Guidelines for structural intervention of existing concrete structures using cement-based materials

March, 2018

Japan Society of Civil Engineers

Foreword

Concrete structures constitute many social infrastructures, and their required functionality and performance change with the times. Take transportation infrastructures for example. They have seen greater increases in traffic volume and vehicle weight than anticipated when they were originally constructed. What needs to be considered with respect to the residual risk of load exceedance and what is required in terms of the residual performance to be achieved have changed as well with changes in the social structure. That is why actual concrete structures experience phenomena that could not be imagined when they were designed.

Keeping social infrastructures in good shape for a long time is a social demand imposed on engineers. Upgrading these infrastructures costs society massive sums of money, and replacing them is often extremely difficult. This is what makes them “social infrastructures”. The purpose of these guidelines is to meet the needs of the times by repairing and strengthening structures constructed in the past while keeping them in service. It is also effective and, at times, necessary to avoid future potential risks proactively for structures that have yet to suffer damage or degradation. In the design and construction of new structures, options should be made available in the context of standards to reduce the life cycle cost by including intervention in the original maintenance plan, as seen with periodical repainting of steel structures and periodical replacement of aircraft parts.

The Concrete Committee has been continuously conducting research and studies on civil engineering technology concerning concrete structures. We went ahead of the times instigating research and studies on measures for the degradation of social infrastructures, an issue that is now receiving wider social recognition. The standard specifications for concrete structures regarding maintenance, whose first edition was established in 2001, were the Japan Society of Civil Engineers’ first technical recommendations related to maintenance and repair. In the 1990s, the Working Group on Retrofit Design of Concrete Structures was created under the Subcommittee on Revision of Standard Specification of JSCE's Concrete Committee, and “Concrete Library 95, Guidelines for Retrofit of Concrete Structures, Draft, 1999.9” was published in 1999. The guidelines were the first to have ever been published by JSCE in connection with strengthening. They have been continuously in use as a technical document that discusses the methods of strengthening in an organized manner.

In response to the technical advances made after the publication of “Concrete Library 95, Guidelines for Retrofit of Concrete Structures, Draft, 1999.9”, on the other hand, there was a growing call for their revision. By revising these guidelines, we have created this concrete library, “Guidelines for Structural Intervention of Existing Concrete Structures Using Cement-Based Materials”, which focuses on the overlaying and jacketing methods using cement-based materials among the strengthening methods covered by the above-mentioned document and reflects the latest knowledge. The guideline title has been changed from “Guidelines for Retrofit” to “Guidelines for Structural Intervention” because the terms “repair” and “strengthening” have taken on different definitions as well as because of changes of the times. I expect that the new guidelines will be used as an informative technical document in advancing more rational utilization of structural intervention methods using cement-based materials and promote further development of structural intervention methods that are still in a state of evolution.

March 2018

Concrete Committee of Japan Society of Civil Engineers
Koichi MAEKAWA, Chairman

Preface

It has been quite a while since intense discussions began on the maintenance and repair of degraded or damaged social infrastructures, and the Concrete Committee launched full-scale efforts to address this issue as early as in the 1990s. As part of the efforts, the committee published “Concrete Library 95, Guidelines for Retrofit of Concrete Structures, Draft, 1999.9” in 1999 as its first strengthening-related guidelines. The guidelines provided an overview of the strengthening methods available at the time and described the strengthening design methods for the technically established external cable method, external bonding method, overlaying method and jacketing method. They have been selling well for a long time since its publication in part because there were no similar guidelines. As technology advanced, however, the need arose to update their contents. In 2000, the Concrete Committee published “Concrete Library 101, Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets, 2000.7” regarding the FRP external bonding method and jacketing method covered in “Guidelines for Retrofit of Concrete Structures, Draft”. After that, the Committee on Hybrid Structures published “Hybrid Structure Series 09, Guidelines for Repair and Strengthening of Structures using Externally Bonded FRP, JSCE, 2018” in 2018, reflecting the latest technology. With respect to the overlaying and jacketing methods using cement-based materials, on the other hand, there had been no move to update the guidelines until the Subcommittee on Structural Intervention of Existing Structures using Cement-based Materials was set up in December 2016. This subcommittee was established by the Japan Society of Civil Engineers, on the request of a group of 27 construction companies and associations utilizing the overlaying method led by Nara Construction Co., Ltd., for the purpose of creating guidelines covering the latest knowledge. The subcommittee consists of experts from the private sector, government and academia and 47 members and executive members from the entrusting companies. The subcommittee has three internal working groups that are in charge of top-surface overlaying, bottom-surface overlaying and jacketing covered in the guidelines, respectively, as well as a common working group that deals with the items common to all these methods.

Titled “Guidelines for Structural Intervention of Existing Concrete Structures Using Cement-Based Materials”, the guidelines cover the overlaying and jacketing methods using mortar including polymer cementitious mortar (PCM) and concrete and consist of the Common, Top-Surface Overlaying, Bottom-Surface Overlaying and Jacketing sections. In addition, “Standard for Intervention of Structures” has been established as a common standard for these guidelines and “Hybrid Structure Series 09, Guidelines for Repair and Strengthening of Structures using Externally Bonded FRP, JSCE, 2018” drafted at the same time by the Committee on Hybrid Structures. This standard document is expected to serve as a common standard for other intervention methods for concrete structures and hybrid structures. Furthermore, appendixes have been created to describe the state-of-the-art of the three construction methods covered by the guidelines, typical examples of construction work and design examples including specific performance verifications.

The new guidelines are based on the advances in technology made since the publication of “Concrete Library 95, Guidelines for Retrofit of Concrete Structures, Draft, 1999.9” in 1999. Considering these technological advances, the features of the guidelines can be summarized as follows: ① Support of new materials (e.g., PCM); ② improvement in contents based on the track record of application (e.g., specifications for ensuring integrity in top-surface overlaying); ③ introduction of new verification methods (e.g., verifications of crack width and peeling in bottom-surface overlaying); and ④ response to the revision of higher-level standard specifications for concrete structures. As for the revision of standard specifications for concrete structures, the introduction of "Standard Specifications for Concrete Structures-2001, Maintenance" was the biggest change. The intervention methods using cement-based materials that are covered herein are basically intended to restore or improve mechanical performance. Since these methods are also expected to improve durability, however, the guidelines take this into consideration as well.

Lastly, I would like to extend my gratitude to the subcommittee members and executive members who were instrumental in the creation of the guidelines. Special thanks go to Secretary General Takumi Shimomura and Working Group Coordinators Shigehiko Saito, Mutsumi Mizukoshi, Hitoshi Furuuchi and Takeshi Maki, who serve as members of the executive meeting, as well as to Secretaries Kouichi Satoh, Hikotsugu Hyodo, Hiroshi Nakai and Akira Kobayashi. The guidelines feature a body of knowledge that is at the cutting edge on a global level, and I expect them to be used as guidelines useful for actual work not only in Japan but in the rest of the world through appropriate efforts such as making them international standards. Also, the intervention methods using cement-based materials are still in a state of technological evolution, and I look forward to seeing the contents of the guidelines updated continuously.

March 2018

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Guidelines for Structural Intervention of Existing Concrete Structures Using Cement-Based Materials

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Standard for Intervention of Structures

CHAPTER 1 GENERAL PROVISIONS

1.1 Scope

This standard for intervention of structures defines the intervention requirements that are common to various types of structure.

[Commentary] In order for a structure to continue to meet specified performance requirements throughout its design service life, appropriate maintenance is required after the structure is put into service, in addition to appropriate design and proper construction. Maintenance of a structure involves evaluating its performance based on information obtained through inspections and, if restoration or improvement of performance is judged to be necessary, undertaking necessary intervention work. This standard defines the requirements common to various intervention methods that should be met in the intervention of structures composed of steel and concrete.

When a structure is repaired, it is necessary not only to apply various repair methods, such as crack repair, patching repair, surface treatment, replacement of missing parts and addition of parts, for the purpose of restoring its performance to the originally specified level, but also to reduce the effects of those factors that cause the deterioration of the performance. In the strengthening of a structure, it is necessary to apply various strengthening methods, such as addition of sections, replacement and addition of members, addition of support points, addition of reinforcing materials and introduction of stress, so that the specified performance requirements are met regardless of the initial performance level, as well as to check that the strengthened structure meets the specified performance requirements by means of an appropriate verification method.

While many intervention methods have been proposed and put into practical use in the past, it has been confirmed that some of them proved not to be as effective as expected or quickly became ineffective. The reasons for this include lack of sufficient understanding of properties of materials used, the structure not designed to ensure performance restoration or improvement, absence of the required construction environment and lack of understanding of causes of performance degradation. It is necessary to thoroughly verify and keep records of whether the applied intervention method is as effective as expected.

This standard sets forth the common requirements regarding the intervention planning, design, construction and post-intervention maintenance that apply irrespective of the intervention method used. In applying a specific intervention method, it is assumed that guidelines that concretely specify the intervention method are referenced in addition to the following related standards published by the Japan Society of Civil Engineers.

Standard Specifications for Concrete Structures-2012, General Principles, Standard Specifications for Concrete Structures-2017, Design, Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Specifications for Concrete Structures-2013, Maintenance

Standard Specifications for Steel and Composite Structures-2016, I General Provision, II Structural Planning, III Design, Standard Specifications for Steel and Composite Structures-2016, Constructions, Standard Specifications for Steel and Composite Structures-2016, Maintenance

Standard Specifications for Hybrid Structures-2014, General Principles, Standard Specifications for

Hybrid Structures-2014, Design, Standard Specifications for Hybrid Structures-2014, Constructions, Standard Specifications for Hybrid Structures-2014, Maintenance

Guidelines for Structural Intervention of Existing Concrete Structures Using Cement-Based Materials-2018

Hybrid Structure Series 09, Guidelines for Repair and Strengthening of Structures using Externally Bonded FRP, JSCE, 2018

1.2 Terms and Definitions

The following terms are defined for use in this standard.

Design service life: The designed period during which a structure or members fulfill the required performance.

Repair: An act of restoring the mechanical performance of a structure to the level it possessed when put into service. Or a measure aimed at eliminating the impact on a third party or restoring or improving the appearance or deterioration resistance of materials.

Strengthening: An act of improving the mechanical performance of a structure to a level higher than that it possessed when put into service.

CHAPTER 2 FUNDAMENTALS OF INTERVENTION

2.1 General

(1) Intervention of a structure must be performed, with the performance to be restored or improved identified, so that the structure after intervention fulfills the required performance for a specified period of time.

(2) Intervention shall involve creating a plan that covers the processes from intervention design and construction to post-intervention maintenance.

(3) Intervention shall be performed based on the relationship between the remaining service life and the period during which the performance is considered possible to sustain, taking into consideration the cost benefit, life cycle cost, etc.

[Commentary] (1) Intervention of a structure requires that the performance of the target structure be evaluated by means of an appropriate method and that the performance to be restored or improved and the level of restoration or improvement be identified. It is also necessary to clarify the period of time for which the effect of the applied intervention method is to last, in order to ensure that the structure after intervention continues to fulfill the required performance during the remaining design service life. Without appropriate intervention based on the performance evaluation of the structure, measures tend to be ad hoc, potentially resulting in the required performance restoration or improvement failing to be achieved or the structure after intervention experiencing a degradation in performance soon.

In order for the structure after intervention to fulfill the required performance during the specified design service life, it is important to gain sufficient understanding of properties of materials used, design the structure so as to ensure performance restoration or improvement and secure the required construction environment, as well as to appropriately understand causes of performance degradation and reduce their effects. When selecting materials to be used, it is necessary to take into consideration the service life of bonding materials, adhesive in particular and the applicable environmental conditions among other things. If the required construction environment including temperature and humidity is not secured when intervention is performed, the expected effect cannot be obtained, potentially preventing the structure from exhibiting the required performance or leading to an early degradation in performance. Besides, in the case of intervention of a structure that has undergone a degradation in materials, the structure will likely suffer a degradation again soon if the removal of the degraded parts or the identification of the cause of the degradation is not done appropriately. It is therefore necessary to clarify the period of time for which the structure after intervention is to sustain its performance and to implement appropriate maintenance.

(2) The intervention plan needs to be formulated after reviewing the structural and construction plans in the design phase to ensure the performance restoration or improvement while at the same time reviewing the maintenance plan for the structure after intervention to ensure that the effect of intervention lasts for a specified period of time.

(3) The performance evaluation of an existing structure, which is performed prior to intervention, reveals the safety margin of the limit value for each performance requirement identified during the inspection of the structure and the period of time for which the performance is to be sustained. If the design service life of the structure after intervention is not clarified in the post-intervention performance evaluation, unexpected intervention work may need to be repeated in the design

service life, possibly resulting in an increase in the life cycle cost. It is therefore important to perform intervention in such a way as to minimize the life cycle cost, based on the relationship between the remaining service life of the facility to which the intervention target structure belongs and the period during which the structure after intervention is to sustain its performance. Particularly, in the selection of the intervention method, the cost benefit and life cycle cost of each candidate method should be considered.

