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The Basic Concept of Reformation Construction Method Selection and Reformation Design of Existing Mooring Facilities

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Synopsis

In recent years, various reformation construction methods have been developed in order to meet requests for existing mooring facilities such as deepening, high earthquake resistance, facilities obsolescence. However, the methods have some problems at the improvement design stage of the reformation of existing port facilities. This study presents a basic concept to solve these problems.

1) Current reformation construction methods including methods that were rejected in past reformation design examples are collected widely. Moreover, the methods are classified according to stability improvement mechanism. The result of collections and classifications shows basic concepts of reformation construction methods selections.

2) The subjects in the design of the reformation methods of construction are extracted and common subjects are arranged. Based on common subjects, the common recognition that the designers should have the basic concept of reformation design is shown in this study.

Key Words: existing port facility, mooring facility, reformation design, reformation method, select reformation method

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1. Introduction

1.1 Background

In recent years, the number of existing mooring facilities that require improvements such as depth increases to address the growth in vessel sizes, improvement of earthquake-resistant performance, and measures against aging (hereinafter referred to as “existing mooring facilities”) has been rising, and various methods have been developed or proposed to implement such improvements. Before starting an improvement design, in general, several methods considered applicable under various design conditions are selected, and by making a comprehensive judgment from the viewpoints of economy, constructability, and maintenanceability, a method considered optimal for the given conditions is adopted.

However, among the improvement designs that are currently implemented, the improvement methods suggested as candidates may greatly vary even when the design conditions are similar, and therefore it is possible that the most suitable improvement method is overlooked. One potential cause of such oversight is that the method for extracting candidate improvement design methods has not been standardized. There are many cases of improvement design where there is a plan to use part or all of an existing mooring facility, so such a design has a complicated improvement cross-section compared to designs for brand-new facilities and there are many issues to consider. For this reason, the number of options for improvement methods tends to be large. However, the concept of extracting candidate improvement methods has not been standardized and, in reality, improvement methods are extracted within the scope of each designer’s assumptions.

Furthermore, as the target cross-section of improvement design is a complicated cross-section as stated above, in many cases the standard design method for improvement has not been established. In such cases, it is necessary to clarify the technical matters to check in order to adopt a given method and conduct relevant technical examinations, but it is very difficult to discuss several methods in the same way in a short time. Therefore, even when an improvement cross-section made using a candidate method is rational, such a method is often excluded from the candidates at a relatively early stage of design if its design method has not been established partly because of the constraints of time allocated for design. It is expected that the number of improvement designs for existing mooring facilities will keep increasing into the future. However, to make it possible to select a rational improvement cross-section in the time available, it is necessary for all parties involved to recognize and organize the basic concept of improvement design, including examination procedures for the smooth progress of improvement design and verification items for performance assessment.

1.2 Objectives

The objectives of this study are to present the basic concept concerning improvement of existing mooring facilities that serves as a guide for selecting improvement methods and to present the basic concept on improvement design as common recognition that designers should hold when considering improvement designs for what are often complicated structures, as a measure to address the issue presented in 1.1.

1.3 Structure of this document

This document is organized as shown in Figure 1.1.

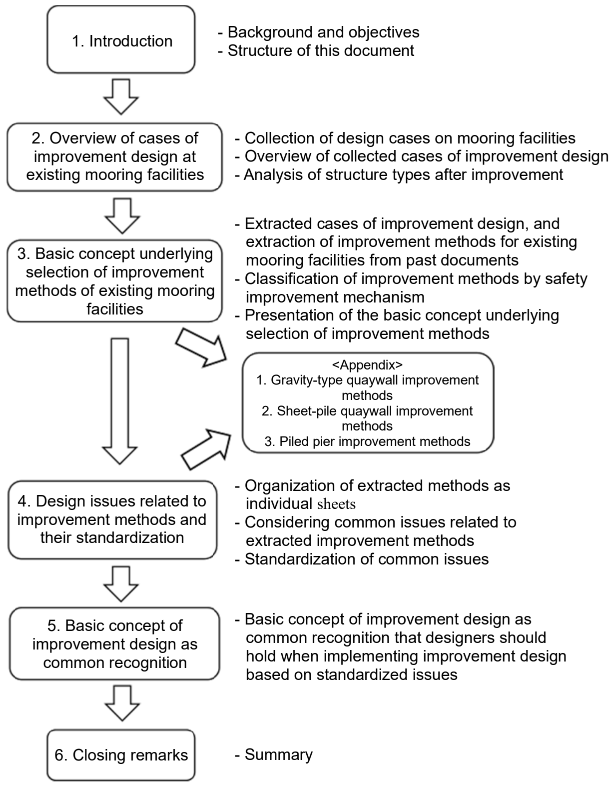


Figure-1.1 Structure of this document

Chapter 2 presents an analysis of basic information, including purposes of improvements and breakdown of changes of structure before and after improvements, based on cases of improvement design at existing mooring facilities (112 cases in total). In Chapter 3, improvement design cases presented in Chapter 2 are handled and documents are investigated, and improvement methods for existing mooring facilities including methods with no track records are broadly extracted. Furthermore, in that chapter, all the extracted improvement methods (72 methods) are classified using the stability improvement mechanism (the definition of this term is presented in Chapter 3) and the basic concept that serves as a guide for method selection is presented. Chapter 4 considers the issues related to the improvement methods extracted in Chapter 3, and common issues are standardized and summarized regardless of method type. Finally, Chapter 5, based on the issues standardized in Chapter 4, presents the basic concept of improvement design as a common recognition that designers should hold when designing improvements.

The Appendix summarizes, in the form of individual sheets, the characteristics of all the improvement methods extracted in Chapter 3, the issues surrounding the stability improvement mechanism and design, and that standardized issues that are summarized in Chapter 4.

2. Overview of cases of improvement design at existing mooring facilities

2.1 Overview of cases of improvement design

(1) Target improvement design cases

a) Overview of collected cases

Design cases are being collected nationwide as basic materials for the revision of *Technical Standards and Commentaries for Port and Harbour Facilities in Japan*[1] planned for 2018. Takano et al.[2] are discussing the points to note in improvement design based on these design cases, and this study also includes discussions based on the same materials. Details including the period for which design cases have been collected will be mentioned later.

Design cases are collected from all over Japan, as the National Institute for Land and Infrastructure Management is making requests to regional development bureaus and other organizations (Hokkaido Regional Development Bureau, Okinawa General Bureau, and Regional Development Bureaus) and port and harbor managers throughout Japan with assistance from the Ministry of Land, Infrastructure, Transport and Tourism's Ports and Harbours Bureau. As submission of design cases is not mandatory, only the design materials that can be provided by regional development bureaus and other organizantions, as well as by port and harbor managers throughout Japan, are collected, and not all the design cases in Japan are covered.

b) Target methods

Takano et al.[2] define "improvement design" in their document as: a series of actions to make some changes to an existing facility in response to a request (purpose of improvement) in order to continue using it; because there are requests to extend the working life of an existing facility, the act of extending the working life is also regarded as an improvement. This document also contains a discussion based on this definition. However, while Takano et al.[2] handle minor improvements such as updates to coating protection and cathodic protection of steel members like steel sheet pile in order to extend the working life as examples of improvement design, this study excludes these improvement case examples. In other words, among improvements to extend the working life, the scope of this study is limited to improvement methods that require new structural design, including reduction of actions on existing structures at the time of improvements and reinforcements to strengthen existing structural members.

c) Number of case examples

There have been 908 design cases collected from the Takano et al.[2] document, spanning 1999 to 2014. From them, based on the definition of improvement design as stated above, 262 cases regarded as improvement designs have been extracted (130 cases of protective facilities for harbors; 132 cases of mooring facilities). In this study, among cases extracted from the Takano et al.[2] document, 112 are set as targets in 2015 and 2016: specifically, 105 improvement design cases with gravity-type quaywalls, sheet-pile quaywalls, and piled piers, which are main structure types of mooring facilities, and an additional 7 other cases. The added improvement design cases in 2015 and 2016 have been collected anew from regional development bureaus.

(2) Overview of structure types before improvement

a) Structure types

The target structure types before improvement in this study comprise three structure types, namely gravity-type quaywalls, sheet-pile quaywalls, and piled piers. In the cases collected this time, the percentages of those structure types are: 51% for gravity-type quaywalls, 34% for sheet-pile quaywalls, and 15% for piled piers (Figure 2.1).

b) Planning depth

The planning depths of the existing mooring facilities in the target improvement design cases are shown in Figure 2.2. The planning depths have been classified as −3.0 m for small-scale water depth, −4.5 m as the water depth at the boundary between the inclined wharf and quaywall, −7.5 m for water depth that allows berthing of cargo ships of approx. 5,000 DWT based on the standard value in the berth main specifications shown in *Technical Standards and Commentaries for Port and Harbour Facilities in Japan*,[1] −9.0 m for water depth that allows berthing of cargo ships of 10,000 DWT or above, and −12.0 m for water depth that allows berthing of cargo ships of 30,000 DWT or above. Regarding the target improvement design cases, those with a planning depth of existing mooring facilities of −9 m to less than −12 m account for 20% and those with −12.0 m or above account for 25%, showing a slightly higher percentage of mooring facilities with a large planning depth.

c) Number of years elapsed

Figure 2.3 shows years elapsed since the start of services at the point when the existing mooring facilities went through improvement design. Note that the collected design material also includes cases in which the information at the time when an existing mooring facility was built is unknown because the facility is very old and cases in which it is not possible to read the year in which an existing facility entered service. Therefore, the data have been summarized for 85 cases remaining as a result of excluding cases with unknown working life from the target 112 cases stated in (1).

Among the collected cases, the number of those where improvement design was conducted in the 40th to 49th year of service is the largest, and that of cases with improvement design in the 10th to 19th year of service is the second greatest. There have been no such cases where improvement design was conducted in the 1st to 9th year of service, while there are 16 cases with improvement design in the 50th year or more.

In terms of the number of cases by structure type, for gravity-type quaywalls, the number of cases with improvement design in the 10th to 19th years is the largest, and for sheet-pile quaywalls, that with improvement design in the 40th to 49th years is highest. The number of cases for piled piers is small, but once elapsed years reach 30 or more, the numbers tend to increase slightly. The reasons for different distribution tendencies of elapsed years among structure types will be described later.

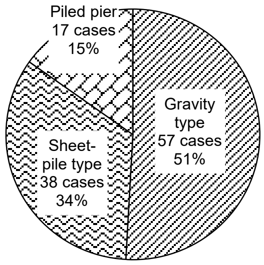


Figure 2.1 Structure types before improvement

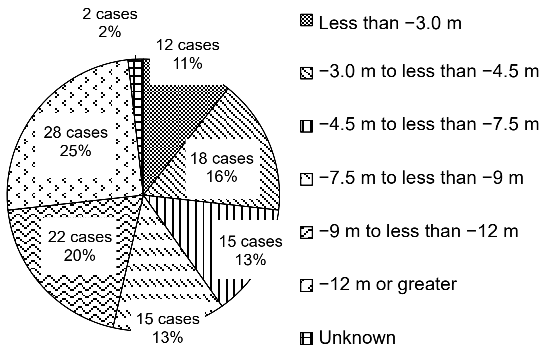


Figure 2.2 Planning depths of existing mooring facilities

2.2 Analysis of cases of improvement design

(1) Purpose of improvement

Figure 2.4 (a) shows the breakdown (percentages) of purposes of improvement in all the cases of target improvement design (total mooring facilities). The purposes of improvement have been classified into "depth increase," "reinforcement against earthquakes," and "measures against aging," which are large in number, and "others" for purposes of improvement other than those mentioned above.

The purposes of improvement categorized as "others" include changes to cargo handling equipment, measures against overtopping waves (change of the crown height of mooring facilities), and changes of usage (improvement from a mooring facility into a revetment, improvement from a revetment into a mooring facility). For details, refer to the document by Takano et al.[2)]

In some cases, improvements may be made for multiple purposes, such as "depth increase" and "reinforcement against earthquakes." For this reason, the total value for improvement purposes exceeds 100%.

This figure (Figure 2.4 (a)) shows that for the cases of improvement design in this study, the number with a purpose of "measures against aging" is the largest (44.6%), and "reinforcement against earthquake" (42.0%), "depth increase" (33.0%), and "others" (20.5%) follow in this order.

Figure 2.4 (b) to Figure 2.4 (d) show the breakdown of purpose of improvement by structure type (gravity-type quaywall, sheet-pile quaywall, piled pier). These figures show that, when focusing on "measures against aging," the percentage of cases with this improvement purpose is large for sheet-pile quaywalls and piled piers compared to gravity-type quaywalls. According to the information contained in the design calculations, regarding sheet-pile quaywalls, there are many cases of measures against decreasing cross-section strength that is mainly due to corrosion of front sheet piles. For piled piers, almost half the cases with "measures against aging" are those with measures against corrosion of steel pipe piles, and the remaining half are cases with measures against deterioration of the superstructure. As shown above, although the number of collected cases is limited in this study, improvements for the purpose of "measures against aging" tend to be conducted more on mooring facilities that use steel members. This is thought to be the reason for many cases of improvement design in the 40th to 49th year of service for sheet-pile quaywalls and many cases of improvement design in the 30th or later year of service for piled piers in the elapsed year trends stated above.

When focusing on "depth increase," the percentage of cases with a purpose of "depth increase" for piled pier is greater than that for gravity-type quaywalls and that for sheet-pile quaywalls. When looking at "reinforcement against earthquakes," the percentage of cases with a purpose of "reinforcement against earthquakes" for piled piers is the largest and those for gravity-type quaywalls and for sheet-pile quaywalls follow in that order. However, regarding the relationship between these differences

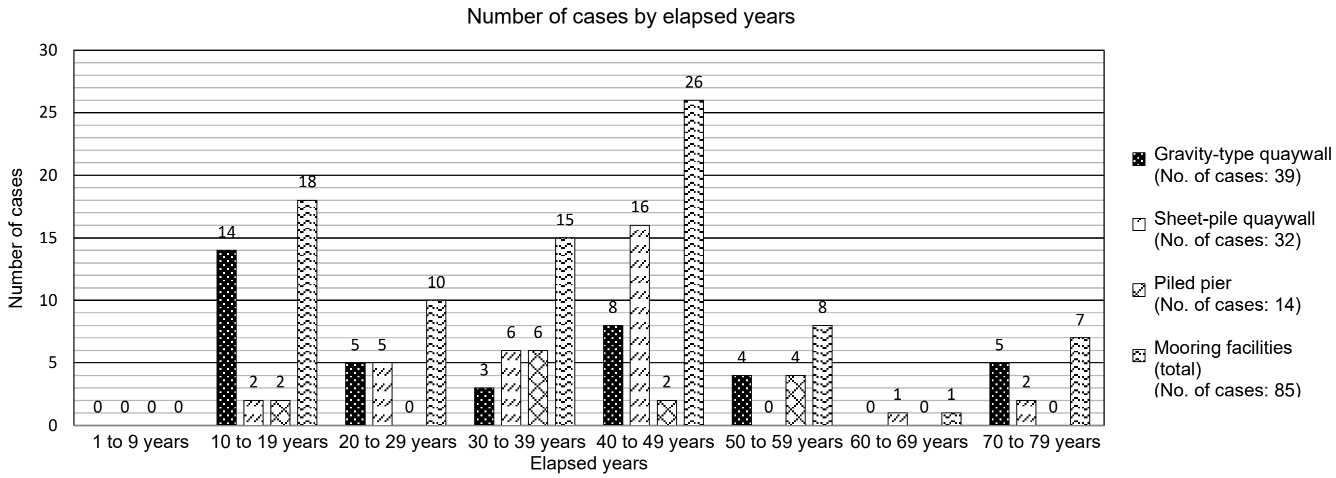
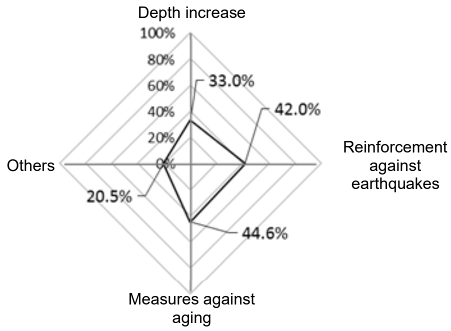


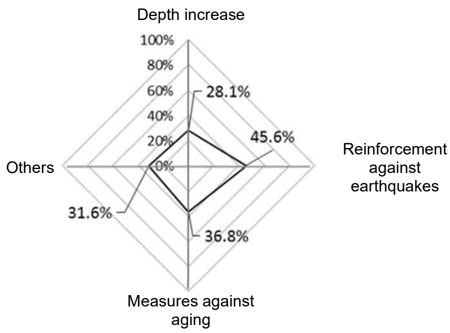
Figure 2.3 Elapsed years of service of existing mooring facilities in collected cases of improvement design

and the structure types of existing mooring facilities, analysis is impossible because the number of collected cases is too small.

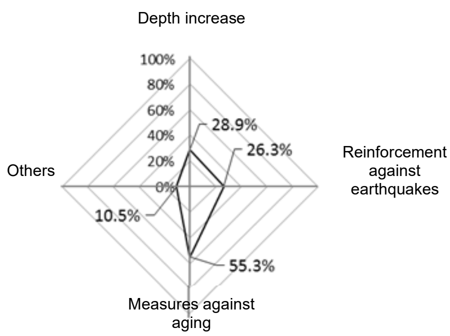
Finally, when examining “others,” the percentage of cases with this for gravity-type quaywalls is 31.6%, which is higher than that for sheet-pile quaywalls and that for piled piers. According to the information contained in the design calculation, half of the cases for “others” are those concerning a change to the crown height of mooring facilities, including height reductions to improve the usability of mooring facilities with a water depth of −3.5 m or below and height increases to prevent flooding. As for crown height changes, in many cases the improvements were carried out at a point within 20 years from when the facilities entered service. This led to many cases of improving gravity-type quaywalls in the 10th to 19th year of service as shown in Figure 2.3. Figure 2.5 shows the change in crown height before and after improvement. The changes are around 50 cm for both increased and reduced crown height.



