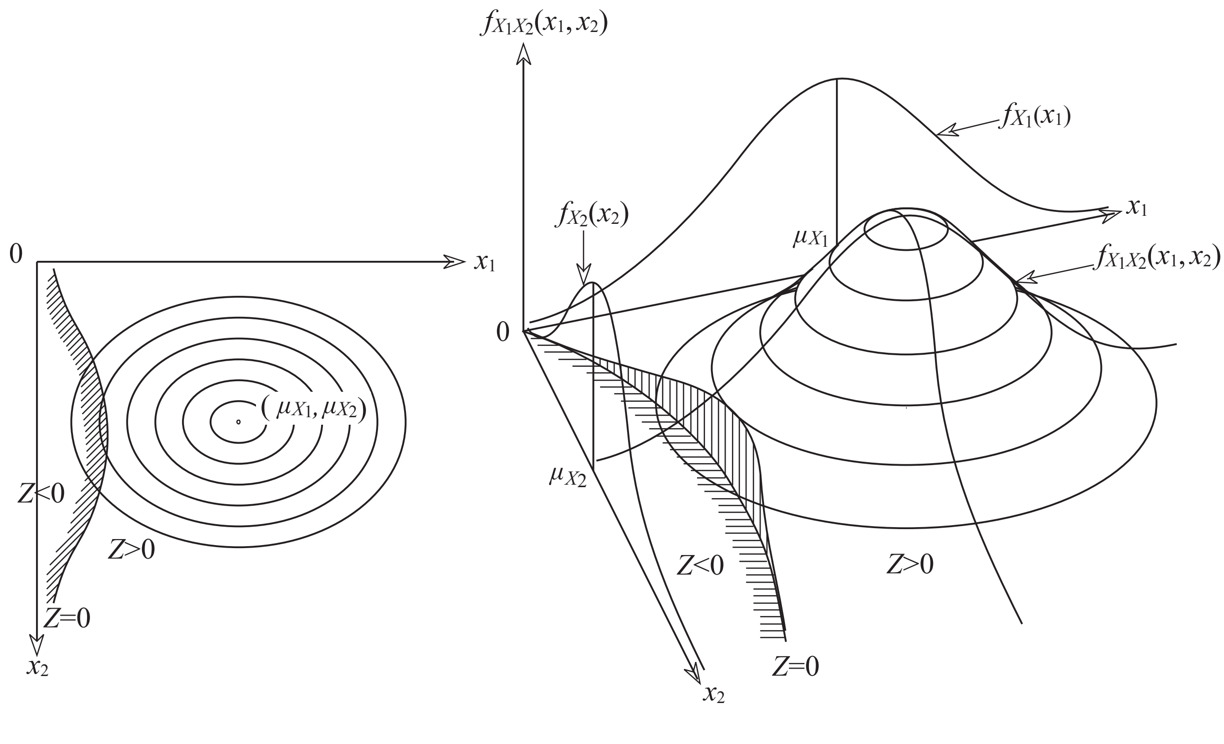


Fig. A-1.1 Concept of Failure Probability

Fig. A-1.1 shows the concept of failure probability for a simple case of two independent variables, where $fx_1(x_1)$ and $fx_2(x_2)$ are marginal probability density functions, and the bell-shaped $fx_1x_2(x_1, x_2)$ is a joint probability density function. In the cases of two variables, the joint probability density distribution can be expressed as a bell-shaped distribution in a three-dimensional space and its multiple integrals gives the volume. The multiple integrals in the whole domain results in the volume = 1. The failure probability is given by the failure domain of this joint probability density function, i.e., the volume of the domain shown by $Z < 0$ in **Fig. A-1.1**.

The application of this multiple integrals to actual problems is, however, difficult in many cases. Triple or higher-order multiple integrals is generally difficult. In some cases, joint probability density functions cannot be expressed in an explicit form. In almost all cases, therefore, the value of failure probability is not assessed directly from equation **(A-1.1)** but by Monte Carlo simulation (hereafter called MCS).

The following shows the general procedure of MCS:

① Pseudo-random numbers (uniform random numbers) are generated.

② The uniform random numbers are transformed into random numbers having a necessary probability distribution and a correlation.

③ The safety of the structure concerned is evaluated using the combination of obtained random numbers.

④ The above evaluation is performed a large number of times, and the number of trials judged as failure is divided by the total number of trials to determine the failure probability.

The random numbers generated by computer follow a certain rule depending on needs, and hence are called pseudo-random numbers. Methods such as the multiplicative congruence method and linear congruence methods have been widely used as algorithms for generating uniform random numbers. Likewise, at present, build-in functions for various applications frequently use these methods. It should be noted, however, that the problem of cycle length, which is one of the requirements for random number generation algorithms, has been pointed out in the case of the linear congruence method. For this reason, other algorithms such as Mersenne Twister are often used. The source code of Mersenne Twister is available on the internet.

The transformation of uniform random numbers into other probability distributions is carried out by inverse operation of the probability distribution function. For example, the following equation **(A-1.3)** can be used for the transformation into normal random variables:

$$x_i = \mu_x \left\{ 1 + \Phi^{-1}(r_i) V_x \right\} \quad \text{(A-1.3)}$$

where r_i is a uniform random number, Φ is the standard normal cumulative distribution function, and μ and V are the average value and the coefficient of variation, respectively.

In addition, the method proposed by Box and Muller [5] is also widely used for transformation into normal random variables. Other transformation methods include the one using the central limit theorem, which uses the fact that the sum of random numbers having the same probability distribution approximates a normal distribution. However, in applying this method, care is necessary with regard to the applicability of the distribution tail, because a very small failure probability is normally required for structures, and accurate evaluation of such a small failure probability demands exact reproducibility of the tail of the probability distribution. Accordingly, due consideration of the applicability of the distribution tail is necessary, especially in assessing value of failure probability.

In the cases where random variables are correlated, independent random variables must be converted into correlated random variables using the covariance matrix transformation.
MCS is the method for obtaining an approximate solution from equation **(A-1.5)** as an alternative to using multiple integrals as shown in equation **(A-1.4)**.

$$p_f = \int \cdots \int I\left[g(\mathbf{x}) \le 0\right] f_{\mathbf{X}}(\mathbf{x}) d\mathbf{x} \quad \text{(A-1.4)}$$

$$p_f \approx \frac{1}{N} \sum_{j=1}^{N} I\left[g(\hat{\mathbf{x}}_j) \le 0\right] \quad \text{(A-1.5)}$$

where I is a failure judgment function. The above expression becomes 1 for $I < 0$ and zero for other cases.

When using MCS, the number of trials must be set carefully because the validity of approximation in equation **(A-1.5)** depends on the number of trials. In MCS, the number of trials is generally set so that the coefficient of variations of the failure probability [equation **(A-1.6)**] will become sufficiently small.

$$V(\hat{p}_f) = \sqrt{\frac{\hat{p}_f(1-\hat{p}_f)}{N}} \frac{1}{\hat{p}_f} \approx \frac{1}{\sqrt{\hat{p}_f N}} \quad \text{(A-1.6)}$$

where V is the coefficient of variation, p_f is the assessed value of failure probability by MCS, and N is the number of trials.

Following Shooman, [6] the error ε attributable to MCS can be calculated from equation **(A-1.7)**.[4] From this, it can be understood that a small failure probability is likely to result in large error if the number of trials is insufficient. Therefore, evaluation of probability based on a small number of trials due to the calculation load in each trial must absolutely be avoided.

$$\varepsilon\% = \sqrt{\frac{1-p_f}{p_f N}} \times 200\% \quad \text{(A-1.7)}$$

Several methods have been devised to improve the calculation efficiency of MCS while maintaining the necessary calculation accuracy. These are collectively called Variance Reduction Techniques (VRTs), while the primitive MCS with no special sampling techniques is called the crude Monte Carlo method. It is thought that VRTs will be used as a standard technique in the future.

The Importance Sampling Method is a typical VRT.[7), 8)] This method introduces the sampling density function $h(\mathrm{x})$ in equation **(A-1.8)**] into equation **(A-1.4)**. In determining the sampling density function, information on the design point obtained from the FORM, as described below, are used in many cases.[7), 8)] It must be noted that the improper setting of the sampling density function may result in slow convergence.

$$p_f = \int \ldots \int I[g(\mathbf{x}) \leq 0] \frac{f_{\mathbf{X}}(\mathbf{x})}{h(\mathbf{x})} h(\mathbf{x}) \, d\mathbf{x} \tag{A-1.8}$$

Methods of improving calculation efficiency other than the importance sampling method include, for example, the Adaptive Sampling method, [9), 10)] the Markov Chain Monte Carlo (MCMC) method, [11), 12)] the Latin hypercube sampling method, [13)] etc. Other methods use Low Discrepancy Sequences called quasi-random numbers [14)] without using the pseudo-random numbers described above.