2.2 Intervention Plan

(1) When the intervention plan is formulated, the current condition of the intervention target structure must be taken into consideration.

(2) When the intervention plan is formulated, the intervention design, construction and post-intervention maintenance must be taken into consideration comprehensively.

(3) An appropriate system must be put in place to ensure the implementation of intervention.

[Commentary] (1) Generally, structural intervention is performed while the existing structure is kept in service. For this reason, there are often strict restrictions on the study of the existing structure and the intervention construction. It is important to take into full consideration the working environment and safety of workers among other things, as well as to formulate a meticulous plan to ensure that the structure after intervention fulfills the required performance. In the inspection conducted prior to intervention, therefore, it is necessary to appropriately grasp the current condition of the target structure.

To perform intervention, a detailed study of the existing structure needs to be planned in order to obtain the information necessary for intervention design and construction review. Particularly, the intervention method to be applied shall be selected through comprehensive judgment based on results of the study of the existing structure.

(2) The intervention plan shall be formulated so as to ensure that the structure after intervention fulfills the required performance, by comprehensively reviewing the structural plan, construction plan and post-intervention maintenance plan in the design phase, taking into consideration the structure's importance, design service life, service conditions, construction method, quality control and inspection status, maintainability, etc. Also, to ensure rational intervention, this plan needs to be linked with the maintenance plan of the target structure.

(3) Since intervention of a structure is expected to face strict restrictions in many aspects including the construction period, ensuring the implementation of intervention requires that an appropriate system for implementation be established by securing the necessary organization, personnel, materials, budget, etc.

2.3 Flow of Intervention

(1) Intervention of a structure shall be performed, based on the formulated intervention plan, through the study of the existing intervention target structure, intervention design, construction, recording and post-intervention maintenance.

(2) In the study of the existing intervention target structure, the information necessary for rational intervention design and steady construction shall be obtained.

(3) In the intervention design, it shall be verified by means of an appropriate method that the structure after intervention fulfills the required performance throughout the specified period of time.

(4) The construction for intervention shall be conducted so as to ensure that the performance specified in the design is achieved.

(5) To perform the maintenance of the structure after intervention effectively, information regarding the conducted study, design and construction shall be recorded.

(6) Appropriate maintenance shall be performed to ensure that the structure after intervention sustains the required performance for the specified period of time.

[Commentary] (1) Intervention of a structure shall be performed, based on the formulated intervention plan, through the study of the existing structure, intervention design, performance verification and construction for intervention, as shown in Fig. C2.3.1. With intervention-related information recorded, it shall then proceed to post-intervention maintenance.

(2) In performing intervention, the information necessary for intervention design and construction shall be obtained by conducting a detailed study or by other appropriate means. In the intervention design, the selection of the method and the determination of structural details require information such as the action on the existing structure (load and environmental conditions), boundary conditions (relationship with adjacent structures and members and deformed spatial distribution) and the condition of the materials in the existing structure. In the construction for intervention, the determination of the construction method and processes requires information such as the environmental conditions of the existing structure, the construction space, the temporary material storage site and the state of service.

(3) In the intervention design, a structural plan including the selection of the method shall be formulated and structural details shall be determined to ensure that the structure after intervention fulfills the specified performance. Also, a performance verification shall be conducted to make sure that the intervention target performance is restored or improved and that the structure fulfills the specified performance not only immediately after the intervention but throughout the remaining design service life. In intervention, it is necessary to clarify the properties and performance expected of the materials, parts and members to be newly bonded, as well as the level of integrity to be used as a design condition after bonding.

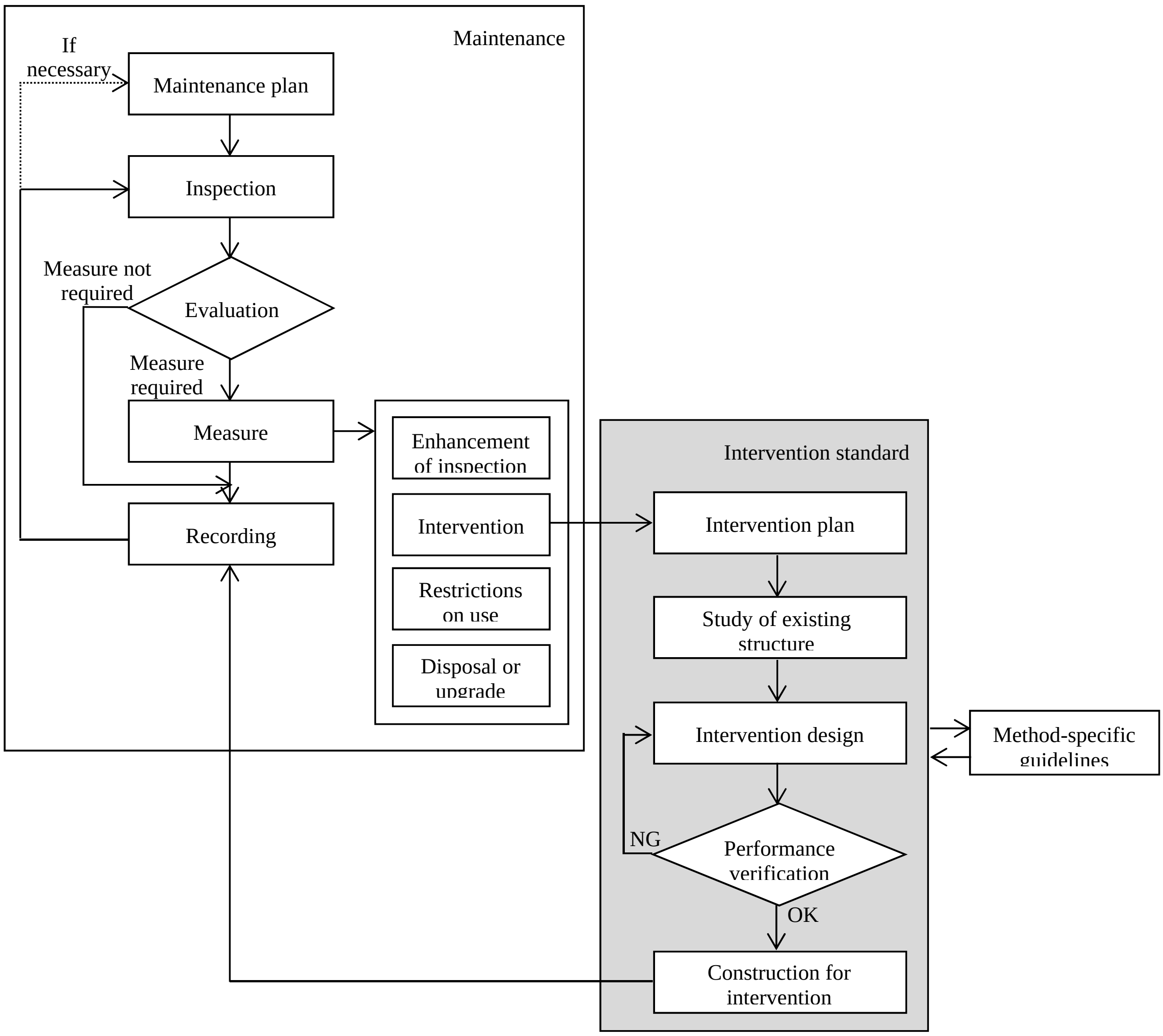


Fig. C2.3.1 Flow of intervention

(4) In the construction for intervention, an appropriate construction plan shall be created and necessary inspections shall be conducted in each stage of the construction work so that the structure after intervention can exhibit the designed performance. In intervention, the bonding surfaces of the existing structure need to be processed appropriately for bonding reinforcing materials, parts and members. Bonding materials are often susceptible to the effects of temperature and humidity, and special care needs to be taken about the environmental conditions during construction.

(5) It is necessary to appropriately record the results of the study of the existing structure conducted during intervention and the information related to design and construction, as well as to hand over these records for post-intervention maintenance. After intervention is complete, in

particular, the existing parts are often difficult to evaluate from the changes in appearance and, therefore, it is necessary to appropriately record the information about the changes in the existing parts, their treatment, etc. Also, depending on the bonding material used for intervention, the environmental conditions during construction may need to be recorded.

(6) It is necessary to perform appropriate maintenance so that the structure after intervention sustains its performance for the specified period of time. During the inspection, it shall be checked that the specified level of integrity exists between the existing parts and repaired or strengthened parts, with the focus on the condition of the bonded parts. Depending on the materials used for intervention, periodical treatment such as surface protection may be needed. Also, if the repaired or strengthened structure has a change, it is necessary to pay attention to whether the change is not progressing, whether the cause of the change is appropriately grasped, etc.

CHAPTER 3　INTERVENTION DESIGN

3.1 General

In the intervention design, a rational structural plan and structural details must be established, based on the results of the study of the existing structure, so that the structure after intervention fulfills the required performance, and it must be verified by means of an appropriate method that the required performance is fulfilled throughout a specified period of time.

[Commentary]　In the intervention design, an intervention method shall be selected that ensures the required performance restoration or improvement and, after a structural plan and structural details are established that are appropriate for the current condition of the existing structure, it shall be verified by means of an appropriate method that the structure after intervention fulfills the required performance throughout a specified period of time. Before conducting the intervention design, a detailed study of the target existing structure shall be done to obtain the information necessary for the design. Particularly, if a change is present, it is necessary to grasp its degree and extent while at the same time estimating its impact over time during the remaining design service life and giving due consideration in the design.

In most cases, intervention of an existing structure in service is performed under strict restrictions. A rational structural plan shall be formulated, giving consideration to construction and post-intervention maintenance, to ensure that the structure after intervention fulfills the required performance.

In the performance verification of the structure after intervention, it is necessary to check that the structure after intervention will fulfill the required performance throughout the design service life, by means of a verification method that allows the impact of intervention on the members or structure to be taken into consideration appropriately, based on the preconditions for the applied intervention method.

3.2 Study of the Existing Structure

(1) The condition of the existing intervention target structure must be studied in detail.

(2) The restrictions on the existing structure must be studied.

[Commentary]　(1) In the study of the existing structure, the condition of the intervention target structure shall be grasped in detail and the information necessary for selecting applicable intervention methods shall be obtained by studying the causes of performance degradation. In the intervention design and construction, it is necessary to grasp the surface condition of the parts subject to intervention, the properties of the materials in the existing structure, the actions on and environmental conditions of the existing structure and, if any change is present, its type, spatial distribution, etc. If the intervention history is available, the design and construction records, the current condition and others shall be studied and the results shall be taken into consideration when selecting applicable intervention methods.

Table C3.2.1 Examples of restrictions

Category	Restrictions
Temporal restrictions	Construction time, service status (road closure, traffic control)
Spatial restrictions	Structural dimensions, construction space, adjacent structures, temporary storage site
Action-induced restrictions	Traffic load, initial stress, adjacent structures

(2) In the study of the existing structure, it is necessary to grasp the restrictions to be imposed when considering the intervention design and construction. As shown in Table C3.2.1, there are different categories of restrictions, such as temporal restrictions, spatial restrictions and action-induced restrictions. The construction time depends on the service status of the existing structure, such as a road or lane being closed or a railway being closed outside business hours or being out of service, which significantly impacts the selection of the intervention method and the establishment of the structural plan.

With regard to spatial restrictions, it is necessary to secure a construction space for the structure and a temporary storage site for materials and grasp the impact of adjacent structures among other things. Also, conducting the intervention design rationally requires grasping the history of the actions currently and previously exerted on the existing structure. Equally important are giving consideration to the surrounding environment during the intervention work and studying the suitability of the structure after intervention to the landscape.

3.3 Structural Plan

(1) The intervention method shall be selected and structural details shall be determined, taking into consideration the structural properties, materials, construction method, maintenance method, economy, etc., so as to ensure that the structure after intervention fulfills the required performance.

(2) Consideration must be given to ensure that the structure after intervention sustains the required levels of safety, serviceability and restorability throughout the design service life.

(3) Such factors as the restrictions on construction, construction timing and construction period shall be taken into consideration.

(4) Consideration must be given to ensure that post-intervention maintenance is performed appropriately, factoring in the structure's importance, design service life, service conditions, environmental conditions, maintainability, etc.

(5) The safety factor to be used for verification must be established appropriately according to the current conditions of the existing structure and the structure after intervention.