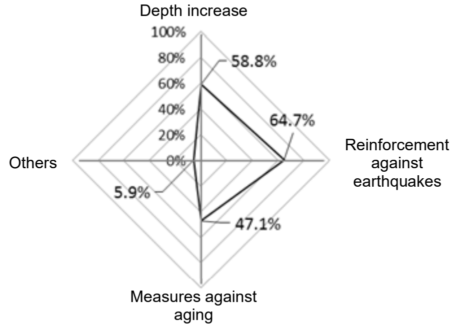
(a) Mooring facilities in total (112 cases)



(b) Gravity-type quaywalls (57 cases)



(c) Sheet-pile quaywalls (38 cases)



(d) Piled piers (17 cases)

Figure 2.4 Purposes of improvement by structure type

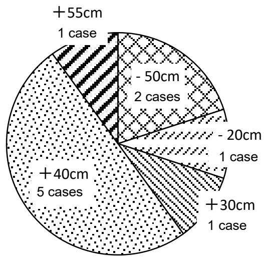


Figure 2.5 Amounts of change in crown height (gravity-type quaywalls)

(2) Structure type after improvement

a) Improvement method that uses existing structures and that which does not

Improvement methods can be classified into two types from the viewpoint of use of existing structures. One type is where a new structure is installed at the front or rear face of an existing one, or the existing structure is removed and a new one is installed. In this case, the existing structure is not used as a structural member of the new one (however, it may be left in place or used as a non-structural member), or it is no longer used for its original purpose by, for example, changing an existing quaywall into a revetment. This type of method is within the range of improvement, but it is a type of improvement method close to new construction (hereinafter referred to as an “improvement method that does not use an existing structure”).

The other type is an improvement method in which all or part of an existing structure is used as a structural member constituting an improvement cross-section (hereinafter referred to as an “improvement method that uses an existing structure”). Figure 2.6 shows the percentages of cases with “improvement method that does not use an existing structure” and cases with “improvement method that uses an existing structure,” respectively, in all the cases. The figure also shows the percentages for all the structure types (gravity-type quaywalls, sheet-pile quaywalls, piled piers) and their respective percentages.

This figure indicates that the number of cases employing an “improvement method that does not use an existing structure” is greater as a whole (approx. 55%). In the breakdown based on structure type, for the gravity type, the number of cases employing an "improvement method that uses an existing structure" is larger (approx. 58%). On the other hand, for sheet-pile quaywalls and piled piers, the number of cases employing an "improvement method that does not use an existing structure" is greater (sheet-pile quaywalls: approx. 74%, piled piers: approx. 59%). According to the information contained in the design calculations, the rate of "measures against aging" for sheet-pile quaywalls is high in terms of the purpose of improvement. One reason for this high rate is that installing new structures is judged as a reasonable improvement in many cases because the strength of front sheet piles deteriorates due to corrosion and the existing facilities are judged as unusable due to pitting corrosion in the splash zone. For sheet-pile quaywalls, one of the reasons for the above high rate is that a large-scale improvement, including installation of an anchorage, is required for securing the stability in many cases, and building a new structure is often deemed more economical than using an existing one.

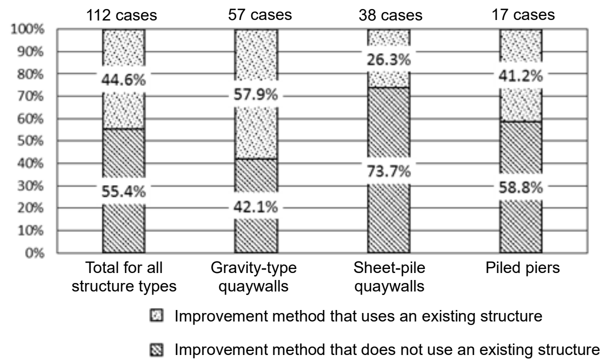


Figure 2.6 Rates of new construction of structure

b) Changing the structure type before and after improvement (for "improvement method that does not use an existing structure")

The changes of structure type before and after improvement in "improvement method that does not use an existing structure" are shown in Figure 2.7. The percentages of employing the same structure type as the existing structure one are 61% for gravity-type quaywalls, 53% for sheet-pile quaywalls, and 78% for piled piers, which means that for all the structure types, no changing the structure type before and after improvement accounts for the majority.

As for "other" structures after improvement, there is one case of change from sheet-pile type to cellular-bulkhead type, and there are two cases of change from piled pier to steel pipe sheet-pile well type.

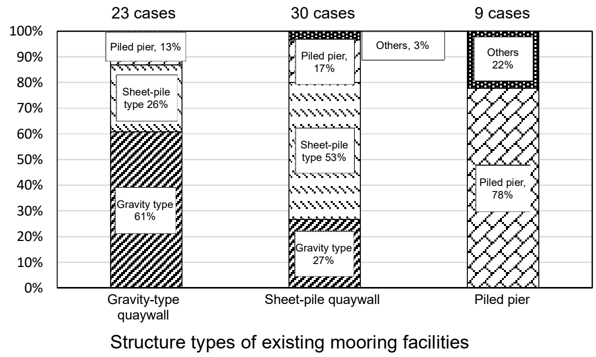


Figure 2.7 Changing the structure type at time of new construction

c) Displacement of face lines

Figure 2.8 depicts the extent of displacement of face lines before and after improvement in all. This figure shows that cases with no change in face line positions before and after improvement make up the majority (approx. 63% of all the collected cases). Even when moving face lines forward, the distance is 4 m or less in many cases. This is because when improving existing mooring facilities, an improvement method that minimizes the forwarding distance as much as possible is selected due to restrictions on the sea-fronting area and in view of economy. On the other hand, there are cases where face lines are moved forward by a long distance or retracted toward the land. However, according to the information contained in the design calculations, in many cases the positions of face lines in these cases are determined based on planned restrictions such as changes in facility usage and alignment of face lines with neighboring structures.

d) Planning depth before and after improvement

To address the increase in vessel size, there are cases where the planning depth of a mooring facility is changed before and after improvement due to deepening works. Figure 2.9 shows the extent of changed planning depths of mooring facilities before and after improvement. Seventy-four cases with no planning depth change have been omitted from this figure. The figure shows that regardless of how deep the planning depth is before improvement, there are as many as 27 design cases where the depth has been increased by 1 to 2 m (around 71% of cases with changed planning depth). For facilities with an original planning depth exceeding −7 m, the increase in depth is as much as 4 m in some cases. On the other hand, there are cases (three cases) with reduced water depth in accordance with actual use by vessels.

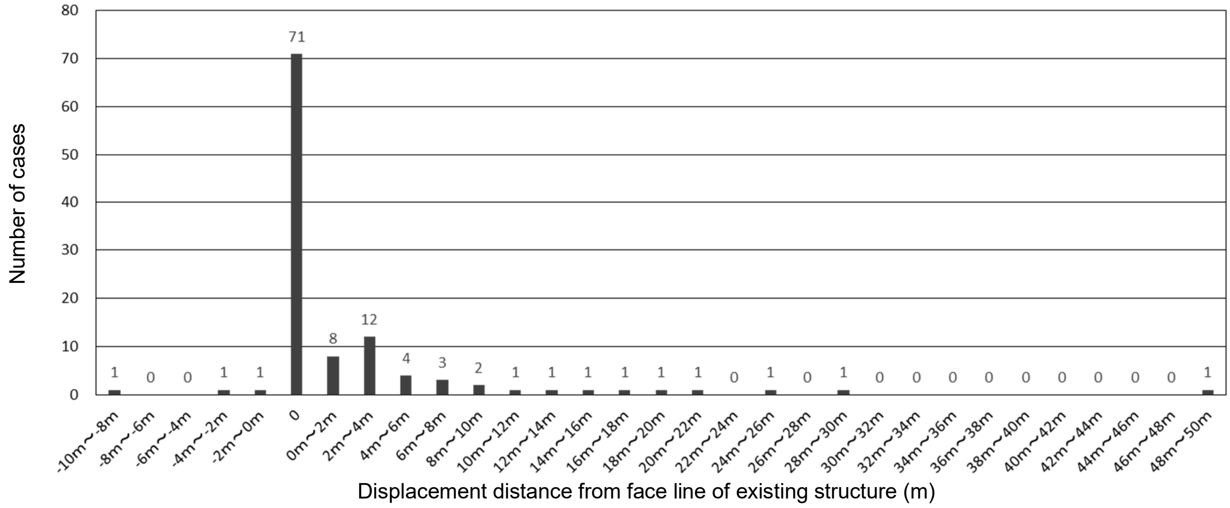


Figure 2.8 Displacement amounts of face lines

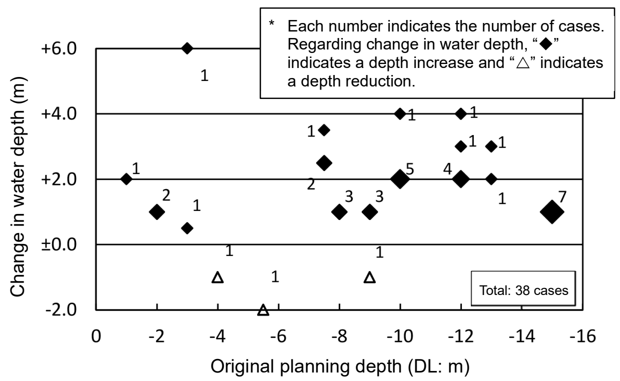


Figure 2.9 Changes in planning depths

3. Basic concept underlying selection of improvement methods for existing mooring facilities

3.1 Study method

(1) How to organize the basic concept underlying conventional improvement methods

In this chapter, we collect a range of improvement methods for existing mooring facilities and classify them based on structure type (gravity-type quaywalls, sheet-pile quaywalls, and piled piers) by focusing on the principles that raise the stability of existing structures (hereinafter referred to as "stability improvement mechanisms") for all the collected conventional improvement methods. The stability improvement mechanisms mentioned in this section are organized from a broad perspective so that the mechanisms can be easily applied, and classified as principles that are considered to affect verification items under conventional design methods as well as verification items for newly developed design methods, for example.

Regarding specific organizing methods, this document provides cross-section drawings of all improvement methods and overviews of method principles in the form of lists, and the details of each stability improvement mechanism are explained by illustrating representative improvement cross-sections.

Regarding the extracted conventional improvement methods, see the Appendix for the stability improvement mechanisms, overviews of methods, effectiveness for static stability verification items, issues in terms of use, construction, and maintenance of mooring facilities obtained from design cases as well as standardized design issues concerning methods explained in Chapter 4. These are organized on a structure-type basis in the form of individual sheets.

According to the result of the above organizing of improvement methods on a structure-type basis, 3.5 presents the basic concepts underlying selection of improvement methods for improvement design of existing mooring facilities. The basic concept is presented so that utilizing materials related to the methods summarized in 3.2 to 3.4 based on this basic concept will help alleviate the issue mentioned in Chapter 1, that "the most suitable improvement method may be overlooked."

(2) How to extract conventional improvement methods

We have extracted conventional improvement methods for mooring facilities by extracting the improvement design cases as described in detail in Chapter 2 and by investigating existing documents so as to avoid missing methods as much as possible.

Concerning the former, we have extracted improvement methods employed at the basic design stage as well as improvement methods listed as candidates for primary selection and secondary selection at time of method selection (at the time of comparative design). However, in many cases, improvement methods with track records are listed as candidates, and new methods with no track record and methods at the research and development stage could be overlooked at the stage of method selection. Therefore, we also investigated the latter document types.

We set the scope of document investigation to papers presented at academic conferences and documents published by associations, individual companies, and other parties, and conducted an investigation in June 2017 through a web search and by other means.

Note that this study also features a range of methods with no track record and those at the research and development stage, so there are design and construction methods included that have not become fully established.

3.2 Comprehensive descriptions of improvement methods for gravity-type quaywalls

(1) Stability improvement mechanism provided by improving gravity-type quaywalls

The four main verification items for static phenomena in gravity-type quaywalls are: 1) caisson sliding; 2) caisson overturning; 3) bearing capacity of the foundation ground; and 4) circular slip failure of the foundation ground. The stability of each verification item changes depending on the balance among factors including earth pressure, the caisson's weight and center of gravity, frictional resistance force, size and width of the foundation mound, strength of the supporting ground, and other factors. Therefore, to improve the stability stated above, it is necessary to reduce the effect of factors acting on the load side or increase or add the effect of factors acting on the resistance side.

Considering the above, the following are available as stability improvement mechanisms in cases where an "improvement method that uses an existing structure" is applied to a gravity-type quaywall, as shown in Figure 3.1.

① Reducing the active earth pressure
② Increasing the sliding/overturning resistance force by increasing the caisson's weight
③ Increasing the frictional resistance force
④ Increasing the foundation bearing capacity
⑤ Increasing the sliding/overturning resistance force by supporting the caisson
⑥ Having another structure bear the resistance force

Here, ① reduces the effect of the factors acting on the load side, and ② to ⑥ increase or add to the effect of the factors acting on the resistance side.

Regarding stability improvement mechanisms when applied to cases of an "improvement method that does not use an existing structure," the following are available.

⑦ Having a new structure bear the load
⑧ Changing the usage of an existing structure

In many cases when a new structure is to bear an external force, the new structure is built at the front or rear face of an existing gravity-type quaywall, and no consideration whatsoever is given to the influence of existing structures on either the load side or the resistance side in the structure's design. When changing the usage of an existing structure, a new structure is built at the front face of an existing gravity-type quaywall, and the existing structure is changed to a revetment, or to an auxiliary structure for the newly built structure.

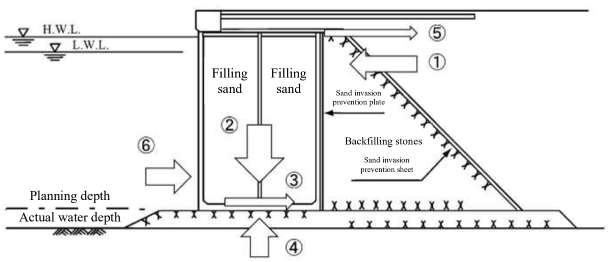


Figure 3.1 Stability improvement mechanism for a gravity-type quaywall
(when applying an improvement method that uses an existing structure)

(2) Result of extracting improvement methods for gravity-type quaywalls

Figure 3.2 to Figure 3.5 list 28 methods extracted as improvement methods for gravity-type quaywalls. The figures show schematic diagrams of improvement methods and overviews of them. These methods are sorted in accordance with the classification of stability improvement mechanisms ① to ⑧ shown in (1) above, and they are appended with serial numbers from G-1 to G-28, respectively. Appendix Table 1 in the Appendix provides, in the form of individual sheets, sorted results of the stability improvement mechanisms, characteristics, effective verification items, issues with terms of use, construction, and maintenance of quaywalls obtained from design cases, and issues with each method presented in Chapter 4 on the basis of improvement methods for gravity-type quaywalls.

Table 3.1 clearly indicates the stability improvement mechanisms to which respective methods belong and the investigation methods by which they were extracted (A: extracted from improvement design cases; B: extracted from past documents). It includes 22 methods of "improvement methods that use an existing structure" (stability improvement mechanisms ① to ⑥) and 6 methods of "improvement methods that do not use an existing structure" (stability improvement mechanisms ⑦ to ⑧).

Table 3.1 Extracted methods for improving gravity-type quaywalls

Method	Stability improvement mechanism	A (improvement design case)	B (past document)
G-1	① Reducing the active earth pressure	O	3)
G-2		O	3)
G-3		O	3)
G-4		O	3), 4)
G-5		O	3)
G-6	② Increasing the sliding/overturning resistance force by increasing the caisson's weight	O	3)
G-7		O	3)
G-8		O	3)
G-9		O	3)
G-10		O	-
G-11	③ Increasing the frictional resistance force	O	3)
G-12		O	-
G-13	④ Increasing the foundation bearing capacity	O	3), 5)
G-14		O	-
G-15	⑤ Increasing the sliding/overturning resistance force by supporting the caisson	O	3), 6)
G-16		O	3), 7)
G-17	⑥ Having another structure bear the resistance force	O	3)
G-18		O	3)
G-19		O	3)
G-20		O	-
G-21		O	-
G-22		-	8)
G-23	⑦ Having a new structure bear the load	O	-
G-24		O	3)
G-25	⑧ Changing the usage of an existing structure	O	3)
G-26		O	3), 9)
G-27		O	3)
G-28		O	3)

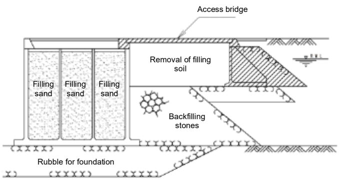
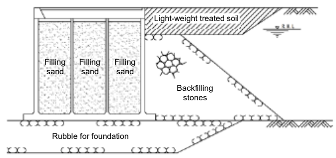
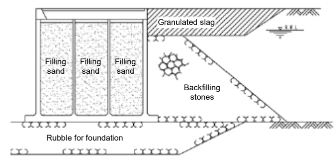
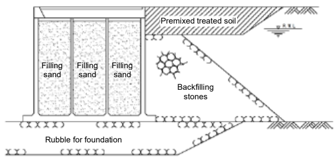
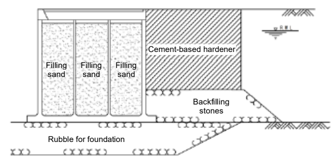
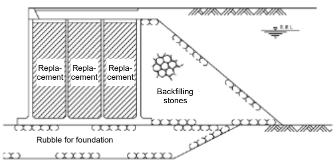
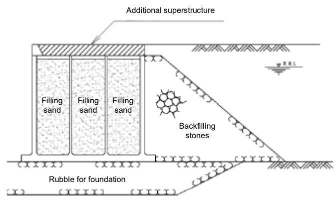
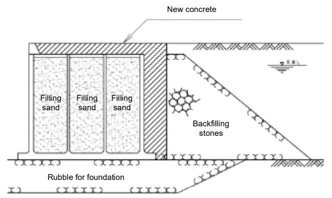
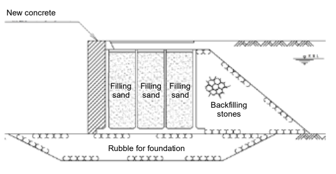
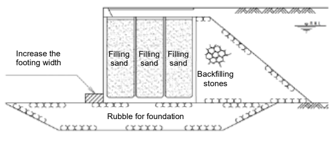
Stability improvement mechanism	Reducing the active earth pressure		
Method No.	G−1	G−2	G−3
Schematic diagram			
Overview	Removing the backfilling stones reduces the active earth pressure. Earth-retaining sections need to be installed behind the part to be replaced.	Putting lightweight treated soil in place after removing backfilling stones, etc. reduces the active earth pressure.	Putting granulated slag in place after removing backfilling stones, etc. reduces the active earth pressure.
Method No.	G−4	G−5	
Schematic diagram			
Overview	Putting premixed treated soil in place after removing backfilling stones, etc. reduces the active earth pressure.	Hardening the ground by stirring and mixing in cement-based hardener and placing it as backfilling behind the caisson reduces the active earth pressure.	
Stability improvement mechanism	Increasing the sliding/overturning resistance force by increasing the caisson's weight		
Method No.	G−6	G−7	G−8
Schematic diagram			
Overview	Increasing the weight of caisson by replacing or improving the filling material increases the sliding resistance force.	Adding a superstructure to increase the weight of the structure increases the sliding resistance force.	Integrating the caisson with the concrete placed behind the caisson to increase the weight of the structure increases the sliding resistance force.
Method No.	G−9	G−10	
Schematic diagram			
Overview	Integrating the caisson with the concrete placed at the front face of the caisson to increase the weight of the structure increases the sliding resistance force.	Increasing the width of the caisson's footing, mainly increases the overturning resistance force or reduces the subgrade reaction force.	