(2) Level 2 Reliability-based Design Method

The level 2 reliability-based design method assesses the reliability index β, instead of the failure probability, in order to determine the cross-sectional dimensions so as to obtain a value of β greater than the permissible value. The failure probability of a structure decreases as the reliability index increases. In some cases, the reliability index was formerly called the safety index. However, this document will use the term “reliability index.” (The term reliability index is also used in ISO 2394 and elsewhere.)

The reliability index β and the failure probability p_f have the relation shown by equation **(A-1.9)**. **Fig. A-1.2** is a graphic representation of this relationship.

$$p_f = \Phi(-\beta) = 1 - \Phi(\beta) \tag{A-1.9}$$

where Φ is the standard normal cumulative distribution function.

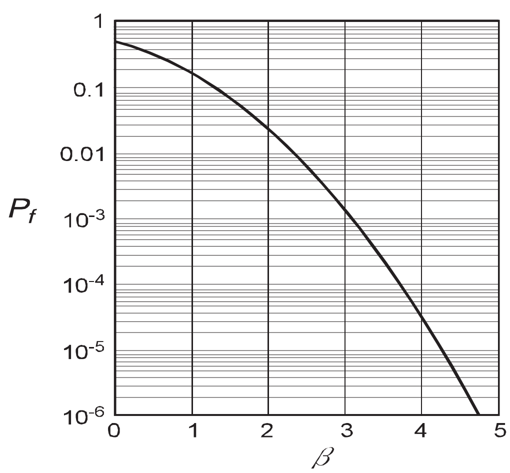


Fig. A-1.2 Relationship between Reliability Index and Failure Probability

Cornell [15)] first formulated the reliability index β. Since the method uses only the first and second order moments (called average value and variance, respectively) of limit state function, it is called the First-Order Second-Moment (FOSM) method.

Assuming that the limit state function Z simply consists of two variables of the resistance R and the action effect S ($Z = R - S$), the reliability index can be obtained from equation **(A-1.10)**. **Fig. A-1.3** shows a graphic representation.

$$\beta = \frac{\mu_Z}{\sigma_Z} = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_S^2}} \tag{A-1.10}$$

where μ is the average value and σ is the standard deviation.

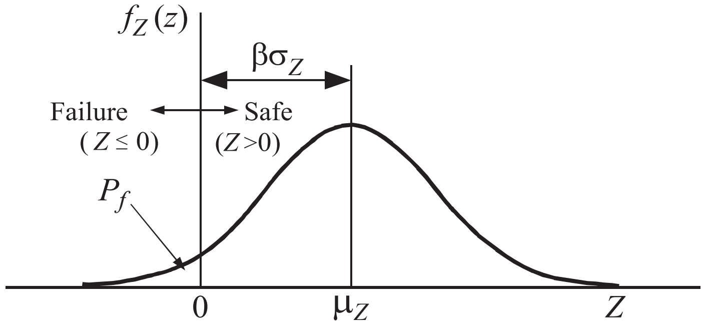


Fig. A-1.3 Reliability index β

The above is the expression for the case of two variables. As a more general expression in the FOSM, the limit state function g is developed around its average value by Taylor's series expansion method. The average and standard deviation of the limit state function are evaluated by using terms up to the first order as shown in equation **(A-1.1)**.

When the limit state function consists of mutually independent random variables x_i (i = 1, ---, n), the average value and standard deviation are evaluated by equations **(A-1.12)** and **(A-1.13)**, respectively. It must be noted that the expression is different when the variables are correlated.

$$g(X) = g(\overline{X}) + \sum_{i=1}^{n} \left(\frac{\partial g}{\partial x_i} \right)_{\overline{X}} \left(x_i - \overline{x_i} \right) \tag{A-1.11}$$

$$\mu[g] = g\left(\overline{X}\right) \tag{A-1.12}$$

$$\sigma[g] = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial g}{\partial x_i} \right)_{\overline{X}}^2 \sigma_{xi}^2} \tag{A-1.13}$$

where μ is the average value and σ is the standard deviation. The mark ¯ attached to variables such as X and xi indicates the average value of the symbol.

Equation **(A-1.14)** gives the reliability index.

$$\beta = \frac{\mu(g)}{\sigma(g)} \tag{A-1.14}$$

The reliability index determined by FOSM has the following defects: It does not reflect probability distribution of random variables. It uses a linear approximation at the average value of the limit state function, and does not consider the probability distribution based on random variables , it may give a non-negligible error when the limit state function is nonlinear, and it gives different reliability indexes depending on differences in the form of expression used for the limit state function (for example, $Z = R - S$ and $Z = R/S - 1$). At the present time, therefore, more accurate approaches such as the FORM described below are generally used. However, in cases, where the object of verification is the amount of deformation and the degree of damage of the structure obtained by nonlinear seismic response analysis, and where the calculation of the failure probability and reliability index using the MCS described above or the FORM and SORM described below involves a heavy calculation load, using the FOSM is considered a simple and easy option for reliability evaluation.

Hasofer and Lind [16] proposed a reliability index which overcomes the defects of FOSM. The index gives accurate results within the range of the first order approximation when the random variables are normal. Rackwitz and Fiessler [17] later proposed a method which extends that method to the cases of random variables other than normal ones. Their method is called FORM (First-Order Reliability Method).

In FORM, random variables are transformed into mutually independent standard normal random variables, and the limit state function in the standardized space consisting of standard normal random variable vectors is assessed. Next, a search is made to identify the shortest distance from the origin of the standardized space to the limit state curved surface (curved surface where the limit state function becomes zero). This distance is defined as the reliability index.

Some points regarding the transformation into standard normal random variables should be noted. First, in the cases of random variables other than normal ones, these are transformed into the normal random variables simultaneously giving the same values of probability density and probability distribution at the position of interest (normal tail transformation). Since the objective here is to find failure probability, the form of the tail distribution has no effect on the failure probability if the probability density and probability distribution are identical. Accordingly, the above transformation into normal random variables will not cause error in the failure probability. Next, in cases where random variables are normal and are also mutually correlated, these must be transformed into a linear combination of independent normal random variables by Cholesky decomposition. Furthermore, in cases of mutually correlated general random variables (random variables other than normal ones), it is also necessary to use the Resenblatt transformation, [18] Nataf transformation [19], etc.

In assessment of the reliability index using FORM, it is necessary to search for the shortest distance between the origin of the standardized space and the limit state curved surface. Therefore, this method can be considered as a kind of optimization problem. Various procedures for calculating the reliability index have been proposed (see References 3) and 4) for details), including a method of calculating convergence on the original coordinate system. Whichever method is used, it is necessary to note that cases in which convergence is very slow or does not occur are conceivable, depending on conditions. As described below, the process of searching for the shortest distance requires the calculation of the directional cosine, and therefore, that of the partial differentiation of the limit state function. However, if the analytical partial differentiation is not possible, numerical differentiation may be used.

The reliability index used in FORM can be expressed as shown in **Fig. A-1.4** for the simple case of two independent variables as the random variables. A feature of FORM is to use the linear approximation of the limit state function with a certain point (design point) as the center for simplification to a problem in two-dimensional space, as shown in **Fig. A-1.3**, and express the reliability index as the distance between the origin and the failure point, without calculating the volume (in the case of two variables) as shown in **Fig. A-1.1**. The fact that error is set to the minimum point in this approximation is of vital importance. Because this is the point where the joint probability density shows its maximum value on the limit state curve surface (surface where the limit state function is zero), this is the search point. **Fig. A-1.4** differs from **Fig. A-1.1** in that the variables are transformed into the standardized space, and as a result, the joint probability density has its maximum value at the origin and is expressed by the concentric contours. Thus, the design point is the point giving the shortest distance from the origin to the limit state curved surface.

