Part IV Reference Technical Data for Part I

Chapter 1 Reference Matters in the Design and Other Stages

(English translation of this section from Japanese version is currently being prepared.)

1 Major Reference Books

(English translation of this section from Japanese version is currently being prepared.)

Chapter 2 Fundamentals of the Reliability-based Design Method

1.1 Summary of the Reliability-based Design Method

1.1.1 General

"Structure reliability" is defined broadly as "the ability for structures to satisfy the required design performance during a specific period," and, in a narrow sense, as "the probability that structures do not reach the limit state during their working life." On the other hand, since failure probability is "the probability that structures reach the limit state during their working life," the failure probability and reliability are related as "failure probability = 1.0 − reliability."[1] This leads to an understanding that reliability analysis is "a method to quantitatively describe the uncertainty of individual basic variables related to the performance of structures based on the probability distribution, and calculate the failure probability based on probability theory." The reliability-based design method can be called "a design method to determine how to design based on the result of reliability analysis."

"Technical Standards and Commentaries for Port and Harbour Facilities in Japan (2007)" adopted the reliability-based design method at a full scale. The reliability-based design method has been adopted worldwide by the Structural Eurocodes (a European uniform standard) and by the AASHTO (a leading design standard in North America), among others. It should be noted that international standards such as "ISO 2394: General principles on reliability for structures" also apply the reliability-based design method a standard design method,[2] and it is currently recognized as the only method that can reasonably treat various uncertainties unavoidable in structural design.

This book also describes the reliability-based design method as a representative performance verification method. This chapter describes general ideas and technical details[3] regarding the reliability-based design method in the context of this book.

1.1.2 Classification of the Reliability-based Design Method

The classification of the reliability-based design method[1), 4), 5)] is described in **Part I, Chapter 1, 3.9.1 (2)** and is restated here:

(1) Level 3 Reliability-based Design Method

A reliability-based design method for directly calculating failure probability using a probability calculation based on the probability distribution of each basic variable.

(2) Level 2 Reliability-based Design Method

A reliability-based design method for evaluating the reliability index β using a probability calculation based on the average, distribution, and covariance of each basic variable (not dependent on the probability distribution), and evaluating performance so that β is equal to or exceeds the limit value.

(3) Level 1 Reliability-based Design Method

A reliability-based design method for deterministically verifying performance by introducing some partial factors to the performance verification equation and substituting the equation with characteristic values for the basic variables in order to ensure a safety margin. This is also called the "partial factor method." The partial factor is determined with the level 3 or 2 reliability-based design method, which is called the "code calibration."

1.2 Basic Concept of Failure Probability and Target Safety Level

1.2.1 Notes on Reliability Analysis

With progress being made in research on the reliability-based design method, the classification and interpretation of various uncertainties concerning design and the quantification of such uncertainties (estimation of probability distribution) due to limited available data are being recognized as significant problems, especially when dealing with naturally-derived materials such as external forces and ground, as well as errors in modeling. Based on the above, the reliability analysis can be understood as "a method to methodically sort and systemize different factors regarding uncertainties related to the performance of structures, statistically quantify individual factors of uncertainties, and calculate the failure probability according to the probability theory."

On the other hand, organization of individual factors of uncertainties and their adequate statistical quantification may not always be possible in actual reliability analysis. Specific reasons are exemplified below:

(1) Difficulties in the Classification of Uncertainties

Literature on traditional structural reliability analysis classifies factors of uncertainties in structure design as below:[2)]

① Spatiotemporal variation of external forces acting on structures, mechanical properties of materials, and physical quantities such as geometric shape.

② Statistical estimated errors due to the estimation of uncertainties in physical quantities from samples.

③ Errors in modeling due to the simplification and idealization of design calculation models. Errors in modeling are generally defined by the following equation:

$$\text{Errors in modeling} = \frac{\text{Actual (observed) response}}{\text{Response expected by a model}} \qquad \textbf{(1.1.1)}$$

④ Conversion errors when converting results from different surveys to physical quantities directly necessary for design.[6)–8)]

However, quantification of uncertainties as in the above classification may not necessarily be possible since actual analysis of uncertainties produces a variety of uncertainty-related data from individual structures. It may be difficult to individually extract these uncertainties in many cases and often only multiple uncertainties can be estimated.

For example, a traditional design method may be able to estimate uncertainties in the whole design method using a full scale experiment or examples of damage, even if it is unknown how the factors of uncertainties in individual basic variables contribute. In some cases, uncertainties may also be suspected to have been double-counted or missed. Proper engineering judgement, including sorting data, by applying comprehensive knowledge of structure design and considering details regarding the acquired data is needed in specific aspects of each reliability analysis.

(2) Difficulties in the Quantification of Uncertainties

The quantification of uncertainties always requires estimation using some statistical data. However, these data always have inherent qualitative and quantitative problems. Restriction in the number of data and uneven distribution of many collected data ranges require close attention to statistical analysis for the quantification of uncertainties, while there are unavoidable limitations. In some cases, certain factors make it impossible to quantify uncertainties based on data, which forces quantification based on an experienced engineer's expert judgement.

1.2.2 The Concept of Failure Probability as an Absolute Criterion of Structural Reliability in This Book

The reliability analysis has many problems as mentioned above in stages prior to probability calculation based on the probability theory, and the degree also differs by the target problem. Thus, it may be doubtful if uncertainty, or the failure probability, built upon certain assumptions is an absolute criterion of structural reliability. This is the reason why this book considers that comparisons of failure probabilities between different kinds of structures and making judgements by overestimating failure probability as an absolute criterion should be withheld at this time.

On the other hand, it was understood that the relative comparison of reliability analyzed by similar methods based on homogeneous data was effective, so a performance verification method was constructed in this book. This implies that making comparisons of failure probabilities of structures of the same type is effective to a considerable degree.

1.2.3 Main Methods to Determine a Target Safety Level

A target safety level is mainly determined using the following three methods:

① Setting a similar reliability level of a structure designed by existing design standards as the target safety level.

② Setting the target safety level by comparing it to different background risks.

③ Setting by optimizing economic indices such as life cycle costs and expected costs.

(1) Currently, method ① is often used because structures designed using existing design standards usually already have long performance records, and thus, the reliability of such structures is considered to have been socially recognized. Moreover, the fact that there is no sufficient confirmation if the value of reliability obtained by current reliability analysis is meaningful in every case, as an absolute criterion of reliability is considered to be another reason why many calibrations are done using this method. By contrast, a relative comparison of the reliability of homogeneous

structures is considered to be sufficiently meaningful. The level of reliability of homogeneous structures is generally equalized with the code calibration in this method.

(2) Method ② using background risk is utilized for different policymaking based on risks in many areas. Proper setting of environmental limit values of chemical substances is the typical example.[9)] This method intends to determine the target safety level of structures by referring to various risks of events existing in society. Examples of degrees of risks existing in society are summarized in Honjo et al.[10)]

(3) Method ③, which intends to minimize so-called expected total costs (construction cost plus expected failure cost, which is obtained by multiplying damage, including social costs when the structure fails, by the failure probability), appears to be reasonable.[11)] However, as there are many problems such as accuracy of failure probability as an absolute criterion, cost estimation when failed, and forecasts of socioeconomic changes within the working lives of structures, this method seems to pose many problems for actually calculating the target safety level at this time.

(4) The target safety level may be set after evaluating it as the system reliability for multiple limit states of structures. This method, for example, evaluates system reliability as the reliability of a serial system[12)] after calculating the failure probability using the failure mode of sliding, over-turning, and bearing capacity at a gravity-type wharf. In this case, the whole system is considered to fail if either of the above failure modes occurs.

However, the impact the limit state of each failure mode gives to the performance (stability) of the whole structure can differ by failure mode, and there is a possibility that the conventional design method (safety factor method) has also taken this into account when considering a safety margin. Consequently, this book considers that reasonable partial factors can be set by conducting calibration targeting reliability of current design methods for each limit state rather than mechanically calculating the system reliability. This book, therefore, does not take account of system reliability when setting the target safety level.

1.2.4 Setting Processes for the Target Safety Level in This Book

The "Technical Standards and Commentaries for Port and Harbour Facilities in Japan (2007)" fully introduced the reliability-based design method as a performance verification method. As stated above, classification and organization of factors of uncertainties as a basis are important in reliability analysis. When presenting a verification equation using partial factors regarding the structural form and the failure mode on which the reliability was analyzed in this book, close investigation of factors of uncertainties included in the failure mode and so on, which are conceivable at this time in reliability analysis, led to a review of everything including the target safety level in the reliability analysis. As for the reasoning behind these settings, see the references listed in the "Facilities" section. **Fig. 1.2.1** below shows a basic flow up to the setting of partial factors.

1. Overview and review of the safety level
- Comparison between criteria (the 1999 Criteria and the 2007 Criteria)
- Review of target safety levels (as required)

▼

2. Reliability analysis utilizing the Monte Carlo simulation
- Calculation of the failure probability
- Setting of a target failure probability (by failure mode)

▼

3. Setting of partial factors in the load and resistance factor design
- Comparison and examination of partial factor formats
- Evaluate conformance to target failure probability and effect to design result (including convenience), and adopt a partial factor format which requires as few partial factors as possible.

Fig. 1.2.1 Basic Flow up to the Setting of Partial Factors Applied in This Book

1.3 Adoption of a Load and Resistance Factor Design for the Level 1 Reliability-based Design Method

1.3.1 General

The form of performance verification equations adopted in this book (a.k.a. "format") is a partial factor method based on a load and resistance factor design (hereinafter called the "load and resistance factor design"), which is different than the partial factor method based on a material factor design adopted in the "Technical Standards and Commentaries for Port and Harbour Facilities in Japan (2007)" (hereinafter called the "material factor design"). This section describes the differences between these formats and concepts, and the reasons why the load and resistance factor design was finally adopted.

1.3.2 Partial Factor Method

Here, the material factor design and the load and resistance factor design are defined as follows, respectively. The term "partial factor method" collectively indicates both approaches and may be understood as being synonymous with the level 1 reliability-based design method. For details, please refer to Honjo et al.[10), 13)]

(1) Partial Factor Method Using a Material Factor Design

A material factor design is a performance verification method constructed with the concept of processing different uncertainties in performance verification at their sources. It features the introduction of many partial factors and processing of uncertainties in proximity to their sources. For example, it evaluates a design value by multiplying a characteristic value of each material by a partial factor, then substitutes the design value into the performance verification equation to verify the performance.

$$R\left(\gamma_{r1}x_{rk1},\dots,\gamma_{rn}x_{rkn},\gamma_{R1'},\dots,\gamma_{Rn'}\right) \geq S\left(\gamma_{s1}x_{sk1},\dots,\gamma_{sm}x_{skm},\gamma_{S1'},\dots,\gamma_{Sm'}\right) \tag{1.3.1}$$

where

γ_{ri} : partial factor to multiply characteristic value x_{rki} (a basic variable on the resistance side)

γ_{si} : partial factor to multiply characteristic value x_{ski} (a basic variable on the load side)

These partial factors are applied considering physical uncertainties inherent to materials and loads and statistically estimated errors. $\gamma_{Ri'}$ and $\gamma_{Si'}$ are partial factors applied to the modeling errors, redundancy, and vulnerability in design calculations. Partial factors are adjusted to ensure a safety margin finally necessary for structures. Note that the material- or load-related basic variables substituted into the performance verification equation in the material factor design are not characteristic values before being multiplied by a partial factor, but are values already multiplied by a partial factor (called "design values").