Figure 3.2 Improvement methods for gravity-type quaywalls (1)

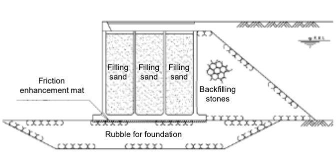
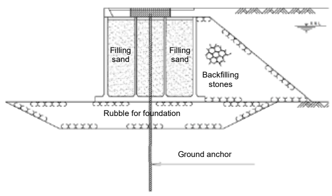
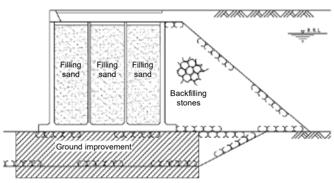
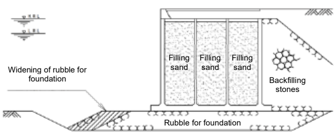
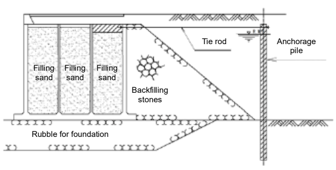
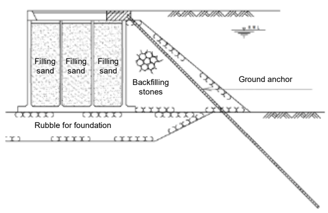
Stability improvement mechanism	Increasing the frictional resistance force		
Method No.	G-11	G-12	
Schematic diagram			
Overview	Laying friction enhancement mats at the bottom of the caisson increases the friction of the caisson's bottom surface.	Introducing initial tension to the anchor increases the ground contact pressure of the caisson and boosts the frictional resistance.	
Stability improvement mechanism	Increasing the foundation bearing capacity		
Method No.	G-13	G-14	
Schematic diagram			
Overview	Improving the ground of the caisson's foundation increases the bearing capacity and liquefaction strength of the foundation ground.	Widening the foundation rubble mound increases the bearing capacity of the foundation mound.	
Stability improvement mechanism	Increasing the sliding/overturning resistance force by supporting the caisson		
Method No.	G-15	G-16	
Schematic diagram			
Overview	Installing an anchorage pile behind the caisson and connecting it to the existing caisson via a tie rod increases the sliding and overturning resistance forces.	Obliquely installing a ground anchor in the caisson from above increases the sliding and overturning resistance forces.	

Figure 3.3 Improvement methods for gravity-type quaywalls (2)

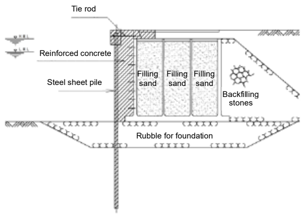
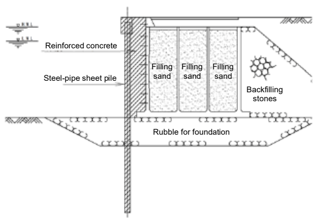
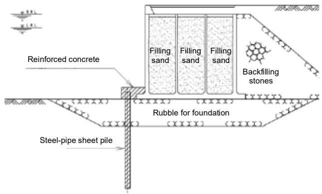
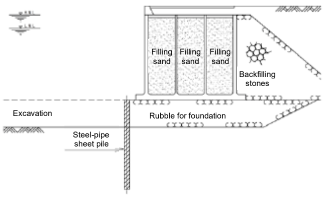
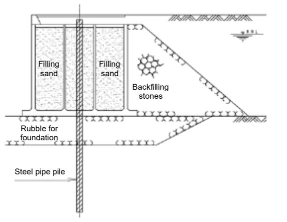
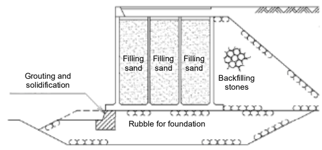
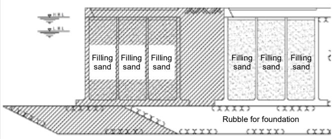
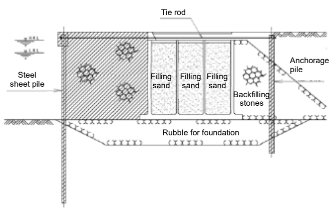
Stability improvement mechanism	Having another structure bear the resistance force		
Method No.	G−17	G−18	G−19
Schematic diagram			
Overview	Installing sheet piles on the front face and connecting them to the existing caisson by a tie rod, increases the sliding resistance force.	Installing sheet piles on the front face and placing concrete between the sheet pile and the existing caisson to integrate them increases the sliding resistance force.	Installing foot protection sheet piles at the surface immediately in front of the existing caisson and bonding it with the existing sheet piles under water increases the sliding resistance force.
Method No.	G−20	G−21	G−22
Schematic diagram			
Overview	Installing cantilevered steel-pipe sheet piles in front of the existing caisson and then conducting excavation increases the depth.	Installing steel-pipe piles inside the existing caisson increases the sliding resistance force.	Improving/solidifying part of rubble mound and then conducting excavation increases the depth.
Stability improvement mechanism	Having a new structure bear the load		
Method No.	G−23	G−24	
Schematic diagram			
Overview	A new gravity-type structure is constructed at the front face of the existing caisson. This new structure bears the active earth pressure.	New sheet piles with anchorage piles are installed at the front face of the existing caisson. These new sheet piles bear the active earth pressure.	

Figure 3.4 Improvement methods for gravity-type quaywalls (3)

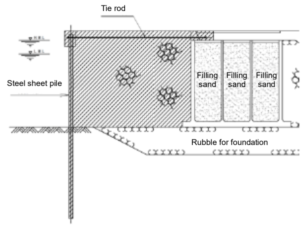
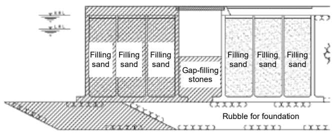
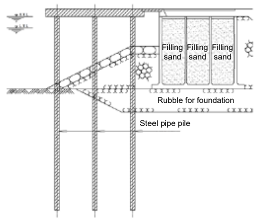
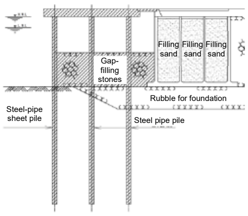
<table>
<tr><td>Stability improvement mechanism</td><td colspan="3">Changing the usage of an existing structure</td></tr>
<tr><td>Method No.</td><td>G-25</td><td>G-26</td><td>G-27</td></tr>
<tr><td>Schematic diagram</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Overview</td><td>Sheet piles are installed at the front face of the existing caisson, so the existing caisson serves as an anchorage. The sheet piles bear the active earth pressure.</td><td>A new caisson is constructed at the front face of the existing caisson. The gap-filling stones suppress displacement of the existing caisson.</td><td>A new piled pier and rubble mound are constructed at the front face of the existing caisson. The existing caisson receives the passive resistance force from the mound.</td></tr>
<tr><td>Method No.</td><td>G-28</td><td></td><td></td></tr>
<tr><td>Schematic diagram</td><td>
</td><td></td><td></td></tr>
<tr><td>Overview</td><td>A piled pier with an earth retaining function is installed at the front face of the existing caisson. The existing caisson receives the passive resistance force from the gap-filling stones.</td><td></td><td></td></tr>
</table>

Figure 3.5 Improvement methods for gravity-type quaywalls (4)

(3) Improvement methods that use an existing structure

a) Reducing the active earth pressure (stability improvement mechanism ①)

For gravity-type quaywalls, reducing the active earth pressure behind the caisson decreases the resultant force on the load side toward the caisson. Therefore, it is possible to improve the stability for the verification items of caisson sliding, caisson overturning, and bearing capacity of the foundation ground. As methods with the potential to reduce the active earth pressure, methods G-1 to G-5 in Figure 3.2 are available. Here, Figure 3.6 shows a schematic diagram of method G-2 as a representative example.

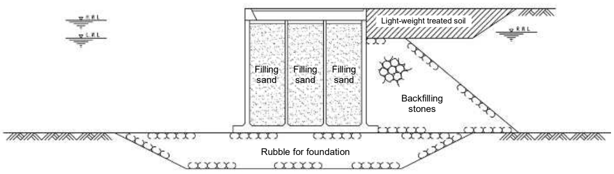


Figure 3.6 Example of a construction method that reduces the active earth pressure (G-2)

This method (Figure 3.6) involves replacing the backfill soil behind the caisson with light-weight soil, reducing the weight per unit volume of some of the soil to decrease the active earth pressure. Methods G-1 and G-3 to G-5, as with method G-2, intend to reduce the active earth pressure by replacing or removing the ground at the back or improving the ground at the back.

b) Increasing the sliding/overturning resistance force by increasing the caisson's weight (stability improvement mechanism ②)

For gravity-type quaywalls, increasing the caisson's weight increases the caisson sliding and overturning resistance forces. Therefore, it is possible to improve the stability for the caisson sliding and overturning verification items. Methods G-6 to G-10 in Figure 3.2 are available as methods that could increase caisson's weight. Here, Figure-3.7 shows a schematic diagram of method G-9 as a representative example.

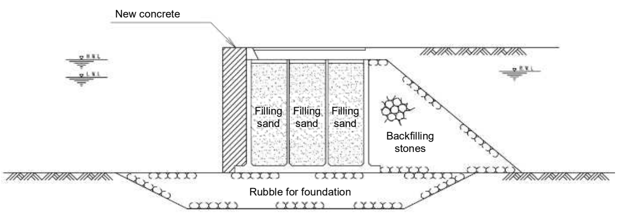


Figure 3.7 Example of a construction method that increases caisson's weight (G-9)

This method (Figure 3.7) involves placing new concrete at the front face of the caisson and integrating that concrete with the caisson. This raises the weight of the structure to increase the caisson sliding and overturning resistance forces. The intention of methods G-6 to G-8 and G-10 is to place concrete on the top or rear face of the caisson or its footing or replace or improve the filling sand to increase the caisson's weight.

c) Increasing the frictional resistance force (stability improvement mechanism ③)

For gravity-type quaywalls, raising the friction coefficient or vertical force between the caisson and the foundation mound increases the frictional resistance force against loads. Therefore, it is possible to improve the stability for the verification item of caisson sliding movement. Regarding methods with the potential to increase the frictional resistance force, methods G-11 and G-12 in Figure 3.3 are available. Here, Figure 3.8 shows a schematic diagram of method G-11 as a representative example.

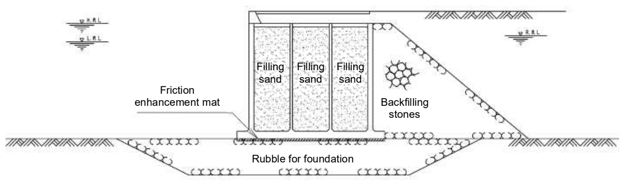


Figure 3.8 Example of a construction method that increases the frictional resistance force (G-11)

This method (Figure 3.8) involves laying friction enhancement mats at the caisson's bottom face, to increase the frictional resistance force. Method G-12 involves installing anchors perpendicular to the caisson and integrating the anchors with the caisson to increase the vertical reaction force that is generated between the caisson and foundation mound as a way to increase the frictional resistance force.

d) Increasing the foundation bearing capacity (stability improvement mechanism ④)

For gravity-type quaywalls, the resistance force of the foundation ground is raised by increasing the strength of the foundation ground or widening the foundation mound in front of the caisson. Therefore, it is possible to improve the foundation ground's bearing capacity and stability against circular slip failure. Methods G-13 to G-14 in Figure 3.3 have the potential to increase the bearing capacity of the foundation ground, and here, Figure 3.9 shows a schematic diagram of method G-13 as a representative example.

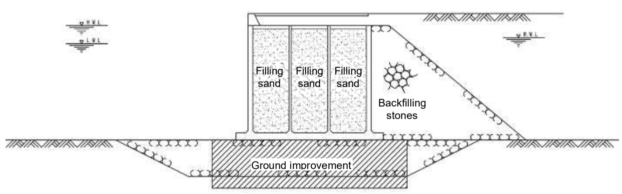


Figure 3.9 Example of a construction method that increases the bearing capacity of foundation ground (G-13)

This method (Figure 3.9) involves improving the ground under the foundation mound and rubble mound to increase the bearing capacity of the foundation ground. The aim of method

G-14 is to increase the bearing capacity of the foundation against slip of the foundation ground by widening the rubble mound.

e) Increasing the sliding/overturning resistance force by supporting the caisson (stability improvement mechanism ⑤)

For gravity-type quaywalls, applying a force in the direction opposite to the load acting on the caisson increases the caisson sliding and overturning resistance forces. Therefore, it is possible to improve the stability for the verification items of sliding and overturning. Methods G-15 to G-16 in Figure 3.3 are available as methods with the potential to increase the sliding resistance and overturning resistance by supporting the caisson. Here, Figure 3.10 shows a schematic diagram of method G-16 as a representative example.

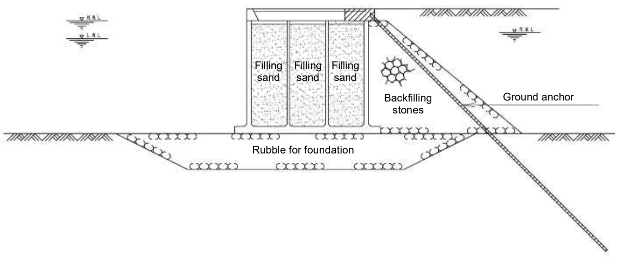


Figure 3.10 Example of a construction method for supporting a caisson (G-16)

This method (Figure 3.10) involves installation of ground anchors behind the caisson. The anchors, which are fixed in place in the ground, and the caisson are integrated to increase the sliding and overturning resistance forces mainly in the event of an earthquake. The aim of method G-15 is to increase the sliding and overturning resistance forces by installing the anchorage piles used for sheet-pile quaywalls at the back and connecting them with the caisson with tie rods.

f) Having another structure bear the resistance force (stability improvement mechanism ⑥)

For gravity-type quaywalls, installing structural members that bear the resistance force to the load acting on the caisson increases the sliding resistance force. Therefore, it is possible to improve the stability for the verification item of sliding movement, and methods G-17 to G-22 in Figure 3.4 are available to do this. Here, Figure 3.11 shows a schematic diagram of method G-19 as a representative example.

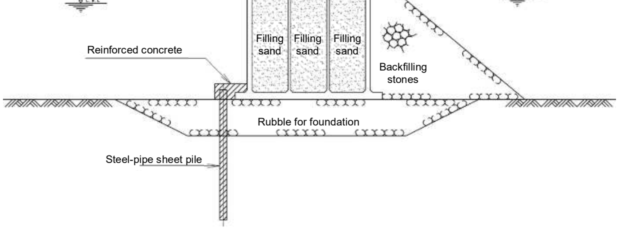


Figure 3.11 Example of a construction method for bearing sliding resistance (G-19)

This method (Figure 3.11) involves installation of steel-pipe sheet piles at the front face of the caisson and using concrete to integrate the steel-pipe sheet piles with the caisson. Here, steel-pipe sheet piles compensate for the lack of sliding resistance force. Furthermore, methods G-17, G-18, and G-21 involve placing sheet piles at the front face in the same way and driving steel-pipe piles into the caisson for reinforcement if the sliding resistance force is insufficient. Method G-20 involves installing steel-pipe sheet piles that hold the retaining mound in front of the caisson face, and method G-22 prevents the caisson from starting to slide together with the foundation by partially solidifying the foundation.

(4) Improvement methods that do not use existing structures

a) Having a new structure bear the load (stability improvement mechanism ⑦)

When a new structure is built at the front face of an existing caisson, the new structure will be designed to bear all the forces acting on the existing one and no consideration will be given to the existing caisson in the structure's design. For this reason, newly installed structures that do not use existing structures must satisfy all the same verification items as the designs of ordinary new structures. Methods G-23 to G-24 in Figure 3.4 are available as improvement methods in which a new structure bears the loads. Here, Figure 3.12 shows a schematic diagram of method G-23 as a representative example.

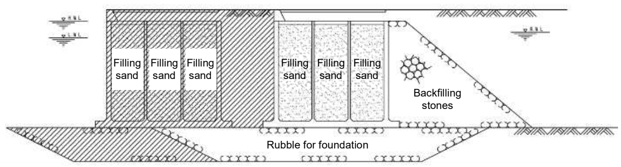


Figure 3.12 Example of a construction method using a new structure (G-23)

This method (Figure 3.12) involves building a new gravity-type structure at the front face of the existing caisson, and the new structure bears all the acting loads. In method G-24, a sheet-pile structure at the front face of the existing caisson is the new structure that bears acting loads.

b) Changing the usage of an existing structure (stability improvement mechanism ⑧)

When a new structure is built in front of an existing caisson, the existing caisson may change usage to a revetment or an auxiliary structure for the new structure. When rubble or other material is installed in front of the existing caisson, the rubble, etc. at the front provide a resistance force for the existing caisson. Methods G-25 to G-28 in Figure 3.5 are available as methods that change the usage of an existing structure. Here, Figure 3.13 shows a schematic diagram of method G-27 as a representative example.

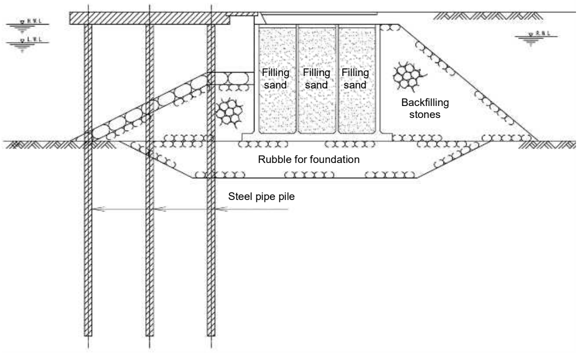


Figure 3.13 Example of a construction method that changes the usage of an existing structure (G-27)

This method (Figure 3.13) involves building a new piled pier in front of the existing caisson and converting the existing caisson into a revetment. Arranging rubble below the piled pier provides a resistance force to the existing caisson due to passive earth pressure. Methods G-26 and G-28 involve installing a new gravity-type structure and a piled pier that also serves as earth-retaining sections, respectively, in front of an existing caisson. In method G-25, new sheet piles are installed on the front face of the existing caisson to use the existing caisson as an anchorage.

3.3 Comprehensive descriptions of improvement methods for sheet-pile quaywalls

(1) Stability improvement mechanism provided by improving sheet-pile quaywalls

There are five main verification items concerning static phenomena in sheet-pile quaywalls, namely: 1) sheet pile embedded length; 2) sheet pile stress; 3) tie rod stress; 4) circular slip failure of the foundation ground; and 5) anchorage stress. The stability related to each verification item changes depending on the balance among the earth pressure, the strength and section modulus of the sheet piles, tie rods, and anchorages, the strength of the front face or supporting ground, and other factors. Therefore, to improve the stability stated above, it is necessary to reduce the effect of factors acting on the load side or increase or add the effect of factors acting on the resistance side.