[Commentary] (1) and (2) For intervention of a structure, it is necessary to select an intervention method that ensures the required performance restoration or improvement. Also, structural details shall be determined taking into full consideration the characteristics of the selected intervention method and the preconditions for use of the method.

Repair of a structure shall be performed for the purpose of restoring its performance to a specified level so as to reduce the effects of the factors that cause performance degradation. Typically, repair is aimed at:

- Repairing changes in members such as cracks, deformation and corrosion
- Replenishing members and parts
- Removing degraded parts
- Removing degradation factors
- Reducing the effects of the factors that cause performance degradation

Strengthening of a structure shall be performed for the purpose of improving the performance of that structure to a level higher than that it possessed when put into service so as to ensure that the strengthened structure fulfills the required performance. The general strengthening methods include:

- Replacement of members
- Addition of sections
- Addition of members
- Addition of support points
- Addition of reinforcing materials

Table C3.3.1　Examples of intervention methods for the purposes of performance restoration and improvement

Purpose of intervention	Means of intervention	Intervention method
Maintenance or improvement of mechanical resistance	Replacement of members	Concrete repaving method High-tension bolt replacement method
	Addition of sections Addition of reinforcing materials	Mortar overlaying Concrete overlaying Mortar jacketing Concrete jacketing Steel plate jacketing FRP jacketing Plate splicing method/steel plate external bonding method FRP external bonding method
	Addition of members	Girder addition method Wall addition method Brace addition method
	Addition of support points	Support point addition method
	Introduction of stress	Prestressing introduction method
Maintenance or improvement of material degradation resistance	Surface protection of members	Surface covering method/coating method Surface impregnation method Patching repair method
	Electrochemical corrosion control	Electric corrosion prevention method Desalination method Realkalization method Electrodeposition method
	Sealing of cracks and suppression of progress of cracks	Injection method Filling method Stop-hole method

- Introduction of stress

For intervention of a structure, an appropriate method shall be applied according to the required performance so that the performance judged to need to be restored or improved achieves the specified level. Table C3.3.1 lists examples of the general intervention methods classified by the type of performance to be restored or improved. For intervention relating to safety and serviceability, a method shall be selected for the purpose of maintaining or improving the mechanical resistance of materials or members. For intervention relating to material degradation resistance that is intended to ensure that safety and serviceability achieve the required levels of performance during the design service life, a method shall be selected for the purpose of maintaining or improving the resistance to the degradation of materials.

In the intervention design of a structure, since new materials or members are bonded to the existing structure, it is necessary to consider how to establish the integrity between the existing parts and repaired or strengthened parts after intervention, how to establish the stress transferring mechanism between the existing parts and repaired or strengthened parts, etc. Also, it is important to fully understand how the applied intervention method contributes to the restoration or improvement of the rigidity and load bearing capacity of the structure after intervention and how long its effect lasts. The intervention design involves considering structural details according to the actual measured values of the existing structure in addition to the design documents created at the time of new construction.

When considering the intervention method to be applied, it is necessary to clarify the design service life of the structure after intervention and pay attention to the material degradation resistance of the repaired or strengthened parts during the design service life after intervention along with possible changes over time in the materials of the existing parts during the remaining design service life.

(3) Since intervention of an existing structure often faces strict restrictions on construction as construction work has to be done with the structure kept in service, securing a construction space is difficult because of adjacent structures and so forth. Therefore, due consideration needs to be given to construction in the intervention design. Also, it is important to formulate a structural plan taking into consideration the materials used, construction method, construction period, etc. so as to secure the specified level of integrity between the existing parts and repaired or strengthened parts.

(4) In order for the structure after intervention to fulfill the required performance during the design service life, appropriate post-intervention maintenance is needed, which makes it necessary to consider maintainability and other factors in the structural plan. Particularly, changes in the existing parts may become difficult to check visually after intervention and, therefore, consideration shall be given to the suppression of progress of changes, control of the causes of changes, etc.

(5) In the performance verification of the structure after intervention, an appropriate safety factor shall be established taking into consideration the current condition of the existing structure and the condition in which the structure is expected to be placed during the remaining design service life. If detailed information about the current condition of the existing structure can be obtained, it may be possible to set a smaller safety factor than that established in the design at the time of new construction.

The material factor of the materials of the existing parts shall be established, taking into consideration the comparison with the design values, spatial distribution and so forth, if the actual measured values of the existing structure are available. Particularly, the compressive strength of concrete of the existing parts is often greater than the design value established at the time of new construction, and the impact on the failure mode to be established should be considered. When a relatively recently developed material is used for intervention, the material factor shall be established taking into full consideration the impact of its construction conditions and its long-term characteristics.

The action factor may be established based on the actual measured values of the actions previously exerted on the existing structure and the actions expected to occur during the remaining design service life after intervention.

The structural analysis factor shall be established taking into consideration the method of bonding the existing parts and repaired or strengthened parts, the boundary conditions of the existing structure, etc.

The member factor of the existing parts may be established taking into consideration the construction records and the actual measured values of the existing structure.

The structure factor shall be established taking into consideration the importance of the structure and the social impact expected when the structure reaches its limit state among other things, as well as the condition at the time of intervention.

3.4 Design Values of Materials

(1) Materials of the required quality must be used for intervention of a structure.

(2) The characteristic values and design values of the materials used for intervention must be established by means of an appropriate method.

(3) The period during which the materials used sustain the required quality must be grasped to clarify the design service life of the structure after intervention.

(4) The characteristic values of the materials in the existing structure must be established by means of an appropriate method, and the material factor to be used for the design values may be established taking into consideration the conditions in which the existing structure is currently placed.

[Commentary]　(1) and (2) In order for a repaired or strengthened structure to fulfill the required performance throughout the design service life, it is important that the materials used for intervention sustain the required quality. Table C3.4.1 shows examples of materials used for intervention. Materials used for intervention include cement-based materials and reinforcing materials that comprise repaired or strengthened parts, bonding materials used to bond or anchor the exiting parts and repaired or strengthened parts, filling or injection materials for filling missing sections and spaces, surface protection materials used to protect the surfaces of concrete and steel and rust-proofing materials to prevent steel corrosion. Other materials, such as primers for increasing adhesion between adhesive and repaired or strengthened parts and unevenness adjusting materials for adjusting the surface unevenness, are also used for base coating and surface treatment. To ensure that the established effect of intervention is obtained, it is necessary to check that each of the materials has the required quality and to pay attention to the compatibility of the combinations of the materials used.

Table C3.4.1　Examples of materials used for intervention

Category	Type
Cement-based materials	Normal-strength concrete, high-strength concrete Short-fiber reinforced mortar/concrete Plasticized concrete High-fluidity concrete Polymer cementitious mortar/concrete
Reinforcing materials	Reinforcing steel, prestressed concrete steel Steel plate Reinforcing FRP, structural FRP
Bonding materials	Resin-based/cement-based adhesive Anchor reinforcing bar
Filling and injection materials	Non-shrink grout Antiwashout underwater mortar/concrete Polymer cementitious mortar Resin-based injection materials
Surface protection materials	Resin paint Polymer cement paste/mortar Silane-based/silicate-based impregnation materials Continuous fiber sheet
Rust-proofing materials	Resin paint Nitrite-based/chelate reaction-based/amino alcohol-based rust-proofing agent Anode material

The properties of the materials used for intervention include those physical properties used for design such as strength, modulus of elasticity, stress-strain relationship, creep property, coefficient of thermal expansion and density, as well as construction-related properties such as usable time, curing time and viscosity. Particularly, since the properties of resin-based adhesive and other materials are greatly affected by temperature and humidity, it is necessary to select appropriate materials according to the environmental conditions at the time of construction, the service conditions of the structure after intervention and so on.

The characteristic values of the materials used for intervention shall be established based on the testing methods specified in the relevant Japanese Industrial Standard (JIS) documents and the standards published by the Japan Society of Civil Engineers as well as the quality certificates issued by the material manufacturers.

(3) To clarify the design service life of the structure after intervention requires being able to fully grasp the period during which the materials used for intervention sustain the required quality and to evaluate changes over time in the effect of intervention. If the period during which the quality of materials is guaranteed is not clear or any new material is used for which little information is

available about changes in quality over time, a method for periodically checking the quality of the materials used should be considered in the post-intervention maintenance so that re-repair, upgrade or other necessary action can be performed at the right time.

(4) The characteristic values of the materials in the existing structure shall be established based on the results of the study of that structure or the design documents and other relevant information. The material factor of the materials of the existing parts may be established, taking into consideration the comparison with the design values, spatial distribution and so forth, if the actual measured values of the existing structure are available. Particularly, the compressive strength of concrete of the existing parts is often greater than the design value established at the time of new construction, and the impact on the failure mode to be established should be considered. When a relatively recently developed material is used for intervention, the material factor shall be established taking into full consideration the impact of its construction conditions and post-intervention service requirements as well as its long-term characteristics. Also, consideration shall be given to the compatibility between the materials in the existing structure and the materials used for intervention.

3.5 Actions

(1) In the performance verification of the structure after intervention, the actions expected during the intervention construction and the remaining design service life shall be considered in appropriate combinations according to the limit state for the required performance.

(2) The characteristic values of actions shall be established taking into consideration the actions exerted on the existing structure before the verification and the environmental conditions in which the existing structure has been placed.

(3) In the performance verification of the structure after intervention, the burden of the actions on the existing parts and repaired or strengthened parts shall be taken into consideration appropriately.

[Commentary] (1) and (2) The performance verification of the structure after intervention is performed for the actions expected during the remaining design service life. The characteristic values of the actions and action factors during the design service life should be established rationally taking into consideration the actions exerted on the existing structure before the verification. Also, since the intervention construction may be performed with the structure in service or a permanent load imposed on the existing parts, due consideration needs to be given to the actions expected during construction as well.

When establishing the characteristic values of the actions and action factors, consideration should be given to the current condition of the existing structure as well as to the actions exerted before the verification, their effects, the environmental conditions in which the structure has been placed and so forth. For example, the characteristic values and action factors can be established rationally by grasping the actual measured values of variable actions and taking into consideration the environmental actions actually exerted on the structure.

(3) In the performance verification of the structure after intervention, the burden of the actions on the existing parts after intervention and the repaired or strengthened parts needs be established appropriately. In the case of intervention, it is common that the weight of the repaired or strengthened parts is added to the existing parts, while the permanent action on the existing parts is not redistributed to the repaired or strengthened parts.

The load bearing capacity and rigidity of the structure after intervention differ depending on the level of integrity established between the existing parts and repaired or strengthened parts. The relationship between the action burden of the existing parts and that of the repaired or strengthened parts should be thoroughly considered. If the load bearing capacity and rigidity of the existing parts are lower than those of the repaired or strengthened parts, it is necessary to check by means of an appropriate method that the composite structure can exhibit the expected load bearing capacity and rigidity.

3.6 Performance Verification

(1) The performance verification of the structure after intervention shall be performed by establishing limit states relative to performance requirements either for a structure during construction and the remaining design service life or for each of its structural members and checking that the structure or structural members having the structural details assumed in the intervention design, such as shape, dimensions and reinforcement arrangement, do not reach any limit state.

(2) In performing the performance verification, the preconditions for the performance verification shall be met.

(3) The response values corresponding to the verification indices shall be calculated by conducting a structural analysis using an appropriate analysis model relating to the actions for the limit states established based on the current condition of the structure as well as the structure after intervention.

(4) The limit states shall be generally established relative to safety, serviceability and restorability, and the performance verification shall be performed by comparing the limit values with the response values in principle.

[Commentary] (1) Basically, the performance verification of the structure after intervention shall be performed according to the performance verification method adopted at the time of new construction. Note that the performance level required for the structure after intervention should be established rationally taking into consideration the current condition and remaining design service life of the structure.

(2) To use a scope-specified verification method for the performance verification of the structure after intervention requires a set of preconditions for the verification method, such as:

- Study related to durability (preconditions for changes over time due to environmental actions, study of initial cracks, etc.)

- Structural details (those used as preconditions for the verification)

- Study related to construction (construction considerations used as preconditions for the verification)

If any change has occurred to the existing structure or there is the possibility that the preconditions assumed at the time of new construction are not met, it needs to be checked in the performance verification of the structure after intervention that the existing parts meet the preconditions for the verification method to be applied.

(3) In the performance verification of the structure after intervention, the response values of the structure after intervention shall be calculated taking into consideration the bonding status between the existing parts and repaired or strengthened parts. In other words, it is necessary to perform appropriate modeling by paying attention to what type of stress transfer is achieved between the existing parts and repaired or strengthened parts by the intervention method to be applied. It is also important to take into consideration the effects of the actions exerted before the verification, such as changes to the structure, residual deformation and stress.