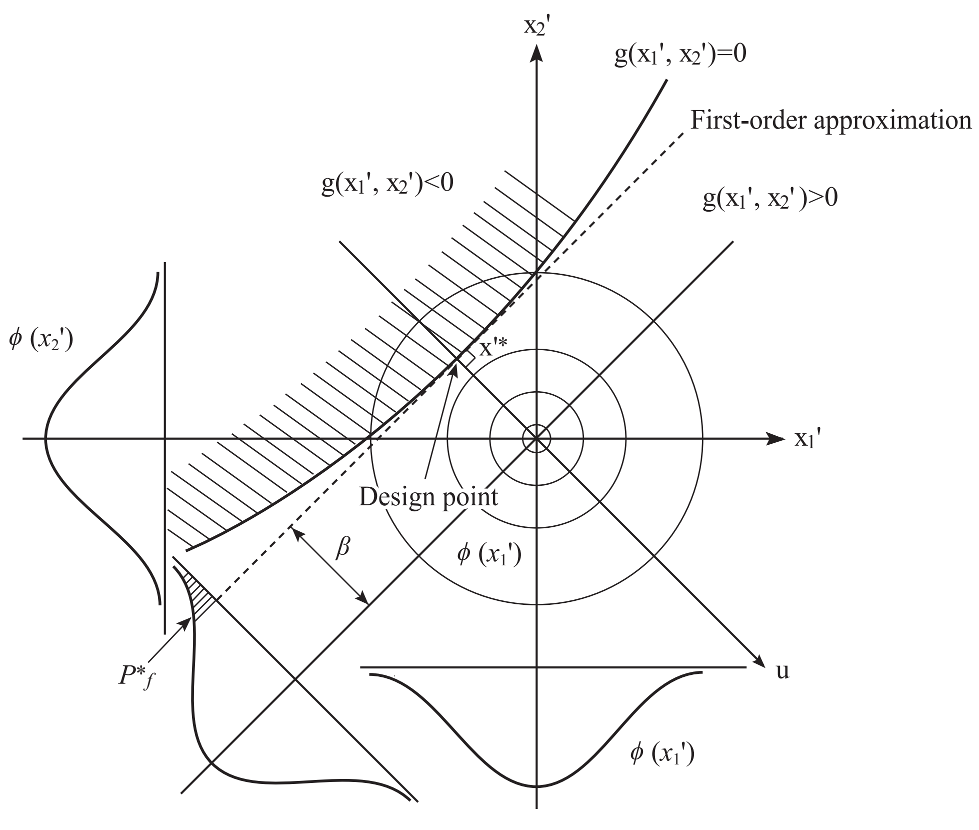


Fig. A-1.4 Reliability Index in FORM

In the cases where random variables are normal and have no mutual correlation, as dealt with by Hasofer and Lind, [16] the reliability index is expressed by equation **(A-1.15)**.

$$\beta = \frac{\mu_Z}{\sigma_Z} = \frac{\sum_i^n \left(\left. \frac{\partial Z}{\partial X_i} \right|_{X^*} \right) \left(\mu_{X_i} - X_i^* \right)}{\sqrt{\sum_i^n \left(\left. \frac{\partial Z}{\partial X_i} \right|_{X^*} \right)^2 {\sigma_{X_i}}^2}} \tag{A-1.15}$$

where

Z : limit state function
X : value of stochastic variable X at the failure point
μ : average value
σ : standard deviation

The process of calculating the reliability index requires the calculation of the sensitivity factor α expressed by equation **(A-1.16)**. The sensitivity factor α is a linear approximate coefficient of limit state function.

$$\alpha_{X_i} = \left(\left. \frac{\partial Z}{\partial X_i} \right|_{X^*} \right) \frac{\sigma_{X_i}}{\sigma_Z} = -\frac{X_i'}{\beta} \qquad (i=1,2,\cdots,n) \tag{A-1.16}$$

where

$$X_i' = \frac{X_i^* - \mu_{X_i}}{\sigma_{X_i}} \tag{A-1.17}$$

Equation **(A-1.16)** expresses the directional cosine of the reliability index to each random variable axis in the standardized space (see **Fig. A-1.5**). The sensitivity factor has a positive value for the parameters on the resistance side and a negative value for those on the action effect side, their sum of squares being 1 when the random variables have no correlation with each other. As is clear from the figure, as the absolute value of the sensitivity factor of a variable approaches 1, the standardized value at the failure point tends to coincide more closely with the reliability index. This means that the variable has a large effect on the reliability index.

In cases where random variables are mutually correlated, the correlation coefficient ρ between the random variables is considered in the standard deviation and sensitivity factor of the limit state function, which are expressed by equations **(A-1.18)** and **(A-1.19)**, respectively.

$$\sigma_Z' = \sqrt{\sum_i^n \sum_j^n \left(\left. \frac{\partial Z}{\partial X_i} \right|_{X^*} \right) \left(\left. \frac{\partial Z}{\partial X_j} \right|_{X^*} \right) \rho_{X_i,X_j} \sigma_{X_j} \sigma_{X_i}} \tag{A-1.18}$$

$$\alpha_i' = \sum_j^n \left(\left. \frac{\partial Z}{\partial X_j} \right|_{X^*} \right) \rho_{X_i,X_j} \sigma_{X_j} \Big/ \sigma_Z' \tag{A-1.19}$$

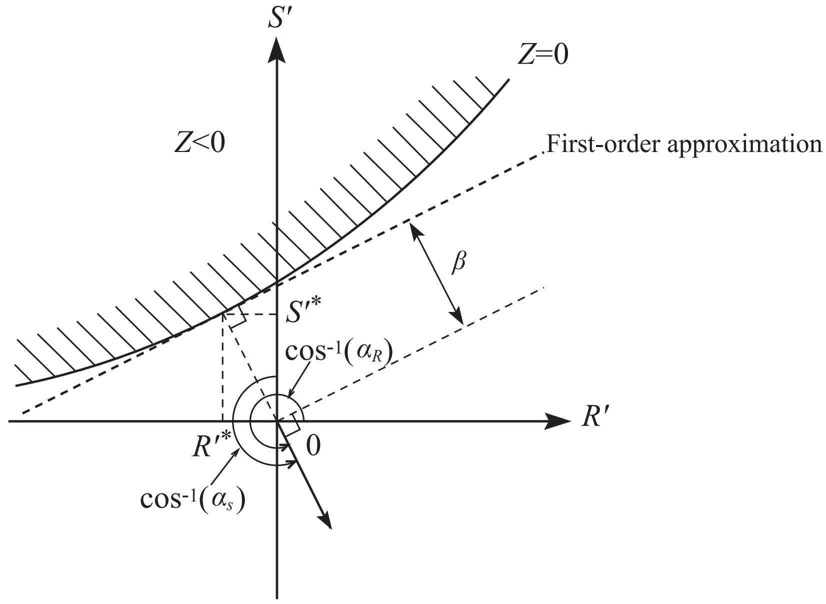


Fig. A-1.5 Reliability Index β and Sensitivity Factor α

The application of the FORM enables accurate evaluation of the reliability index within the range of the first-order approximation. It must be noted, however, that FORM uses the first-order approximation of the limit state function to evaluate the reliability index. For example, when the hatched area in **Fig. A-1.5** shows a real failure domain, FORM approximates it by the dotted line in the figure, causing an error corresponding to the area between the solid and dotted lines. Therefore, in cases where the limit state curved surface shows strong nonlinearity, the FORM may cause error which cannot be ignored.

As an approach to solving the problem inherent to FORM, the Second-Order Reliability Method (SORM) has been proposed.[20] SORM corrects the reliability index obtained by FORM according to the curvature of the limit state curved surface, as shown in equation **(A-1.20)**.

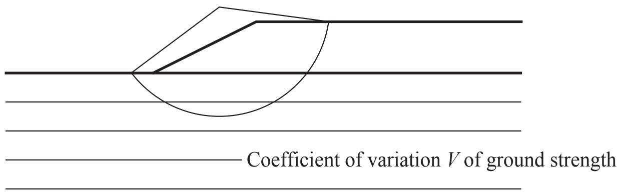
$$P_f \approx \Phi(-\beta)\sum_{j=1}^{k}\left[\prod_{i=1}^{n-1}(1-\beta\kappa_i)\right]^{-1/2}$$
$$\kappa_i = -\left[\frac{\partial^2 y_n}{\partial y_i^2}\right] \tag{A-1.20}$$

where

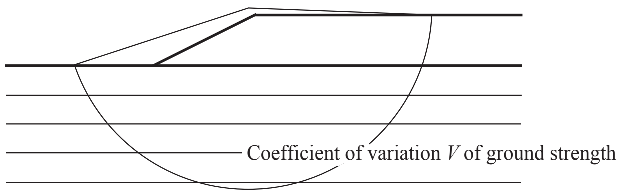
β : reliability index obtained by the FORM, κ_i: principal curvature of the i-th limit state curved surface.