Considering the above, the following are available as stability improvement mechanisms in cases where an “improvement method that uses an existing structure” is applied to a sheet-pile quaywall, as shown in Figure 3.14.

① Reducing the active earth pressure
② Increasing the passive earth pressure
③ Reducing the sectional force generated by supporting sheet piles
④ Increasing the strength by reinforcing sheet piles

Here, ① reduces the effect of the factors acting on the load side, and ② to ④ increase or add the effect of the factors acting on the resistance side.

Regarding stability improvement mechanisms when applied to cases of an “improvement method that does not use an existing structure,” the following are available.

⑤ Having a new structure bear the load
⑥ Changing the usage of an existing structure

In many cases when a new structure is to bear an external force, the new structure is built at the front or rear face of an existing sheet-pile quaywall, and no consideration whatsoever is given to the influence of existing structures on either the load side or the resistance side in the structure’s design. When changing the usage of an existing structure, a new structure is built at the front face of an existing sheet-pile quaywall, and the existing structure is changed to a revetment.

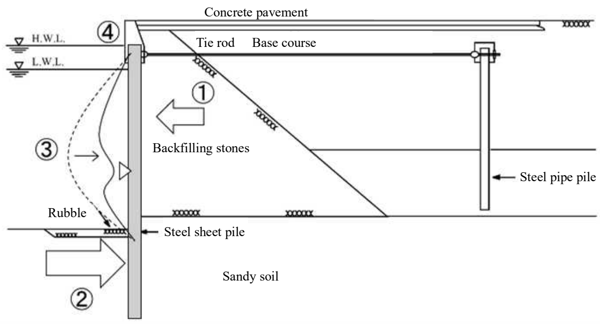


Figure 3.14 Stability improvement mechanism for a sheet-pile quaywall
(when applying an improvement method that uses an existing structure)

(2) Results of extracting of improvement methods for sheet-pile quaywalls

Figures 3.15 to 3.17 list 26 methods extracted as improvement methods for sheet-pile quaywall. The figures show schematic diagrams of improvement methods and overviews of them. These methods are sorted in accordance with the classification of stability improvement mechanisms ① to ⑥ shown in (1) above, and they are appended with serial numbers from S-1 to S-26, respectively. In Appendix Table 2 in the Appendix provides, in the form of individual sheets, the stability improvement mechanisms, etc. for the methods, organized according to the improvement methods for sheet-pile quaywalls.

Table 3.2 clearly indicates the stability improvement mechanisms to which respective methods belong to and the investigation methods by which the respective methods were extracted (A: extracted from improvement design cases; B: extracted from past documents). It includes 17 methods of “improvement methods that use an existing structure” (stability improvement mechanisms ① to ④) and 9 methods of “improvement methods that do not use an existing structure” (stability improvement mechanisms ⑤ to ⑥).

Table 3.2 Extracted methods for improving sheet-pile quaywalls

Method	Stability improvement mechanism	A (improvement design case)	B (past document)
S-1	① Reducing the active earth pressure	○	3)
S-2		○	3)
S-3		○	3)

S-4		○	3)
S-5		○	3)
S-6		-	10), 11)
S-7	② Increasing the passive earth pressure	○	3)
S-8	③ Reducing the sectional force generated by supporting sheet piles	○	3), 12)
S-9		○	3), 13)
S-10		○	3)
S-11		○	-
S-12		-	14)
S-13		○	-
S-14	④ Increasing the strength by reinforcing sheet piles	○	3)
S-15		○	3)
S-16		○	3)
S-17		○	3)
S-18	⑤ Having a new structure bear the load	○	-
S-19		○	-
S-20		○	-
S-21		○	-
S-22		○	-
S-23		○	-
S-24		○	-
S-25	⑥ Changing the usage of an existing structure	○	3)
S-26		○	3)

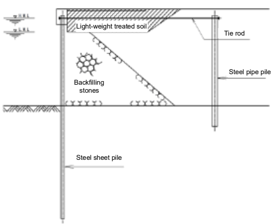
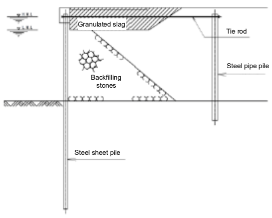
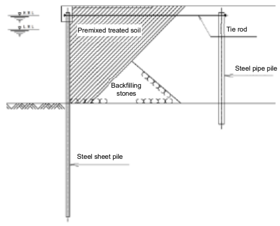
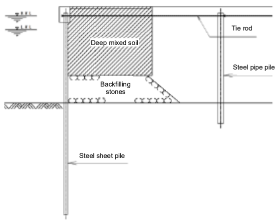
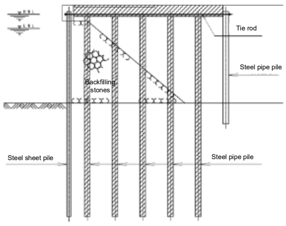
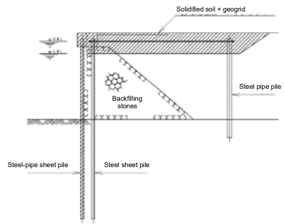
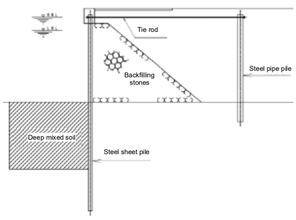
Stability improvement mechanism	Reducing the active earth pressure		
Method No.	S−1	S−2	S−3
Schematic diagram			
Overview	Putting light-weight treated soil in place after removing backfill soil, etc. reduces the active earth pressure.	Putting granulated slag in place after removing backfill soil, etc. reduces the active earth pressure.	Putting premixed treated soil in place after removing backfill soil, etc. reduces the active earth pressure.
Method No.	S−4	S−5	S−6
Schematic diagram			
Overview	Solidifying backfill soil with cement reduces the active earth pressure.	Installing a shelf-type structure at the back reduces the surcharge and the weight of the upper soil layer.	Replacing the soil behind sheet piles with solidified soil and integrating them by using a planar reinforcing member (geogrid) provides the frictional resistance force.
Stability improvement mechanism	Increasing the passive earth pressure		
Method No.	S−7		
Schematic diagram			
Overview	Improving the foundation ground in front of the sheet piles increases the passive resistance force.		

Figure 3.15 Improvement methods for sheet-pile quaywalls (1)

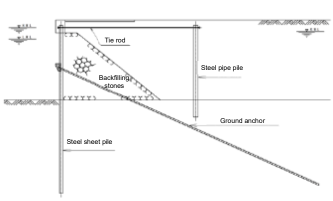
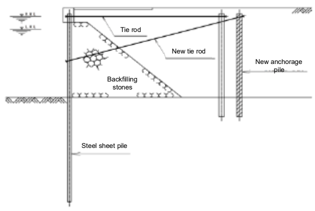
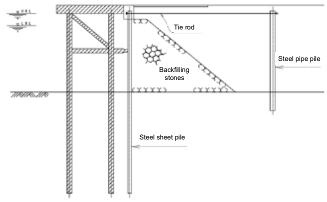
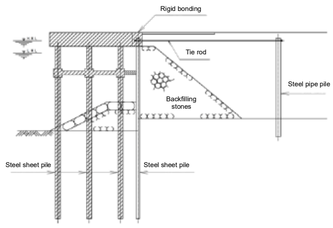
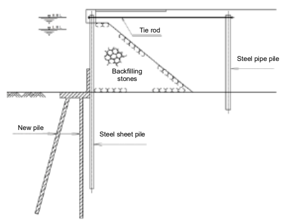
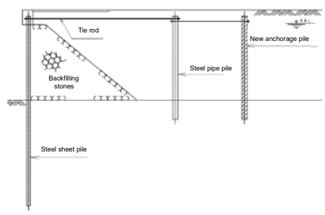
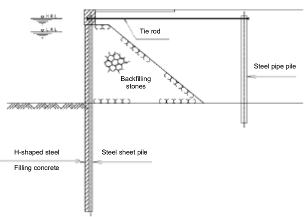
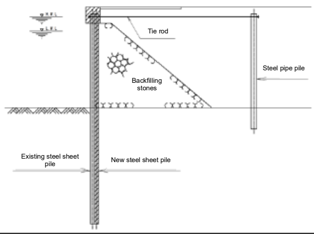
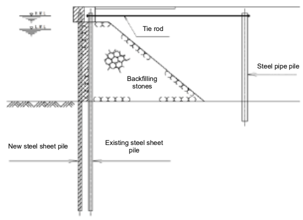
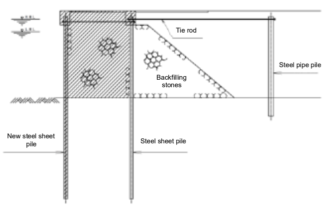
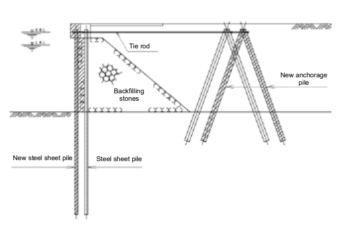
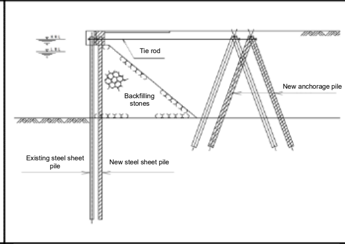
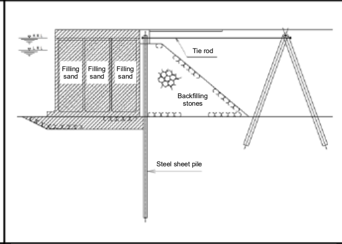
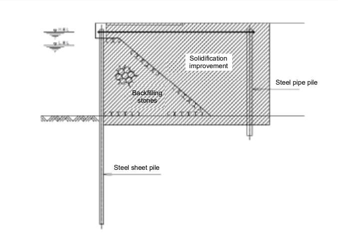
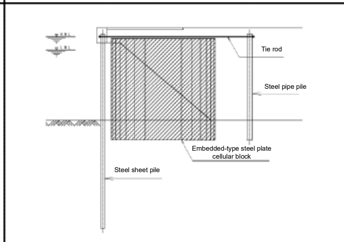
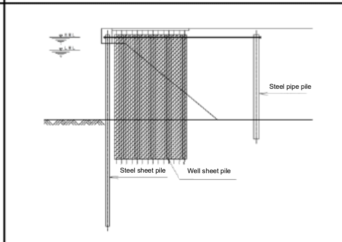
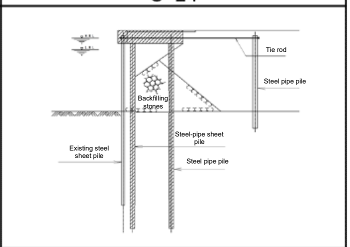
Stability improvement mechanism	Reducing the sectional force generated by supporting sheet piles		
Method No.	S−8	S−9	S−10
Schematic diagram			
Overview	Installing a supporting point at the midpoint between the seabed ground and the existing tie rod reduces generated sectional force.	Installing a new tie rod at the midpoint between the seabed ground and the existing tie rod reduces the generated sectional force of the steel sheet piles.	Installing a supporting point (waling) at the midpoint between the seabed ground and the existing tie rod reduces generated sectional force. The supporting point reaction force is supported by a jacket-type structure or the like.
Method No.	S−11	S−12	S−13
Schematic diagram			
Overview	Installing a supporting point (waling) at the midpoint between the seabed ground and the existing tie rod, reduces generated sectional force. The supporting point reaction force is supported by a piled pier.	Installing an L-shaped block (with foundation pile) at the front faces of the sheet piles reduces the generated force applied to the tie rods via the resistance force from the L-shaped block.	Increasing the number of anchorage piles distributes the reaction force of the existing anchorage piles.
Stability improvement mechanism	Increasing the strength by reinforcing sheet piles		
Method No.	S−14	S−15	S−16
Schematic diagram			
Overview	The sheet piles are reinforced with concrete and H-shaped steel (for steel-pipe sheet piles), etc.	Installing sheet piles at the immediate back face of the existing sheet piles integrates those sheet piles and increases the strength.	Installing sheet piles at the immediate front face of the existing sheet piles integrates those sheet piles and increases the strength.
Method No.	S−17		
Schematic diagram			
Overview	Installing sheet piles at the front face of the existing sheet piles and changing the existing structure into a double-sheet pile structure, with the existing ones serving as the anchorage sheet piles, makes the double sheet piles bear the active earth pressure.		

Figure 3.16 Improvement methods for sheet-pile quaywalls (2)

Stability improvement mechanism	Having a new structure bear the load		
Method No.	S-18	S-19	S-20
Schematic diagram			
Overview	Installing new sheet piles at the front faces of the existing sheet piles makes the new sheet piles bear the active earth pressure.	Placing new sheet piles behind the existing sheet piles makes the new sheet piles bear the active earth pressure.	Installing a new gravity-type structure in front of the existing sheet piles makes the new gravity-type structure bear the active earth pressure.
Method No.	S-21	S-22	S-23
Schematic diagram			
Overview	Conducting solidification improvement of the ground behind the existing sheet piles makes the solidified ground, instead of the existing sheet piles, bear the active earth pressure as a gravity-type structure.	Installing embedded-type steel plate cellular blocks behind the existing sheet piles makes the cellular blocks, instead of the existing sheet piles, bear the earth pressure.	Wells are installed behind the existing sheet piles to bear the earth pressure conveyed through the steel-pipe sheet piles. Or, wells contain the existing sheet piles to reinforce them.
Method No.	S-24		
Schematic diagram			
Overview	By installing a new piled pier structure integrated with the existing sheet piles behind the existing sheet piles, the new piled pier, also serving as earth-retaining sections, is made to bear the active earth pressure.		

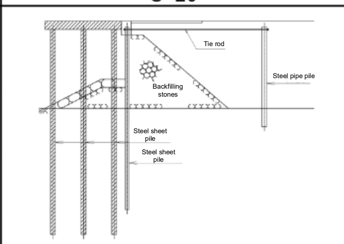
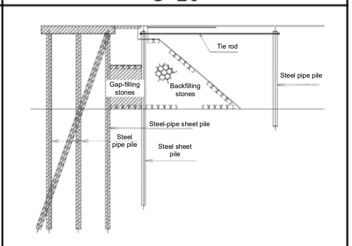
Stability improvement mechanism	Changing the usage of an existing structure	
Method No.	S-25	S-26
Schematic diagram		
Overview	A piled pier (without an earth retaining structure) is installed in front of the sheet piles, and the resistance force of the existing sheet piles is increased by the rubble mound in front of the existing sheet piles.	A piled pier (with an earth retaining structure) is installed in front of the sheet piles, and displacement of the existing sheet piles is suppressed by the gap-filling stones in front of the existing sheet piles.

Figure 3.17 Improvement methods for sheet-pile quaywalls (3)

(3) Improvement methods that use an existing structure

a) Reducing the active earth pressure (stability improvement mechanism ①)

For sheet-pile quaywalls, reducing the active earth pressure behind the sheet piles decreases the resultant force on the load side toward the sheet piles. Therefore, it is possible to improve the stability for the verification items of sheet pile embedded length, sheet pile stress, tie rod stress, and anchorage stress. Methods S-1 to S-6 in Figure 3.15 are available as methods with the potential to reduce the active earth pressure. Here, Figure 3.18 shows a schematic diagram of method S-1 as a representative example.

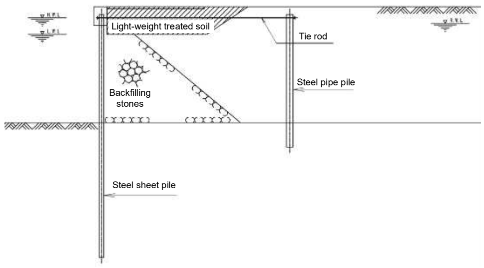


Figure 3.18 Example of a construction method that reduces the active earth pressure (S-1)

This method (Figure 3.18) involves replacing the backfill soil behind the sheet piles with light-weight soil, reducing the weight per unit volume of some of the soil to decrease the active earth pressure. Methods S-2 to S-6, as with method S-1, intend to reduce the active earth pressure by replacing the soil at the back, improving the ground, or installing a structure at the back.

b) Increasing the passive earth pressure (stability improvement mechanism ②)

For sheet-pile quaywalls, the ground resistance force is increased by increasing the passive earth pressure. Therefore, it is possible to improve stability mainly for the verification item of the sheet pile embedded length. Method S-7 in Figure 3.15 is available as a method with the potential to increase the passive earth pressure. Here, Figure 3.19 shows a schematic diagram of method S-7 as a representative example.

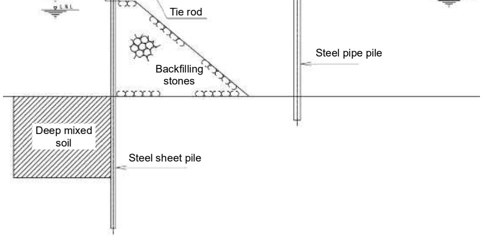


Figure 3.19 Example of a construction method that increases the passive earth pressure (S-7)

This method (Figure 3.19) involves improving the ground in front of the sheet piles to increase the strength of the ground, thereby increasing the passive resistance force.

c) Reducing the sectional force generated by supporting sheet piles (stability improvement mechanism ③)

For sheet-pile quaywalls, providing multiple supports at the sheet piles on the front reduces the sectional force generated in the sheet piles on the front. Therefore, it is possible to improve the stability of the verification items of sheet pile embedded length, sheet pile stress, tie rod stress, and anchorage stress. Methods S-8 to S-13 in Figure 3.16 are available as methods with the potential to reduce the generated sectional force through installation of sheet pile supports. Here, Figure 3.20 shows a schematic diagram of method S-9 as a representative example.

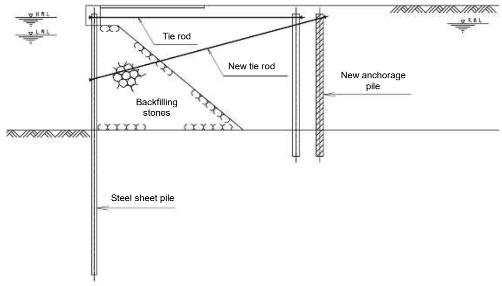


Figure 3.20 Example of a construction method that supports sheet piles (S-9)

This method (Figure 3.20) involves installation of new anchorages behind the sheet piles and provision of new supports at around the midpoint between the seabed ground and the existing tie rods to reduce the generated sectional force. The aim of method S-8 is to reduce the generated sectional force by installing anchors and providing new supports at a point between the seabed ground and existing tie rods. The aim of methods S-10 to S-13 is to reduce the generated sectional force by providing support at the connection between a new structure installed in front of the sheet piles and the existing sheet piles.

d) Increasing the strength by reinforcing sheet piles (stability improvement mechanism ④)

For sheet-pile quaywalls, reinforcing the existing sheet piles to increase their strength raises the section modulus and rigidity of the sheet piles. Therefore, it is possible to improve the stability mainly for the verification item of sheet pile stress. Methods S-14 to S-17 in Figure 3.16 are available as methods with the potential to increase the strength through reinforcement. Here, Figure 3.21 shows a schematic diagram of method S-14 as a representative example.