(2) Partial Factor Method Using a Load and Resistance Factor Design

A load and resistance factor design (LRFD) is a design concept that ensures a safety margin during performance verification by applying a partial factor to multiply a resistance value calculated based on a characteristic value. The load side introduces a partial factor to multiply the corresponding load value and increases the load. The LRFD often integrates resistance values, but a format to divide into several terms similar to the load side is also proposed. Here, these two forms are described together:

$$\gamma_R R\left(x_{k1},\dots,x_{kn}\right) \geq \sum_j \gamma_{Sj} S_j\left(x_{k1},\dots,x_{kn}\right) \tag{1.3.2}$$

$$f_R\left(\gamma_{R_1}R_{1k}(x_{1k},\cdots x_{pk}),\cdots,\gamma_{R_m}R_{mk}(x_{1k},\cdots x_{pk})\right) \geq f_S\left(\gamma_{S_1}S_{1k}(x_{1k},\cdots x_{pk}),\cdots,\gamma_{S_n}S_{nk}(x_{1k},\cdots x_{pk})\right) \tag{1.3.3}$$

where

γ_R or γ_{Ri} : partial factor to multiply a resistance value (hereinafter "resistance factor")

γ_{Si} : partial factor to multiply a load value (hereinafter "load factor")

R or R_i : resistance value

S_i : load (effect) value

In this way, the LRFD is a performance verification method that ensures a safety margin by calculating the resistance side as functions (simple addition in many cases) of (characteristic values of) several resistance values, multiplying each term by the resistance factor, and combining load factors.

The format of performance verification equations of **equations (1.3.2)** and **(1.3.3)** shown here looks slightly different from the equation shown in the "Common" section, but they are inherently the same. In other words, this book indicates that performance verification using the partial factor method may usually be conducted with the following **equations (1.3.4)** to **(1.3.6)**:

$$m \times \left(\gamma_i \frac{S_d}{R_d} \right) \leq 1.0 \qquad \textbf{(1.3.4)}$$

$$S_d = f\left(\gamma_{S_1} S_{1k}, \cdots, \gamma_{S_n} S_{nk}\right) = f\left(\gamma_{S_1} S_{1k}(x_{1k}, \cdots x_{pk}), \cdots, \gamma_{S_n} S_{nk}(x_{1k}, \cdots x_{pk})\right) \qquad \textbf{(1.3.5)}$$

$$R_d = f\left(\gamma_{R_1} R_{1k}, \cdots, \gamma_{R_m} R_{mk}\right) = f\left(\gamma_{R_1} R_{1k}(x_{1k}, \cdots x_{pk}), \cdots, \gamma_{R_m} R_{mk}(x_{1k}, \cdots x_{pk})\right) \qquad \textbf{(1.3.6)}$$

where

S_d : design value of a response value

R_d : design value of a limit value

γ_i : partial factor to consider the significance of structures, social influence when the limit state is reached, etc. (structural factors). Unless otherwise specified, γ_i = 1.0 and is not described in this book.

m : adjustment factor (a value corresponding to the allowable safety factor in the traditional safety factor method or allowable stress method/working stress design. Equivalent to what was processed by the structural analysis factor in the 2007 version.)

S_{jk} : characteristic value of an effect of action j (j = 1..n)

γ_{Sj} : partial factor to multiply a characteristic value S_{jk} of an effect of action j

S_i ( ) : equation to calculate a characteristic value S_{jk} of an effect of action j

R_{jk} : characteristic value of resistance (strength) j (j = 1..m)

γ_{Rj} : partial factor to multiply a characteristic value R_{jk} of resistance (strength) j

R_j ( ) : equation to calculate a characteristic value R_{jk} of resistance (strength) j

x_{jk} : characteristic value of a basic variable x_j (j = 1..p)

If a partial factor is determined by calibration based on a reliability analysis, adjustment factor m = 1.0 and usually γ_i = 1.0. In this case, **equation (1.3.4)** coincides with **equation (1.3.3)**.

1.3.3 Merits and Demerits of a Partial Factor Method Using the Material Factor Design

The merits of a material factor design over a load and resistance factor design are as follows:

① Processing uncertainties at their source is intuitively reasonable.

② Because each uncertainty is processed at its source, the performance verification equation can be adapted to different situations by aligning the partial factor corresponding to the item where individual uncertainty changes. Practically, when a new construction method or technology is adopted, items concerning their reliability can be rapidly adjusted by aligning factors.

However, current knowledge hardly makes it possible to explain uncertainties in design as accumulated factors of individual uncertainties in the design of many structures. Adjusting uncertainties at their source could be unreasonable because:

① Not all uncertainties have been clarified individually and quantitatively.

② Uncertainties for the whole design method could be quantitatively understood if a load test or a failure example exists. However, it would be extremely difficult to divide the entirety of the uncertainties into individual factors and quantify them.

③ If a structure's behavior is forecasted with a design value adjusting a characteristic value by a partial factor, behavior deviating from the most plausible behavior of structures will increase. In designing structures (especially ground structures), it is recognized that the designer's engineering judgement is important, and they should design in principle by tracing the most plausible behavior of structures as much as possible up to the final design stage so that such judgements can soundly function. However, the material factor design is opposed to this principle.

1.3.4 Merits and Demerits of the Partial Factor Method Using a Load and Resistance Factor Design

The merits of a material factor design are demerits of the load and resistance factor design, and vice versa.

① Designers can trace the most plausible behavior of structures up to the final design stage using a load and resistance factor design which calculates design based on the characteristic values of basic variables. This conforms to the principle that designers should trace the most plausible behavior of structures as much as possible up to the final design stage so that their engineering judgement can soundly function.

② When designing ground structures which intricately interact with the ground, a reduction of basic variables, such as in the material factor design, does not necessarily act on the side of safety for the structural design.

③ If uncertainties regarding the design calculation model are obvious from examples of failures with full-scale structures, or from a database of test results in conditions close to the behavior of full-scale structures, the uncertainties are those which, as a whole, reveal many intervening factors of uncertainties. Uncertainties found in the behavior of existing structures can be realistically sought by introducing uncertainties obtained from these data. What can be determined based on these data is the resistance factor applied to calculated resistance values.

④ The load and resistance factor design is closer to the verification form of the safety factor method or allowable stress method/working stress design, which practitioners have become more accustomed to than the material factor design, and which feels more familiar once introduced.

1.3.5 Reasons for the Adoption of a Partial Factor Method Using a Load and Resistance Factor Design

The partial factor method using the load and resistance factor design has been adopted as a format of partial factors in this book because the merits for the load and resistance factor design are currently considered to be better than those for the material factor design as a format of the partial factor method in the performance verification equation for structures after organizing the pros and cons of both designs.

In particular, this is because the load and resistance factor design is a performance verification method with which a designer can trace the most plausible behavior of a structure as much as possible up to the final design stage. Furthermore, individual uncertainties in design are not necessarily obvious at this time, so uncertainties as a whole design method should be clarified by future data acquisition.

Note that the level 1 reliability-based design method is a convenient way to take account of the "economy of design" of standard structures (for efficient design). It is also possible to use the level 3 reliability-based design method directly for especially important structures.

1.4 Theory of Reliability Analysis

1.4.1 Failure Probability and Reliability Index

This section provides a simple explanation of the probability theory and terms necessary to understand the reliability analysis.

Fig. 1.4.1 shows a plane consisting of two random variables (action S and resistance R) and the condition of probability distribution on this plane. The function showing the probability distribution of the two variables is called the "simultaneous probability density function" and is represented by $f_{RS}(r, s)$. The probability theory defines the sum of probabilities that all events occur as 1.0, so the volume of the bell-shaped simultaneous probability density function shown in **Fig. 1.4.1** is 1.0.

The reliability analysis uses a performance function $g(R, S)$ which divides the S-R plane into a non-destruction range and destruction range, and defines the limit state plane as a plane when the function is 0. The non-destruction range and the destruction range correspond to positive values of $g(R, S)$ and negative values of $g(R, S)$, respectively. $g(R, S)$ is denoted Z ($Z = g(R, S)$). In this case, the failure probability calculates the volume of the simultaneous probability density function of the hatched area in **Fig. 1.4.1**. Here, we explained it using a reliability analysis problem composed of two variables that can be drawn, but the same explanation essentially applies to cases where the probability space and the performance function composed of multiple variables are introduced.

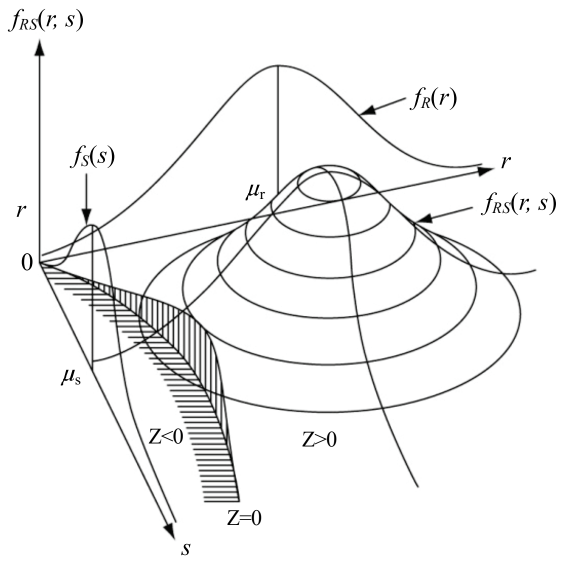


Fig. 1.4.1 Conceptual Diagram of Failure Probability Calculation

Fig. 1.4.2 shows the same concept as in **Fig. 1.4.1** with a slightly different representation. **Fig. 1.4.2** represents the bell-shaped simultaneous probability density function with contours and simplifies the performance function $Z = g(R, S)$ to a linear function R-S. The limit state plane separating the non-destruction range from the destruction range forms a positive 45-degree line from the origin. Because $Z = R$-S, a probability density function of the safety margin Z, shown in the figure, can be obtained when showing the volume of the simultaneous probability density function at $Z = z$ on the Z axis in a direction perpendicular to the limit state plane as shown in **Fig. 1.4.2**. The failure probability is also the area where Z is not positive in the probability density function.