(4) The performance verification of the structure after intervention shall be performed with appropriate verification indices established for limit states relative to performance requirements. Generally, the verification indices established at the time of new construction may be used. However, if there is any change to the existing parts or special consideration is necessary as to the integrity between the existing parts and repaired or strengthened parts, appropriate verification indices need to be established.

CHAPTER 4 CONSTRUCTION FOR INTERVENTION

4.1 General

The construction for intervention must be performed by formulating an appropriate construction plan taking into consideration the properties of the materials used, restrictions on construction, etc. so as to ensure that the quality assumed in the design is secured and that the structure after intervention fulfills the required performance.

[Commentary] In order for the structure after intervention to fulfill the required performance throughout the design service life, it is necessary to perform the construction for intervention while securing the quality assumed in the design. In the construction for intervention, the expected effect of intervention may not be fully obtained unless construction control and quality control are implemented as appropriate for the properties of the materials used. For intervention, an appropriate construction plan shall be formulated based on the construction standards related to the materials used and other relevant information. Also, the intervention construction of an in-service structure requires the formulation of a meticulous construction plan because there are often strict restrictions on the construction period and space.

In intervention of an existing structure, it is possible that the expected effect of intervention may not be obtained or that the structure may suffer a degradation again soon unless changes to the existing parts are treated appropriately. When performing intervention, therefore, it is important to take appropriate measures, such as ensuring the removal of degraded parts and degradation factors and reducing the effects of causes of degradation, and to keep detailed records of treatment methods and regions.

4.2 Construction Plan

(1) A plan for the construction for intervention must be formulated taking into consideration the structural conditions of the existing structure, environmental conditions for construction and construction conditions and paying attention to the safety of work and environmental burden as well.

(2) The intervention construction plan shall specify the inspection methods to check construction and quality, along with the construction methods and procedures appropriate for the properties of the materials used.

[Commentary] (1) When formulating the intervention construction plan, the overall process, construction method, materials used, quality control, inspection, safety, environment burden and other necessary items shall be examined taking into consideration the restrictions on construction including the construction period, environmental conditions, safety and economy as shown in Table C3.2.1. Also, a study of the existing structure shall be conducted in advance to grasp the current condition of the structure and the restrictions on construction. The intervention construction for an existing structure in service often has to be performed in a construction environment different from that available at the time of new construction due to the limited construction time, narrow construction space, etc. Therefore, methods to ensure quality and safety of work need to be examined thoroughly.

The construction plan shall cover all the processes of construction, quality control and inspection and be provided in written form for reference by the engineers in charge of these processes.

(2) In the case of intervention of a structure, since the properties of the materials used may be greatly affected by environmental conditions, such as the temperature and humidity during construction, it is necessary to consider appropriate construction methods and procedures to ensure that the effect expected in the design is obtained. Also, the inspections shall be studied that are to be performed in each individual phase of construction to check the quality of the materials used and the contents of construction work.

4.3 Construction

(1) The construction for intervention must be performed according to a construction plan.

(2) The construction for intervention must be performed under the direction of engineers with sufficient knowledge and experience in the materials used and the construction methods applied.

(3) The handling of the materials used for intervention, including transportation, storage, mixing, manufacture, processing and use, must be done with the properties of the individual materials in mind.

(4) The intervention materials or members must be bonded after appropriate base coating of the existing parts, taking into consideration the construction conditions, environmental conditions, etc., so that the structure after intervention fulfills the required performance.

(5) An appropriate finish must be applied so that the structure after intervention fulfills the required performance throughout the specified period of time.

[Commentary] (1) and (2) The construction for intervention shall be performed efficiently according to a formulated construction plan while ensuring the safety of work. Generally, whether construction succeeds or fails greatly depends on the abilities of the engineers engaged in the work. It is therefore important to assign engineers with sufficient knowledge and experience in the intervention methods applied and have the construction work proceed under the direction of those engineers. In performing construction, it is necessary to clarify the scope of responsibility and authority of each engineer.

(3) The materials used for intervention shall be handled by means of the methods that are respectively specified for those materials. For example, fiber-base and resin-base materials used for intervention may experience degradation or change in their properties when exposed to ultraviolet light, heat or water. When these materials are transported or stored, therefore, it is necessary to avoid an environment exposed to direct sunlight, high temperature, etc. and ensure that the temperature and humidity conditions are met.

(4) The intervention materials or members need to be bonded according to appropriate construction procedures, taking into consideration the construction conditions and environmental conditions, so that the structure after intervention fulfills the required performance. The preprocessing and base coating for bonding involve removing degraded parts, vulnerable parts, protrusions, dirt and fouling from the existing structure, arranging the shape of the surface and so on. Then, after the application of an unevenness adjusting material and primer and the application and impregnation of adhesive, the intervention materials or members shall be securely bonded or

anchored. In this process, the materials used need to be mixed and agitated at the specified mix proportion and thorough controls need to be exerted for time management during bonding as well as for ensuring that environmental conditions are met. In an environment where the temperature is low or an environment that is wet due to rainwater or for some other reason, ensuring that environmental conditions during construction are met is particularly important because the bonding quality of some of the materials may become poor.

When the materials or members are bonded mechanically using anchors, bolts, etc., it is necessary to make efforts to minimize the impact on the existing parts, such as conducting a meticulous prior study.

If the existing structure has a history of intervention and, if the repaired or strengthened parts are appropriately removed or intervention is performed so as to embrace the repaired or strengthened parts, the status of material degradation, bonding condition, etc. need to be evaluated appropriately.

(5) An appropriate finish needs to be applied to the surface after intervention so that the requirements related to weather resistance, fire resistance, shock resistance, appearance and so on are met. Also, it is important to protect the bonded part (boundary part) between the existing parts and repaired or strengthened parts to ensure material degradation resistance. General finish processes include the coating process (measures for ultraviolet, temperature and appearance protection), surface protection process (measures for ultraviolet, external damage and collision protection) and fire-resistant and flame-resistant covering process (measures for fire protection).

4.4 Inspection

(1) An inspection must be conducted in each phase of construction and upon completion of construction so that the structure after intervention fulfills the required performance.

(2) An inspection must be conducted based on predetermined judgment criteria by means of a method of proven reliability.

(3) If the construction or quality is judged to be nonconforming as a result of an inspection, an appropriate corrective measure must be taken.

[Commentary]　(1) An inspection shall be conducted with regard to the quality of the materials used, the performance of manufacturing and processing equipment, constructed members and structure, etc. in order to ensure that the structure after intervention fulfills the required performance throughout the design service life. For the construction for intervention, a plan shall be formulated in advance with regard to the inspection items, inspection method, judgment criteria, execution timing, frequency, allocation of personnel, etc., taking into consideration the efficiency of construction work and economy. The inspection items for the construction for intervention include an inspection of the storage condition of resin-based materials, organic solvent, etc., an inspection of the surface condition and dimensions for base coating, an inspection of the method of use of bonding materials, amount of use, usage environment, etc. and inspection of the positions and dimensions of repaired or strengthened parts.

(2) The inspection method and judgment criteria differ depending on the type of structure, the materials used, the intervention method applied, etc., and they need to be established in advance to ensure an efficient and secure inspection. Also, it is important that they are objective and have proven reliability. Generally, the method and judgment criteria specified in the relevant Japanese Industrial Standard (JIS) documents and the standards published by the Japan Society of Civil

Engineers shall be used. In the construction for intervention, it is particularly important to check through an inspection that the specified quality is achieved for the bonding of intervention materials or members.

(3) If the construction or quality is judged to be nonconforming as a result of an inspection, a corrective measure, such as performing the construction again or changing the materials used, shall be considered. In the construction for intervention, if bonding the intervention materials or members again is difficult, it is necessary to carefully consider the procedure and contents of construction work in advance.

4.5 Records

Information about the construction for intervention must be recorded and appropriately stored.

[Commentary] In each phase of construction for intervention, information about the construction conditions, environmental conditions, etc. shall be recorded, along with quality control and inspection results. Such information not only is used to formulate a maintenance plan in post-intervention maintenance but is also useful in assuming the cause of change and considering corrective measures in the event of re-degradation, early performance degradation, etc.

CHAPTER 5　POST-INTERVENTION MAINTENANCE

5.1 General

The structure after intervention must be maintained appropriately so that it sustains the required performance throughout the remaining design service life.

[Commentary] In order for the structure after intervention to fulfill the required performance throughout the remaining design service life, it is necessary to perform appropriate maintenance and check that the effect of intervention is sustained. Not only does the structure after intervention have new parts and members, such as repaired or strengthened parts bonded to the existing parts, but it is also possible that other parts and members are affected. Therefore, maintenance shall be performed after appropriately reviewing the pre-intervention maintenance plan.

5.2 Inspection

(1) The inspection of the structure after intervention shall be performed to check that the effect of intervention is sustained.

(2) The inspection of the structure after intervention shall be performed, paying attention to the impact of intervention on regions other than those parts and members to which intervention has been applied.

[Commentary] (1) The inspection of the structure after intervention needs to check that those parts and members to which intervention has been applied exhibit the expected effect. Particularly, grasping the condition of bonding between the existing parts and repaired or strengthened parts is extremely important for sustaining the effect of intervention. Also, the condition of surface protection to ensure the material degradation resistance of the repaired or strengthened parts shall be checked.

In the inspection of the structure after intervention, since performing intervention may make it difficult to check the condition of the existing parts visually or by other direct means, it is necessary to consider an alternative means in advance such as an indirect checking method. Particularly, if the removal of degraded parts and degradation factors, the reduction in the effects of causes of performance degradation, etc. are insufficient, re-degradation or early performance degradation is likely and, therefore, it is necessary to consider conducting the inspection such that the occurrence and progress of changes can be grasped appropriately.

(2) If intervention has been applied only to some members or to a limited group of parts, the application of intervention may bring about changes, such as environmental actions or load actions, to regions other than the repaired or strengthened parts and members. For example, it is possible that the application of intervention may produce differences in stress distribution, moisture distribution in concrete, mass transfer characteristic, electrochemical equilibrium, etc. between the existing parts and the repaired or strengthened parts, potentially causing unexpected new changes. Therefore, it is important to conduct the inspection so as to grasp the condition of the entire structure appropriately, rather than paying attention only to those parts and members to which intervention has been applied.

5.3 Evaluation

(1) The performance evaluation of the structure after intervention must be performed by means of an appropriate evaluation method based on the information obtained through the inspection.

(2) In the performance evaluation, the impact of intervention must be taken into consideration appropriately.

[Commentary] (1) Basically, the method adopted for the performance evaluation of the existing structure may be applied to the performance evaluation of the structure after intervention. However, since it is possible that the application of intervention may make an evaluation based on changes in appearance difficult, the use of an alternative means should be considered by reviewing the evaluation method, applying a monitoring technique, etc.

(2) When evaluating the performance of the structure after intervention, it is necessary to take into consideration the impact of intervention for the modeling of structures, actions, etc. Particularly, consideration needs to be given appropriately to the modeling of repaired or strengthened parts and their bonding, the modeling associated with changes in action conditions and boundary conditions, changes in stress distribution associated with intervention, etc. according to the intervention method applied.

5.4 Measures

(1) If periodical measures are assumed for the structure after intervention, those measures must be taken securely.

(2) If any measure is judged to be necessary as a result of the performance evaluation, that measure must be taken so that the structure performance after the measure is taken is sustained for a specified period of time.

[Commentary] (1) Depending on the intervention method, periodical measures, such as surface protection repair or upgrade, may be assumed. A rational judgment shall be made, based on the results of the performance evaluation as well, and necessary measures shall be taken.

(2) If a degradation in the performance of the structure is confirmed and additional measures are judged to be necessary, regardless of whether the design service life of the structure after intervention has not ended, the scope of intervention, the materials used, the intervention method, etc. shall be reviewed and appropriate measures shall be taken to ensure that the desired effect can be obtained.

Guidelines for Structural Intervention of Existing Concrete Structures Using Cement-Based Materials - Common Section

CHAPTER 1 GENERAL PROVISIONS

1.1 Scope

These guidelines specify the standards for design and construction to be applied for structural intervention of concrete structures using cement-based materials.

[Commentary] These guidelines specify the standards for design, construction and post-intervention maintenance that are to be applied for performing intervention work using cement-based materials with the aim of improving the performance of existing concrete structures. The intervention dealt with in these guidelines is intended to restore, sustain or improve the mechanical performance of concrete structures. When the intervention is aimed at restoring or improving durability, reference should be made to relevant documents such as “Concrete Library 107, Recommendation for Design and Construction of Electrochemical Corrosion Control Method, 2011.11” and “Concrete Library 119, Recommendation for Concrete Repair and Surface Protection of Concrete Structure, 2005.4” published by the Japan Society of Civil Engineers.