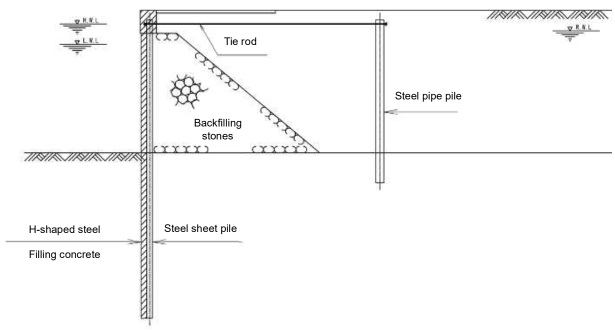


Figure 3.21 Example of a construction method that reinforces sheet piles (S-14)

This method (Figure 3.21) involves covering the sheet piles on the front with concrete or installing H-shaped steel members or the like in the steel-pipe sheet piles, thereby increasing the sectional strength of the sheet piles. Methods S-15 to S-17 reinforce the steel-pipe sheet piles by placing piles in them and increase the sectional strength by installing new sheet piles in front of and behind the existing sheet piles to integrate those sheet piles.

(4) Improvement methods that do not use an existing structure

a) Having a new structure bear the load (stability improvement mechanism ⑤)

When a new structure is built in front of or behind existing sheet piles, the new structure will be designed to bear all the loads acting on the existing sheet piles, and no consideration will be given to the existing sheet piles in the structure's design. For this reason, newly installed structures that do not use existing structures must satisfy all the same verification items as the designs of ordinary new structures. Methods S-18 to S-24 in Figure 3.17 are available as methods in which a new structure bears the loads. Here, Figure 3.22 shows a schematic diagram of method S-18 as a representative example.

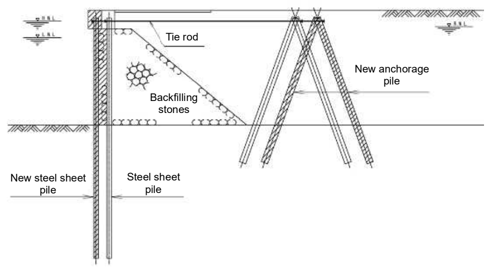


Figure 3.22 Example of a construction method using new structure (S-18)

This method (Figure 3.22) involves installation of new sheet piles in front of the existing ones, and the new structure bears all the acting loads. In methods S-19 to S-24, in the same way, the new structure is made to bear the acting loads through installing it in front of or behind the existing sheet pile.

b) Changing the usage of an existing structure (stability improvement mechanism ⑥)

When a new structure is built in front of existing sheet piles, the existing sheet piles may change to a revetment. When rubble or other material is installed in front of the existing sheet piles, the rubble, etc. at the front provide a resistance force for the existing sheet piles. Methods S-25 to S-26 in Figure 3.17 are available as methods that change the usage of an existing structure. Here, Figure 3.23 shows a schematic diagram of method S-25 as a representative example.

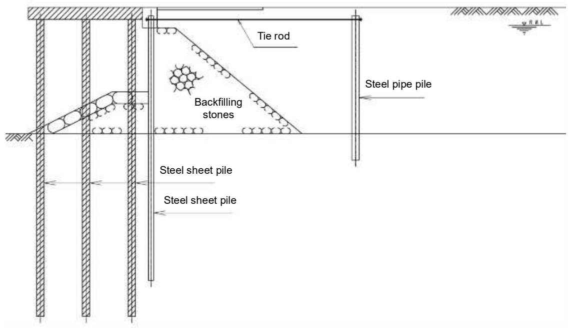


Figure 3.23 Example of a construction method that changes the usage of an existing structure (S-25)

This method (Figure 3.23) involves building a new piled pier in front of the existing sheet piles and converting the existing sheet piles into a revetment. Arranging rubble below the piled pier provides a resistance force to the existing sheet piles due to passive earth pressure. In the method S-26, a new piled pier, which also serves as earth-retaining sections, is installed in front of the existing sheet piles.

3.4 Comprehensive descriptions of improvement methods for piled piers

(1) Stability improvement mechanism provided by improving piled piers

There are two main verification items concerning static phenomena in piled piers, namely 1) pile stress and 2) pile embedded length. The stability of each verification item changes depending on the balance among loads such as ship berthing force and seismic inertia force and the strength and section modulus of pier piles. Therefore, to improve the stability stated above, it is necessary to reduce the effect of factors acting on the load side or increase or add the effect of factors acting on the resistance side. However, among factors that affect the load side, there are many that are determined as given conditions, such as ship berthing force and seismic inertia force. Therefore, in many cases, it is difficult to reduce those factors.

Considering the above, the following are available as stability improvement mechanisms in cases where an "improvement method that uses an existing structure" is applied to a piled pier, as shown in Figure 3.24.

① Distributing the stress generated in piles

② Increasing the horizontal rigidity

③ Increasing supporting ground strength

④ Increasing the strength through reinforcement

Here, ① reduces the effect of the factors acting on the load side, and ② to ④ increase or add the effect of the factors acting on the resistance side.

As another stability improvement mechanism, the following is available.

⑤ Changing the structure type

When changing the structure type, new structural members are installed and the usage of the structure is changed to an earth retaining structure. The structure will resist loads including active earth pressure, not originally assumed loads such as ship berthing force and seismic inertia force.

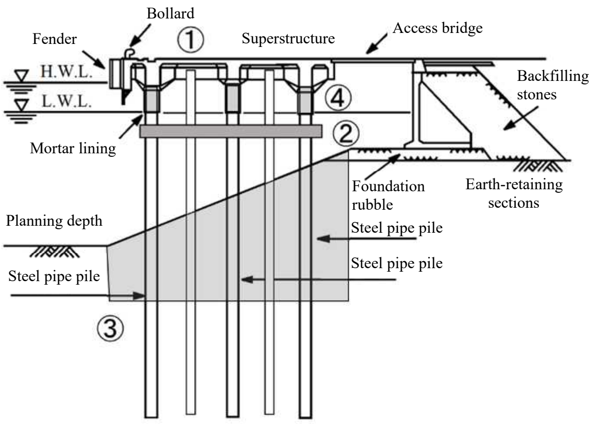


Figure 3.24 Stability improvement mechanism for pile piers (when applying an improvement method that uses an existing structure)

(2) Results of extracting of improvement methods for a piled pier

Figures 3.25 to 3.26 list 18 methods extracted as improvement methods for piled piers. The figures show schematic diagrams of improvement methods and overviews of them. These methods are sorted in accordance with the classification of stability improvement mechanisms ① to ⑤ shown in (1) above, and they are appended with serial numbers from P-1 to P-18. In Appendix Table 3 in the Appendix provides, in the form of individual sheets, stability improvement mechanisms, etc. organized on the basis of improvement methods for piled piers.

Table 3.3 clearly indicates the stability improvement mechanisms to which respective methods belong and the investigation methods by which the respective methods were extracted (A: extracted from improvement design cases; B: extracted from past documents). They include 15 methods of "improvement methods that use an existing structure" (stability improvement mechanisms ① to ④) and 3 methods that change the structure type (stability improvement mechanism ⑤).

Table 3.3 Extracted methods for improving piled piers

Method	Stability improvement mechanism	A (improvement design case)	B (past document)
P-1	① Distributing the stress generated in piles	○	3)
P-2		○	3)
P-3		○	3)
P-4	② Increasing the horizontal rigidity	○	3)
P-5		-	15)
P-6		○	3), 16)
P-7		-	17)
P-8	③ Increasing supporting ground strength	○	3)
P-9		○	-
P-10		○	-
P-11		○	-
P-12		○	-
P-13	④ Increasing the strength through reinforcement	○	3)
P-14		○	3)
P-15		○	3)
P-16	⑤ Changing the structure type	○	3)
P-17		○	3)
P-18		-	18)

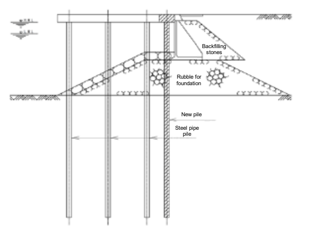
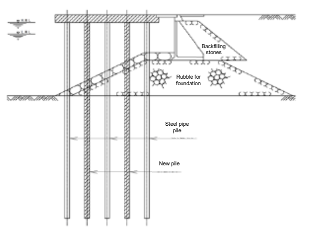
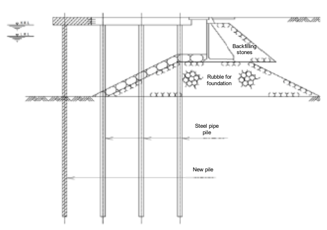
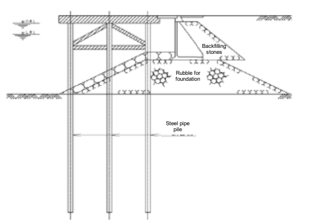
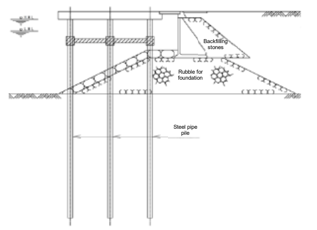
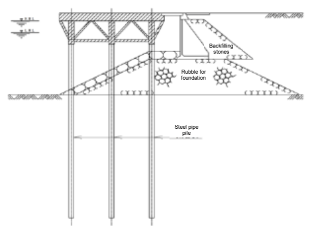
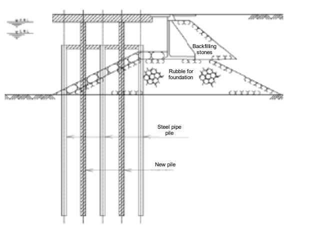
Stability improvement mechanism	Distributing the stress generated in piles		
Method No.	P−1	P−2	P−3
Schematic diagram			
Overview	Adding piles at the immediate back face of the existing piled pier (between the existing piled pier and the earth retaining structure) to integrate the existing piled pier and the superstructure distributes the stress.	Installing new piles at the midpoint between existing piles distributes the stress (superstructure is removed and newly constructed).	Adding piles in front of an existing piled pier and integrating them with the existing piled pier by means of a superstructure distributes the stress.
Stability improvement mechanism	Increasing the horizontal rigidity		
Method No.	P−4	P−5	P−6
Schematic diagram			
Overview	Connecting piles with brace members increases the rigidity of the piles.	Installing brace members at the midpoint between piles changes the distribution of generated sectional force.	Making a truss structure in which steel girders forming a frame are placed over the foundation piles suppresses the generated sectional force and displacement of steel pipe piles in the event of an earthquake.
Method No.	P−7		
Schematic diagram			
Overview	Connecting the existing piles and new piles with horizontal members transmits the load, and the existing piles and the new piled pier resist earthquake load as one.		

Figure 3.25 Improvement methods for piled piers (1)

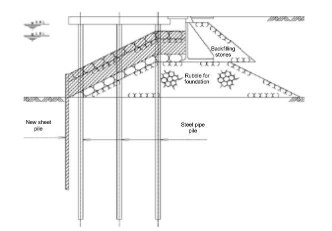
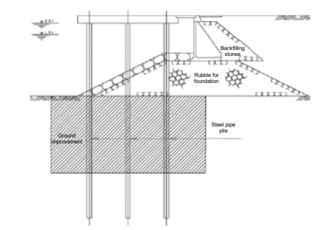
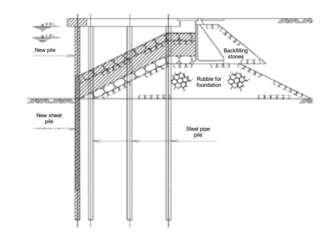
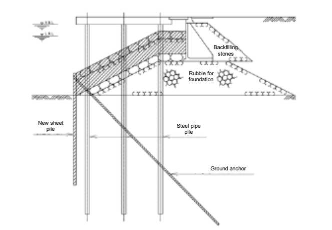
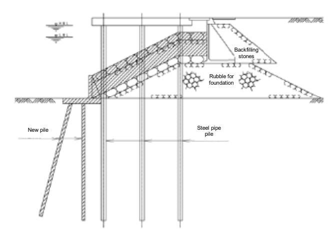
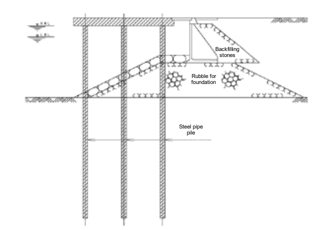
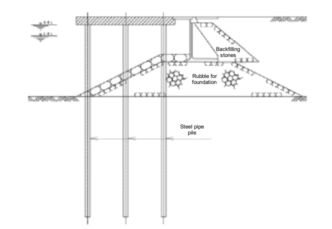
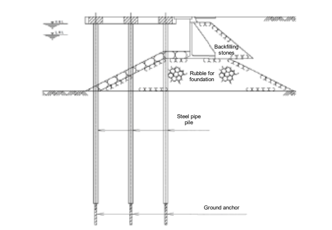
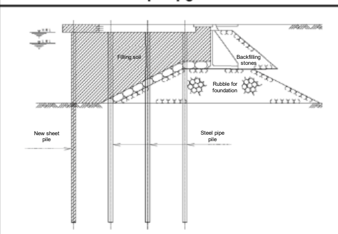
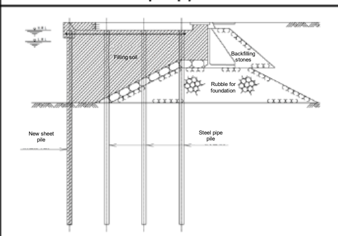
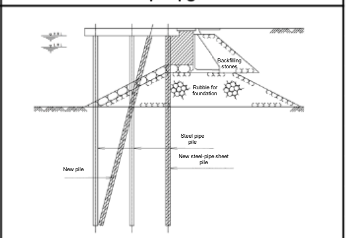
Stability improvement mechanism	Increasing supporting ground strength		
Method No.	P-8	P-9	P-10
Schematic diagram			
Overview	Installing foot protection sheet piles at the front and reducing the protrusion length of the piles with rubble, etc. increases the resistance force.	Conducting ground improvement of the supporting ground increases the strength of the ground and boosts the bearing capacity.	Integrating the foot protection at the front with the piled pier and reducing the protrusion length of the pile with rubble, etc. increases the resistance force.
Method No.	P-11	P-12	
Schematic diagram			
Overview	Installing anchor-pile type steel sheet piles at the front and reducing the protrusion length of the piles with rubble, etc. increases the resistance force.	Installing an L-shaped retaining wall at the front and reducing the protrusion length of the piles with rubble, etc. increases the resistance force.	
Stability improvement mechanism	Increasing the strength through reinforcement		
Method No.	P-13	P-14	P-15
Schematic diagram			
Overview	Reinforcing the piles with concrete, double pipe, etc. increases the resistance force.	Improving the superstructure increases the superstructure's resistance to pile stress.	Installing vertical anchors increases the pull-out resistance force of the existing pile.
Stability improvement mechanism	Changing the structure type		
Method No.	P-16	P-17	P-18
Schematic diagram			
Overview	Installing sheet piles at the front face of the existing piled pier integrates the sheet piles with the existing piled pier by means of the superstructure, changing the structure to a shelf-type structure. This shelf-type structure bears the active earth pressure.	By installing sheet piles at the front face of the existing piled pier, the existing piled pier is used as an anchorage. The newly installed sheet piles bear the active earth pressure.	Changing the structure to a piled pear, which also serves as earth-retaining sections, and installing a batter pile suppresses displacement.

Figure 3.26 Improvement methods for piled piers (2)

(3) Improvement methods that use an existing structure

a) Distributing the stress generated in piles (stability improvement mechanism ①)

In a piled pier, the stress generated in piles can be distributed by installing a structural member that bears the load acting on the piled pier. Therefore, it is possible to improve the stability for the verification items of pile stress and pile embedded length. Methods P-1 to P-3 in Figure 3.25 are available as methods that distribute the stress. Here, Figure 3.27 shows a schematic diagram of method P-2 as a representative example.

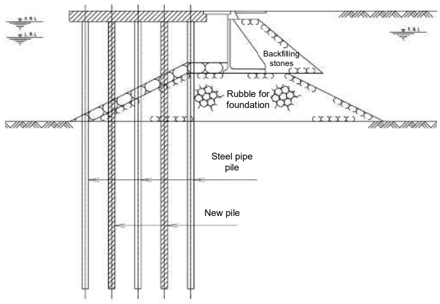


Figure 3.27 Example of a construction method that distributes stress (P-2)

This method (Figure 3.27) involves the installation of new piles between existing ones and integrating them as a structure by means of a newly installed superstructure to distribute the stress. The aim of methods P-1 and P-3 is to distribute the stress by installing new piles in front of or behind the existing piled pier.

b) Increasing the horizontal rigidity (stability improvement mechanism ②)

For piled piers, the generated sectional force is reduced by enhancing the horizontal rigidity of the piled pier structure. Therefore, it is possible to improve the stability for the verification item of pile stress. Methods P-4 to P-7 in Figure 3.25 are available as methods that enhance horizontal rigidity. Here, Figure 3.28 shows a schematic diagram of method P-6 as a representative example.

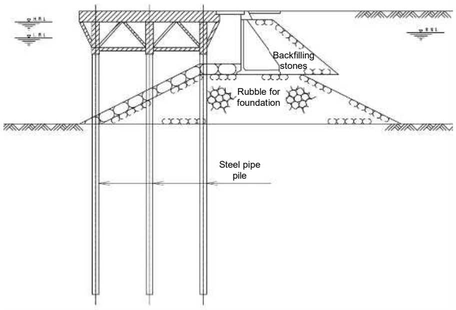


Figure 3.28 Example of a construction method that enhances horizontal rigidity (P-6)

This method (Figure 3.28) involves connecting a structure that combines a superstructure manufactured at an onshore yard, the upper part of steel pipe piles, and horizontal members to the upper part of the existing pier piles to enhance the horizontal rigidity. The aim of methods P-4, P-5, and P-7 is to increase the horizontal rigidity by installing horizontal members.

c) Increasing supporting ground strength (stability improvement mechanism ③)

For piled piers, the ground resistance force acting on the piles is increased by boosting the strength of the supporting ground. Therefore, it is possible to improve the stability for the verification items of pile stress and pile embedded length. Methods P-8 to P-12 in Figure 3.26 are available as methods that increase the supporting ground strength. Here, Figure 3.29 shows a schematic diagram of method P-8 as a representative example.