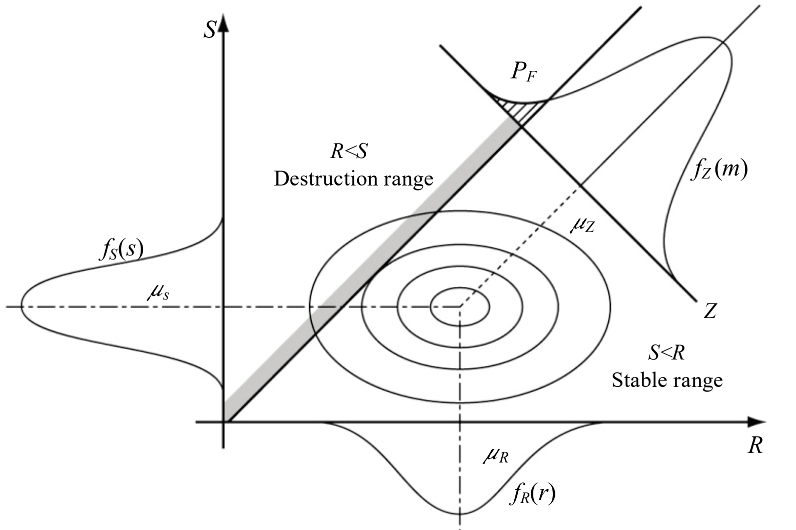


Fig. 1.4.2 Probability Density Function of the Safety Margin When the Performance Function Z = R-S

The average and variance of the safety margin Z are $\mu_Z = \mu_R - \mu_S$ and $\sigma_Z^2 = \sigma_R^2 + \sigma_S^2$, respectively, where the average of R is μ_R, the standard deviation is σ_R, the average of S is μ_S, and the standard deviation is σ_S. **Fig. 1.4.3** shows the probability density function of the safety margin Z in a different way. A reliability index β may be used instead of the failure probability P_f in the reliability-based design method. This reliability index is defined as follows using the average and variance of the safety margin:

$$\beta = \frac{\mu_Z}{\sigma_Z} = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_S^2}} \qquad \text{or} \qquad \mu_Z = \beta\sigma_Z \tag{1.4.1}$$

The reliability index β is a scale to show the magnitude of margins that the average of the safety margin has over its standard deviation. Moreover, β can be directly connected to the failure probability P_f and is given in the following equation if the safety margin Z is normally distributed.

$$P_f = \Phi(-\beta) = 1 - \Phi(\beta) \tag{1.4.2}$$

Here, Φ is a standard normal probability distribution function and β and P_f have the relationship shown in **Fig. 1.4.4** and **Table 1.4.1**.

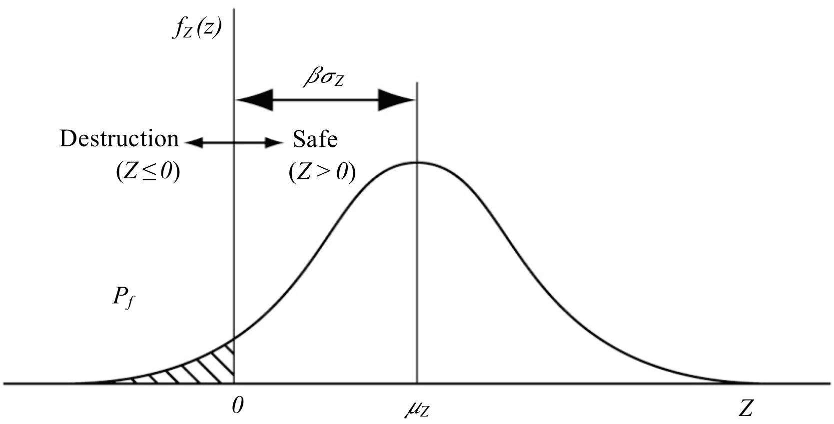


Fig. 1.4.3 Distribution of the Safety Margin Z and the Reliability Index β

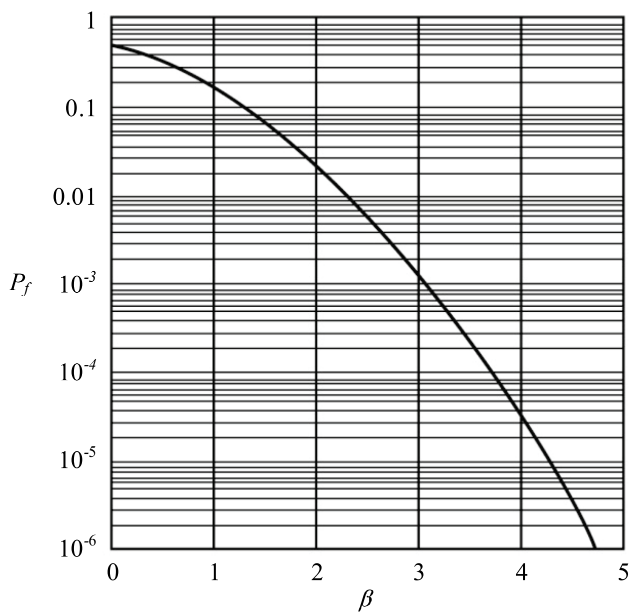


Fig. 1.4.4 Relationship between the Reliability Index β and the Failure Probability P_f

Table 1.4.1 Relationship between the Reliability Index β and the Failure Probability P_f

P_f	10^{-1}	5×10^{-2}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
β	1.28	1.64	2.32	3.09	3.72	4.26	4.75

1.4.2 Calculation Method of Partial Factors with the Design Value Method and Notes

The code calibration to determine an actual partial factor value must take account of the following points irrespective of the format relating to the partial factor.

① There are many non-unique combinations of factors to secure structure reliability.

② It is difficult to find a combination of factors that gives neither too much nor too little reliability under any conditions since even structures of the same type are designed under different conditions.

① means that many combinations of partial factor values are possible because some partial factors are going to secure a safety margin which only one factor (safety factor) secured in the past.

② means that, for example, it is very difficult to secure uniform reliability with a combination of partial factors having the same value for quay walls of different water depths when considering reliability of gravity-type wharves.

The basic concept of the design value method is a proposed method to resolve the problem ① above and determine a partial factor value used in the level 1 reliability-based design method.[1), 2)] The basic concept of the design value method determines factors concerning all load values and resistance values, or all basic variables in relation to the design points and characteristic values. Design points in this context indicate points having the maximum likelihood (the maximum product of probability densities of basic variables) among points on the limit state plane (a plane the performance function of which is zero) in a space composed of load values and resistance values. **Fig. 1.4.5** shows design points ($S(x^*)$, $R(x^*)$) on the plane composed of load values $S(x)$ and resistance values $R(x)$. Therefore, it may be said that the design point is the point most plausible to reach the limit state among combinations of load values and resistance values on the limit state plane.

The design value method determines the load factor γ_S and the resistance factor γ_R using the following equation after determining the design point for structures having the target reliability as a reference point.

$$\gamma_S = S(\mathbf{x}^*) \big/ S(\mathbf{x}_k), \qquad \gamma_R = R(\mathbf{x}^*) \big/ R(\mathbf{x}_k) \tag{1.4.3}$$

where x_k indicates the characteristic value vector of the basic variable.

The design value method generally takes into account many cases that adequately cover the range of load specifications and ground conditions to which the design method is considered to be applied in code calibration. Then, load factors and resistance factors are evaluated by the design value method, and a partial factor which satisfies the given reliability for most of them is determined by soundly utilizing engineering judgement.

The design value method can also be considered a practical method to resolve the problem ① above. Therefore, it does not resolve the problem ② above, and in some cases, it may be a cross section of a level higher than the specified target safety level when calibrating codes concerning partial factors in this book, although the applicable conditions are sufficiently taken into consideration. As a result, note that there is an option in which a designer evaluates reliability by directly calculating the failure probability using the level 3 reliability-based design method as appropriate.

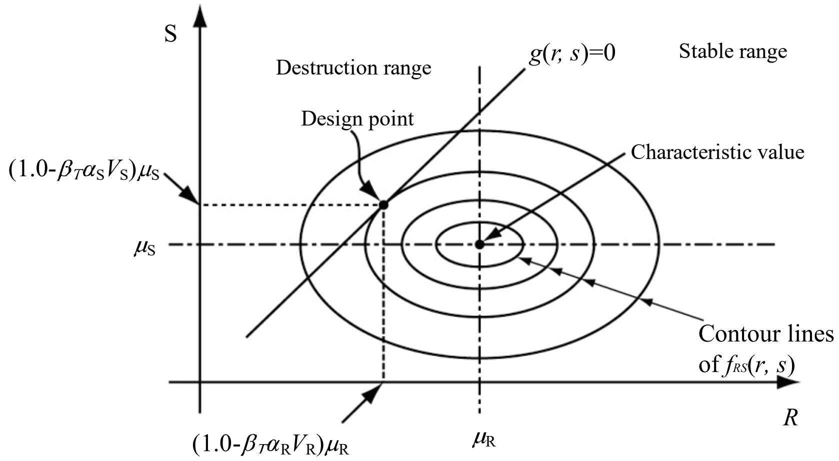


Fig. 1.4.5 Conceptual Diagram of the Design Points

1.4.3 Simple Calculation Theory of Partial Factors

The basic concept of the design value method has been explained above. Application of this method as it now requires repeated design calculations to determine design specifications that satisfy the target reliability under each design condition. In contrast to this, a method is proposed to determine an approximate partial factor without repeated design calculations. In particular, the following equation gives a load factor and resistance factor in the simplest case where the performance function is $Z = R\text{-}S$.

$$\gamma_R = \frac{\mu_R}{R_k}\left(1.0 - \beta_T \alpha_R V_R\right) \tag{1.4.4}$$

$$\gamma_S = \frac{\mu_S}{S_k}\left(1.0 - \beta_T \alpha_S V_S\right) \tag{1.4.5}$$

where

μ_R : average value of R

σ_R : standard deviation of R

V_R : variation factor of R

μ_S : average value of S

σ_S : standard deviation of S

V_S : variation factor of S

R_k and S_k are named for each characteristic value, β_T is the target safety index, and α_R and α_S are sensitivity factors, and are defined as follows:

$$\alpha_R = \frac{\sigma_R}{\sqrt{\sigma_R^2 + \sigma_S^2}}, \quad \alpha_S = -\frac{\sigma_S}{\sqrt{\sigma_R^2 + \sigma_S^2}} \tag{1.4.6}$$

Equations (1.4.4) and **(1.4.5)** easily give a partial factor for any target safety index without finding a cross section which has the target safety reliability by repeated design calculations. However, note that this is a relationship that assumes that the sensitivity factor does not vary even when the target safety level varies to a certain extent. Moreover, instead of using this technique, this book calculates partial factors using the Monte Carlo simulation shown below.

All basic variables in the design value method are linear and are exact solutions when normally distributed, but are otherwise approximations. Details regarding these solutions are described in general textbooks on structural reliability, etc.[1)–5)]

1.5 Monte Carlo Simulation (MCS) as a Tool for Reliability Analysis

1.5.1 Advantages of Using the MCS

Structural engineers, among others, began a full-scale study of reliability analysis and reliability-based design method in the 1960s. Computers were still in their infancy, and streamlining the probability calculation through complex structural calculations was a major challenge. However, advances in computers and enormous progress made in random number generation methods made it possible to calculate probabilities using the Monte Carlo simulation (MCS). The MCS also has an advantage in that the calculation itself is intuitive.

Reliability analysis in this book was conducted using the MCS according to the following general procedure:

① Generate basic variable values (random numbers) constituting the performance function according to the probability distribution to which their variables conform.

② Calculate the performance function Z using the acquired combination of random numbers to evaluate if structures exceed the limit states concerned.

③ Conduct the above evaluation many times and obtain a failure probability by dividing the number of $Z \leq 0$ evaluations by the number of all trials.

As seen from this procedure, a reliability analysis using the MCS has many advantages such as easily understandable failure probability calculations, executable only with basic knowledge of probability calculation, and relatively hassle-free programming for probability calculation, and thus easily avoidable miscalculations of probability since it calculates deterministic performance functions multiple times.

Fig. 1.5.1 shows a result of the MCS analysis of stability against sliding of permanent state, gravity-type wharves.[14) Although this MCS takes into consideration seven basic variables, the figure plots the total value (load value) of the calculated action side and the total value (resistance value) of the resistance side. The total number of trials is 500,000 and the estimated failure probability is 1.10×10^{-1} (=54,921/500,000).