An important point in reliability analysis is the proper selection of an accurate method according to the characteristics of the problem concerned.

Another point to note in reliability analysis is a problem of the spatial autocorrelation of the ground characteristics.[21] The natural sedimentary ground is thought to have a correlation distance of several tens of meters horizontally and several meters vertically. Accordingly, the reliability index and the failure probability must be assessed giving proper consideration to the vertical correlation in particular. This issue is critically important in dealing with problems such as analysis of circular slip failure.



1) Small slip arc: The number n of stochastically independent soil layers crossed by the slip arc is small.



2) Large slip arc: The number n of stochastically independent soil layers crossed by the slip arc is large.

Fig. A-1.6 Effect of Spatial Autocorrelation

Fig. A-1.6 is a schematic illustration of this problem using circular slip failure problems as an example. If only vertical correlation is considered, the number of stochastically independent soil layers crossed by a small slip arc and a large arc is different, as shown in the figure. In such cases, the coefficient of variation of slip resistance will differ depending on the size of the arcs. For example, assuming for simplicity that soil layers which are more than several meters apart are independent, the coefficient of variation of resistance when an arc crosses n independent layers can be expressed as the $n^{1/2}$th power of V.[22] When assessing value of failure probability using MCS, the physical properties of the ground may be sampled according to the autocorrelation function.

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ANNEX 2 Partial Factor and System Reliability

(1) Partial Factor

As shown by equations **(1.6.9)** and **(1.6.10)**, the partial factor is set based on the estimation accuracy, sensitivity factor, and target reliability index of the design parameter. Future progress in research, the development of new materials, and other factors may improve the estimation accuracy of design parameter, and changes in target safety levels from the viewpoint of life cycle cost and other considerations are also conceivable. In such cases, it is necessary to set the partial factors properly, as the sensitivity factors of the design parameters will change. As methods of setting the partial factor in these cases, the following are considered possible:

① Method of modifying the partial factor using the sensitivity factor adopted before the change in reliability.

② Method of modifying the partial factor corresponding to the change in reliability.[23)]

③ Method of setting the partial factor by perform ingrecalibration.

The above method ③ is the most preferable from the viewpoint of appropriate setting of the partial factor. Method ② enables simple but reasonable design, and the simplest method ① can also be used.

In cases where the target reliability index β_T is changed to β_T', the simple method ① may be used in setting partial factors if the partial factor is set with either equation **(1.6.9)** or equation **(1.6.10)** (in which case β_T used in the equation is written as β_T'), using the sensitivity factors, coefficients of variation, and bias of the average values shown in the table of partial factors for each type of structure.

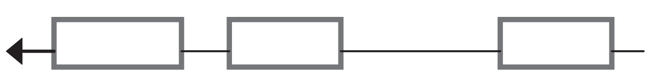
On the other hand, in setting of partial factors using method ② when the target reliability index β_T is changed to β_T', the partial factors can be set by calculating β_T'' for use in setting the partial factor from the target reliability indexes β_T and β_T', the sensitivity factor, and the coefficient of variation before and after the change, and using equations **(1.6.9)** or **(1.6.10)** (writing β_T as β_T'') based on the result.

In cases where method ③ is applied, the partial factor may be set by equation **(1.6.9)** or **(1.6.10)** by performing level 2 or higher level reliability-based design to reevaluate the sensitivity coefficient, and using the target reliability index and sensitivity factor after the change and the coefficients of variation and the bias of the average values shown in the table of partial factors for each type of structure.

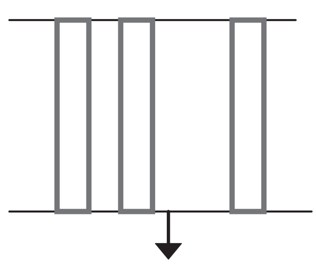
Adoption of new types of structures and structures having the features of multiple conventional structural types is also conceivable. These issues are discussed in Reference 24), which describes the method of setting partial factors for the sloping top breakwater covered with wave-dissipating blocks which has features of two structural types, the breakwater covered with wave-dissipating blocks and the sloping top breakwater.

(2) System Reliability

In performance verification of structures, verification limited to a single failure mode is rarely sufficient. Performance verification of multiple failure modes is normally necessary. For example, taking the problem of stability of a breakwater against external stability as an example, it is necessary to consider three failure modes, namely, sliding, overturning, and foundation failure. It is necessary to assess the value of failure probability of the structure as a system taking into account such multiple failure modes. Structural systems are generally of two types, the series system or the parallel system. A practical issue is the problem of combinations of these systems. From the viewpoint the external stability of breakwaters, any of the failure modes of sliding, overturning, or foundation failure is considered as the failure of the structural system. Thus, this type of system is called a series systems. On the other hand, in the cases where the superstructure is supported by multiple piles, as in piers, yielding of a single pile is not directly considered failure. Such systems are called parallel systems. In other words, series systems suffer system failure when any failure mode occurs, whereas parallel systems fail only when all failure modes occur. The essential definition of the system failure of piers is as described above. However, it should be noted that this document specifies performance-base codes considering a safety allowance.



(a) Series system



(b) Parallel system

Fig. A-2.1 System Reliability

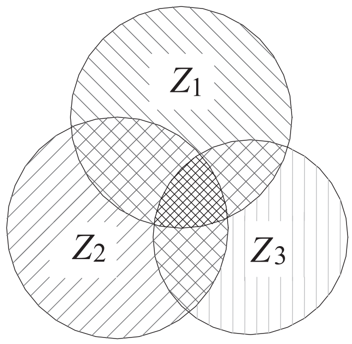


Fig. A-2.2 System Reliability (Case of Three Modes)

In evaluations of system reliability, it is necessary to assess the possibility of higher-order simultaneous failures among various modes. **Fig. A-2-2** shows a conceptual diagram for three modes, where Z_1, Z_2, and Z_3 are failure modes. Referring to the figure, equation **(A-2.1)** is a general formula for calculating the system failure probability *P(F)* when the number of modes is *n*.

$$P(F) = \sum_{i=1}^{n} P(Z_i) - \sum\sum_{i<j}^{n} P(Z_i \cap Z_j) + \sum\sum\sum_{i<j<k}^{n} P(Z_i \cap Z_j \cap Z_k) - \sum\sum\sum\sum_{i<j<k<\ell}^{n} P(Z_i \cap Z_j \cap Z_k \cap Z_\ell) + \cdots \quad \text{(A-2.1)}$$

where Z_i is the *i*-th failure mode.

In cases where the modes can be considered independent, equation **(A-2.2)** expresses the system failure probability.

$$P(F) = 1 - \prod_{i=1}^{n} \left[1 - P(Z_i)\right] \quad \text{(A-2.2)}$$

When modes are mutually correlated, the system failure probability cannot be assessed as simply as in the above equation. Therefore, system reliability has been evaluated with a certain latitude. Ditlevsen [25] bounds are well-known example of this (equation **(A-2.3)**).

$$P(Z_1) + \sum_{i=2}^{n} \max\left[\left\{P(Z_i) - \sum_{j=1}^{i-1} P(Z_j \cap Z_i)\right\}, 0\right] \le P(F) \le \sum_{i=1}^{n} P(Z_i) - \sum_{i=2}^{n} \max_{j<i} P(Z_j \cap Z_i) \quad \text{(A-2.3)}$$

With the Ditlevsen bounds method, a very wide range of reliability may be given in some cases, depending on conditions. Accordingly, it is generally necessary to perform the Monte Carlo Simulation (MCS) in order to assess system reliability. In the cases of two modes, however, system reliability can be evaluated easily using the FORM results. The system reliability in this case is given by equation **(A-2.4)**. Use of Owen's method [26] makes it possible to reduce the integral degree of the double integral term (third term in the right side of equation **(A-2.5)**) to one. In this case, equation **(A-2.5)** gives the system failure probability.

$$P(F) = \Phi(-\beta_1) + \Phi(-\beta_2) - \int_{\beta_1}^{\infty}\int_{\beta_2}^{\infty} \frac{1}{2\pi\sqrt{1-\rho_{12}^2}} \exp\left[-\frac{1}{2}\left(\frac{z_1^2 - 2\rho_{12} z_1 z_2 + z_2^2}{1-\rho_{12}^2}\right)\right] dz_1 dz_2 \quad \text{(A-2.4)}$$

$$P(F) = \Phi(-\beta_1) + \Phi(-\beta_2) - \Phi(-\beta_1)\Phi(-\beta_2) - \int_{0}^{\rho_{12}} \frac{1}{2\pi\sqrt{1-t^2}} \exp\left[-\frac{1}{2}\left(\frac{\beta_1^2 - 2t\beta_1\beta_2 + \beta_2^2}{1-t^2}\right)\right] dt \quad \text{(A-2.5)}$$

where ρ_{12} is the correlation coefficient of the failure modes 1 and 2 and is expressed by equation **(A-2.6)** using the inner product of sensitivity factor vectors.

$$\rho_{12} = \sum_{x} \alpha_{x,1}\alpha_{x,2} \tag{A-2.6}$$

where $\alpha_{x,i}$ is the sensitivity factor of the parameter x in the i-th failure mode.