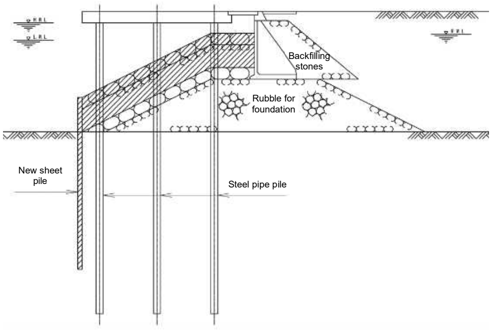


Figure 3.29 Example of a construction method that increases the supporting ground strength (P-8)

This method (Figure 3.29) involves installation of earth-mound retaining sheet piles right beneath the face line of the piled pier and increasing the rubble mound height to increase the resistance force against the piles (increasing the embedded length is expected to produce the same apparent effect as that of increasing the strength of the supporting ground). Similarly, methods P-10 to P-12 increase the resistance force against the piles by using anchorage sheet piles, an L-shape retaining wall, and sheet piles that also serves as pier piles instead of earth-mound retaining sheet piles. Method P-9 is designed to increase the supporting ground strength by improving the ground.

e) Increasing the strength through reinforcement (stability improvement mechanism ④)

For piled piers, the sectional performance of the steel pipe piles is expected to be improved by increasing the strength through reinforcing the steel pipe piles. Therefore, the stability for the verification item of pile stress can be improved. Methods P-13 to P-15 in Figure 3.26 are available as methods that increase the strength. Here, Figure 3.30 shows a schematic diagram of method P-13 as a representative example.

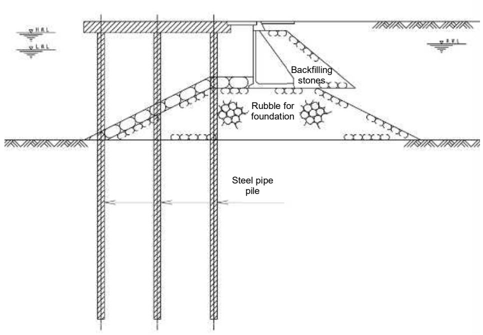


Figure 3.30 Example of a construction method that increases strength (P-13)

This method (Figure 3.30) involves covering existing piles with concrete or concrete filling, double-piping, etc. to increase the sectional strength of the steel pipe piles. Method P-14 aims to secure the necessary strength by reinforcing the superstructure, while method P-15 is designed to increase the pull-out resistance force by passing anchors through the piles.

(4) Changing the structure type (stability improvement mechanism ⑤)

The aim of this method is to improve stability against the acting load by changing the piled pier structure into another structure type by installing a new structure in front of the existing piled pier or adding new structural members. Methods P-16 to P-18 in Figure 3.26 are available as methods that change the structure type. Here, Figure 3.31 shows a schematic diagram of method P-17 as a representative example.

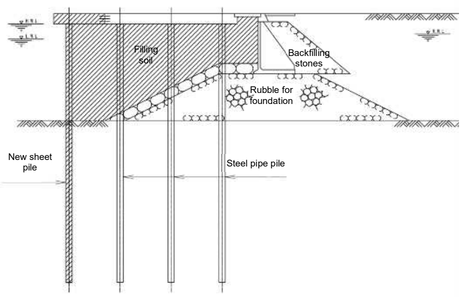


Figure 3.31 Example of a construction method that changes the structure type (P-16)

This method (Figure 3.31) involves changing the structure from a piled pier structure to a shelf-type structure by installing new sheet piles at the front face of the existing piled pier and filling in the space beneath the piled pear so that the new structure bears all the acting loads. Method P-17 changes the structure to a sheet pile structure by installing new sheet piles at the front face of the existing piled pier and using the existing pier pile as an anchorage. Method P-18 changes the structure to a piled pier structure that also serves as earth-retaining sections by changing the land-side piles of the existing piled pier to a sheet-pile wall.

3.5 Basic concept of selecting improvement methods

(1) Basic concept

By referring to the classification of the stability improvement effects (mechanisms) of the improvement methods explained in 3.2 to 3.4, it is possible to extract the method suitable for the target existing mooring facility from among a wide variety of them. The basic concept underlying extraction is explained below.

First, consider the principle of improvement that is effective for the structure type and structural cross-section of the existing mooring facility, and arrange the stability improvement mechanisms that can be obtained by design. The stability improvement mechanisms need to be extracted without omitting any. Next, exhaustively investigate the existing methods that can be classified into the same stability improvement mechanism on the basis of the extracted stability improvement mechanisms and, at the same time, examine whether a new improvement method can be created. Following these steps makes it possible to extract all the improvement methods for the existing mooring facility.

To improve a given existing gravity-type quaywall, sheet-pile quaywall, and piled pier mooring facility, refer to the following contents presented in 3.2 to 3.4.

- Classification of stability improvement mechanisms (Figure 3.1, Figure 3.14, Figure 3.24)
- Lists of conventional improvement methods (Figures 3.2 to 3.5, Figures 3.15 to 3.17, and Figures 3.25 to 3.26)
- Individual sheets of conventional improvement methods (Appendix)

(2) Selecting an improvement method

After making sure to extract a wide variety of improvement methods in step (1), it is necessary to narrow down the improvement methods. Because extracting improvement methods has been conducted by focusing on the stability improvement mechanisms, a large number of methods can be listed. To efficiently narrow down the improvement methods, it is effective to clearly set various restrictions imposed on the respective projects. In addition, by associating the set details of the restrictions with the applicable improvement methods, it is possible to easily check which restriction can exert what kind of influence on the available improvement method options. By organizing these matters in advance, it is also possible to set priorities for the restrictions, which can be adjusted among the concerned parties. In addition, by using the individual sheets for conventional improvement methods as mentioned earlier, it is also possible to exclude in advance improvement methods that are judged to have an extremely low applicability to the given project.

As an example of associating the set details of restrictions with applicable improvement methods, Figure 3.32 shows the result of organizing improvement methods based on whether the structure in question is a gravity-type quaywall, a sheet-pile quaywall, or a piled pier, focusing on whether improvement construction of an existing mooring facility is possible from the sea side or possible only from the land side. This result shows that, for a gravity-type quaywall for example, if construction from the sea side only is permitted, only those improvement methods classified as face-line front-face construction as shown on the left side of the figure can be employed. However, the figure also shows that, if the condition is eased to permit construction from the land side as well, it is possible to use an improvement method classified as face-line back-face construction, and in some cases, it is also possible to create an improvement method that combines construction from the face-line front face and from the face-line back face.

(3) Using the concept to select the structure type for a new facility

The basic concept underlying selection of an improvement method for an existing mooring facility as shown in (1) and (2) above can also be used to select the structure type when designing a new facility. In other words, once the methods have been organized according to the preconditions of the target position, when selecting the structure type, it is possible to grasp in advance what kinds of methods can be selected to counter aging in the future, to enhance functions including deepening and seismic strengthening, and to aid recovery in the event of disaster. Furthermore, it is also possible to estimate the difficulty of making future improvements and to obtain an estimate of life cycle cost with consideration given to improvement.

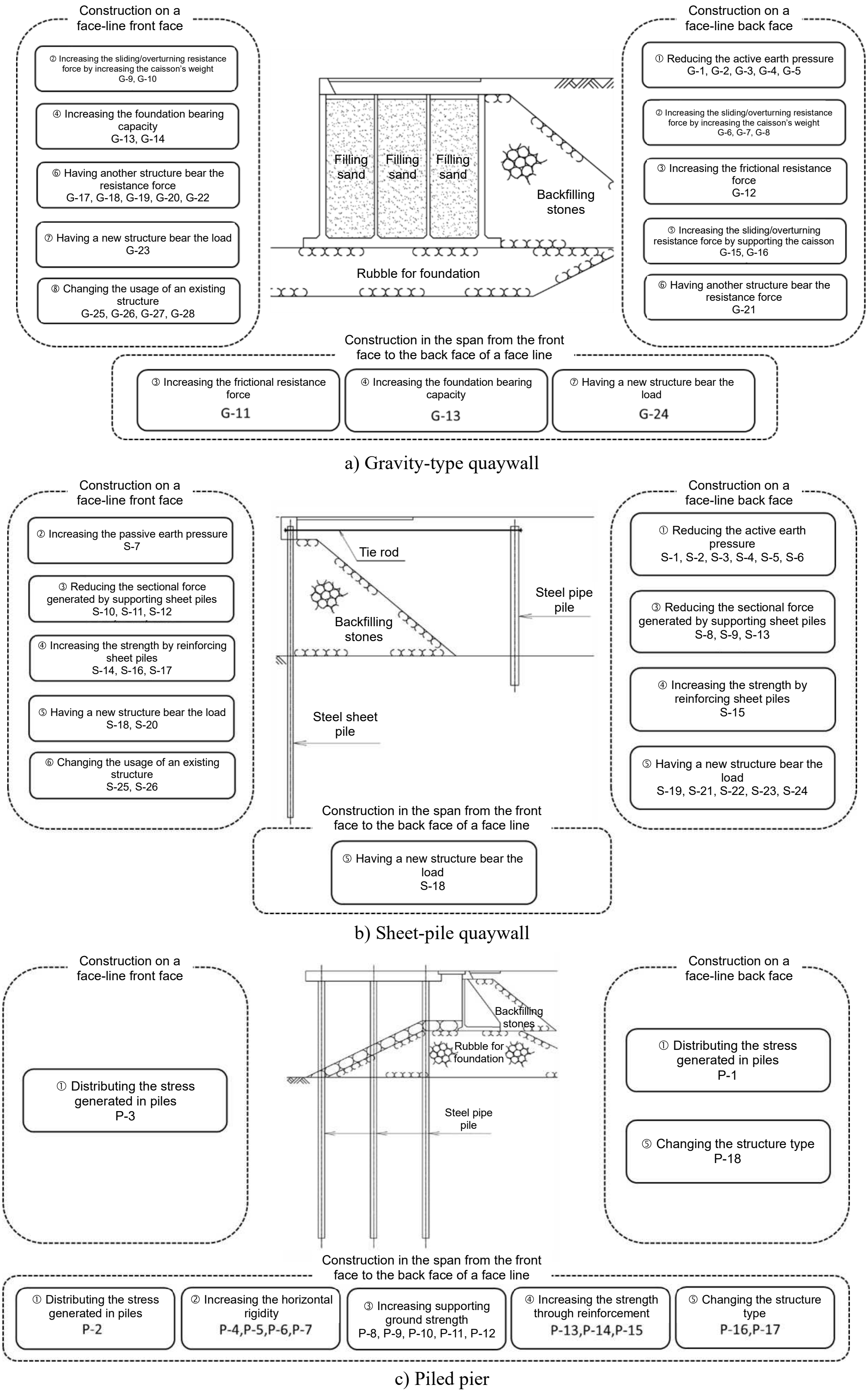


Figure 3.32 Example of comprehensively organizing improvement methods (organizing by construction position)

4. Design issues related to improvement methods and their standardization

4.1 Points of focus when considering design issues with improvement methods

(1) Points of focus when considering issues

In this chapter, we consider the issues related to the improvement methods based on the result of organizing the improvement methods for existing mooring facilities presented in Chapter 3. Then, recognizing the issues not only as issues with these methods, but also as large common issues regardless of the type of method, we will standardize those issues.

Before starting an examination on the issues related to these methods, we need to remember that while the cross-section of a new structure basically consists of a single structure (Figure 4.1), each improvement cross-section comprises various structures including the existing structure, the structure(s) added to it, and any new structure that bears the acting force as a new mooring facility. To efficiently find issues in improved cross-sections where multiple structures are combined as stated above, we are going to consider these issues by focusing on the following points. Figure 4.2 shows schematic diagrams of the points of focus. This figure provides schematic diagrams as well as representative improvement methods to show more specific points of attention.

a) Combination of structures

b) Constituent members of a structure

c) Positional relationships among structures

In this study, in standardizing issues common to improvement methods, the entire structure in which existing structures and added structures coexist is called a "structural system," and an existing structure or an added structure is called a "structural unit" for the purpose of organization toward standardizing the issues.

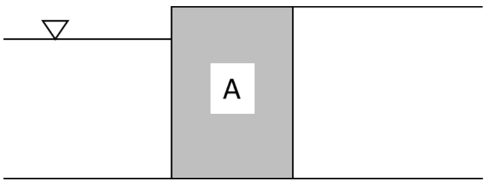
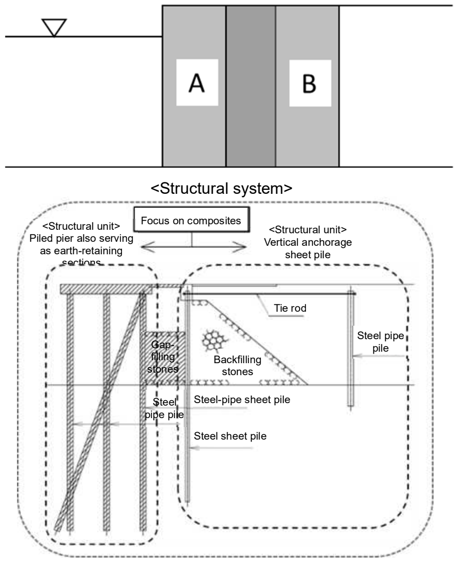
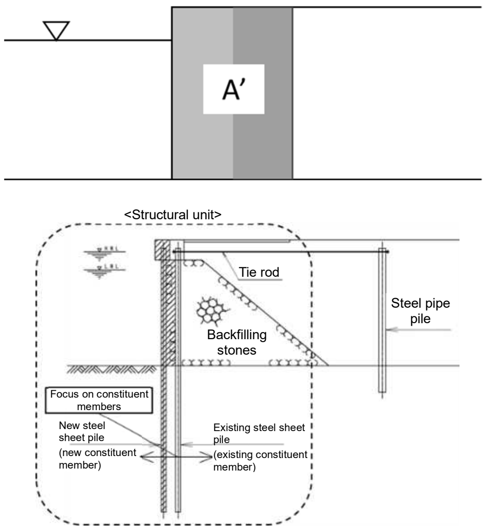


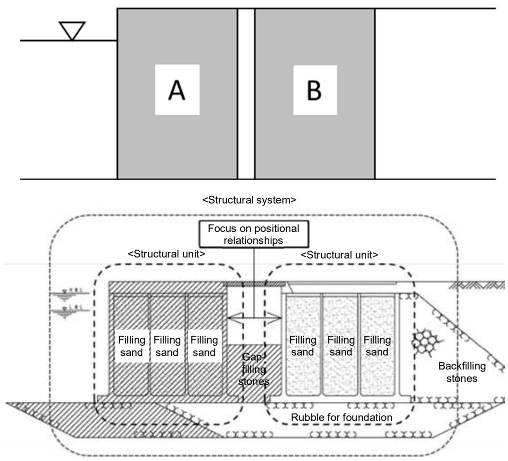
Figure 4.1 Schematic diagram of the cross-section of a new structure



a) Combination of structures



b) Constituent members of a structure



c) Positional relationships among structures

Figure 4.2 Schematic drawings of points of focus to consider issues

(2) Extracting improvement methods to be used for organizing common issues

In this study, we consider the issues in design of improvement methods that have been extracted in Chapter 3 by focusing on the viewpoint of standardizing design issues as stated above. Here, we present the results of the following eight methods to exemplify representative issues concerning the point of focus stated above.

In the eight methods listed here, methods 1) to 3) are representative examples concerning the combination of structures; method 4) is a representative example concerning constituent members of a structure; and methods 5) to 8) are representative examples concerning positional relationships among structures. Although some methods have multiple issues, in this study we narrow them down to a single common issue, consider it and standardize it.

1) Newly constructing a shelf structure behind existing sheet piles (S-5)
2) Constructing a new piled pier that also serves as earth-retaining sections in front of existing sheet piles (S-23)
3) Installing sheet piles at the front face of an existing piled pier and converting the existing piled pier to an anchorage (P-17)
4) Installing sheet piles in front of existing sheet piles and integrating those sheet piles (S-16)
5) Installing additional anchorages behind existing sheet piles (S-9)
6) Installing anchorages in addition to existing anchorage piles (S-13)
7) Installing a new caisson in front of an existing caisson (G-26)
8) Installing new anchorage sheet piles at the front face of existing sheet piles (S-18)

4.2 Considering common issues related to designing improvement methods and standardizing them

(1) Newly constructing a shelf structure behind existing sheet piles (S-5)

a) Overview of the method

Figure 4.3 shows a schematic diagram of a method for constructing a new shelf structure behind existing sheet pile (S-5). This method involves installing a new shelf-type structure behind the existing anchor sheet pile quaywall and having the shelf-type structure bear the surcharge on the apron and the weight of soil layer on the shelf-type structure to reduce the active earth pressure acting on the back of the sheet piles. Consideration is given to the assumption that the existing anchorage sheet piles and the shelf-type structure are not integrated with each other, and that the superstructure on the shelf-type structure is installed in a way that avoids the existing tie rods.

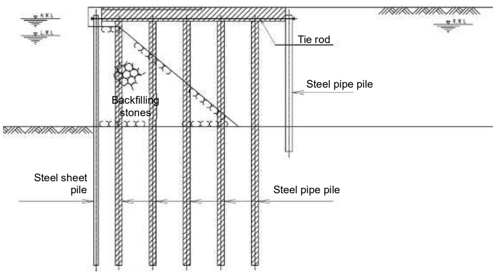


Figure 4.3 Schematic diagram of method S-5

b) Issues with the method

One example of a design issue related to this method is that while displacement in the cross-sectional direction is expected to occur in the event of an earthquake, the deformation behavior could be different between the existing structure and the added structure because the existing anchorage sheet piles and the shelf-type structure are not integrated into one structure.

Because the improvement cross-section produced by this method consists of different structure types, namely sheet piles and piles, it is possible that a phase difference could occur between structure types, different deformation behaviors occur, those structures affect each other, and as a result, an action occurs that was not taken into account in the currently-used standard design methods.

c) Standardizing the issue

When viewing this method from the point of focus shown in 4.1, a shelf-type structural unit is added to the existing structural unit of existing anchorage sheet piles. As a structural system, this is a composite one consisting of different structure types, namely anchorage sheet piles and a shelf-type structure.

The issue with this method as exemplified in b) is that as two structural units have different structure types, it is possible to estimate the behavior of each structural unit, but it is not possible to estimate the behavior of the structural system. This issue can be standardized as an "issue related to the behavior of structural systems where multiple structure types are in a composite state."

(2) Constructing a new piled pier that also serves as earth-retaining sections in front of existing sheet piles (S-23)

a) Overview of the method

Figure 4.4 shows a schematic diagram of a method for constructing a new piled pier that also serves as earth-retaining sections at the front face of existing sheet piles (S-23). This method involves installing a piled pier integrated with earth-retaining sheet piles at the front face of the existing sheet piles and having the piled pier function as a mooring facility, which changes the usage of the existing anchorage sheet piles to a revetment. Because gap-filling stones are installed between the newly installed piled pier that also serve as earth-retaining sections and the existing sheet piles, the existing sheet piles receive the passive earth pressure and therefore the resistance force increases.