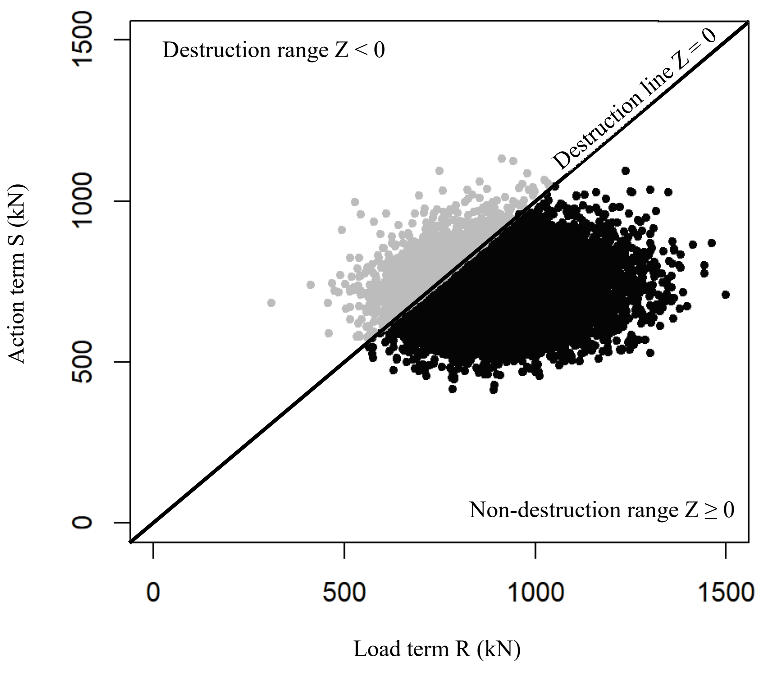


Fig. 1.5.1 Example of MCS Results of Sliding at Gravity-type Wharves[14)]

1.5.2 Setting of Partial Factors by the MCS

Calculation of partial factors using the MCS based on the design value method is relatively easy. Specifically, search for a design point with the highest likelihood among the points generated by the MCS and sufficiently close to the limit state, and calculate a partial factor with **equations (1.4.4)** and **(1.4.5)** using a characteristic value.

Refer to **Reference 14)**, which describes in detail an example of the calibration of load factors and resistance factors using the concept of design value method using the MCS found in this book.

1.5.3 Trial Times of the MCS

Significant progress in computing speed is one of the reasons why the MCS is frequently used for probability calculation. Dramatic progress in the generation method of uniform random numbers, which is a source for the generation of random numbers conforming to different probability distributions, also contributed to the use of the MCS. For example, Mersenne Twister, a current standard feature in computation languages such as R, MATLAB, and C++, and developed by Makoto Matsumoto and Takuji Nishimura (1998), is characterized by a very long period (2^{19937}-1) and high speed generation, and provides a highly reliable random number generation environment for the MCS in reliability analysis. Many standard computation languages functionalize random number generation according to different kinds of probability distributions and users can effortlessly obtain useful and highly reliable random numbers.

The number of MCS trials required for executing stable MCS is an important problem. One example of classical MCS literature, Rubinstein (1981),[15)] deals with this problem using basic probability theory. These results suggest that ensuring 50 to more than 100 samples in the destruction range is considered to be a guide for MCS trials necessary to evaluate stable failure probability. In other words, evaluation of a failure probability around 10^{-3} needs no less than approximately 10^5 MCS trials, and around 10^{-4} needs no less than approximately 10^6 MCS trials. It is also important to confirm that the failure probability converges as the number of trials increases.

Focused sampling is a typical method among several MCS methods proposed to efficiently estimate low failure probability. However, different characteristics of such methods require sufficient consideration of the nature of the problems before application. Low failure probability also needs to fully take account of the engineered significance of computed probability.

1.5.4 Other Supplementary Notes

Some basic variables comprising a performance function may be dependent and correlated. For example, wave power and wind power acting on offshore structures are considered to have a strong correlation.[16)] These instances require generation of random numbers considering the correlation between the basic variables generated. For such methods, refer to References.

Random fields such as these need to be generated for reliability evaluations concerning inhomogeneous continuums modeled by random fields, such as ground, in particular. For an overview of typical methods and methods for reliability evaluations using easy modeling, Honjo, Otake, Kato (2012), Otake, Honjo (2012), and their references are useful.[17), 18)]

[References]

1) Thoft-Christensen, P. and Baker, M.J.: Structural Reliability Theory and Its Application, Springer-Verlab,1982.(Translated by Murotsu, et al.: Structural Reliability Theory and Its Application, Springer-Verlag Tokyo, 1986)

2) ISO(1998) : International Standard ISO/IS2394, General principles on reliability for structures.

3) Honjo, Y., Otake, Y.: Philosophy and Practice of Reliability Design Method and Performance Design: Focusing on Ground Structures, GIHODO SHUPPAN, 2018.

4) Hoshiya, M., Ishii, K.: Reliability Design Method of Structures, Kajima Institute Publishing, 1986.

5) Melchers, R. E.: Structural Reliability Analysis and Prediction, John Wiley & Sons, Inc.,1999.

6) Honjo, Y., Otake, Y.: Development of Geotechnical Reliability Analysis Method by a Simplified Procedure and its Application to Shallow Foundations, Journal of Japan Society of Civil Engineers C, 70(4), 372-388, 2014.

7) Otake, Y., Honjo, Y.: Characterization of Model Error In Geotechnical Structural Design, Journal of Japan Society of Civil Engineers C (Geosphere Engineering), 70(2), 170-185, 2014.

8) Otake, Y., Honjo, Y.: Characterization of Model Error In Geotechnical Structural Design, Journal of Japan Society of Civil Engineers, C, 70(2), 186-198, 2014.

9) Nakanishi, J.: Theory of Environment Risks, Iwanami Shoten, Publishers, 1995.

10) Y. Honjo, ,T.C. Kieu Le, T. Hara, M. Shirato, M. Suzuki and Y. Kikuchi, Code calibration in reliability based design level I veri.cation format for geotechnical structures, Geotechnical Safety and Risk (Proc. of IS-Gifu) (eds. Y. Honjo, M. Suzuki, T. Hara and F. Zhang) ,CRC press, pp.433-452,2009.(Unpublished Japanese version available)

11) Nagao, T., Shibasaki, R., Ozaki, R.: Steady level 1 reliability design method to minimize expected total cost considering economic losses, Proceedings of Structural Engineering Vol. 51A, pp.389-400, 2005.

12) Yoshioka, K., Nagao, T., Washio, T., Moriya, Y.: Reliability analysis concerning external stability problems of gravity-type special breakwaters, Proceedings of Costal Engineering Vol. 51, pp.751-755, 2004.

13) Honjo, Y., Suzuki, M.: Overview of design code development using reliability design method, "Course: Design code and reliability design method of ground structures", Journal of Ground Engineering Vol.58, No.10, pp.53-60, 2010.

14) Takenobu, M., Nishioka, S., Sato, T., Miyata, M.: A basic study on the level 1 reliability design method based on load and resistance factor approach ~ performance verifications of sliding failure and overturning failure for caisson type quaywalls in permanent situation ~, NILIM Technical Note No.880, 2015.

15) Rubinstein, R.Y., Simulation and the Monte Carlo Method, John Wiley and Sons, 1981.

16) Nagao, T.: A study on the combination method of correlated wave and wind actions, NILIM Report No.48, 2011.

17) Honjo, Y., Otake, Y., Kato, H.: a Simplified Scheme to Evaluate Spatial Variability and Statistical Estimation Error of Local Average of Geotechnical Parameters in Reliability Analysis, Journal of Japan Society of Civil Engineers C, 68(1), 41 -55, 2012.

18) Otake, Y., Honjo, Y.: Verification of a Simplified Geotechnical Reliability Analisis Scheme of Spatial Variability Based on Local Average of Geotechnical Parameters, Journal of Japan Society of Civil Engineers C, 68(3), 475-490, 2012.

Chapter 3 Consideration for Environment

1 General

1.1 Water Quality

Water quality means the properties of water and its various physical characteristics (water temperature, salt content, transparency, turbidity, etc.), chemical characteristics (pH, concentration of nutrients, dissolved oxygen (DO), chemical oxygen demand (COD), etc.) and biological characteristics (chlorophyll, organic materials, etc.).

Water quality changes biologically and chemically, and physically moves and diffuses together with a medium (seawater). It changes from time to time by absorbing external energy (tides, meteorological phenomena, river discharges, etc.), and the characteristics may vary daily or hourly. In addition, the spatial distribution of water quality shows local characteristics and at the same time has dispersion effect to make even distribution in the system (**Fig. 1.1.1**).[1] It is important that even when each water quality item changes, it is able to maintain a range of appropriate values.

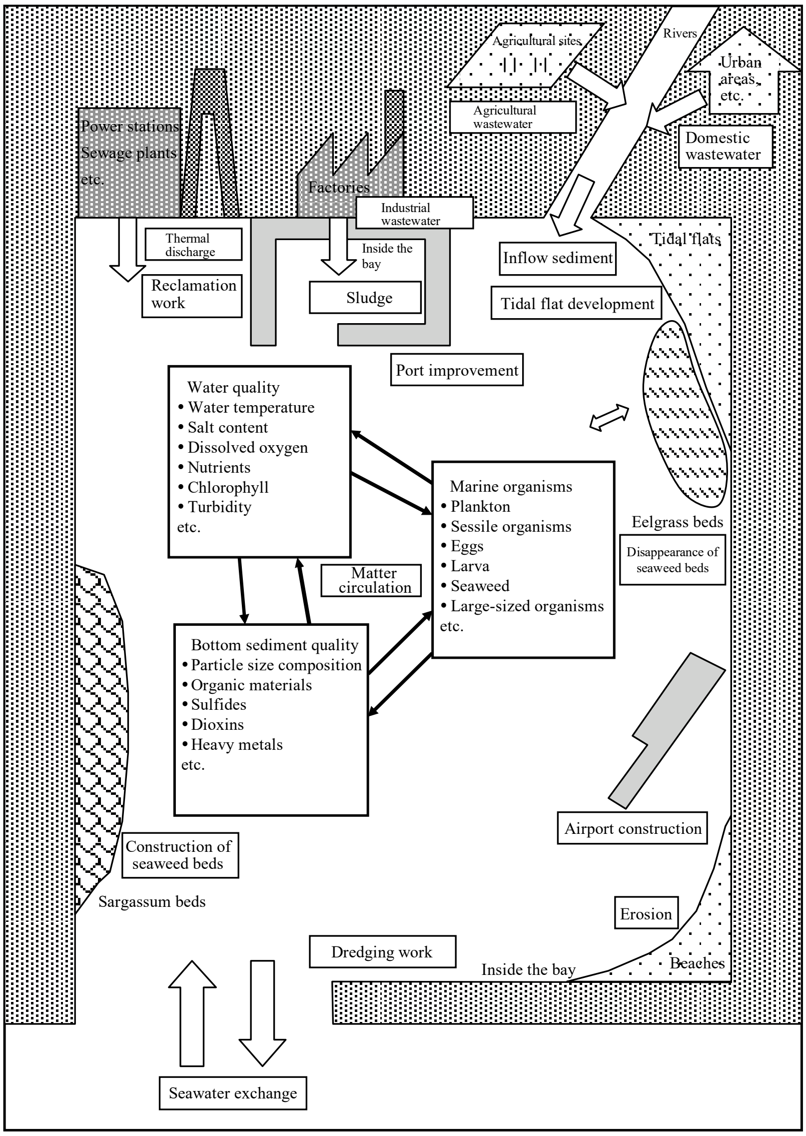


Fig. 1.1.1 Relationship between Water Quality, Bottom Sediment Quality and Marine Organisms[1]

The Basic Environmental law stipulates that "the water quality criteria for water areas desirable to preserve human health and life shall be specified," and specifies "environmental water quality standard concerning the protection of human health (health items: 27 water quality parameters including cadmium, but excluding fluorine and boron in coastal waters)" and "environmental water quality standard concerning the conservation of living environments (11 water quality parameters in total for coastal waters: pH, COD, DO, coliform group, n-hexane extracts, total nitrogen, total phosphorus, total zinc, nonylphenol, linear alkylbenzenesulfonate and its salt, bottom layer DO)," in particular. In 2016, bottom layer dissolved oxygen (bottom layer DO) was added to the living environmental parameters in order to help the survival of fishes and preys in the bottom layers of water areas, and conserve and restore areas where populations of aquatic organisms utilizing the bottom layers can be conserved through adequate reproduction.