In 1999, the Japan Society of Civil Engineers published “Concrete Library 95, Guidelines for Retrofit of Concrete Structures, Draft, 1999.9” as guidelines for structural intervention of concrete structures, which specified the design and construction methods concerning the external cable method, fiber-reinforced plastic (FRP) external bonding method, steel plate external bonding method, FRP jacketing method, steel plate jacketing method, overlaying method and concrete jacketing method. Also, in 2000, “Concrete Library 101, Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets, 2000.7” was published, which specified the design and construction methods to be applied when performing intervention by bonding continuous fiber sheets to concrete structures or jacketing concrete structures with continuous fiber sheets. These guidelines have been revised to align their contents with “Standard Specifications for Concrete Structures-2013, Maintenance” established after the publication of the above-mentioned guidelines while taking into consideration the knowledge obtained from the past intervention projects. Of the methods dealt with in “Concrete Library 95, Guidelines for Retrofit of Concrete Structures, Draft, 1999.9”, these guidelines cover the overlaying and jacketing methods using cement-based materials and deals with the following intervention methods.

Top-surface overlaying: A method in which the thickness of the top surface of the existing concrete members is increased using cement-based materials (applicable to highway bridge decks, etc.)

Bottom-surface overlaying: A method in which the thickness of the bottom surface of the existing concrete and bar members is increased using cement-based materials (applicable to highway bridge decks, tunnel linings, box culverts, waterways, beams, etc.)

Jacketing: A method in which the periphery of the existing concrete bar members is jacketed with cement-based materials (applicable to columns, bridge piers, rigid-frame pier beams, etc.)

Assuming that the standard requirements regarding the intervention of existing structures are as set forth in the "Standard for Intervention of Structures", these guidelines consist of a common section specifying the common requirements not dependent on the method of performing intervention using cement-based materials and method-specific sections, each describing the specifics of an individual method.

The requirements not mentioned herein shall be as set forth in the following standard specifications.

Standard Specifications for Concrete Structures-2012, General Principles

Standard Specifications for Concrete Structures-2017, Design

Standard Specifications for Concrete Structures-2017, Materials and Constructions

Standard Specifications for Concrete Structures-2013, Maintenance

1.2 Fundamentals of Intervention

(1) Intervention of a structure must be performed so that the structure after intervention fulfills the required performance throughout the remaining design service life.

(2) Intervention of a structure shall be performed, after an intervention plan is formulated, through the study of the existing intervention target structure, intervention design, construction, recording and post-intervention maintenance.

[Commentary] (1) Intervention of a structure shall be performed, based on results of the performance evaluation conducted during maintenance, for the purpose of sustaining the performance of the structure according to the scenario established in the maintenance plan or restoring or improving the degraded or insufficient performance. If the situation deviates from the originally established scenario for some reason such as the level of performance required for the structure changing with changes in social conditions or the surrounding environment of the structure, the maintenance plan shall be reviewed taking into consideration the timing and extent of intervention, the period for which its effect will last, etc. After intervention, the structure is required to fulfill the required performance throughout the remaining design service life. If there are fears of re-degradation or any change in the required performance level is expected, it is necessary to clearly establish the period for which the effect of intervention will last and consider performing intervention work again. It is desirable to take into consideration the cost benefit and life cycle cost in the remaining design service life, among other things, when establishing the extent of intervention and the period for which its effect will last.

(2) In order to perform intervention rationally and effectively, it is important to first clarify the required performance and design service life of the structure and then formulate an intervention plan that puts together the organized basic information about the target structure, the timing of and system for the implementation of intervention, the intervention design and construction methods, the contents of post-intervention maintenance, etc. Intervention of a structure shall be performed, based on the formulated intervention plan, according to the flow shown in Fig. C1.2.1. Note that, for the method-independent intervention-related standard requirements, reference shall be made to the "Standard for Intervention of Structures". These guidelines specify the standard intervention methods using cement-based materials.

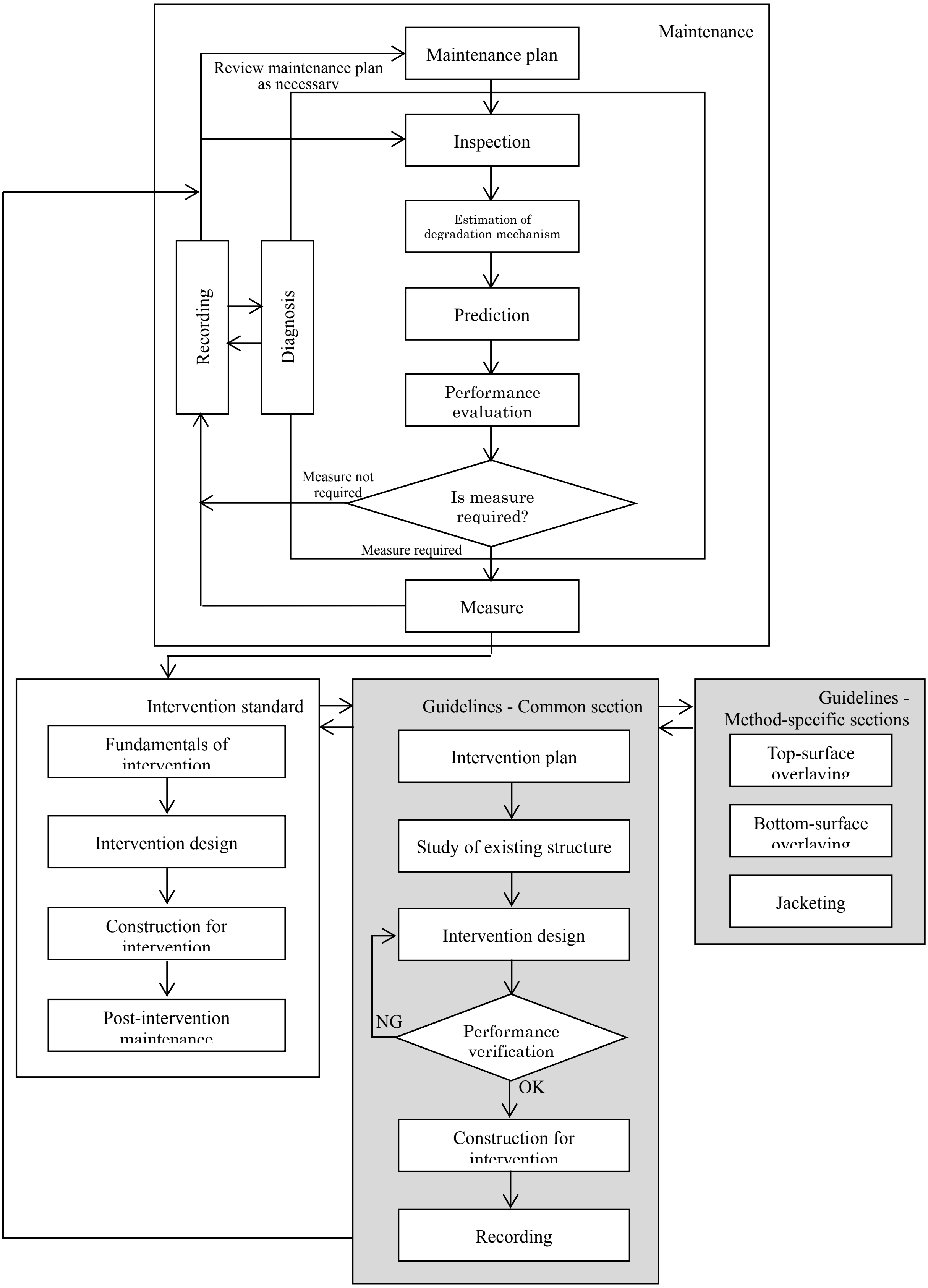


Fig. C1.2.1　Positions of the guidelines and the flow of intervention

1.3 Terms and Definitions

The following terms are defined for use in these guidelines.

Thickening property: Property related to the thickness of polymer cementitious mortar or other mortar material that can be applied per layer

Bonding material: A material, such as primer, anchor grouting material or adhesive, that is applied or grouted to bond concrete members, concrete and mortar or concrete and reinforcing material

Filling material: A material injected to fill the gap between a reinforcing material, such as intermediate penetrating steel, and concrete

Intermediate penetrating reinforcing material: A reinforcing material, such as intermediate penetrating steel or continuous fiber reinforcing material, that is placed to improve the toughness of bridge piers

Ultrarapid hardening cement: A type of concrete with a typical mix proportion that develops a compressive strength as high as 20 to 30 N/mm^2 within 2 to 3 hours of placement. Currently in circulation are pulverized clinker whose main component is calcium aluminate, Portland cement mixed with an appropriate amount of finely pulverized calcium sulfoaluminate and cement whose main component is magnesium phosphate.

Reinforcing material: Steel material or continuous fiber reinforcing material used to sustain the required performance of a structure or to restore or improve performance

Polymer cementitious mortar: Mortar that uses cement and a cement mixing polymer as a bonding material

Overlaying material: A cement-based material that bonds existing members and reinforcing materials added for the purpose of intervention

FRP grid: Resin-impregnated continuous fiber reinforcing materials formed into a grid shape

CHAPTER 2 STUDY OF THE EXISTING STRUCTURE

2.1 General

The existing structure for which intervention is to be considered shall be studied to obtain the information necessary for intervention design and construction.

[Commentary] Before performing structural intervention using cement-based materials, it is necessary to conduct a detailed study of the target structure in order to obtain the information needed to consider intervention design and construction.

2.2 Study

2.2.1 Study using documents, records, etc.

When a study is conducted using documents, records, etc., the climatic conditions, environmental conditions, geographical conditions and other relevant conditions of the local site shall be grasped in detail from the following viewpoints.

(i) Formulation of material and structural plans

(ii) Formulation of a construction plan

(iii) Post-intervention maintenance

[Commentary] Generally, the workability and hardening characteristic of cement-based materials greatly change depending on the construction environment, such as temperature and, therefore, it is necessary to grasp the climate of the local site during the period when construction is planned to be performed. Also, intervention using cement-based materials requires that the restrictions of the local site regarding the construction space as well as the carry-in and installation of materials and equipment be grasped before a specific construction plan is formulated.

2.2.2 On-site study

On the site, a study shall be conducted to check the existing concrete structure for degradation, damage and initial defects from the following viewpoints.

(i) Securing of integrity between the existing parts and strengthened parts

(ii) Prediction of durability and degradation after intervention

[Commentary] In obtaining the expected effect of intervention using cement-based materials, integrity between the repaired or strengthened parts and existing structure is important. Ensuring integrity requires taking necessary measures based on the understanding of degradation such as carbonation of the surface of the existing structure, damage such as cracks, sprinkling or leakage of water, etc.

Degradation of a concrete structure after intervention progresses at a different rate depending on the type of cause and degree of degradation. Therefore, before intervention is performed for a damaged concrete structure, it is necessary to grasp the cause and degree of degradation.

CHAPTER 3　INTERVENTION DESIGN

3.1 General

In intervention, a rational structural plan must be formulated and structural details must be established based on that plan so that the structure after intervention fulfills the required performance throughout the remaining design service life.

[Commentary] The intervention design involves establishing a structural plan and structural details to ensure that intervention restores the performance of the existing structure to the required level and that the structure after intervention fulfills the required performance throughout the remaining design service life. In the case of intervention using cement-based materials, increasing the rigidity of repaired or strengthened members is easy while the members become heavier as well. It is important that the structural plan establish an appropriate intervention method, taking into consideration the current condition of the existing intervention target structure, intervention construction conditions, maintainability after intervention and so forth.

In structural details, appropriate methods of bonding and anchoring reinforcing materials shall be established to ensure integrity between the existing parts and strengthened parts that is necessary for the structure after intervention to meet the specified performance requirements. Also, the load share and stress redistribution of the existing parts and strengthened parts before and after intervention shall be clarified and the sectional strength and rigidity of the strengthened members shall be established according to the structural properties of the intervention target members, the intervention method and so forth.

In the performance verification of the structure after intervention, safety factors such as material factors and action factors shall be established appropriately, taking into consideration the current condition of the existing structure and the condition in which the structure is expected to be placed during the remaining design service life. When establishing member factors, it is possible to consider and reflect the construction records and actual measured values of the existing parts.

3.2 Structural Plan

(1) In the structural plan, the intervention method shall be selected, taking into consideration the structural properties, materials, construction method, maintenance method, economy, etc., so as to ensure that the structure after intervention fulfills the required performance.

(2) Consideration must be given to ensure that the structure after intervention sustains the required levels of durability, safety, serviceability and restorability throughout the design service life.

(3) The structural plan shall take into consideration the restrictions on construction.

(4) In the structural plan, consideration must be given to facilitate post-intervention maintenance, factoring in the structure’s importance, design service life, service conditions, environmental conditions, maintainability, etc.