Taking as an example the system reliability assessment method for the external stability of breakwaters adopted in this document, system reliability can be assessed with sufficient accuracy, [27] even with the upper limits given by equation **(A-2.3)**, as sliding is frequently the dominant mode among the three failure modes of sliding, overturning, and foundation failure.

In addition, research is also underway on the assessment of third or higher-order system reliability within the framework of first-order approximation methods. The methods under study replace the problem of system reliability in systems with correlated modes of failure with the problem of system reliability in systems having equivalent independent modes of failure. Among them, FOMN (First-Order Multinormal approach) [28), 29] and PCM (Product of Conditional Marginals) [30] are well known.

(3) Recent Developments in Reliability Analysis Methods

Taking as examples cases in which it is necessary to assess reliability for residual deformation and the degree of damage of mooring facilities affected by ground motion, simple assessment of the probability distribution of the residual deformation and degree of damage included in the limit state function is difficult because these values must be obtained by second or higher-order nonlinear seismic response analyses, and an extremely large number of analyses is necessary to calculate their probability distribution. In such cases, the application of methods such as the MCS, FORM, and SORM is accompanied by difficulties. A conceivable alternative is a simple evaluation of reliability by FOSM. Because FOSM evaluates the average and standard deviation of the limit state function through several analyses, the calculation load is dramatically reduced. For actual research examples, see References 31), 32), and 33).

Reliability analysis is also applicable to the optimization problems in maintenance strategies which consider deterioration of the material of existing steel structures.[34]

The use of stored data and analysis results obtained through the adoption of reliability-based design method systems reduces variations in the evaluation of various parameters, contributing to reduced construction costs.[35] Therefore, consistent efforts to accumulate various types of statistical data are extremely important.

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Chapter 2 Construction, Improvement, or Maintenance of Facilities Subject to the Technical Standards

1 Design of Facilities Subject to the Technical Standards

Ministerial Ordinance

Design of Facilities Subject to the Technical Standards

Article 2

1 The facilities subject to the Technical Standards shall be properly designed to satisfy their performance requirements and to avoid adverse effects on their structural stability during construction while considering environmental conditions, usage conditions, and other conditions to which the facilities concerned are subjected.

2 The design of facilities subject to the Technical Standards shall be made by properly setting their design working life.

3 The requirements other than those specified in the preceeding two paragraphs for designing the facilities subject to the Technical Standards shall be provided by the Public Notice.

Public Notice

Consideration for Construction and Maintenance in Designing

Article 4

Design of the facilities subject to the Technical Standards shall be conducted with due consideration for proper construction and maintenance of the facilities.

[Technical Note]

1.1 Design Working Life

(1) For determining design working life, the objectives of the facilities concerned, their usage conditions of the surroundings such as other facilities, as well as the effects of design working life on the setting of actions for performance verification and on material selection considering environmental effects, shall be properly taken into consideration.

(2) For determining of design working life, the classification of design working life defined in ISO 2394 (1998) shown in **Table 1.1** may be referred. The standard design working life of port facilities is the one based on the values for Class 3 in the table.

Table 1.1 Concept of Classification of Design Working Life Defined in ISO 2394 (1998)

Class	Expected design working life (year)	Example
1	1 - 5	Temporary structures
2	25	Replaceable structural elements such as bridge abutment beams and bearings
3	50	Buildings and other public structures, structures other than the below
4	100 or longer	Memorial buildings, special or important structures, large-scale bridges

(3) Structural Robustness
It is desirable for the design of facilities subject to the technical standards to ensure their structural robustness, as well as verifying their performance (i.e. verifying their compliance with the performance requirements specified in the Ministerial Ordinance for the Technical Standards). Structural robustness refers to the performance that actions such as unexpected fires, crashes, etc. applied to the facilities concerned or their partial destruction have no fatal effect on the whole structural system.

2 Construction of Facilities Subject to the Technical Standards

Ministerial Ordinance

Construction of Facilities Subject to the Technical Standards

Article 3

The facilities subject to the Technical Standards shall be properly constructed based on the construction standards provided by the Public Notice to satisfy their performance requirements, while considering environmental conditions, usage conditions, and other conditions to which the facilities concerned are subjected.

[Commentary]

(1) Construction of Facilities Subject to the Technical Standards

The provision defines constructability as one of performance requirements for all facilities subject to the technical standards. Construction is the action to actually construct or improve designed facilities. The construction of facilities subject to the technical standards must meet the performance requirements demanded by their designers.

2.1 General

The technical standards concerning construction of port and harbor facilities are specified by the Public Notice to set forth the details necessary for construction of the facilities subject of the Technical Standards (Public Notice of Ministry of Land, Infrastructure, Transport and Tourism No. 364 of 2007), which is referred to as the "Public Notice for Construction" hereinafter.

2.2 Substance Set as Construction Plans

Public Notice for Construction

Construction Plans

Article 2

1 Those who construct or improve facilities subject to the technical standards, including contractors, shall normally prepare construction plans to accurately, smoothly, and safely construct the facilities concerned.

2 Construction plans shall normally include the subjects listed in the following items:

(1) Construction methods of the facilities concerned

(2) Supervision methods for construction work of the facilities concerned

(3) Supervision methods for construction safety of the facilities concerned

(4) Requirements other than those listed in the above three items to accurately, smoothly, and safely construct the facilities concerned.

3 Those who construct or improve facilities subject to the technical standards shall normally modify their construction plans when required by changes in work progress or construction site situations.

2.3 Substance Set as Construction Methods

Public Notice for Construction

Construction Methods

Article 3

1 Those who construct or improve facilities subject to the technical standards shall specify construction methods taking account of the conditions, in accordance with Article 6 of the Ministerial Ordinance, under which the facilities concerned are placed.

2 Construction methods shall normally specify the subjects listed in the following items:

(1) Construction procedures and the construction specifications of each construction stage from the beginning to the completion of the facilities concerned

(2) Types and specifications of the major working vessels and machines used for constructing the facilities concerned

(3) Substance and timing of the measures taken to construct the facilities concerned other than those listed in the preceding two items

2.4 Content of Construction Management

Public Notice for Construction

Construction Management

Article 4

1 Those who construct or improve facilities subject to the technical standards shall properly supervise construction works in compliance with the criteria provided in the following items:

(1) Management items, content of management, management methods, quality standards, measurement frequencies, and methods to analyze measurement results shall be specified on the materials and structural members used for the facilities concerned, and the quality standards required for the materials and members shall be ensured.

(2) Management items, measurement methods, measurement densities, measurement units, methods to analyze measurement results, and allowable ranges shall be specified for the shape of the facilities concerned, and the shape required for the facilities shall be ensured.

2 Those who construct or improve facilities subject to the technical standards shall normally supervise progress status and work schedule management taking into account the offshore operations by working vessels to facilitate smooth construction, in addition to the items specified in the preceding items.

3 Those who construct or improve facilities subject to the technical standards shall make use of measurement records obtained from construction management for maintenance program so as to facilitate the proper maintenance of the facilities concerned.

2.5 Substance Set as Construction Safety Management

Public Notice for Construction

Construction Safety Management

Article 5

Those who construct or improve facilities subject to the technical standards shall study the subjects listed in the following items in compliance with the relevant laws and regulations concerning safety of port facility construction work, properly perform safety management, and make efforts to prevent accidents and disasters when constructing the facilities concerned:

(1) Measures to ensure safety under the construction conditions and construction methods of the facilities concerned

(2) Measures to ensure safety against abnormal phenomena

(3) Measures other than those listed in the preceding two items to prevent accidents and disasters

2.6 Structural Stability during Construction

Public Notice for Construction

Structural Stability during Construction

Article 7

Those who construct or improve facilities subject to the technical standards shall perform temporary works as necessary to prevent the structures of the facilities concerned from losing structural stability during construction.