Other water quality criteria in water areas include environmental criteria based on **the Act on Special Measures concerning Countermeasures against Dioxins** and non-statutory criteria such as water quality criteria for fisheries set forth to maintain the habitation and breeding of useful aquatic organisms, continue unhindered fishery operations and retain the economic value of fishery marine products, etc. Water criteria for fisheries specify the standard values for organic materials (11 parameters including COD) and toxic materials (63 parameters including cadmium). Moreover, water quality criteria for bathing areas have been summarized by the "Council to Discuss the Quality of Comfortable Bathing Areas," which specify the amount of feces-origin coliform groups, the existence of oil slicks, COD, transparency, etc.[2)]

1.2 Sediment Quality

Sediment quality means properties of sediments and deposits on the sea bottom and tidal flats in tidal zones reflecting the long history of the environment, and can be used as a time-integrated environmental indicator that reveals the history of long-term variations and evidence of disturbances by events in contrast to the water quality.[1)] Therefore, the vertical structure of the bottom sediment quality deposited beneath the seabed also provides important information as well as the bottom sediment quality on the surface of the seabed. Furthermore, beyond water quality, spatially local distribution is another characteristic of bottom sediment quality.

In regard to the criteria for sediment quality, the Ministry of the Environment's **Guideline for Processing, Disposal and Others of Sediment Quality** specifies the concentration of mercury, PCBs and dioxin in the sediment of which aqueous concentration is at a level not harmful to human health as the elimination criteria of sediment quality. For sediment quality, prohibition against disposing sediments from sea bed exceeding the criteria and approval for sea disposal of dredged sediment and other materials are judged based on the environmental criteria per **the Act on Special Measures concerning Countermeasures against Dioxins** and **the Act to Prevent Marine Pollution and Maritime Disasters** (Act on Prevention of Marine Pollution and Maritime Disasters). As for water quality criteria for fisheries of the sediment quality, there are criteria restricted by COD, the content of sulfides and other materials, and criteria restricted by dissolution tests for cadmium and other materials.[1)]

1.3 Organisms

Marine organisms are the primary component of an ecosystem and exist through interrelationships by means of complex food chains (grazing food chains and detritus food chains) at sea and with spatial and temporal hierarchies (**Fig. 1.3.1**). The survival strategies of marine organisms are the r-strategy type, which stands out in areas with a large amount of environmental variation and rapidly recovers after a decrease in number, and the K-strategy type, which stands out in areas with limited environmental variation and slowly recovers after a decrease in number. When preserving marine organisms, attention needs to be paid to the survival strategies of the target organisms, competing organisms, mixing of alien species and so on.

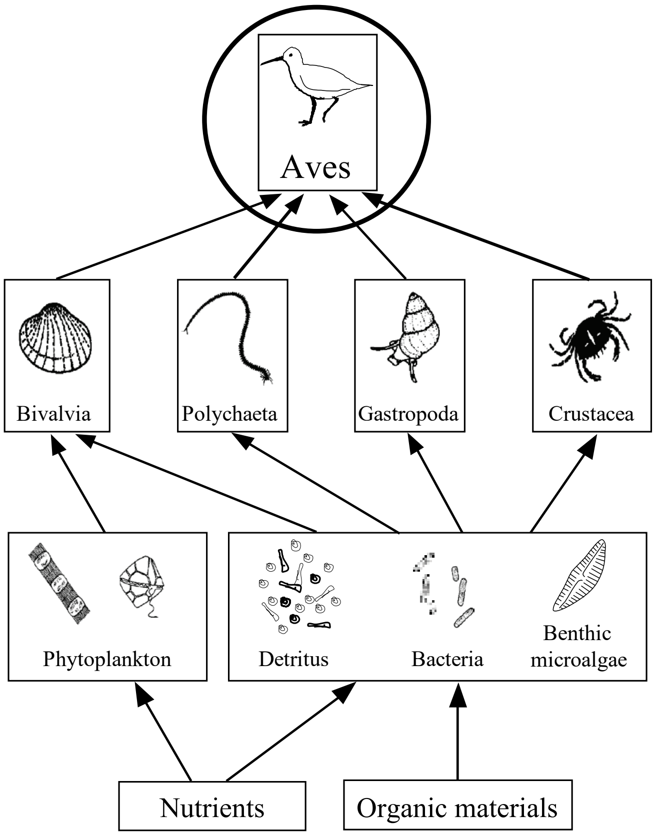


Fig. 1.3.1 Relationship between Marine Organisms that are Components of Tidal Flat Ecosystems[3)]

1.4 Ecosystem

Coastal ecosystems have functions such as habitats for marine organisms, purification of water quality, material circulation, biological production and amenity-oriented functions which are exerted in physical, chemical and biological processes and are made up of complicated relationships, therefore, the results of human intervention cannot be fully predicted. As a result, comprehensive and adaptive efforts for conservation, restoration and creation of these ecosystems are indispensable.[4)]

What characterizes an ecosystem are the relationships between living organisms and abiotic environments (water sediment quality, flow, etc.) and interactions between marine organisms. The relationships between different ecosystems are also important in determining the coastal water environment. It is necessary to try to understand the whole picture when looking at the complex relationships between these elements (**Fig. 1.4.1**).[4)] [5)] For consideration of the environment, it is necessary to consider the influences on the notable species and biological community that comprise the ecosystem, as well as extract the environmental factors influencing their survival, growth and breeding, and understand the proper ranges of each of these areas as quantitatively as possible.

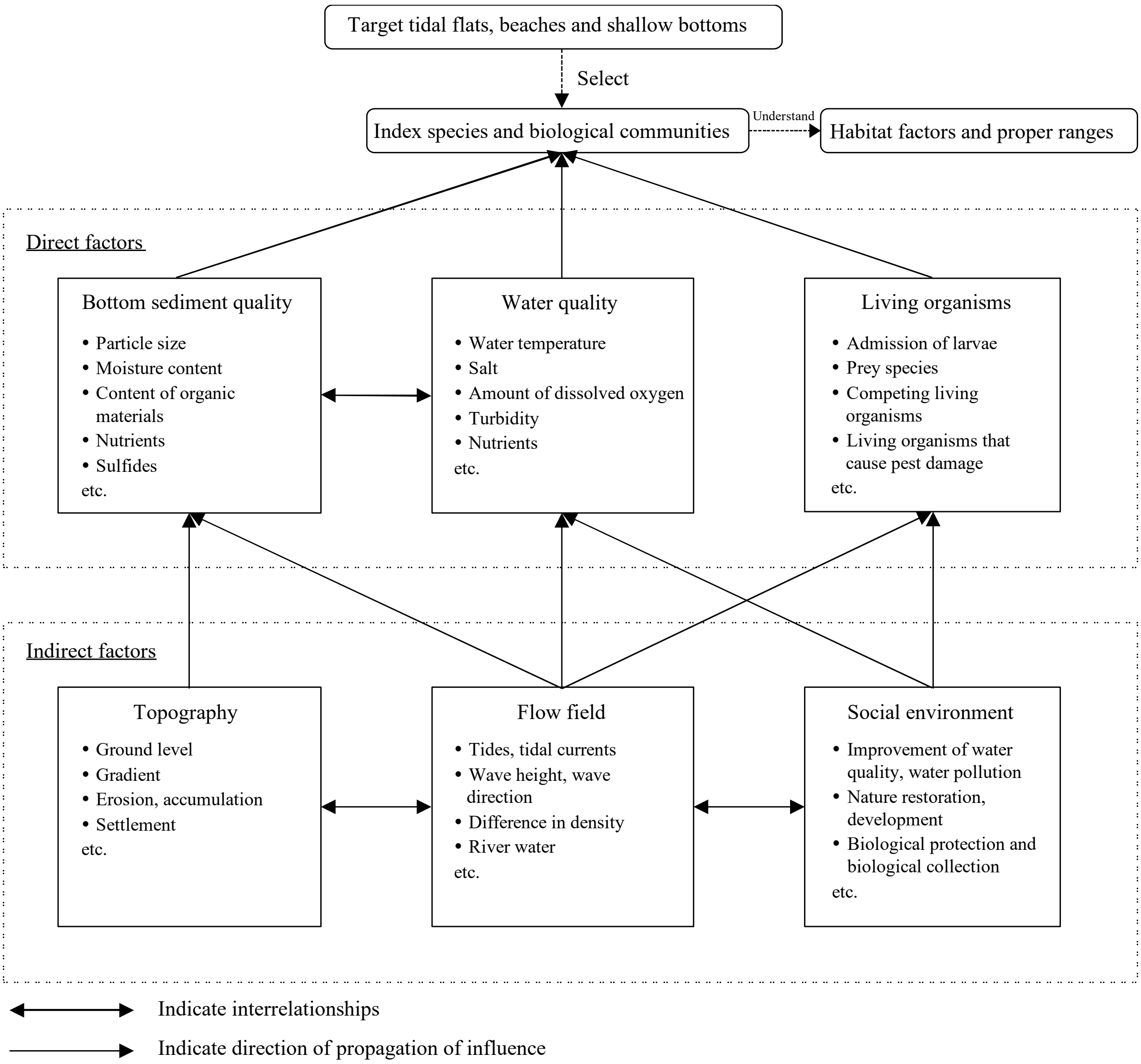


Fig. 1.4.1 Propagation Flow of Environmental Factors Influencing Species and Biological Communities[6)]

An ecosystem provides ecosystem services (benefits) for regulation, provision and culture, and a variety of marine organisms make the basis of those services (**Table 1.4.1**). As for the variety of marine organisms in particular, **the Strategy for Maintaining Diversity of Marine Organisms** was developed in March 2011 for the long-term utilization of marine ecosystem services. The strategy shows that the diversity of marine organisms supports our "lives and livelihoods."[6) 7)] Among the ecosystem services, the regulating service that absorbs carbon dioxide in the air and stores organic materials in marine sediment, which is provided by the blue carbon ecosystem, is becoming more important since the Paris Agreement (**Table 1.4.2**).[8)]

Table 1.4.1 Summary of Ecosystem Services

<table>
<tr><td rowspan="2">Supporting services[7)]

Supporting services are necessary for the production of all other ecosystem services. Supporting services often exert indirect and very long-term effects on people, while changes in provisioning, regulating and cultural services exert direct and short-term effects on people.</td><td>Provisioning services[7)]

Provisioning services are products obtained from an ecosystem and include food, fiber, fuel, genetic resources, chemical substances, natural medicines, materials for ornaments and fresh water.</td></tr>
<tr><td>Regulating services[7)]

Regulating services are benefits obtained from the adjustment of ecosystem processes and include regulation of air quality, climate, water and soil erosion, as well as water purification and waste treatment, prevention of diseases, pest control, pollination and protection from natural disasters.</td></tr>
</table>

Supporting services include soil formation, photosynthesis, primary production, nutrient salt circulation and water circulation.	**Cultural services**[7] Cultural services are non-material benefits people obtain from an ecosystem through the improvement of spiritual quality, intellectual development, introspection, amusement and aesthetic experiences, and include cultural diversity, spiritual value, religious value, a body of knowledge, educational value, inspiration, aesthetic value, social value, sense of place, cultural heritage value, amusement and tourism.