[Commentary] (1) In the structural plan, an appropriate intervention method shall be selected to ensure that intervention restores or improves the target performance of the existing target structure to the required level. These guidelines specify how to implement the following intervention methods.

- Top-surface overlaying: This method increases the thickness of existing concrete members by placing and integrating cement-based materials onto the top surface of the members so as to improve the safety, serviceability, durability and other properties of a concrete structure. The method is applied to highway bridge decks in many cases, and sustaining the effect of strengthening requires ensuring sufficient integrity between the existing parts and overlaying parts.

- Bottom-surface overlaying: This method improves the flexural property, shear property and fatigue property by placing reinforcing materials on the bottom surface of existing surface or bar concrete members (tension side) and integrating cement-based materials. To prevent peeling of the overlaying parts requires ensuring sufficient integrity between the existing parts and overlaying parts.

- Jacketing: This method restores or improves mechanical performance, such as flexural load-carrying capacity, shear capacity and toughness, as well as durability and other performance properties, by placing reinforcing steel or FRP grids around the existing concrete bar members or in the grooves on the concrete surface and jacketing the entire periphery of the members with cement-based materials, such as concrete or polymer cementitious mortar, so that the materials integrate with the existing members. To obtain the expected effect of strengthening requires thoroughly considering the anchoring method for the edges of the strengthened parts, the jacketing height and so on.

When considering the intervention method, the type of the intervention materials and the methods of bonding these materials (bonding and anchoring methods) shall be established according to the conditions of the intervention target structure to ensure that the structure after intervention fulfills the required performance. When considering structural details, not only the design documents created at the time of new construction but also the current condition of the existing structure identified through on-site measurements and other activities shall be taken into consideration.

(2) In order to ensure that the structure after intervention fulfills the required performance throughout the remaining design service life, it is common either to prevent reinforcing materials from degrading or changing due to environmental actions during the design service life or to design the intervention so as to minimize the impact of degradation such that the performance of the structure will not decline even if degradation occurs. If a change has already occurred in the intervention target structure, it is necessary to consider an appropriate measure to prevent the progress of the change from affecting the effect of intervention. Ensuring integrity between the existing parts and strengthened parts is particularly important for preventing the structure after intervention from experiencing early performance degradation.

(3) In order for the structure after intervention to exhibit the required performance, structural planning needs to be performed taking into full consideration the restrictions on construction. Since intervention of an existing structure is expected to face strict restrictions on the construction period, construction space, etc. due to service conditions and other factors, it is important to consider ways to ensure the required levels of construction accuracy and quality in the carry-in and installation of reinforcing materials as well as in the bonding work.

(4) It is important to consider intervention methods and materials to be used in order to ensure that maintenance work such as inspections and performance evaluations can be efficiently conducted on the structure after intervention as well as to minimize the costs required for corrective measures. Where intervention materials are bonded, in particular, the condition of the existing parts

may be difficult to check and, therefore, it is desirable to consider ways to appropriately grasp changes that may occur in the structure after intervention.

3.3 Structural Details

(1) The bonding method of reinforcing materials must be established appropriately to ensure that the structure after intervention achieves the required level of integrity.

(2) The reinforcing materials to be used and the structural properties of the strengthened parts must be established so that the structure after intervention sustains the required load bearing capacity and rigidity.

[Commentary] (1) Generally, the serviceability and safety verification of the structure after intervention assumes that the existing parts and strengthened parts are integrated to resist external forces. When establishing structural details, it is necessary to consider a bonding method that ensures sufficient integrity for the structure after intervention.

(2) The type of reinforcing material and the structural properties of the strengthened parts need to be established, taking into consideration the differences in load bearing capacity and rigidity between the existing parts and strengthened parts, to ensure the load bearing capacity and rigidity required for the structure after intervention. If the rigidity ratio of the existing parts and strengthened parts is large, care needs to be exercised because a sufficient strengthening effect may not be obtained depending on the bonding method. It is important to give full consideration in advance as to how to make the existing parts, bonded parts and strengthened parts resistant to each load level, respectively. Note that there is the need to fully grasp the reinforcement arrangement of the existing parts in the study of the existing structure, including whether round bars are used.

In the structure after intervention, the permanent action (dead load) on the existing structure is borne by the existing parts alone, and the integrated structure bears the variable action (live load) in addition to the weight of the strengthened parts. It is important to set the rigidity ratio of the existing parts and strengthened parts appropriately and to control the load sharing ratio and resistance mechanism.

Care needs to be taken to prevent the existing parts from being damaged or integrity from being impaired by time-dependent deformation of reinforcing materials or bonding materials, such as creep occurring in reinforcing materials or adhesive due to the stress of a permanent action. Also, there are cases in which the existing parts restrict the shrinkage of the strengthened parts and a thorough consideration of indirect actions is necessary.

CHAPTER 4 MATERIALS

4.1 General

The materials used for intervention must be of proven quality.

[Commentary] The quality of the materials used for intervention needs to be checked by means of an appropriate method according to their method of use and combination. The quality of the materials used for the existing structure, as well as the quality of the materials used for intervention, and the design values of these materials shall be determined as set forth in this chapter. The properties of the materials in the existing structure subject to intervention may be different from those assumed in the design phase at the time of new construction due to the various factors in the construction phase as well as the load and environmental actions during the service life. In strengthening design, the characteristic values of the material physical properties and material factors of the existing concrete members need to be determined appropriately taking this fact into consideration. Materials not specified herein may be used as long as they fulfill the required performance in accordance with the intent of this chapter.

4.2 Materials in the Existing Structure

(1) The design values of the materials in the existing structure shall be determined based on results of studies and inspections.

(2) The characteristic values of the physical properties of the materials in the existing structure shall take into consideration the variations in measured values obtained through inspections and ensure that most of the measured values do not fall below them. If the values of the material physical properties can be determined based on results of studies and inspections separately from the characteristic values of the material physical properties, those values may be used.

(3) Generally, the material factors of the materials in the existing structure shall be determined in accordance with "Standard Specifications for Concrete Structures-2017, Design, General Requirements". However, if the properties of the materials in the existing structure are different from those assumed at the time of new construction or the service conditions after intervention are different, the material factors may be determined appropriately taking into consideration the environmental conditions and other factors.

[Commentary] (1) and (2) The characteristic values of material physical properties are determined by the distribution of test values and the likelihood that test values lower than the characteristic values will be obtained. The examples given in "Standard Specifications for Concrete Structures-2017, Design, General Requirements" assume a likelihood of 5%. As for the materials in the existing structure, it is also essential to determine the characteristic values in a similar manner. In general, however, there are few sample test values from inspections, which makes it difficult to identify the distribution of test values. Therefore, it has been decided here to make an overall judgment of inspections in order to estimate the characteristic values of material physical properties. For example, if the steel used in the existing structure has missing sections or the like due to corrosion, the cross-sectional area of the steel may be determined using measured values or estimated values calculated by means of an appropriate method.

While the characteristic value of the tensile strength of steel is not thought to be dependent on time, the tensile property changes as the cross-sectional area decreases. Here, it has been decided to reflect this in design by taking into consideration the changes in the cross-sectional area of the steel used in the existing structure. The other characteristic values related to steel need to be determined according to the condition of corrosion, the history of previously applied stresses and so forth. If the steel has been subjected to considerable corrosion or stresses exceeding the yield strength, it must be noted that the bond property, fatigue property, elongation property, etc. have altered.

(3) As for the materials in the existing structure, the material factors at the time of new construction differ from those at the time of intervention. At the time of new construction, the material factors are determined taking into consideration various factors including the purpose of use, design service life, load and environmental conditions, construction and maintenance. At the time of intervention, on the other hand, the material factors should be determined based on the load and environmental conditions, material properties, design service life after intervention and other factors identified through inspections. If the condition of the existing structure identified through inspections is consistent with that assumed in the design, the material factors may be determined in accordance with "Standard Specifications for Concrete Structures-2017, Design, General Requirements".

In general, the specified design strength was used as the characteristic value for the compressive strength of the concrete used in new structures, and the design value was derived by dividing this value by the material factor. The characteristic value of the concrete in the existing structure, on the other hand, is known from inspections, thus resulting in less uncertainty. By taking this into consideration, the material factor can be reduced. When determining the flexural strength, tensile strength, bonding strength, bearing strength and other characteristic values of concrete materials from the characteristic value for the compressive strength in accordance with Section 5.3 of "Standard Specifications for Concrete Structures-2017, Design, General Requirements", the material factors must be handled carefully taking into consideration the condition of deterioration of the concrete materials.

4.3 Materials Used in Repaired or Strengthened Parts

4.3.1 General

The quality of the materials used in repaired or strengthened parts may be indicated by the compressive strength or tensile strength, as well as by other strength properties, Young's modulus and other deformation properties and material properties such as thermal properties, durability and water-tightness, as required for the performance verification. As for the strength properties and deformation properties, the effect of the loading rate must be taken into consideration as necessary.

[Commentary] Table C4.3.1 lists the types of materials generally used for the intervention methods discussed in these guidelines. Materials used for the intervention include cement-based reinforcing materials, such as concrete and mortar, and steel, continuous fiber and other reinforcing materials, as well as filling materials used as necessary, such as grout material, and bonding materials used to bond the repaired or strengthened parts and existing parts, such as anchors and adhesive.

Table C4.3.1 Examples of the types of materials used for intervention methods

Cement-based materials	Reinforcing materials	Filling materials	Bonding materials
- Normal-strength concrete - High-strength concrete - Short-fiber reinforced mortar/concrete - Plasticized concrete - High-fluidity concrete - Expansive concrete - Polymer cementitious mortar/concrete	- Reinforcing steel - Prestressed concrete steel - Continuous fiber reinforcing materials	- Non-shrink grout - Non-shrink mortar - Expansive concrete	- Primer - Adhesive (resin-based, cement-based) - Anchor - Anchor grouting material

4.3.2 Cement-based materials

(1) The quality of cement-based materials may be indicated by the compressive strength or tensile strength required for the repaired or strengthened structure to exhibit its performance, as well as by other strength properties, Young's modulus and other deformation properties and material properties such as thermal properties and water-tightness. Particularly, consideration shall be given to the integrity with the existing concrete members as well as to the property of bonding with reinforcing materials and durability.

(2) In principle, high-quality cement-based materials shall be selected and an optimal mix proportion shall be determined by performing trial mixing by means of an appropriate mixing design method so as to minimize the change in quality over time after hardening.

[Commentary] (1) Cement-based materials refer to mortar, concrete and other materials used for top- and bottom-surface overlaying and jacketing. The quality requirements for these cement-based materials vary depending on the type and level of performance required for the repaired or strengthened structure. Currently, the materials used for overlaying or jacketing differ depending on the target method, and the materials of the appropriate types and quality are used. Here, the generally used cement-based materials are described, but this is not meant to prevent the use of other materials. It is necessary that cement-based materials shrink little, attain practical strength quickly and have excellent cracking resistance, flexural property and shear property. Also, they need to have excellent fatigue durability when used with top-surface overlaying or bottom-surface overlaying employed to strengthen bridge decks. With bottom-surface overlaying, whereby cement-based materials are applied to the bottom surface, these materials need to have particularly excellent bonding strength to ensure integrity with existing concrete members.

In general, with top-surface overlaying, steel fiber reinforced concrete utilizing high early strength cement, such as ultrarapid hardening cement or high early strength Portland cement, is used. With bottom-surface overlaying, polymer cementitious mortar with high bonding strength is used. With reinforced concrete jacketing, because it is important to make sure no voids are created between the overlaying parts and existing parts, plasticized concrete or high-fluidity concrete with a slump of approximately 18 cm is used, in some cases, together with an expansive material to reduce shrinkage.

The quality of cement-based materials is indicated not only by the compressive strength but by various other material properties as well. The strength properties are indicated by static strength, such as compressive strength, tensile strength, flexural strength and bonding strength, and fatigue strength. For the overlaying and jacketing methods, the bonding strength and fatigue strength are important material properties. Also, in addition to Young's modulus and Poisson's ratio, indices of mechanical properties, including toughness and cracking resistance, may be required as deformation properties for the overlaying and jacketing methods. However, generalized numerical handling methods for these properties are still in the research stage and have not been established yet.

(2) In general, cement-based materials are either provided as ready mixed concrete or mixed at the site. The quality of fresh concrete from the time mixing is complete until the concrete is laid changes over time and affects not only constructability but the material properties of the hardened concrete. Therefore, it is necessary to establish the mixing conditions so that the properties required for the hardened concrete are attained and to perform trial mixing in order to check the quality by means of the slump, air content, compressive strength and other material properties. Also, care needs to be exercised when selecting and mixing materials so as to prevent alkali-aggregate reaction and other problems from occurring due to the materials used.