References

1) Japan Port Association: Standard Specifications for Port Construction Work, Japan Port Association, 2004
2) Working Vessels Association: Catalogue of Working Vessels in Japan, Working Vessels Association, 1991
3) Japan Port Association: Standard Specifications for Port Design, Survey and Study, Japan Port Association, 2004

3 Maintenance of Facilities Subject to the Technical Standards

Ministerial Ordinance

Maintenance of Facilities Subject to the Technical Standards

Article 4

1 The facilities subject to the Technical Standards shall be properly maintained according to their maintenance programs to satisfy their performance requirements through their working life.

2 The maintenance of the facilities subject to the Technical Standards shall be carried out while considering environmental conditions, usage conditions, and other conditions to which the facilities concerned are subjected.

3 For the maintenance of facilities subject to the Technical Standards, necessary maintenance work and other activities shall be executed appropriately upon a comprehensive evaluation based on the results of inspection and diagnosis of the damage, degradation, and other changes in the state of the facilities concerned in its entirety.

4 For maintenance of facilities subject to the Technical Standards, appropriate safety countermeasures shall be undertaken which include those such as establishing well-defined operational manuals and other methods of hazard prevention to ensure the safe usage of the facilities concerned and other facilities surrounding them.

5 Requirements other than those specified in the preceding paragraphs for the maintenance of facilities subject to the Technical Standards shall be provided by the Public Notice.

[Commentary]

(1) Maintenance of Facilities Subject to the Technical Standards

① Since facilities subject to the Technical Standards are generally placed under severe natural conditions, material deterioration, damage of members, scouring, settlement, sedimentation, etc. of the foundation mounds, etc. often cause performance degradation during the design working life of the facilities. Planned and proper maintenance is hence needed to prevent the facilities concerned from failing to satisfy their performance requirements during their design working life. Effective and accurate maintenance plans shall be established.

② Facilities subject to the Technical Standards need to be properly maintained based on appropriate maintenance plans and criteria taking into account structural types, structural characteristics of members, and types and qualities of materials, as well as the natural conditions surrounding the facilities concerned, their usage status, future plans, design working life, importance, substitutions, and difficulty levels in inspection, diagnosis, and maintenance work.

③ The maintenance of facilities subject to the Technical Standards means a series of procedures to accurately grasp changes in the facilities such as degradation and damage through timely and appropriate inspection and diagnoses, to comprehensively evaluate the results, and to take proper measures such as necessary maintenance work.
Here "damage" refers to the unexpected changes in structures or members caused by excessive effects of accidental actions such as earthquakes and typhoons, and "deterioration" means the slow change in the qualities and characteristics of materials caused by environmental effects over a period of time. The damage and degradation, including the displacements and deformations occurring in structures and members, are collectively called the changes of structures and members.

④ The maintenance of facilities subject to the Technical Standards requires the planned and proper inspection and diagnosis, comprehensive evaluation, and maintenance work of the facilities concerned. The basic concepts of the maintenance of the facilities concerned and the methods, details, timing, frequencies, and procedures of their inspection and diagnosis shall be specified in advance as maintenance planning documents.
Maintenance work required as a result of a comprehensive evaluation includes not only hardware side measures, such as maintenance work, repair work, and strengthening work to recover the performance of structures and members and prevent performance degradation from occurring, but also software side measures such as temporary actions to stop services, restrict services, limit loads, and secure safety.

⑤ Since facilities subject to the Technical Standards include not only structures such as protective facilities for harbor and mooring facilities but also mechanical equipment such as cargo handling facilities and passenger boarding facilities, the maintenance of facilities subject to the Technical Standards requires the proper use and operation of the facilities concerned sufficiently taking account of their characteristics. The use of the facilities concerned requires specifying in advance actual safety measures, responsibility, and operational rules, in order to widely ensure safety to the operators and the general public not only in normal times but also in rough weather, and to prevent other port facilities integrally functioning with the facilities concerned, such as the quaywalls where cargo handling facilities are installed, from having operational difficulties.

[Technical Note]

3.1 General

(1) Maintenance should be continuously performed over the design working life specified by maintenance plans so that the performance of the structures and members of facilities does not fall below the required level. Here the working life may be considered as the design working life of the facilities concerned at the initial stages of their construction or improvement.

(2) Performance degradation of the structures or members of facilities advance slowly such as the deterioration of structural materials, ground settlement, sand washing out, etc. Facilities subject to the Technical Standards are usually exposed to marine environments, where structural materials such as concrete and steel easily deteriorate and the soft ground tends to cause ground settlement and sand washing out. Accidental actions such as earthquakes and impacts may also cause sudden damage to the facilities.

(3) The maintenance of facilities subject to the Technical Standards is a series of procedures to grasp the degradation of the structures or members due to the damage caused by their physical changes and aging deterioration through timely and accurate inspection and diagnosis, then to comprehensively evaluate the results, and to take proper measures such as necessary maintenance work. It needs to be performed based on appropriate plans and criteria. Here the appropriate plans refer to the maintenance programs described in Section 3.2, and appropriate criteria indicate **Technical Manual for Maintenance and Rehabilitation of Port Facilities**, [1] **Standard Specifications of Concrete Structures (Maintenance)**, [2] etc.

(4) Corrosion control measures for steel may apply the corrosion control levels shown in **Part II, Chapter 11, 2.3 Corrosion Protection** taking account of the performance requirements and design working life of the facilities concerned.

(5) Corrosion protection measures for reinforcing bars in concrete may apply **Part II, Chapter 11, 3.2 Concrete Quality and Performance Characteristics** and **Part III, Chapter 1, 1.1 General**, taking into account the performance requirements and design working life of the facilities concerned. The most basic corrosion protection measures are a reduction of water-cement ratio, an increase in concrete quality using admixtures, or an increase in cover depth. If these measures are insufficient, other measures such as the use of epoxy-coated reinforcing bars, the installation of surface protection, the application of cathodic protection, etc. should be considered. If such measures are expected to be taken during the design working life, it is desirable to consider the use of structures for which measures can be easily taken.

(6) Soil improvement, the most common measures against the soft ground, may be performed based on **Part III, Chapter 2, 4 Soil Improvement Methods.**

(7) It is desirable to conduct scheduled maintenance dredging for waterway and take measures to remedy gradual siltation.

(8) For designing of facilities subject to the Technical Standards, it is necessary to consider in advance planned and proper maintenance inspections and diagnoses in the implementation of maintenance for in the future.

(9) Details necessary for maintenance of the facilities subject to the Technical Standards are specified by the **Public Notice** to set forth the details necessary for maintenance of the facilities subject of the Technical Standards (Public Notice of Ministry of Land, Infrastructure, Transport and Tourism No. 364 of 2007), which is referred to as the "Public Notice for Maintenance" hereinafter.

3.2 Maintenance Programs

Public Notice for Maintenance

Maintenance Programs and Related Plans

Article 2

1 The owners of the facilities subject to the Technical Standard shall normally prepare maintenance plans.

2 Maintenance plans shall normally specify the subjects listed in the following items:

(1) The basic concepts of design working life of the facilities concerned and the maintenance of the facilities as a whole and their structural members

(2) Planned and proper inspection and diagnosis of the damage, degradation, and other changes in the state of the facilities concerned

(3) Planned and proper maintenance work on the damage, degradation, and other changes in the state of the facilities concerned

(4) Maintenance efforts other than those listed in the preceding three items required for maintaining the facilities concerned in a good state

3 The formulation determination of maintenance plans shall take into account the conditions under which the facilities concerned are placed based on Article 6 of the Ministerial Ordinance, such conditions as design working life, structural characteristics, material characteristics, difficulty levels in inspection, diagnosis, maintenance work, the degree of importance of the facilities concerned, and so on.

4 For formulating the maintenance plans, it is recommended to consult with experts who have technical knowledge on maintenance such as damage to the facilities concerned, the inspections and diagnoses of the damage, degradation and other changes in the state of the facilities concerned, the comprehensive evaluations of the maintenance of the whole facilities, maintenance work, and other maintenance activities. The above shall not apply, however, to the cases where the persons responsible for the maintenance programs are the experts in these fields.

5 Maintenance plans shall normally be modified when required by the changes in the uses of the facilities concerned or innovations in maintenance technologies.

6 The provisions of the third and fourth items shall apply to the modification of maintenance programs.

[Commentary]

(1) The owners of facilities subject to the Technical Standards must prepare maintenance programs at the initial time of maintenance and properly maintain the facilities concerned based on the programs. Maintenance programs shall normally specify planned and appropriately applied maintenance items in line with the procedure of maintenance and provide them in the form of maintenance program documents.