Table 1.4.2 Distribution Area and Carbon Storage Rate of Blue Carbon and Other Ecosystems[8]

	Area (× 1,000,000 km^2)	Arial carbon accumulation rate (average value, data range) (ton C/ha/year)	Global carbon accumulation rate (data range) (carbon Tg C/year)
Blue carbon ecosystems			
Seaweed beds	0.33 (0.6)	0.83, 0.56-1.82 (1.37)	27.4-44 (82)
Mangrove forests	0.17 (0.3)	1.39, 0.20-6.54 (1.89)	17-23.6 (57)
Salt marshes	0.4 (0.8)	1.51, 0.18-17.3 (2.37)	60.4-70 (190)
Total of the three ecosystems	0.9 (1.7)	1.23, 0.18-17.3 (1.93)	114-131 (329)
Other marine ecosystems			
River mouths, inner bays, areas outside of bays (excluding the above)	1.8	0.5	81.0
Continental shelf areas	26.6	0.2	45.2
Total of the two above			126.2
Total of the coastal areas			237.6 (454)
Ratio of blue carbon ecosystems			46.89 (0.72)
Deep sea	330.0	0.00018	6.0
Entire marine			243.62 (460)
Ratio of blue carbon ecosystems to the entire marine			45.73 (0.71)

The UNEP Report has been modified. The storage rate is calculated from the amount of organic carbon deposited into the seabed soil per unit area and time. Values in parentheses indicate the maximum value in the data confidence interval.

[References]

1) Japan Marine Surveys Association: Marine Survey Technical Manual - Water quality and sediment -, Japan Marine Surveys Association, 2008.

2) Kawabata, Y.: Hydrometeorology, Chijin Shokan, 1961.

3) Working Group for marine natural reclamation: Handbook of Marine Natural Reclamation, Gyosei, 2003.

4) Supervised by Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Working Group for marine natural reclamation: Practical Handbook for Natural Reclamation of Seashore by Adaptive Management and Standardization of Environmental Consideration, 2007.

5) Japan Marine Surveys Association: Marine Ecosystem Survey Manual, 2013.

6) Furukawa, K.: Targets for conservation, restoration, and creation of coastal environment and recent conditions surrounding their management approach. Journal of Japanese Association for Coastal Zone Studies, Vol.20, No.1, 2007.

7) Millennium Ecosystem Assessment: Ecosystems and Human Well-being: Synthesis, Translated by Yokohama National University 21st Century COE Translation Committee, Ohmsha, 2007.

8) Hori, M., Kuwae, T.: Blue Carbon - CO2 Isolation, Storage, and Utilization in Shallow Sea, Chijin Shokan, 2017.

2 Green Port Structures

2.1 General

Green port structures are those that provide basic functions as port structures and which help marine organisms populate in areas such as tidal flats and shore reefs[1] (**Part III, Chapter 4, 4 Green Breakwaters**, **Part III, Chapter 4, 14.7 Green Revetments**, **Part III, Chapter 5, 2.1.3 Quaywalls** and **Part III, Chapter 5, 5.1.2 Green Piled Jetty**). There are three following configuration types of port structures for coexistence with organisms (**Fig. 2.1.1**):

① Covering type
② Piled jetty type
③ Caisson type

Furthermore, there are three habitat types for organisms added as green port structure

① Sand and silt type
② Gravel type
③ Block type

2.2 Structure Type

(1) Covering type

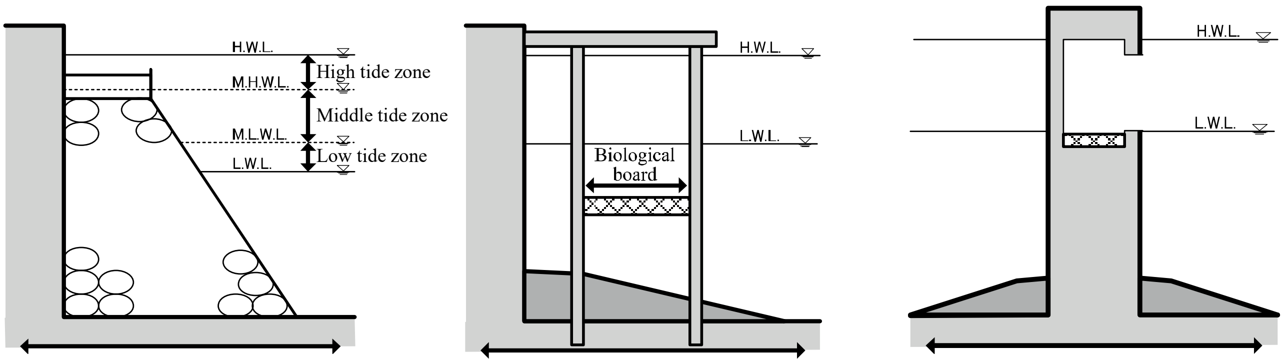
The covering type is a structural type that provides a gentle slope or step-wise structure in front of the port structures or behind of breakwaters, and covers their surfaces with materials such as sand, gravel and blocks. Gentle sloped revetment with coexistence functions with organisms is also classified as the covering type.

(2) Piled jetty type

The piled jetty type is a structural type that provides undersea floorboards or similar that serves as a biological board by utilizing the space under piled jetty.

(3) Caisson type

The caisson type is a structural type that ensures a habitat by devising a structure to make it easy for organisms to grow in compartments in the caisson.



(a) Covering type (b) Piled pier type (c) Caisson type

Fig. 2.1.1 Configuration Types of Green Port Structures[1]

2.3 Habitat Type

The habitat type can be selected and applied from the following three types for any structural type. The selection of habitat type depends on the water depth for installation, water quality, oceanographic phenomena and expected marine organisms.

(1) Sand and silt type

The sand and silt type utilizes sand and silt as a habitat for living organisms. A habitat set to a tidal zone and deeper than a tidal zone for the covering type is a tidal flat and shallow area, respectively. In addition, the use of sand and silt as a biological board in piled jetty type and caisson type also creates a tidal flat or shallow area.

(2) Gravel type

The gravel type uses stone materials as a habitat for marine organisms. The habitat for marine organisms becomes a growth base material for seaweeds and a habitat for sessile organisms depending on the water depth for installation and the environmental conditions.

(3) Block type

The block type uses blocks such as algal reefs and fishing reefs as habitats for marine organisms. The habitat for organisms becomes a growth base material for seaweeds and a habitat for marine organisms such as fish depending on the type of blocks.

2.4 Development Plan

2.4.1 Understanding the Conditions

Green port structures append a habitation function for organisms at the port structures with the assumption that the original functions of the port structures are maintained (**Fig. 2.4.1**). It is also necessary to compile related information such as restrictions on utilization due to ship navigation, berthing and so on in advance.

The purpose of green port structures is to create a habitat for organisms, and thus, effective structures need to be assessed according to the environment of the region concerned. When studying the target organism species, the type of habitat and detailed profiles, it is necessary to understand physical conditions such as the current conditions of the surrounding water surface and waves, conditions of water quality and the habitation situation of marine organisms. Moreover, it is important that the needs of the coastal environment required on the regional level be understood beforehand for effective coordination.

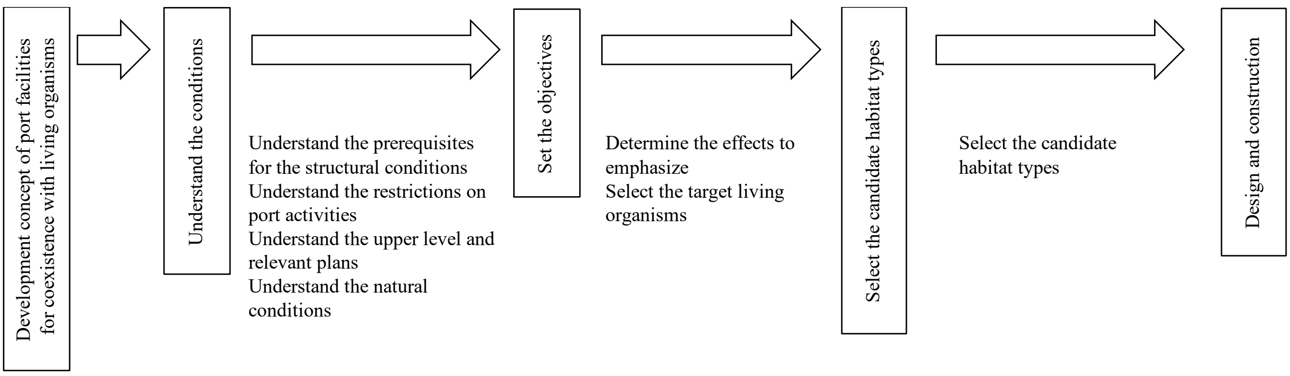


Fig. 2.4.1 Concept Flow of the Development and Planning of Port and Harbor Structures Symbiotic with Organisms

2.4.2 Setting the Objectives

Setting the objectives can be started by determining the effects to emphasize among those expected from the development of green port structures shown in **Table 2.4.1**. Effects obtained from green port structures are divided into two categories: effects obtained from the formation of an ecosystem and collateral effects from the development of bedrock, and they are subdivided into biological, chemical, physical, social and economic effects.

Table 2.4.1 Major Effects Expected from the Development of Green Port Structure

Effects obtained from the formation of an ecosystem	
Biological effects	Improvement of basic productivity
	Provision of a habitat
	Provision of egg-laying and incubation sites
	Provision of food
	Circulation of nutrient salts
Chemical effects	Purification of water quality
	Reduction of CO_2
Physical effects	Weakening of waves and flow
Social effects	Education and research grounds
	Amenity-oriented grounds
Economic effects	Economic effects due to increased interaction among people
Collateral effects from the development of bedrock	
Physical effects	Protection of the coast line
Economic effects	Reduction of maintenance and repair costs

2.4.3 Selection of Candidate Habitat Types

It is necessary to select suitable candidate habitat types that serve the purpose in consideration of the structural restrictions on the port structures and the expected effects mentioned earlier. When there is no need to consider structural restrictions and limitations on port administration and utilization for the target port facilities, it is desirable to determine the expected effects and target species and to select the proper habitat types based on the objectives while taking into consideration the natural conditions of the water areas concerned. **Table 2.4.2** shows the main conditions for the selection of habitat types and examples of target species.