When appropriate testing and analysis have confirmed that the compressive strength and other material properties of cement-based materials, which have been created with an appropriate mixing design through the use of good quality materials, will exhibit almost no change over time, the material properties at the time of verification may be used as those for strengthening construction. With the overlaying and jacketing methods, since cement-based materials are often placed on the outer surface of the structure, protection or some other appropriate measure should be taken to prevent changes in the cement-based materials over time. When changes in the material properties over time can be prevented through appropriate protection, the material properties at the time of verification may be used as those for strengthening construction.

In selecting the materials to be used and determining the mixing design, reference may be made to the following standard specifications, guidelines, etc.

- Design and Construction of Retrofitting Concrete Structures in Future—Tentative Draft for Performance-Based Design for Retrofitting—, Concrete Engineering Series JSCE, No.28, 1998 (Japan Society of Civil Engineers)
- Concrete Library 50, Recommendations for Design and Construction of Steel Fiber Reinforced Concrete, Draft, 1983.3 (Japan Society of Civil Engineers)
- Manual for Top-Surface Overlaying Design and Construction, 1995 (Express Highway Research Foundation of Japan)
- Concrete Library 97, Recommendations for Design of Steel Fiber Reinforced Concrete Columns, Draft, 1999.11 (Japan Society of Civil Engineers)
- Concrete Library 107, Recommendation for Design and Construction of Electrochemical Corrosion Control Method, 2011.11 (Japan Society of Civil Engineers)
- Concrete Library 113, Recommendations for Design and Constructions of Ultra High Strength Fiber Reinforced Concrete Structures, Draft, 2004.9 (Japan Society of Civil Engineers)
- Concrete Library 119, Recommendation for Concrete Repair and Surface Protection of Concrete Structure, 2005.4 (Japan Society of Civil Engineers)
- Recommendation for Shotcreting, 2005.7 (Japan Society of Civil Engineers)
- Concrete Library 127, Recommendations for Design and Constructions for High Performance Fiber Reinforced Cement Composite with Multiple Fine Cracks (HPFRCC), 2007.3 (Japan Society of Civil Engineers)
- Design Guidelines for Seismic Retrofitting of Existing Concrete Railway Viaduct Piers, 2013

- Second Edition for Design Procedures, Part for Maintenance of Bridges, 2017 (Nippon Expressway Research Institute Company Limited)

4.3.3 Reinforcing materials

The quality of reinforcing materials used together with cement-based materials shall be indicated by the compressive strength or tensile strength required for the repaired or strengthened structure to exhibit its performance, as well as by other strength properties, Young's modulus and other deformation properties and material properties such as thermal properties.

[Commentary] Reinforcing materials include reinforcing steel materials, such as reinforcing steel used with cement-based materials and prestressed concrete steel, and bar- or grid-shaped continuous fiber reinforcing materials. They also include steel used to anchor and connect these materials. The reinforcing steel materials should fulfill the quality requirements set forth in the relevant JIS standards. The quality of the reinforcing steel materials shall be indicated by material properties including strength properties such as compressive strength and tensile strength, fatigue strength and deformation properties such as Young's modulus, Poisson’s ratio and the stress-strain relationship. The reinforcing steel materials need to be checked to confirm that they possess mechanically reliable material properties including strength, elongation capacity, Young's modulus and coefficient of linear expansion. The material factors of the reinforcing steel materials shall be determined taking into consideration various factors including the purpose of use, design service life, load and environmental conditions, construction and maintenance. They may be determined in accordance with Section 5.4 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”.

In an extremely salty environment, the design becomes difficult or uneconomical with the salt-shielding property or thick covering of cement-based materials alone. Therefore, it may be more rational to use epoxy-coated reinforcing steel bars or stainless steel bars that have high corrosion resistance. Epoxy-coated reinforcing steel bars have remarkably higher corrosion resistance than normal reinforcing steel, by having the surface of reinforcing steel coated with epoxy resin. Stainless steel bars are reinforcing steel made of stainless steel, and they contain 10.5 percent by mass of chrome or more, which causes an oxide film to form on the steel surface, resulting in excellent corrosion resistance.

Continuous fiber reinforcing materials, used as a substitute for reinforcing steel and prestressed concrete steel, are made by encasing continuous fibers, such as aramid, glass and carbon, with matrix resin. Since there is no fear that these materials may corrode due to chloride ion penetration, the cross-sectional area can be reduced by thinning the covering or by some other means. The physical properties of continuous fiber reinforcing materials differ depending on the type and amount of fiber used, cross-sectional shape and surface condition.

4.3.4 Filling materials

(1) The filling materials must have the required filling property and fluidity and be able to attach the repaired or strengthened members firmly to the existing concrete members.

(2) If the filling materials are required to transfer stress, they must have sufficient strength to fulfill the required performance.

[Commentary] (1) Grout, non-shrink mortar and other filling materials are used that fill the interior of a frame placed inside the existing structure. A filling material having an appropriate filling property and fluidity must be selected according to the interval between the reinforcing materials and cement-based materials and the injection method. Significant bleeding or shrinkage creates gaps in the filled parts, potentially making the filling material unable to fulfill the required performance. Therefore, a test should be conducted in advance to determine the mix proportion and others. When the shear capacity and toughness of bar members are improved by jacketing, the cement-based materials and existing concrete do not necessarily need to be integrated; rather, it is important for them to be attached firmly to each other.
(2) If the weight, live load and other actions of members need to be transferred, it is necessary to use a filling material that has the required strength property.

4.3.5 Bonding materials

(1) As the bonding materials used to bond the repaired or strengthened members and existing concrete members, those proven to meet the specified quality and performance requirements must be selected.

(2) The bonding materials that can ensure integrity throughout the design service life must be selected through full consideration of the actions to be exerted on the repaired or strengthened structure and bonded parts.

[Commentary] (1) Bonding materials such as adhesives and anchors are used to bond the repaired or strengthened members and existing concrete members. Two types of adhesives are available: resin-based adhesives whose base material is epoxy resin or acrylic resin and cement-based adhesives such as polymer cementitious mortar. The bonding strength of an adhesive differs depending on the moisture state and roughness of the bonded parts of the existing concrete members as well as on the environmental conditions including temperature, humidity and wind. Therefore, these should be taken into consideration when selecting the material. The adhesive is required to shrink little when hardened and be of high quality in terms of water-tightness, heat resistance, chemical resistance, etc. while ensuring the usable time required for application. One way of driving anchors into an existing structure is the post-installed anchoring method whereby holes are drilled in hardened concrete and then post-installed anchors are inserted and secured in those holes. Anchors are mainly divided into metallic anchors and adhesive anchors. Post-installed anchors are required to be of high quality in terms of not only mechanical properties and constructability but also durability, fatigue property and so forth. When using or selecting post-installed anchors, reference may be made to “Concrete Library 141, Recommendations for Design and Constructions of Post-installed Anchors in Concrete, 2014.3” published by the Japan Society of Civil Engineers.
The integrity between the existing concrete members and repaired or strengthened members depends not only on the specifications and quality of the bonding material itself, such as an adhesive or anchor, but also on other factors including the strength of the existing concrete

members and whether or not there are cracks or vulnerable parts around those members. If it is judged that the specified performance requirements cannot be met, there arises the need to consider restoring the existing concrete members to a sound condition.

(2) The actions that may be exerted on the repaired or strengthened structure and bonded parts include load actions, such as dead load and live load, and environmental actions, such as creep and shrinkage of cement-based materials, temperature and water supply in the periphery of the structure and intrusion of degradation factors. In a corrosive environment where the supply of water, intrusion of chloride ions or any other problem is expected, care needs to be exercised in selecting the anchor material. As for resin-based adhesives, it is necessary to take into consideration the fact that their bonding strength and other physical properties vary depending on temperature and its history.

It is generally thought that the higher strength the cement-based materials have, the denser their composition becomes, thus leading to improved durability. The long-term integrity between the existing concrete members and repaired or strengthened members, on the other hand, does not necessarily depend on the bonding strength. The requirements for the bonding materials include being able to follow deformation, being not prone to peeling and flaking, having a bonding property that changes little over time and being resistant to the actions of degradation factors. It is desirable to select a bonding material and method that ensure the overall integrity of members even if the integrity between the repaired or strengthened members and existing concrete members is partially impaired by a load or environmental action. As for resin-based adhesives, it is empirically known that those excel in energy absorption until the deformation limit is reached can ensure integrity in a longer term than those with higher strength properties.

4.4 Characteristic Values and Design Values of Materials

4.4.1 General

(1) The characteristic values of the physical properties of the intervention materials shall take into consideration the variations in test values of the material physical properties obtained by means of a specified test method and ensure that the probability of the test values falling below them is at a specified level.

(2) Generally, the material factors of the intervention materials shall be determined in accordance with "Standard Specifications for Concrete Structures-2017, Design". If the material factors are specified separately for the material to be used, those specified values may be adopted.

(3) If standard values are specified, separately from the characteristic values of the material physical properties, for use when construction is performed in accordance with Chapter 7 "Construction", the values obtained by multiplying those standard values by the material modification factors may be used.

[Commentary] (1), (2) and (3) The characteristic values of the physical properties and the material factors of the materials used for intervention shall be the standard values of the design and material strengths of the materials and may be determined in accordance with Chapter 5 of "Standard Specifications for Concrete Structures-2017, Design, General Requirements".

4.4.2 Cement-based materials

The characteristic values of cement-based materials shall be as set forth in Section 5.3 of "Standard Specifications for Concrete Structures-2017, Design, General Requirements". As for cement-based materials not covered by the standard specifications for concrete structures, their characteristic values shall be determined through appropriate testing.

[Commentary] When normal-strength concrete is used as cement-based materials for strengthening members, the characteristic values of the materials should be determined in accordance with Section 5.3 of "Standard Specifications for Concrete Structures-2017, Design, General Requirements". In intervention construction, on the other hand, cement-based materials whose material properties are vastly different from those of normal-strength concrete may be used from the viewpoints of the bonding with existing concrete, the suppression of cracking and so on. In such a case, the characteristic values of the cement-based materials need to be determined based on the tests specified in the relevant Japanese Industrial Standard (JIS) documents, Japan Society of Civil Engineers standards, etc. as well as the quality certificates issued by the material manufacturers. Table C4.4.1 lists examples of the test methods for obtaining the characteristic values of materials. If the strength and other properties of a material changes depending on temperature even in the temperature range under the normal usage environment of the structure, as with polymer cementitious mortar, the characteristic values of the material need to be determined under the temperature condition appropriate for the usage environment.

(i) Strength

The values of the strength properties of a cement-based material are generally based on the strength determined by a test conducted when the material is 28 days old. For intervention construction, however, the structure may be required to go into service quickly. In such a case, the values of the strength properties may be based on the strength determined by a test conducted at an appropriate age of the material, taking into consideration the time load action is exerted.

It is known that, when short fiber or polymer is used, the tensile strength and other strength properties of a cement-based material relative to the compressive strength are greater than those of normal-strength concrete having the same compressive strength. Also, the strength properties substantially differ depending on the type of short fiber or polymer used, the amount used and so forth. It is therefore desirable that the values of the strength properties necessary for the design be obtained through testing. Since the values of the strength properties of a material depend on the construction quality and environmental conditions, it should preferably be possible for the test method to take their effects into consideration.

(ii) Fatigue strength

It has been reported that the flexural fatigue strength of short fiber reinforced concrete is greater than that of normal-strength concrete. At present, however, there is no established formula to calculate fatigue strength according to the type and mix ratio of fiber. It is therefore desirable to accumulate data on fatigue through testing, obtain the S-N curve and determine the characteristic value of fatigue strength.

(iii) Stress-strain curve

An appropriate stress-strain curve for a cement-based material needs to be assumed according to the purpose of the study of the limit state. For the study of the serviceability limit state, the stress-strain curve for a cement-based material may be assumed to be linear based on the characteristic value of Young's modulus. As for short fiber reinforced concrete, it has been reported that deformation performance in post-peak compressive strength or tensile strength is improved. When studying deformation, toughness or other property before the ultimate state is reached, it is desirable to determine an appropriate stress-strain curve.

(iv) Fracture energy

The fracture energy of a cement-based material generally increases in proportion to the amount of short fiber or polymer used. The fracture energy corresponds to the area below the tension softening curve consisting of the crack width and transferred tensile stress. For members where the occurrence and progress of cracking are dominant, giving consideration to the tension soften property may make a rational performance verification possible. The fracture energy of a cement-based material can be obtained through the test specified in JCI-S001 “Method of test for fracture energy of concrete by use of notched beam”.