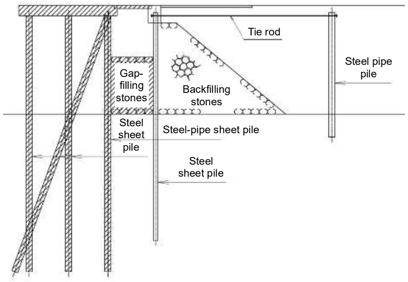


Figure 4.4 Schematic diagram of method S-23

b) Issues with the method

One example of a design issue related to this method is that in the event of an earthquake, there is a possibility that loads acting on the existing sheet piles, such as the active earth pressure, are transmitted through the gap-filling stones and an unexpected load is generated on the piled pier that also serves as earth-retaining sections.

When compared to the piled pier that also serves as earth-retaining sections at the front, the existing anchorage sheet piles have a structure that is likely to deform. These two structures are indirectly connected via the gap-filling stones, and in the event of an earthquake, the existing sheet piles may be displaced while the piled pier that also serves as earth-retaining sections at the front is relatively unlikely to be deformed, which fixed the gap-filling stones in place and suppresses displacement of the sheet piles. In other words, the gap-filling stones contribute a resistance force that suppresses displacement of the existing sheet piles, but at the same time, they may exert a reaction force to the resistance force on the piled pier that also serves as earth-retaining sections.

c) Standardizing the issue

When viewing this method from the point of focus shown in 4.1, a piled pier structural unit that also serves as earth-retaining sections that is newly installed at the front is added to an existing structural unit comprising existing anchorage sheet piles. As a structural system, this indirectly combines structures with different rigidities.

The issue with this method as exemplified in b) is that as two structural units have different rigidities, different deformation behavior occurs, making it impossible to estimate the behavior of the structural system. This issue can be standardized an "issue related to the behavior of structural systems that combine a rigid structure and a soft structure."

(3) Installing sheet piles at the front face of an existing piled pier and converting the existing piled pier to an anchorage (P-17)

a) Overview of the method

Figure 4.5 shows a schematic diagram of a method for installing sheet piles at the front face of an existing piled pier and converting the existing piled pier to an anchorage (P-17). This method involves installing new sheet piles at the front face of the existing piled pier and changing the existing pier pile to an anchorage, with the structure type of the existing mooring facility changing from a piled pier to a sheet-pile quaywall. Filling soil is placed in the space beneath the existing piled pier, and the new sheet piles resist the earth pressure due to the filling soil.

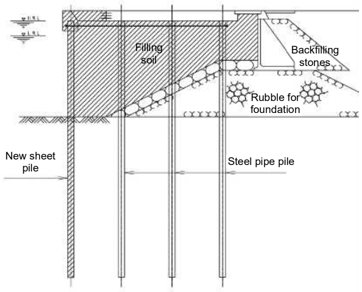


Figure 4.5 Schematic diagram of method P-17

b) Issues with the method

One example of an issue related to the design of this method is that when the sectional performances of the anchorages are not uniform, there is a possibility that the anchorages will behave differently to each other.

While the newly installed sheet piles on the front have uniform sectional performances, the sectional performances of existing pier piles serving as anchorages may become non-uniform due to corrosion of steel members because the existing pier piles have been in service for a certain period of time. If the cross-sections of the anchorages differ from each other, a difference in sectional performance in the face-line direction may occur, possibly causing some stress concentration.

c) Standardizing the issue

When viewing this method from the point of focus shown in 4.1, a structural unit of newly installed sheet piles on the front is added to an existing structural unit of the existing piled pier. As a structural system, this combines a new unit and an old unit.

The issue with this method as exemplified in b) is that as two structural units have new and old structures, there is a possibility that they possess different sectional performances, potentially making it impossible to exhibit the assumed performance as a structural system. This issue can be standardized as an "issue related to the behavior of structural systems where a new structure and an old structure are in a composite state."

(4) Installing sheet piles in front of existing sheet piles and integrating those sheet piles (S-16)

a) Overview of the method

Figure 4.6 shows a schematic diagram of a method for installing sheet piles in front of existing sheet piles to integrate those sheet piles (S-16). This method involves installing new sheet piles at the front face of the existing sheet piles to integrate those sheet piles, thereby enhancing the sectional performance of the front face sheet piles.

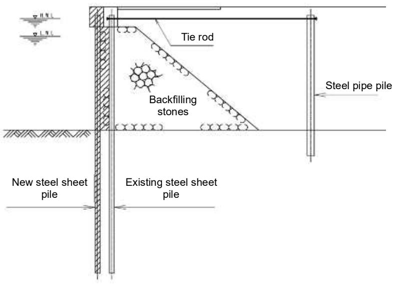


Figure 4.6 Schematic diagram of method S-16

b) Issues with the method

One example of a design issue related to this method is that when the acting earth pressure increases when deepening work, etc. is carried out, there is potential for the stress to concentrate only on one side of the integrated sheet piles.

Although the superstructure integrates the two sheet piles, the sheet piles themselves are not integrated because there is filling stone between them. In the case where the same load acts on these two sheet piles, the stress could concentrate on the sheet pile with a higher sectional performance unless those sheet piles have the same sectional performance. In addition, depending on the positional relationship between those sheet piles and the state of stress transmission due to the filling material, the stress acting on those sheet piles can change.

c) Standardizing the issue

When viewing this method from the point of focus shown in 4.1, as it is not possible to handle the structural units separately because the newly added sheet pile is integrated with the existing sheet pile, the existing sheet pile integrated with the new sheet pile is in such a state where the existing structural unit has been modified and the structural members are in a composite state. In terms of the structural system, there is no issue with the behavior between structural units because the structural system consists of a single structural unit.

The issue with this method as exemplified in b) is that the structural members in the structural unit have different sectional performances or they show different deformation behaviors depending on their arrangement. This issue can be standardized as an "issue related to the behavior of structural units where the existing structural members have been modified."

(5) Installing additional anchorages behind existing sheet piles (S-9)

a) Overview of the method

Figure 4.7 shows a schematic diagram of a method for installing additional anchorage behind existing sheet piles (S-9). This method involves installing additional anchorage piles, installing new tie rods between the seabed ground and existing tie rods, and increasing the support points for the sheet piles, thereby reducing generated sectional force.

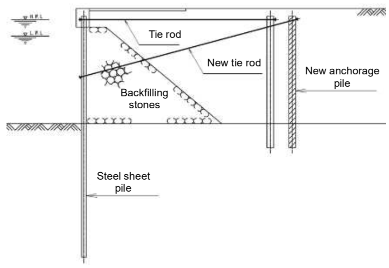


Figure 4.7 Schematic diagram of method S-9

b) Issues with the method

One example of a design issue related to this method is that if the acting earth pressure increases when deepening work, etc. is carried out, because the tension balance of the tie rods that act on the existing anchorage piles and newly installed anchorage piles changes, there is potential for the stress to concentrated on either the newly installed anchorage or the existing one.

In the case where the sectional performance differs between newly installed anchorages and existing ones, if the stress acting on the sheet piles changes, the stress may concentrate on the anchorages with higher sectional performance, possibly changing the tension balance of the tie rods. In addition, as the generated displacement of a sheet pile differs depending on the position of a newly installed tie rod, the stresses generated at the respective tie rod installation positions may differ from each other, possibly causing the stress to concentrate.

c) Standardizing the issue

When viewing this method from the point of focus shown in 4.1, the structure is in such a state where a newly installed anchorage structural unit is added to an existing anchorage sheet pile structural unit. In terms of a structural system, two structural units are connected to a single existing structural unit (front-face sheet pile), and two forces are acting on the existing structural unit.

The issue with this method as exemplified in b) is that because the balance of capabilities that can be exhibited changes due to the arrangement of structural units and the sectional performance, the stress concentrates on one spot. This issue can be standardized as an "issue related to parallel action of two or more structural units."

(6) Installing anchorages in addition to existing anchorage piles (S-13)

a) Overview of the method

Figure 4.8 shows a schematic diagram of a method for installing anchorages in addition to existing anchorage piles (S-13). This method involves installing additional anchorage piles behind the anchorage piles of the existing anchorage sheet piles and connecting the existing anchorage piles and the newly installed anchorage piles with tie rods to increase the resistance force exerted by the anchorage.

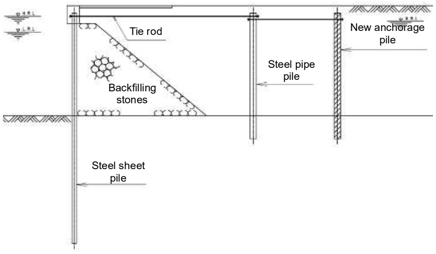


Figure 4.8 Schematic diagram of method S-13

b) Issues with the method

One example of a design issue related to this method is that when the acting earth pressure increases when deepening work, etc. is carried out, it is possible that either the existing anchorage piles or newly installed anchorage piles will not function.

In the case where the sectional performance differs between an existing anchorage pile and a newly installed anchorage pile, the stress may concentrate on the pile with a higher sectional performance and the other anchorage piles may not function, possibly preventing two anchorage piles from exhibiting their capabilities at the same time.

c) Standardizing the issue

When viewing this method from the point of focus shown in 4.1, the structure is in such a state where the structural unit of a newly installed anchorage is added to an existing anchorage sheet pile structural unit. As a structural system, another structural unit is connected to an existing structural unit (front face sheet pile) that is already connected to an existing structural unit (anchorage pile), and two linear forces are acting on the structural unit.

The issue with this method as exemplified in b) is that when the performances of structural units are combined in one direction, the balance of capabilities that can be exhibited changes due to the difference in sectional performance among structural units, which concentrates the stress. This issue can be standardized as an "issue related to the serial action of two or more structural units."

(7) Installing a new caisson in front of an existing caisson (G-26)

a) Overview of the method

Figure 4.9 shows a schematic diagram of installing a new caisson in front of an existing caisson (G-26). This method, by newly installing a caisson in front of the existing caisson and having the newly installed caisson function as a quaywall, the usage of the existing caisson is changed to a revetment. This method increases the resistance force of the existing caisson by installing gap-filling stones between the new caisson and the existing caisson.

b) Issues with the method

One example of a design issue related to this method is that in the event of an earthquake, there is a possibility that loads acting on the existing caisson, such as the active earth pressure, are transmitted through the gap-filling stones and an unexpected acting force is generated.

When a large earth pressure is applied in the event of an earthquake, the gap-filling stones make contribution as a resistance force against sliding or overturning of the existing caisson, but the reaction force to the resistance force may act on the newly installed caisson. When there is a sufficient distance between the existing caisson and the new caisson, the reaction force is unlikely to be transmitted to the new caisson. However, when the distance is short, the reaction force to the resistance force is highly likely to be indirectly transmitted via the gap-filling stones.

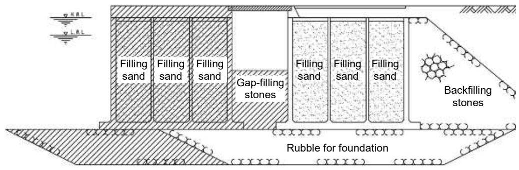


Figure 4.9 Schematic diagram of method G-26

c) Standardizing the issue

When viewing this method from the point of focus shown in 4.1, the structure is in such a state where a structural unit of newly installed caisson is added to an existing structural unit of existing caisson. As a structural system, structural units are indirectly connected.

The issue of this method as exemplified in b) is that when the structural units are arranged closely to each other, the behavior of each structural unit is transmitted. This issue can be standardized as an "issue in close arrangement of two or more structural units."

(8) Installing new anchorage sheet piles at the front face of existing sheet piles (S-18)

a) Overview of the method

Figure 4.10 shows a schematic diagram of a method for installing new sheet piles at the front face of sheet piles (S-18). This method involves installing new anchorage sheet piles at the front face of existing anchorage sheet piles to bear all the earth pressure that had been borne by the existing sheet piles.

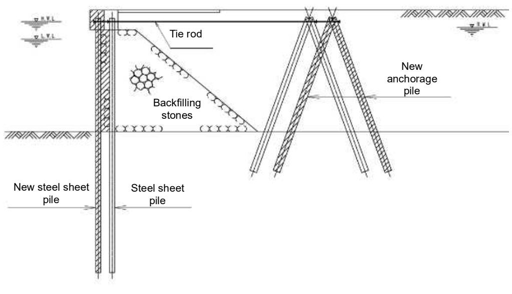


Figure 4.10 Schematic diagram of method S-18

b) Issues with the method

One example of a design issue related to this method is that in the event of an earthquake, there is a possibility that the existing coupled anchorage sheet pile, which is not considered in the structure's design, transfers some of the load to the newly installed coupled anchorage sheet piles.

Because a remaining existing sheet pile could provide an insufficient resistance force against the anticipated load in many cases, it may be significantly displaced when a great force acts on it in the event of an earthquake, etc., and at that point, local stress on the new sheet pile may be generated. In addition, in the event of an earthquake it is possible that the presence of the existing sheet pile may cause deformation behavior that differs from the behavior assumed when using a standard coupled anchorage sheet pile.

c) Standardizing the issue

When viewing this method from the point of focus shown in 4.1, the structure is in such a state where an existing coupled anchorage sheet pile structural unit is replaced with a new coupled anchorage sheet pile structural unit, and as the existing coupled anchorage sheet pile is not considered to be a resistance-side structural member in the structure's design, it serves as a remaining object. As for the structural system, it consists of a replacement structural unit and a remaining object.

The issue with this method as exemplified in b) is that a remaining object not considered as resistance in the structure's design adversely affects the structural system. This issue can be standardized as an "issue related to the influence of a remaining object."

4.3 Summary of standardized issues with improvement methods

Table 4.1 shows a list of standardized issues concerning improvement design. These issues have been extracted from the considered results of improvement methods shown in (1) to (8) in 4.2 as examples by using three points of focus as shown in Figure 4.2. These issues are those based on the following three points of focus.

I) Issues related to the composite state of structural systems
II) Issues related to the composite state of structural units
III) Issues related to the arrangement of structural units

These three issues are further broken down. As shown in Table 4.1, Issue I is classified into three types, Issue II is classified into one type, and Issue III is classified into four types, giving a total of eight standardized issues.

The standardized issues shown in Table 4.1 are matters that should be commonly checked in improvement design regardless of the improvement method employed. If a check of these items reveals any problems, examine appropriate measures to take on an issue-by-issue basis. In reality, however, a single method may include multiple standardized issues, and in such case, it is necessary to discuss measures that are commonly effective for them. When a designer makes an improvement design, Table 4.1 can be used to extract all important common issues that should be checked regardless of the type of improvement method. We have also confirmed whether classification according to the standardized issues shown in Table 4.1 can be applied to methods other than the representative improvement methods mentioned in 4.2. The result is provided at the lowermost level of the individual sheets that are summarized based on the improvement method in the Appendix. Note that standardized issues may not apply to some relatively simple structures such as replacement of backfill soil behind gravity-type quaywalls.

Table 4.1 Standardized issues related to improvement design

Issues based on point of focus	Standardized design issues	Details of issue
I. Issues related to the composite state of structural systems	I-1. Issue related to the behavior of structural systems where multiple structure types are in a composite state	As the structure type differs among multiple structural units, even if the behavior of each structure can be estimated, it is not possible to estimate the behavior of the structural system.
	I-2. Issue related to the behavior of structural systems that combine a rigid structure and a soft structure	As multiple structural units have different rigidities, different deformation behavior occurs and it is not possible to estimate the behavior of the structural system.
	I-3. Issue related to the behavior of structural systems where a new structure and an old structure are in a composite state	When the sectional performance differs between a new structural unit and an existing one, different deformation behavior occurs and it is not possible to estimate the behavior of the structural system.
II. Issues related to the composite state of structural units	II-1. Issue related to the behavior of structural units where the structural members are in a composite state	When the sectional performance differs between an existing member and a new member in a structural unit, different deformation behavior occurs and it is not possible to estimate the behavior of the structural unit.
III. Issues related to the arrangement of structural units	III-1. Issue related to parallel arrangement of structural units	When a resistance force is borne by multiple structural units, the equilibrium of the resistance force changes depending on the positional relationship among the structural units and their sectional performances.
	III-2. Issue related to serial arrangement of structural units	When a single resistance force is borne by multiple structural units, the resistance force that can be exerted changes depending on the difference in sectional performance among the structural units.
	III-3. Issue related to close arrangement of structural units	When multiple structural units are arranged close to each other, the behaviors of the respective structural units affect each other.
	III-4. Issue related to the influence of a remaining object	An existing structure that is not predicted to exert a resistance force affects the behaviors of the structural system and structural unit.

5. Basic concept of improvement design

5.1 Position and utilization method of basic concept of improvement design

(1) Position

Based on the standardized issues concerning improvement design presented in Chapter 4, we propose a basic concept of improvement design that designers should commonly recognize. Figure 5.1 shows the position and overview of the basic concept of improvement design.

Essentially, it consists of "how to proceed with performance assessment" (5.2), "the concept of performance assessment" (5.3), and "considering construction and maintenance" (5.4) (the area enclosed by the dotted line on the right side of Figure 5.1). This basic concept summarizes matters concerning improved cross-sections that tend to be complex in their cross-sectional structure, such as examination of structure plans, establishment of design methods, examination of construction methods, and matters to consider for maintenance, which designers should commonly recognize so that they can fairly assess multiple improvement methods. When conducting comprehensive examinations on these matters, as exemplified in Chapter 4, it is necessary to conduct an advanced and comprehensive performance assessment on how to comprehend the overall behavior of a structural system in which structural units with different behaviors are compounded and how to reflect this behavior in an appropriate design method. In this proposal, advanced and comprehensive assessment means "performance assessment." Note that the concept of the term "performance assessment" used here is different from a simple performance verification that compares given limit values and response values based on a given performance verification method (performance verification).

(2) Method of use

This section shows how to apply the proposal in actual improvement design work.

Actual improvement design, as shown in the flowchart on the left side of Figure 5.1, proceeds in a step-by-step manner through the following stages: 1) the basic policy discussion stage for discussing the overview; 2) method selection, including primary and secondary selections of improvement methods; 3) checking that the structure can be realized, via performance verification after structure calculation for selected multiple improvement methods; and 4) the final comparative examination stage for comprehensively reviewing the above factors as well as factors of economy, constructability, and maintenanceability (basic examination of improvement design). The basic concept of improvement design proposed in this chapter is for discussing multiple improvement methods from a common point of view at each stage of improvement design, and this is done repeatedly during the design stage (black arrows at the center of Figure 5.1). The points to note and basic concept concerning the basic discussion of improvement design are summarized in detail in documents prepared by Takano et al.[2)] We recommend that you refer to this proposal and those documents when proceeding with improvement design.