Table 2.4.2 Main Conditions for the Selection of Habitat Types and Examples of Target Species

Habitat type	Water depth zone	Main conditions for selection	Target species (example)
Sand and silt type	Tidal zone	Relatively calm water surface (where the effects of waves or flow that lead to the outflow of sand are minor) The area should not be a water area where there is a concern for water stagnates and deposits of suspended solids are a concern	[Benthic organisms] Sandworms, clams, Upogebia pusilla, sand bubble crabs, Marcophthalmus japonicas, etc. [Fish] Acanthogobius, Tridentiger obscurus, etc. [Seaweed] Nanozostera japonica [Plants] Phragmites, Suaeda maritima, etc.
Sand and silt type	Deeper than the tidal zone		[Fish] Stone flounder, Paralichthys olivaceus, Portunus trituberculatus, etc. [Other animals] Marsupenaeus japonicus, Squilla, Scapharca broughtonii, etc. [Seaweed] Eelgrass
Gravel type	Tidal zone	High concentration of dissolved oxygen suitable for habitats is expected with minor effects of hypoxic environments, river flushes, etc. Where the formation of seaweed beds is expected, lighting conditions (amount of light, transparency) and salt suitable for growing seaweed can be anticipated.	[Periphyton] Serpulidae, white streaks barnacles, periwinkle, mouse chiton, pacific oyster, orange-striped sea anemone, shore crabs, etc. [Seaweed] Green laver, hijiki, etc.
Gravel type Block type	Deeper than the tidal zone		[Fish] Scorpion fish, *Pseudoblennius cottoides*, Rockfish, etc. [Other animals] Henricia nipponica, Anthocidaris, abalone, etc. [Seaweed] Sargassum, undaria, Sargassum tortile, Eisenia, Ecklonia cava, etc.

[Reference]

1) Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism: Guidelines for Development and Maintenance of Green Port Structures, 2014.

3 Conservation and Restoration of Natural Environment

3.1 Nature Restoration

To help create a society that can coexist with marine organisms, **the Act on the Promotion of Nature Restoration** became effective in 2003. **The Marine Nature Restoration Handbook**[1)] stipulates that nature restoration includes "conservation" to preserve the natural environment we have now, "restoration," targeting past geography, ecosystems and other environmental areas, and "creation," a new goal based on the changed environmental, social and other conditions as a broad interpretation and which does not necessarily demand restoring nature before development (**Table 3.1.1**).

For nature restoration in the broad sense, a variety of technologies such as development of tidal flats and shallow areas, overlaying sand and backfilling borrow pits are available on the water area. For development of tidal flats and seaweed beds, **Part III, Chapter 11, 3.6 Conservation of Natural Environment** may be referred to.

Table 3.1.1 Definition of Nature Restoration-Related Terms

Classification	Term	Description
Conservation	Conservation	To manage so as to conserve the health of habitats for living organisms
	Protection	To maintain the present condition
	Preservation	To let nature take its course and refrain from human intervention
Restoration	Reconstruction	To approximate the previous conditions of once lost habitats for living organisms
	Improvement	To purify contaminated habitats for living organisms
	Recovery	To manually recover the function of habitats for living organisms
Creation	Creation	To manually create habitats for living organisms

Prepared by referring to 1)

3.2 Sand capping

The reasons for the degradation of sediment quality include organification of bottom sediment due to eutrophication of water masses and contamination with toxic chemical substances. The organification of bottom sediment quality is mainly improved by dredging, overlaying sand and improving the bottom sediment quality. Overlaying sand to try to restore a habitat for living organisms as well as improve the bottom sediment quality is often used as a method to restore nature.[2) 3) 4) 5) 6) 7)]

Overlaying sand has the following four main effects: ① it restrains the release of nutrient salts from the sediment during its cycle to reduce eutrophication of the sea water; ② it restrains the hypoxia of the bottom layer by reducing the oxygen demand of the sediment; ③ it reduces the release of toxic chemical substances to the water; and ④ it provides a variety of habitats for living organisms by becoming basis of habitat for benthonic organisms and seaweed as environments for living organisms.

Sustainability of the effects of overlaying sand needs to be adequately considered when planning the overlaying sand[8)] (**Fig. 3.2.1**). Sustainability is obstructed by the outflow of overlaying sand materials due to waves, flow and other forces, sinking due to mixing with the current ground and burial of overlaying sand materials due to deposition of organic substances.

To prevent or reduce the outflow of overlaying sand materials due to waves and flow, it is necessary to understand the influence of waves and flow at seabeds of target area, and to select overlaying sand materials of appropriate grain sizes. If there is not sufficient data to estimate the stability of overlaying sand materials, the stability may be assessed using a numerical model. When the overlaying sand materials are expected to outflow, an adequate thickness of overlaying sand needs to be assessed during the planning stage while considering the amount of outflow and the expected service life.

The bottom sediment of eutrophicated sea area are often soft ground with high organic matter content, and when sand capping is on this soft muddy ground with high organic matter content, the sand sinks into the mud.Even if the sand does not sink immediately after overlaying sand, it may sink after several years by vertical mixing the surface of the bottom sediment due to disturbances from flow and waves. When the overlaying sand materials are expected to sink, it is necessary to assess and estimate the amount of sinking and consider an adequate amount of sand to be injected. It is possible to use hard and steel slags as overlaying sand materials in order to restrain resuspension due to flow and waves as well as the vertical mixing of the surface of bottom sediment.[9)]

For sea area where the burial of overlaying sand materials due to deposits of organic materials is strongly concerned, it is desirable to understand the depositing rate of bottom sediment in advance using sediment traps or other means, and to assess how long the effects of the overlaying sand will persist. For sea area where a large amount of organic materials have been deposited, it will be considered to use coal ash granulated substances which weaken the reduction rate of effectiveness of overlaying sand for the depositing of organic materials in order to retain the overlaying sand effects.[10)]

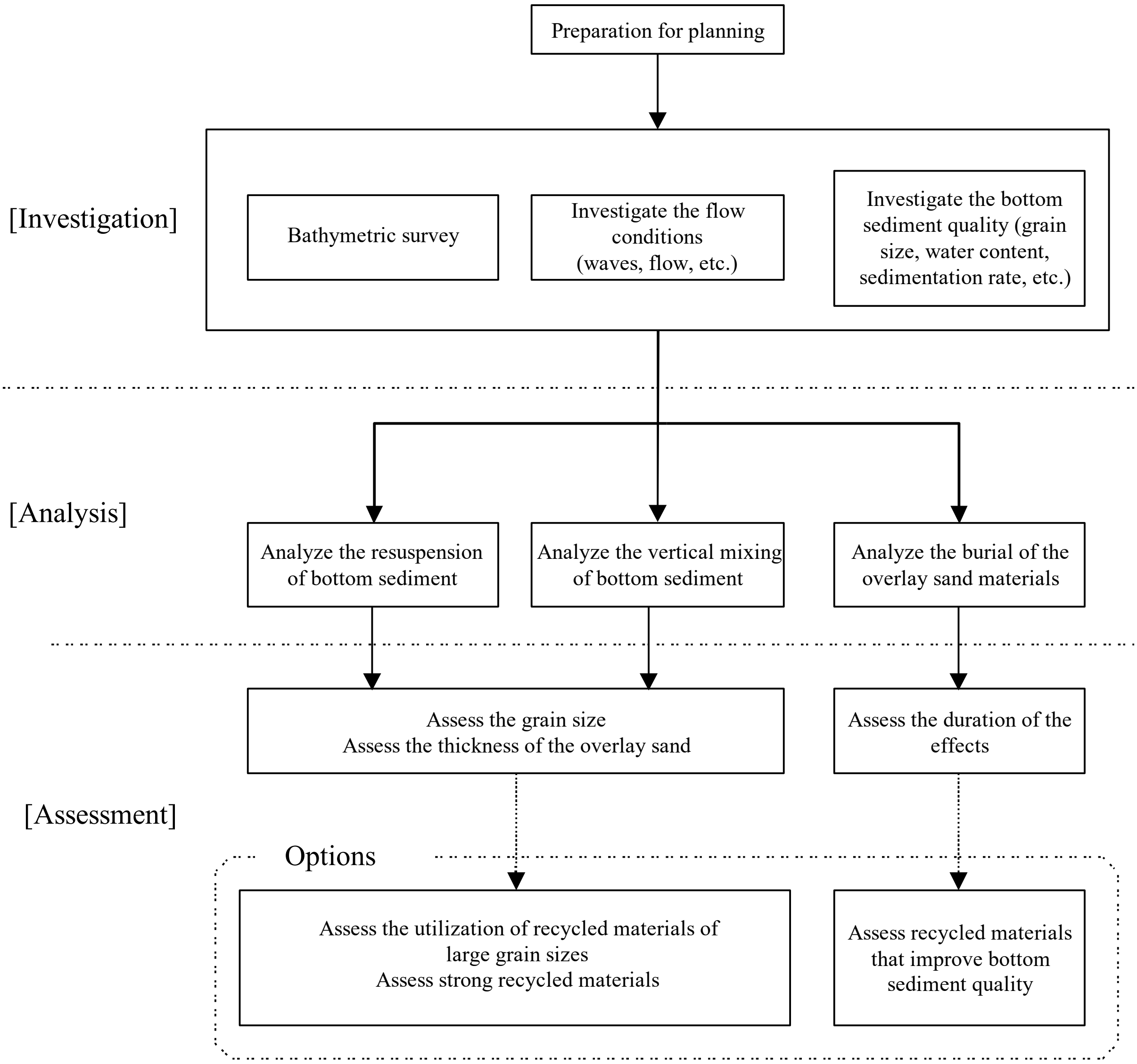


Fig. 3.2.1 Investigation, Analysis and Assessment of Flow in Planning of Overlaying Sand

3.3 Backfill of borrow pits

There are borrow pits of various sizes in domestic coastal areas. These are mainly remains of sea gravel dredging for land reclamation. Borrow pits are classified into the depression type, which is locally and vertically dredged, and the flat type, which extends gently.[11)] This section mainly focuses on the depression type for which improvement to hypoxia is expected through backfilling.