(2) The determination of maintenance programs shall properly specify the maintenance levels shown in **Table 3.2.1** as the basic concepts of the maintenance, taking account of the objectives of installing the facilities concerned, their design working life, performance requirements, design concepts, substitutions, etc.

Table 3.2.1 Maintenance Levels of Facilities Subject to the Technical Standards

Classification	Concept of dealing with damage and deterioration
Maintenance level I	Implementing high-level measures against damage and deterioration to prevent the facilities concerned from failing to satisfy performance requirements during their design working life
Maintenance level II	Frequently implementing small-scale measures at a stage of minor damage and deterioration to prevent the facilities concerned from failing to satisfy performance requirements during their design working life
Maintenance level III	Allowing a certain degree of performance degradation within the scope of meeting performance requirements and implementing large-scale measures once or twice a design working life to deal with damage and degradation ex post facto

(3) Maintenance plans shall specify the methods, details, and implementation timing for inspection and diagnosis, comprehensive evaluations, and maintenance and intervention according to the maintenance levels of the facilities concerned. In formulating the plans, it is necessary to consider the conditions under which the facilities concerned are placed, design working life, structural characteristics, material characteristics, difficulty levels in inspections, diagnoses and maintenance works, and the importance of the facilities concerned. The future performance changes with time of the structural members of the facilities concerned shall also be considered.

3.2.1 Maintenance Programs

(1) The owners of the facilities concerned shall normally prepare the maintenance programs of the facilities. The development of the programs need a consistent philosophy throughout the planning, design, construction, and maintenance of the facilities concerned, and it is hence most reasonable for the owners of the facilities concerned who are the most familiar with these processes to develop the programs.

(2) Maintenance plans shall aim to deliberately and properly maintain the facilities concerned. Maintenance program shall be normally used to specify the maintenance program documents. Other methods may also be used if it is substantially cover the items specified in the maintenance program documents to properly maintain the facilities concerned.

(3) The development of maintenance programs shall materialize the basic concepts of maintenance to the actual work levels of the facilities concerned upon sufficiently studying what their maintenance should be and possible scenarios based on the installation objectives, design working life, and performance requirements.

(4) Facilities subject to the technical standards shall maintain the performance requirements corresponding to the maintenance levels shown in **Table 3.2.1** at any time during their design working life. For that purpose, the initial design must satisfy designated maintenance levels and properly take account of smooth implementation of inspections, diagnoses, and maintenance works corresponding to the designated maintenance levels.

(5) The setting of maintenance levels shall be conducted estimating the performance changes with time of the facilities concerned from the conditions surrounding the facilities such as natural environmental conditions and usage statuses, the structural types of the facilities and the characteristics of their structural members, and the types and quality of the materials used for the facilities, based on the installation objectives, design working life, and performance requirements of the facilities. Maintenance levels are normally set for whole facilities, but in most actual cases, estimating the performance changes with time of the whole facilities concerned is difficult and setting the same maintenance levels for all members and ancillary equipment is unreasonable. Proper maintenance levels shall be hence set for each structural member of the facilities concerned, taking account of the study results of the performance changes with time of the structural members of the facilities and the difficulty levels in inspections and maintenance works, the importance of the facilities, and drawing up a maintenance scenario for the facilities as a whole.

(6) Maintenance programs shall specify inspection and diagnosis plans and the methods, details, timing, frequencies, procedures, etc. of maintenance works, corresponding to the maintenance levels of the facilities concerned and following the basic stages of maintenance. **Fig 3.2.1** shows the standard structure of maintenance program documents and the items to be specified.

(7) The preparation of maintenance program documents may apply **Guide for the Preparation of Maintenance Program Documents for Port Facilities** [3] and **Basic Concepts for the Preparation of Maintenance Program Documents for Port Facilities**.[4]

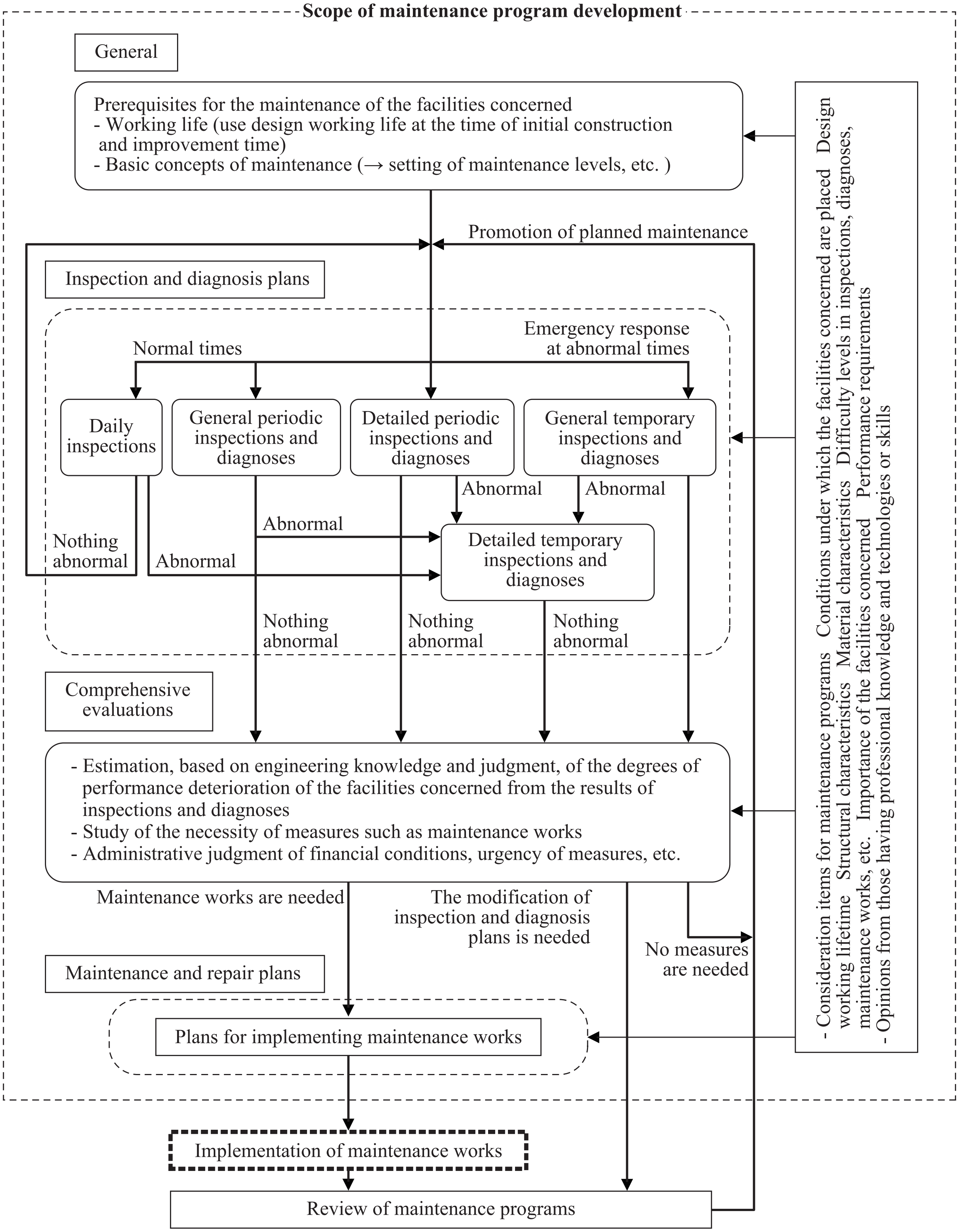

Fig. 3.2.1 Standard Structure of Maintenance Program Documents and the Items to be Specified

3.2.2 Inspection and Diagnosis Programs

(1) General

① Since the changes in the state of structural members of facilities subject to the technical standards are strongly correlated with each other, inspection and diagnosis plans must select items, methods, and procedures for efficient and effective inspections with full understanding of the link of changes in state described in Item (ii).

② Facilities subject to the technical standards have relatively complex structures and their structural members are correlated with each other. Various external factors act on the structures. The occurrence and development of changes are hence complicated. It is desirable for reasonable maintenance to select inspectable damage, degradation that have significant effects on component performance as major changes in state, and inspect and diagnose them. The selection of major changes in state shall fully take account of the linked changes, which are the progressive processes of the causes, occurrence, and effects of changes resulting in the performance deterioration of the facilities. Focusing on and making inspection and diagnosis of the most important linked changes are useful for reasonable maintenance. Refer to **Technical Manual for Maintenance of Port Facilities** [1] for the linked changes of facilities subject to the technical standards.