Because the time available for discussion and the required accuracy differ depending on the stage of the basic examination of improvement design, it is assumed that examination will proceed while selecting items to implement under the "basic concept of improvement design." However, at minimum, it is necessary to finish discussions about all the issues before making the final decision on the improvement method. The matters related to construction work and maintenance that were

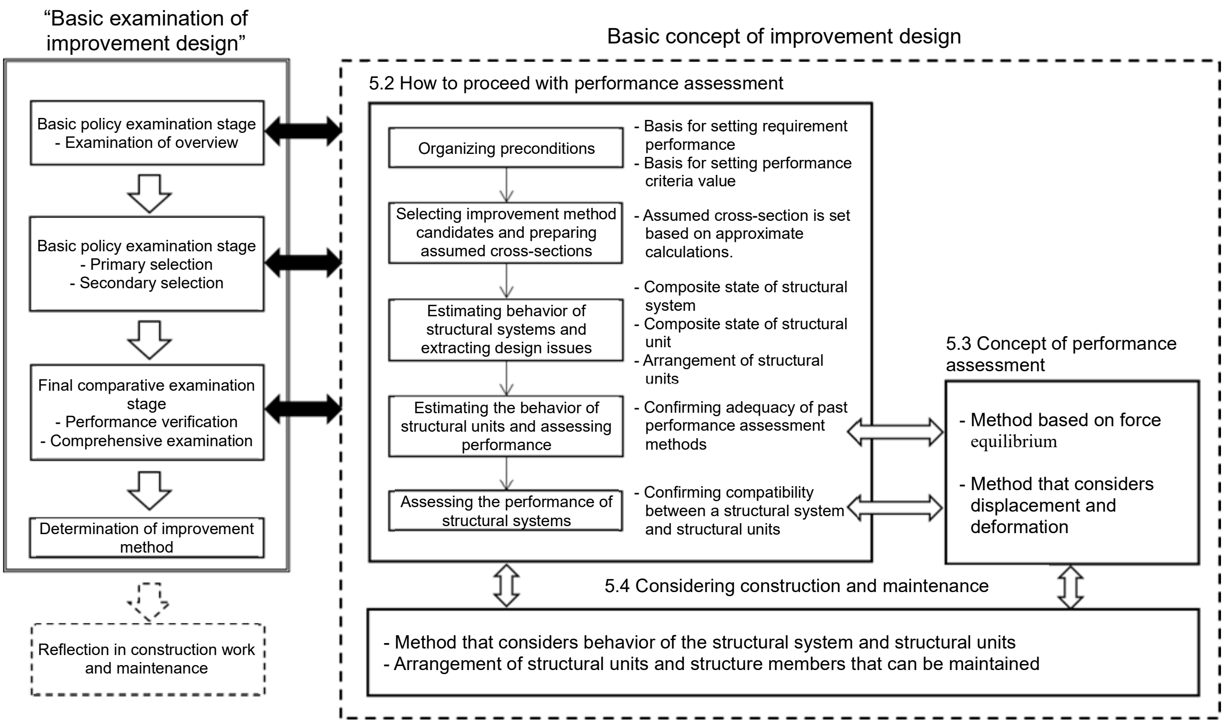


Figure 5.1 Position and overview of basic concept of improvement design

considered in the design stage need to be properly handed over and reflected in the construction and maintenance stages.

Note that as mentioned earlier, the concept of improvement design stated here is not intended for detailed design of each improvement method, but it can be referred to during detailed design. In terms of the need to examine individual cases, improvement design has something in common with developing new types of structures. The framework for the concept of improvement design stated below is considered to be in common to some degree with discussions on applying new types of structures.

5.2 How to proceed with improvement design

(1) Overview of improvement design flow

When formulating a design, including an improvement design, first it is necessary to organize the preconditions. Select appropriate improvement methods based on those preconditions, and prepare cross-sections on the assumption that specific methods will be used.

Then, estimate the behavior of the entire structure (structural system) and the mechanism of resistance force generation for the assumed cross-sections that have been prepared. Based on the estimation result, divide the structural system into structural units, with each exhibiting the function as a single structure. At the same time, focus on the combined state, arrangement and other conditions of the structural system and structural units, and extract the design issues.

Next, examine whether each structural unit has sufficient performance for the function required of it. Finally, assess the performance of the structural system by combining the behaviors and performance of the structural units. At this point, it is necessary to check whether the behavior of the structural system and the behaviors of structural units are consistent with each other. By proceeding with examinations while checking the consistency between the behavior of the structural system and the behaviors of the structural units in this manner, the adequacy of the performance assessment of the structural system is assured. If the consistency between the behavior of the structural system and the behaviors of the structural units is not assured, keep investigating until it is.

The flow of "improvement design as common understanding" is illustrated in the "How to proceed with performance assessment" section of Figure 5.1. The details of each discussion item in the improvement design flow are explained below.

(2) Organizing preconditions

Organizing preconditions is the core of design, not only for improvement design, but also for general designs. This is where matters including design purpose, phenomena and actions to set as performance assessment targets and performance requirements for them, and performance criteria values, which are digitized performance requirements, are set. Regarding performance requirements and performance criteria values, set values by considering the conditions unique to the structure to be designed, not by mechanically setting general details and values presented in relevant laws and regulations, guidelines, technical standards, and others. For this purpose, it is also necessary to organize the grounds for setting those performance requirements and performance criteria values. To prevent these items from differing among related parties, we recommend preparing and sharing a list table or other document. One example of a list table is presented in Table 5.1.

In addition to organizing performance requirements, etc., needless to say it is necessary to collect soil test results of the soil at the site as well as information on the existing structure, etc. Furthermore, in terms of improvement design, it is also necessary to examine how to handle the existing structure. Also, discuss issues such as whether the existing structure will be used as is or as a part of a structural unit and, when it is used, whether the current conditions (cross-sectional shape of the structure, intergrity of structural members, etc.) of the existing structure can be checked at a sufficient level of accuracy. If the existing structure will not be used, examine whether the structure can be removed or there is no choice but to leave it in place. If the existing structure is to be left, consider its influence on the behavior of the structural system and structural units.

The preconditions may differ slightly depending on the improvement method to be applied (handling of an existing structure, etc.). They may be reviewed as necessary depending

Table 5.1 Example of organizing preconditions

Target phenomenon		Setting	Performance requirement	Explanation of performance requirement	Verification item, verification method, and performance criteria value			Remarks
Self-weight, earth pressure (main action)	Persistent situation	To be set in accordance with the size of the dam body and condition of ground behind it	Serviceability	The degree of damage caused by the target phenomenon should remain within the range that the function of the corresponding quaywall can be continuously used without impairment.	Sliding of quaywall Overturning of quaywall Bearing capacity of foundation ground Circular slip failure of ground	L1 reliability design method (partial-factor design method)	Strength-action ratio of 1.0 or more	Set in accordance with page XX of Technical Standards and Commentaries for Port and Harbour Facilities in Japan.
L1 earthquake ground motion	Transientsituation	Return period: 75 years	Serviceability	The degree of damage caused by the target phenomenon should remain within the range that the function of the corresponding quaywall can be continuously used without impairment.	Sliding of quaywall Overturning of quaywall Bearing capacity of foundation ground	L1 reliability design method (partial-factor design method)	Strength-action ratio of 1.0 or more	Set in accordance with page XX of Technical Standards and Commentaries for Port and Harbour Facilities in Japan.
L2 earthquake ground motion	Accidental situation	XX earthquake and epicentral earthquake of magnitude 6.5 * Among largest possible earthquakes in the region, an earthquake that is considered to greatly affect the facility	Restorability	The degree of damage caused by the target phenomenon should stay small enough that the corresponding facility can accommodate XX-ton cargo vessels after XX days have passed since the target phenomenon occurred. The degree of damage caused by the target phenomenon should remain within the range where the original functions of the corresponding facility can be exhibited by XX months of restoration construction.	Deformation of face line	Dynamic response analysis (analysis code XX)	Horizontal displacement of XX cm or less Vertical displacement of XX cm or less	Set with reference to document XX (from past records, we judged that it would be possible to berth even with a displacement of XX cm). The allowable settlement is set in consideration of the region's tide level, use conditions, etc. (For details, refer to XX.)
⋮		⋮	⋮	⋮	⋮	⋮	⋮	⋮

on the progress of the project and the stage of improvement design. It is important to clarify the preconditions for each situation and carry out consistent examinations according to the preconditions.

(3) Selecting improvement method candidates and preparing assumed cross-sections

Select applicable construction methods and prepare assumed cross-sections based on the purpose of improvement and the organized preconditions. When selecting methods, focus on the stability improvement mechanism of the improvement method as shown in Chapter 3, and examine mainly on whether the stability improvement mechanism is effective, referring to the verification results for the existing facility, the purpose of improvement, and the preconditions. As there are cases where the mechanism is effective for the purpose of the improvement but the improvement effect cannot be exhibited due to a precondition (for example, the current condition of an existing structure and the soil properties at the site), it is important to efficiently extract improvement methods by comprehensively organizing the improvement methods presented in 3.5 in accordance with the preconditions. At this point, because the purpose is to examine the applicability of improvement methods, the specifications of assumed cross-sections are set based on approximate calculations, and it is sufficient to confirm that the cross-sections do not become extremely unreasonable.

(4) Estimating behavior of structural systems and extracting design issues

Based on the prepared assumed cross-sections, investigate how the structural system will behave. “Behavior” used here means not only the behavior when an external force acts, but also behaviors during construction, immediately after construction, and after a certain time has elapsed. If the structural system is relatively simple or similar to an existing structure type, the behavior can be estimated to some extent just with a desktop study. For a complicated structural system, however, it will be necessary to estimate behavior by conducting model experiments and numerical analysis. In model experiments and numerical analysis conducted at this stage, modeling of structure cross-sections can be simplified to some degree. On the other hand, for parameters such as soil properties, it is important to set broader experiment and numerical analysis conditions to check behavior patterns of the structural system in question that can occur under different conditions.

Keeping in mind the estimated behavior of the structural system, analyze the structural system and divide into structural units, and extract design issues at the same time. Specifically, with reference to the example presented in Chapter 4, examine which standardized issue is applicable by focusing on the composite state of the structural system, the composite state of structural units, the arrangement of structural units, etc., and reflect the examination in specific issues to work on.

(5) Estimating the behavior of structural units and assessing performance

As the behavior of single structural units appears to be relatively simple, there are many cases where they are discussed based on the conventional knowledge and design methods. However, for improvement design, the scale of structural units, types and magnitudes of acting loads, amounts of deformation in structural units, and other conditions may exceed the scope of conventional knowledge. Therefore, it is important to check the applicability of conventional knowledge and design methods. As such, keeping in mind the design issues extracted earlier, estimate the behavior of the structural unit and assess its performance.

When assessing the performance of a structural unit in improvement design or when preparing a performance assessment on a structural system to conduct later, it is necessary to estimate the behaviors of structural units and assess their performances at different stages of their behavior (stages where the behavior changes from the aspects of deformation amount and deformation mode) in advance. In particular, as the influence of adjacent structures and remaining objects varies greatly depending on the types and magnitudes of loads acting on the structural unit and the deformation condition of the structural unit, this requires careful attention.

(6) Assessing the performance of structural systems

Conduct performance assessments of structural systems based on the results of performance assessments of structural units. At this point, check that the assumed behavior of a structural system and the behavior estimated at the time of performance assessments on structural units are consistent with each other. At the same time, check the responses to the design issues extracted in advance, and adequately assess the performance.

For a structural system with a complicated structure type for which sufficient knowledge is not available, estimate the behavior of the structural system more carefully by finally checking its behavior through conducting an experiment using a large model and by estimating behaviors under various conditions using a numerical analysis method whose adequacy has been confirmed in a model experiment. When there is a possibility that the performance assessment results will be significantly different because of change in the behavioral pattern of the structural system under different conditions, investigate a measure to lead the behavior of the structural system to a specific behavior pattern by adjusting the functions of the structural units.

5.3 Concept of assessing the performance of improvement cross-sections

(1) Overview of the performance assessment method

Regarding general performance assessment methods, there are examination methods mainly based on force equilibrium and others that consider displacement and deformation of structures through using numerical analysis, etc. When the displacement of the structure is small or the structural system and structural units are relatively rigid, which leads to minor structural deformation, it is possible to apply the concept of force equilibrium. However, when the displacement and deformation of a structure is large, because the influence of the resistance force of the ground and the adjacent structure greatly changes due to displacement and deformation, it is dangerous to assess performance using only the equilibrium of forces. Regarding behavior in the event of an earthquake, when the vibration characteristics differ between structural units, it is difficult to check their influence only by simple force equilibrium. In such cases, it is necessary to use numerical analysis, etc. to conduct performance assessment that considers the displacement and deformation of the structure.

In actual practice, the general procedures are as follows: at first, set up a temporary structure cross-section using the force equilibrium method, and assess its performance in cases where the displacement or deformation of the structure is small; then, model the cross-section, and use numerical analysis, etc. to assess the performance in cases where displacement or deformation is large and in the event of an earthquake. The characteristics of those methods are explained simply below. Note that as the description of the performance assessment method used here has something in common with the performance assessment for structural systems and that for structural units, the term “structure” is used in this section as a collective term for structural systems and structural units.

(2) Method based mainly on force equilibrium

Many conventional performance assessment methods are considered to be based mainly on force equilibrium. These methods involve assessing the performance of a structure by the equilibrium of forces acting on the structure in a stationary state. However, in force calculation, many methods employ values obtained that take into account the influence of displacement and deformation of the structure, and therefore those methods do not completely ignore the displacement and deformation of the structure and ground.

One issue with the methods based on force equilibrium is that as a precondition for force calculation, the behavior of the structure is implicitly assumed. For a general structure, the force calculation method is considered to have been established to produce a design on the safe side, but for a complicated structure such as a structure cross-section after improvement, it is unclear whether such a method is suitable. Therefore, when assessing the performance of a structure by a method based on force equilibrium, it is best to check whether the condition of possible displacement and deformation of a structure is generally consistent with the conditions considered when calculating the forces.

On the other hand, the performance assessment based on force equilibrium has the advantage of being relatively easy to implement. For this reason, the method is very useful in setting up temporary improvement cross-sections and making rough estimates. Even for a complicated structure, by organizing possible behavior patterns and assessing performance using a suitable method for each case, it is still possible to assess performance with a method based on force equilibrium to a certain degree of accuracy. In addition, by accumulating knowledge about the structure’s cross-section after improvement, it is possible to enhance the accuracy of the assessment, which is expected to lead to the establishment of a simple design method.

(3) How to consider displacement and deformation of a structure

Numerical analysis, etc. are generally used to consider the displacement and deformation of a structure. For static phenomena, available methods include push-over analysis, and for earthquakes, etc. available methods include dynamic response analysis. Using these methods makes it possible to check the behavior of a structure and assess performance corresponding to the stages of behavior. On the other hand, due to using numerical analysis, etc., those methods are usually more difficult than methods based on force equilibrium.

When using any of these methods, it is necessary to carefully verify the adequacy of the numerical analysis method, etc. to be used. Unless a numerical analysis method that can appropriately express the behavior of the target structure for examination is used, the obtained result cannot be trusted. As such, it is necessary to calibrate (check the method for modeling the cross-section, method for determining various parameters, etc.) the numerical analysis method by, for example, conducting a model experiment in advance. For ordinary types of construction, a certain degree of accuracy is considered to be guaranteed based on past cases, but for complex structures such as structural cross-sections after improvement, as well as cases where an adjacent structure may exert a strong influence, since the number of cases examining the suitability of numerical analysis methods is small, more careful examination is required.

In addition, when conducting numerical analysis, etc., it is also necessary to verify the stability of the results. A slight change in the arrangement of the structure or the ground constant could significantly affect the behavior of the structure obtained as an analysis result. Failing to fully consider the influence of the construction accuracy and the accuracy of ground survey may produce an erroneous assessment. An effective way to counter this issue is to investigate the sensitivities of the parameters for behavior of the structure when conducting the numerical analysis by changing various parameters in the feasible range. This will make it possible to improve the design’s reliability by setting the necessary construction accuracy or implementing design measures to create a structure that will behave in certain ways without fail, in accordance with the investigation results.

5.4 Considering construction and maintenance

As the construction method and the behaviors of the structural system and structural units are closely related to each other, it is necessary to conduct a schematic examination of the construction method from the beginning of the improvement design. In particular, in composite structural units that employ old and new members, it is imperative to consider how to construct the connection between them and reflect the considerations in the performance assessment of the structural units. Furthermore, in a structural system where structural units are arranged adjacent to each other, it is necessary to carefully study the method to avoid causing problems attributable to adjacent construction, assess the performance by considering in advance the influence of the construction, or take other suitable measures. As the force transmission condition between structural units is also considered to be greatly affected by the method, be sure to pay attention to this issue. Improvement design needs to proceed with confirmation that there is a method that can realize the assumptions in design. For example: a force is constantly and evenly distributed to structural units that are arranged in parallel and have the same function; and the force transmission condition via a filling material or improved ground match the contact condition between the filling material/improved ground and a structure in the actual constructed condition. In addition, when using a conventional performance assessment method as an aid, confirm that the assumed construction method suits the performance assessment method (the construction principle is similar). Make sure to confirm that no change will be made to the assumed deformation during or immediately after construction.

Regarding maintenance as well, as with the construction method, it is crucial to schematically examine the maintenance method from the beginning of improvement design. As the structure's cross-section takes a complex form after improvement, the structural units and structural members need to be arranged so that appropriate maintenance can be carried out. For structural parts that are difficult to maintain, consider, for example, employing a structure that does not require measures such as repair and reinforcement during the work life. It is also important to examine the maintenance plan from the viewpoint of preserving various design assumptions during the work life.

6. Closing remarks

In this study, we presented the following two concepts as solutions to problems with improvement design as it is currently implemented.

For the first concept, we presented the basic concept concerning selection of improvement methods by exhaustively extracting the conventional improvement methods for existing mooring facilities and classifying and organizing them by stability improvement mechanism. In Chapter 2, we organized the overviews of improvement design cases that have been used in extracting construction methods. In 3.2 to 3.4, we summarized the stability improvement mechanisms by structure type, and in 3.5, we presented the basic concept underlying selection of improvement methods.

For the second concept, we presented the basic concept of improvement design that designers should commonly recognize based on the issues common to improvement methods. In Chapter 4, we summarized the points of focus for extracting the issues with improvement methods and the standardized issues derived from them, and in Chapter 5, we summarized the procedures for assessing improvement methods from a common point of view, the concept of assessment, and matters to consider based on these issues so that even a new improvement method can be fairly assessed.

Regarding the materials on which the above two concepts are based, the improvement methods for structure types, their stability improvement mechanisms, and their standardized issues are summarized in the Appendix.

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Appendix (available in Japanese only)