The insides of the borrow pits are pocket-shaped, in contrast to the surrounding water area. In addition, water stagnates in these areas, with organic bottom sediment and other materials accumulating and creating deposits, leading to hypoxia and anoxia accompanied by deterioration of water quality. Hypoxia and anoxia not only negatively affect the living organisms living there, but also result in the release of sulfides from sediment which have become reductive and also negatively affect the surrounding water due to blue tides and other forces (**Fig. 3.3.1**).[12] Backfilling of borrow pits reduces the negative effects to coastal environments, and thus, the improvement of these environments can be expected. The report of the Central Environment Council in May 2005, "**On the method of the sixth water quality total volume control**," and the report of the Council of Transport Policy in March 2005, "**On the basic direction of future port environmental policy**," also stipulate that the improvement of sea area environments should be promoted by backfilling deep-mined areas.[13]

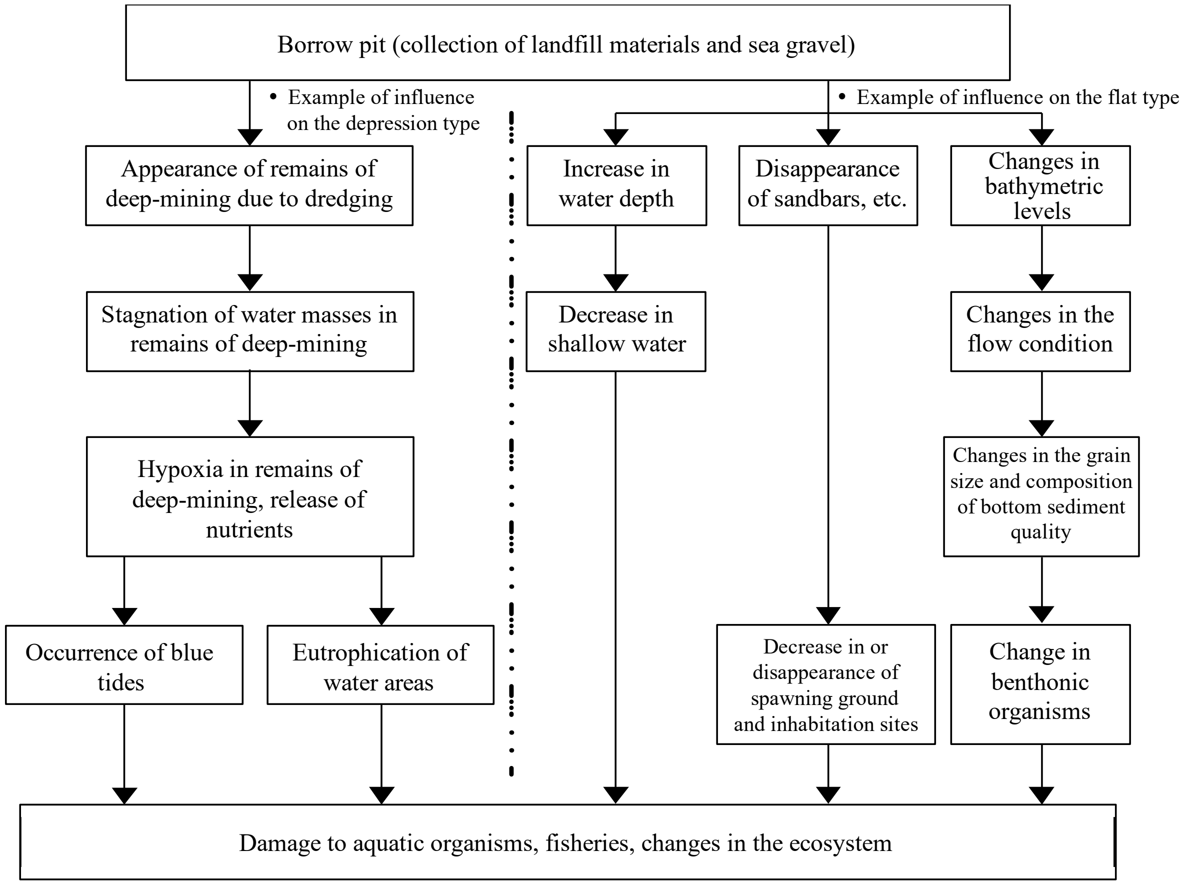
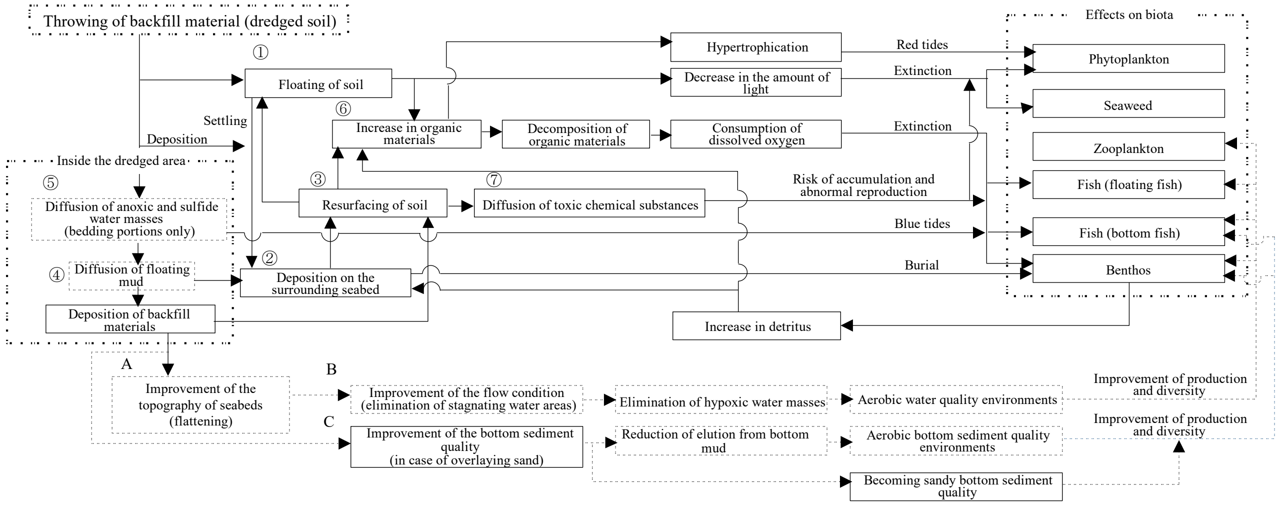


Fig. 3.3.1 Mechanism in Which Borrow Pits Affect Aquatic Organisms[12]

Examples of restoration through backfilling so far include the offshore of Kemigawa in Tokyo Bay, the Mito District in Mikawa Bay, the offshore of Muromigawa in Hakata Bay, and Nakaumi in blackish water.[14) 15) 16)] Dredged sediment obtained in maintenance dredging of navigation channels and basins is often used effectively as backfill material. When dredged soil is used as backfill material, it may be used after solidifying with recycled materials such as cement and iron and steel slag as solidification material and water soluble polymer and other agents as water absorbent material since it is often rich in organic components, silt clay-like materials and weak dredged soil with a high water content.[17] If such recycled materials are used for backfilling, it is desirable to overlay with soil of good quality after the backfill. When no overlaying sand is used, it is necessary to assess the effects on the environment through dissolution experiments or other means in advance.[18]

In the selection of backfill methods for dredged areas, it is necessary to pay attention to oceanographic phenomenal conditions, construction conditions, such as target area and water depth, construction ability, required thickness of the backfill, and cost, and to consider the influence construction exerts on the surrounding environment. For the impact response given to the surrounding water just after throwing the soil and before the effects of restorations can be seen with a focus on the movement of soil during the backfill work, refer to **Fig. 3.3.2**.

When throwing the backfill material, muddy sea water due to the backfill material itself, deposits to the surrounding seabed, resuspension, diffusion and deposition to the surrounding water of existing sediments may happened (**Fig. 3.3.2** ①, ②, ③). Moreover, when throwing the backfill material, it is possible that hypoxic and anoxic water masses stagnating inside will diffuse to the surrounding seabed (**Fig. 3.3.2** ⑤). In this way, it is desirable to minimize the influence construction exerts on the surrounding environment by understanding and assessing the influence of the construction in advance based on the impact response flow as shown in **Fig. 3.3.2**.



Legend (common influences except for the following classifications)
Solid arrow: minus flow; dotted arrow: plus flow
Frame with dotted lines: local depression type; double frame: flattened type of rolling seabeds; solid frame: common

Fig. 3.3.2 Impact Response Flow to the Surrounding Environment during Backfill Work[11)]

[References]

1) Working Group for marine natural reclamation: Handbook of Marine Natural reclamation, Gyosei, 2003.
2) Horie, T., Inoue, S., Murakami, K., Hosokawa. Y.: Study on improving of bottom sediments quality by sand covering in Mikawa Bay. Doboku Gakkai Ronbunshu 533, 225-235, 1996.
3) Ishibashi, H., Mino, S., Okamoto, M., Yamashita, Y., Sakai, Y., Nishibayashi, K., Miyazaki T.: Verification of the durable effect of the sand banking method in Tsuda Bay. Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering), 65(1), 1191-1195, 2009.
4) Ogawa, D., Murakami, K., Katakura N.: Field experiments on the lasting of sand capping technique on nutrient release reduction and the influence of suspended sediments on the effects. Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering), 65(1), 1181-1185, 2009.
5) Murakami, K., Hosokawa, Y., Takano S.: Monitoring on bottom sediment quality improvement by sand capping in Mikawa Bay, Bulletin on Coastal Oceanography, 36(1), 83-89, 1998.
6) Ishibashi, H., Mino, S., Okamoto, M., Yamashita, Y., Sakai, Y., Nishibayashi, K., Miyazaki T.: Verification of the durable effect of the sand banking method in Tsuda Bay. Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering), 65(1), 1191-1195, 2009.
7) Ogawa, D., Murakami, K., Katakura N.: Field experiments on the lasting of sand capping technique on nutrient release reduction and the influence of suspended sediments on the effects. Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering), 65(1), 1181-1185, 2009.
8) Chiba Port Office, Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, For Restoration of Tokyo Bay, 2014.
9) Ports and Harbours Bureau and Civil Aviation Bureau, Ministry of Land, Infrastructure, Transport and Tourism: Guidelines for Recycling in Development and Other Activities in Ports, Airports, and Other Facilities (Revised), 2015.
10) Hiroshima Research and Engineering Office for Port and Airport, Chugoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Guidance for Improvement of the Bottom Sediment Quality by Coal Ash Agglomerated Materials, p.38, 2013.

11) Naito, R., Nakamura, Y., Imamura, H., Sato M.: Under construction effects of geomorphological restoration of subaqueous borrow pits and extraction of related research & development tasks. Proceedings of Civil Engineering in the Ocean, (22), 649-654, 2006.

12) Shibuya, K., Kishira, Y., Umezaki, Y., Katagiri, M.: Study on effective utilization of dredged sand in Nakatsu Port, Proceedings of Coastal Development Institute of Technology, Vol.11, 51-54, 2011.

13) Office of Environmental Impact Assessment Review, Environmental Impact Assessment Division, Environmental Policy Bureau, Ministry of the Environment: Concept for backfilling of borrow pits and others in the sea area (Draft) Tokyo, 13p, 2006.

14) Bureau of Port and Harbor, Tokyo Metropolitan Government, Tokyo Port Terminal Corporation: Brochure for Effective Utilization Business of Dredged Soil

15) Ishida, T., Suzuki, T.: Concept and examples of backfilling of borrow pits. Proceedings of Spring Lectures 2006, Advanced Marine Science and Technology Society, 19-22, 2006.

16) Watanabe, R., Yamasaki, K., Iyooka, H.: Study on the observation for the effect of bottom environment change by restoration of borrow pit in Hakata Bay. Proceedings of Annual Meeting of Environmental Systems Research, 42, 43-48, 2014

17) Numano, Y., Nakaizumi, M., Setoguchi Y.: Study on effective utilization of soft dredged silt at river-fishing ports in the Ariake Sea area. Proceedings of Civil Engineering in the Ocean. (20), 1157-1162, 2004.

18) Inoue, T., Nakamura Y.: Effect of flow velocity on nutrient release from the sediment. Proceeding of Coastal Engineering, JSCE, 49, 1001-1005, 2002.