③ The implementation of planned and proper inspections and diagnoses based on the above-mentioned concept of the linked changes is essential to effectively detect the deterioration which has occurred in facilities subject to the technical standards. The following constitute the inspections and diagnoses of facilities subject to the technical standards:

(a) Initial inspections: They are performed to grasp the initial maintenance state of not only the whole facilities concerned but also their members and ancillary equipment at the completion stages of construction or improvement work, or at the preparation stages of maintenance programs for existing facilities. When they are performed immediately after the completion of construction or improvement work, initial state may be grasped based on the results of quality inspections and workmanship inspections performed at the time of completion.

(b) Daily inspections: They are performed to check routinely inspectable parts for changes in state and their degrees.

(c) Periodic inspections and diagnoses: They are performed to periodically check routinely uninspectable structures and members including the details of changes in state and their degrees. They are classified into general periodic inspections and diagnoses and detailed periodic inspections and diagnoses. The former are conducted on the parts above the sea level mainly by visual inspections or simplified measurement at relatively short intervals. The latter are conducted at relatively long intervals and their objects include the parts on which the former are unpractical.

(d) General temporary inspections and diagnoses: They are performed to check the facilities for changes and their degrees mainly by visual inspections or simplified measurement at the earliest possible stage at abnormal times after the occurrence of earthquakes and rough weather.

(e) Detailed temporary inspections and diagnoses: They are performed when particular or unexpected abnormalities are found from the results of periodic or general temporary inspections and diagnoses.

3.3 Measures Regarding Prevention of Danger

Public Notice for Maintenance

Measures Regarding Prevention of Danger

Article 4

1 The owners of facilities subject to the technical standards shall normally take measures specified in the following items as the measures to clarify the operational methods provided in the fourth item of Article 4 of the Ministerial Ordinance and other safety measures, taking account of natural conditions, usage statuses, and other conditions under which the facilities concerned are placed:

(1) Designation of persons responsible for inspecting or examining and implementing the measures concerned before and after the operation of the facilities concerned

(2) Designation of persons responsible for necessary measures to safely maintain the facilities concerned and responsible for implementing the measures concerned in rough weather

(3) Development of the operational rules required for safely maintaining the facilities concerned or the confirmation of the operational rules prepared by the facility management bodies, in addition to those specified in the preceding two items.

2 The measures provided in the preceding items shall be normally taken by those who have professional knowledge and skills for ensuring of safety of facilities subject to the technical standards and their surrounding facilities which are used integrally with mutual operational relations.

3.4 Measures Dealing with Out-of-Service Facilities

Public Notice for Maintenance

Out-of-Service Facilities Subject to the Technical Standards

Article 6

Proper actions shall be taken as necessary on out-of-service facilities subject to the technical standards such as their removal, proper maintenance, ensuring the safety of their neighboring areas to prevent the facilities concerned from obstructing the development, use, and maintenance of the ports.

References

1) Port and Airport Research Institute (Edition): Maintenance Manual for port facilities, Coastal Development Institute of Technology. 2007

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4 Environmental Consideration

Ministerial Ordinance

Environmental Consideration

Article 5

1 The design, construction, and maintenance of facilities subject to the Technical Standards shall endeavor to preserve the natural environments around a port, to form good landscapes, and to ensure the security of the port area by considering the environmental conditions, usage conditions, and other conditions to which the facilities concerned are subjected.

2 Installation of facilities to be utilized by an unspecified large number of people and subject to the Technical Standards shall consider the safe and smooth usage of the facilities by seniors, handicapped persons, and others whose daily or social lives are restricted due to physical disabilities while considering environmental conditions, usage conditions, and other conditions to which the facilities concerned are subjected.

[Technical Note]

4.1 General

(1) Environmental Consideration
It is desirable for the construction, improvement, and maintenance of facilities subject to the technical standards to consider the natural environment and the good port landscapes of the regions, taking account of the constructability, economy of the facilities concerned, when determining their layouts, scales, and specifications, and selecting their structural types, materials used, and construction methods.

(2) Considerations for Natural Environment
In the construction, improvement, and maintenance of facilities subject to the technical standards, it is necessary to preserve the natural environments of the ports, paying attention to creating a better natural environment, as well as to eliminate bad effects on the natural environments. For the creation of the better natural environments such as beaches, in particular, a comprehensive planning method, which is one of integrated approaches through the planning, design, construction and maintenance of the facilities concerned, and one of adaptive management methods taking account of the variability and uncertainty of the natural environment can be applied. Here the environmental qualities of ports mean water quality, bottom sediment quality, and air quality. It is desirable for the construction, improvement, and maintenance of facilities subject to the technical standards to take account of the effects of the facilities concerned on the habitation of life around of the facilities in terms of changes in the environmental quality.

(3) Primary Factors Controlling the Natural Environment
The actions of tides and waves are the primary factors controlling material advection and diffusion and the habitats for marine organisms related to the natural environment of ports. The construction, improvement, and maintenance of facilities subject to the technical standards need to properly take into consideration that the changes in these actions accompanying the construction of the facilities concerned and related activities spread widely in time and space.

(4) Environmental Quality

① As for water quality, it is desirable to focus not only on the level of water pollutants such as CODs, nutrient salts, floating suspended substances, etc., but also on the phenomena such as the upwelling of low oxygen water mass, blue tides etc., and the occurrence of red tides resulting from water pollution, and study water quality from the viewpoint of sound material circulation.

② As for bottom sediment quality, it is necessary to focus on particle size distributions and the contents of organic matter, trace chemical substances, heavy metals, etc., and pay attention to the spread of the influence, of their interactions with water quality, avoiding secondary pollution such as the accelerated formation of low oxygen bottom water due to their decomposition, the accelerated elution of nutrient salts in low oxygen environments.

It should also be noted that the bottom sediment stirred up by navigating ships tends to cause the emission of offensive odors and the degradation of water quality and that fine particles tend to deposit in calm areas and absorb toxic substances such as heavy metals.

③ As for air quality, it is necessary to focus on the heat, gases such as NO_X, SO_X, CO_2, , and fine particles emitted into the air by ships, vehicles, port cargo handling equipment, and activities of firms located in port areas, etc. They are mostly caused by port activities, although it is also necessary to carefully select working vessels and machines for constructing and maintaining the facilities concerned.

(5) Adaptive Management Methods
The basic concepts of adaptive management methods are to adjust to the changes in the natural environment and social backgrounds, monitor circumstances using the latest information and the most advanced technologies, regularly verify the achievement of individually set objectives, then introduce feed back mechanisms to modify plans if necessary. Implementing adaptive management enables the management bodies of nature recovery projects to learn from experience, adjust to the changes in the factors affecting the characteristics, continuously improve management methods, and verify the appropriateness of management.

(6) Considerations for Forming Good Regional Landscapes
It is desirable for the formation of good regional landscapes to not only give consideration to the appearances of each facility but also understand the landscape implication of the surrounding spaces of the facilities concerned to preserve, use, or improve their landscape values. For good regional landscape formation, it is desirable to perform the planning, design, construction, and maintenance of facilities subject to the technical standards based on a consistent objective or a design concept on landscapes throughout all stages of their design working life.

(7) Considerations for Port Security
It is desirable for port facilities to secure monitoring functions and eliminate blind spots from structures to ensure security according to the characteristics of the facilities.

The important international wharf facilities specified in the **Law for Security of Ships and of Port Facilities (Law No. 31 of April 14, 2004)** also need to meet the technical standards for wharf security equipment provided in the Law.

(8) Considerations for Senior Citizens and Disabled Persons on the Facilities Used by a Number of Unspecified
Persons

It is desirable for the facilities used by a number of unspecified majority of persons such as mooring facilities, beaches, green spaces, etc. to consider that all persons including senior citizens and disabled persons can safely and smoothly use the facilities equipped with ship boarding/unboarding function and amenity-oriented function.

The passenger ship terminals specified in the **Law for Promoting Easily Accessible Public Transportation Infrastructure for the Aged and the Disabled Persons (Law No. 91 of June 21, 2006)** also need to meet the standards provided in the Law.

(9) Considerations for the Recycle of Resources
The construction, improvement, and maintenance need to make efforts to consider the recycle of resources through the proper treatment of construction byproducts and the utilization of recycled resources.

(10) References 1) – 4) provide information on the consideration of port facilities for the natural environment and on adaptive management study.

(11) Reference 5) – 11) provide information on the landscape study of port facilities.

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