(v) Young's modulus

Young's modulus of mortar is generally smaller than that of concrete. Also, Young's modulus of a cement-based material that uses polymers tends to be slightly smaller than that of a cement-based material that does not use polymers. Young's modulus of a cement-based material can be obtained in accordance with JIS A 1149 “Method of test for static modulus of elasticity of concrete”.

(vi) Poisson’s ratio

Poisson’s ratio of a cement-based material can be generally considered to be 0.2 within the range of elasticity in accordance with “Standard Specifications for Concrete Structures-2017, Design”.

(vii) Thermophysical properties

The coefficient of thermal expansion of a cement-based material that uses polymers tends to be greater than that of a cement-based material that does not use polymers. The coefficient of thermal expansion of the generally used polymer cementitious mortar is considered to be 15×10^{-6} or so. Also, the coefficient of thermal expansion varies depending on the rock type of aggregate. The coefficient of thermal expansion of a cement-based material can be obtained using the test methods specified in JSCE-K 561-2003 “Test methods of patching repair materials in concrete structures” and “Guidelines for Control of Cracking of Mass Concrete 2016”. Heat conductivity, specific heat and coefficient of heat diffusion should be determined based on experiments or available previous data.

(viii) Shrinkage

The characteristic value of shrinkage of a cement-based material can be obtained by conducting a test in accordance with JIS A 1129 (shrinkage strain observed using specimens, each measuring 100 × 100 × 400 mm, through 7 days of water curing followed by 6 months of dry curing at a temperature of 20°C and a relative humidity of 60%). The shrinkage of cement-based materials in the repaired or strengthened members should be calculated, taking into consideration such factors as the ambient humidity, rainfall condition, shapes and dimensions of member sections, environmental temperature and material age at the beginning of drying. If auto-shrinkage is dominant in cement-based materials, the shrinkage can be obtained in accordance with JCI-SAS2 “Test methods of auto-shrinkage and auto-swelling of cement paste, mortar and concrete, Draft”.

(ix) Creep

The characteristic value of creep of a cement-based material can be obtained in accordance with JIS A 1157 “Method of test for compressive creep of concrete” if “Standard Specifications for Concrete Structures-2017, Design, General Requirements” is not used. Since creep is affected by the ambient humidity, rainfall condition, shapes and dimensions of member sections, environmental temperature, material age when stress is applied and so on, the creep of cement-based materials in the repaired or strengthened members needs to be calculated taking these factors into consideration.

(x) Coefficient of carbonation rate

This value can be obtained in accordance with Section 5.3.13 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”.

(xi) Diffusion coefficient of chloride ions

This value can be obtained in accordance with Section 5.3.14 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”. When a cement-based material uses polymers, the diffusion coefficient of chloride ions tends to be considerably smaller than that of normal-strength concrete. Therefore, the test method should be selected, taking into consideration such factors as whether the test can be applied or not and the required test period.

(xii) Relative dynamic modulus of elasticity for the freezing-thawing test

This value can be obtained in accordance with Section 5.2.15 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”.

Table C4.4.1 Examples of test methods for cement-based materials

Item	Test method examples
Compressive strength	JIS A 1108: Method of test for compressive strength of concrete
	JIS A 1171: Test methods for polymer modified mortar
	JSCE-G 541-1999: Test method for compressive strength of filling mortar
	JSCE-G 551-2007: Test method for compressive strength and compressive toughness of steel fiber reinforced concrete
	JSCE-G 562-2007: Test method for early strength of sprayed concrete using prism specimen
	JSCE-G 505-1999: The method for compressive strength of mortar and cement paste using cylindrical specimens
Tensile strength	JIS A 1113: Method of test for splitting tensile strength of concrete
Flexural strength	JIS A 1106: Method of test for flexural strength of concrete
	JIS A 1171: Test methods for polymer modified mortar
	JSCE-G 552-2007: Test method for bending strength and bending toughness of steel fiber reinforced concrete
Bonding strength	JIS A 1171: Test methods for polymer modified mortar
	JSCE-K-561-2003: Test methods of patching repair materials in concrete structures
Fracture energy	JCI-S001: Method of test for fracture energy of concrete by use of notched beam
Young's modulus	JIS A 1149: Method of test for static modulus of elasticity of concrete
Coefficient of thermal expansion	JSCE-K-561-2003: Test methods of patching repair materials in concrete structures
	Guidelines for Control of Cracking of Mass Concrete 2016
Shrinkage	JIS A 1129: Methods of test for length change of mortar and concrete
	JIS A 1171: Test methods for polymer modified mortar
	JIS A 6202: Expansive additive for concrete
	JCI-SAS2: Test methods of auto-shrinkage and auto-swelling of cement paste, mortar and concrete, Draft
	JSCE-K-561-2003: Test methods of patching repair materials in concrete structures
Creep	JIS A 1157: Method of test for compressive creep of concrete
Coefficient of carbonation rate	JIS A 1153: Method of accelerated carbonation test for concrete
	JIS A 1171: Test methods for polymer modified mortar
Diffusion coefficient of chloride ions	JSCE-G 571-2007: Test method for effective diffusion coefficient of chloride ion in concrete by migration
	JSCE-G 572-2007: Test method for apparent diffusion coefficient of chloride ion in concrete by submergence in salt water
Relative dynamic modulus of elasticity	JIS A 1148: Method of test for resistance of concrete to freezing and thawing

4.4.3 Reinforcing materials

(1) The characteristic values and design values of steel shall be as set forth in Section 5.4 of "Standard Specifications for Concrete Structures-2017, Design, General Requirements". As for materials not covered by the standard specifications for concrete structures, their characteristic values and design values shall be determined through appropriate testing.

(2) The characteristic values and design values of continuous fiber reinforcing materials shall be as set forth in Section 3.4 of "Recommendation for Design and Construction of Concrete Structure Using Continuous Fiber Reinforcing Materials". As for materials not covered by JSCE-E131 "Specification for continuous fiber reinforcing materials", their characteristic values and design values shall be determined through testing.

[Commentary] (1) The characteristic values and design values of steel not covered by "Standard Specifications for Concrete Structures-2017, Design" need to be determined through appropriate testing or by some other means.

Epoxy-coated reinforcing steel bars must be in compliance with JSCE-E 102 "Specification for epoxy-coated reinforcing steel bars" or proven through experiments to meet quality requirements. It has been reported that the bonding strength of epoxy-coated reinforcing steel bars to concrete is reduced to approximately 85% of that of ordinary reinforcing steel bars. Therefore, care needs to be exercised about the fact that an increase in the bonding loss region leads to an increase of approximately 10% in the flexural crack width when the same reinforcement stress is applied compared with ordinary reinforcing steel bars, as well as about taking appropriate measures such as securing a longer anchoring length. When using epoxy-coated reinforcing steel bars, reference should be made to "Concrete Library 112, Recommendations for Design and Constructions of Concrete Structures Using Epoxy-Coated Reinforcing Steel Bars -Revised Edition-, 2003.11" published by the Japan Society of Civil Engineers.

Stainless steel bars must be in compliance with JIS G4322 "Stainless steel bars for concrete reinforcement" or proven through experiments to meet quality requirements. Three types of stainless steel bars (SUS304-SD, SUS316-SD and SUS410-SD) are specified in JIS G4322. Since the stress-strain relationship and corrosion resistance differ for each type, it is important to have a full understanding of their properties. The coefficient of thermal expansion of stainless steel bars ranges from 10 to 17 μ/°C, depending on the type. Therefore, when they are used in an environment where the temperature changes greatly, care may need to be exercised. When using stainless steel bars, reference should be made to "Concrete Library 130, Recommendations for Design and Constructions of Concrete Structures Using Stainless Steel Bars -Draft-, 2008.8" published by the Japan Society of Civil Engineers.

(2) The physical properties of continuous fiber reinforcing materials differ depending on the type and amount of fiber used, cross-sectional shape and surface condition. Continuous fiber reinforcing materials must be in compliance with JSCE-E131 "Specification for continuous fiber reinforcing materials" or proven through experiments to meet quality requirements. In principle, the tensile test of continuous fiber reinforcing materials shall be conducted in accordance with JSCE-E 531 "Test method for tensile properties of continuous fiber reinforcing materials". It is known that the variations in tensile strength of continuous fiber reinforcing materials are generally larger than those of steel. The characteristic value of tensile strength shall ensure that most of the test values do

not fall below it.

The nominal cross-sectional area shall be used to calculate the characteristic value of tensile strength and Young's modulus, pursuant to JSCE-E 531 “Test method for tensile properties of continuous fiber reinforcing materials”.

The characteristic value of bonding strength of grid-shaped continuous fiber reinforcing materials is determined by the strength of the grid crossings and the bonding property of cement-based materials and existing concrete between grids. It is therefore necessary to check the characteristic value of the combined bonding strength of the continuous fiber reinforcing materials and cement-based materials. When the characteristic value of fatigue strength is determined, the fiber type of continuous fiber reinforcing materials, magnitude and frequency of stress application, environmental conditions and so on shall be taken into consideration. The coefficient of thermal expansion of continuous fiber reinforcing materials needs to be checked through testing because it significantly varies depending on the type of fiber and the method of manufacturing.

The characteristic values and material factors of continuous fiber reinforcing materials shall be as set forth in Chapter 3 of “Recommendation for Design and Construction of Concrete Structure Using Continuous Fiber Reinforcing Materials (Design)”.

4.4.4 Bonding materials

In principle, the characteristic values and design values of a bonding material shall be determined through appropriate testing.

[Commentary] In securing the load bearing performance required for a composite structure that integrates the repaired or strengthened members and existing concrete members, the bonding strength and shear strength obtained when cement-based materials are bonded to concrete are used as the values of strength properties of the bonding material, instead of its mere material strength. When the relative displacement, separation and other changes in the repaired or strengthened members and existing concrete members are allowed, the strength and deformation properties of the bonding material itself may be taken into consideration.

CHAPTER 5 ACTIONS

5.1 General

(1) In the performance verification of a structure, the actions expected during the construction and the design service life shall be considered in appropriate combinations according to the limit state for the required performance. Actions shall include all those that increase or decrease the stress on or deformation of the structure and members and that cause changes in material properties over time.

(2) A design action shall be determined by multiplying the characteristic value of the action by the action factor.

(3) In principle, combinations of design actions shall be as set forth in Chapter 6 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”.

(4) The characteristic values of actions shall be determined individually with respect to the limit states for each performance requirement to be considered.

(5) In principle, the action factor by which to multiply the characteristic value of the action to determine the design action shall be as set forth in Chapter 6 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”.

(6) In the performance verification, the specified actions shall be taken into consideration.

[Commentary] (1) Actions shall include all those that increase or decrease the stress on or deformation of the structure and members and that cause changes in material properties over time. Actions are generally divided into permanent actions, variable actions and accidental actions, according to the duration of action, the extent of variation and frequency of occurrence. Since the performance verification at the time of strengthening is the same as that of an existing structure, the design actions for strengthening design shall be in principle as set forth in Chapter 6 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”.

(3) In general, the combinations of design actions shall be as shown in Table C5.1.1.

(4) and (5) The performance requirements to be considered shall be safety verification, serviceability verification, restorability verification and durability verification. In general, the characteristic values, action factors and action types used for the verification may be determined according to Table C5.1.2.

(6) The action types shall be in principle as set forth in Chapter 6 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”. For the performance verification, all the actions that increase or decrease the stress on or deformation of the structure and members and that cause changes in material properties over time shall be included.

Table C5.1.1 Combinations of design actions

Required performance	Limit state	Combination to be considered
Durability	All limit states	Permanent action + variable action
Safety	Cross-sectional failure, etc.	Permanent action + primary variable action + secondary variable action
		Permanent action + accidental action + secondary variable action
	Fatigue	Permanent action + variable action
Serviceability	All limit states	Permanent action + variable action
Restorability	All limit states	Permanent action + accidental action + secondary variable action

Table C5.1.2 Action factors

Required performance	Limit state	Action type	Action factor
Durability	All limit states	All actions	1.0
Safety	Cross-sectional failure, etc.	Permanent action	1.0 to 1.2
		Primary variable action	1.1 to 1.2
		Secondary variable action	1.0
		Accidental action	1.0
	Fatigue	All actions	1.0
Serviceability	All limit states	All actions	1.0
Restorability	All limit states	All actions	1.0

If it is disadvantageous that the permanent actions other than the self-weight are smaller, then the action factors for the permanent actions should be set to 0.9 to 1.0.

5.2 Actions to Be Considered for the Intervention Design

(1) In the intervention design, it is necessary to appropriately take into consideration the actions that may occur on the existing structure and repaired or strengthened parts.

(2) When the measured values of the actions are known as characteristic values, those measured values may be used as characteristic values if doing so enables rational design.

[Commentary] (1) Note that, when intervention is performed for an existing structure, there are permanent actions that have been applied to that existing structure since before intervention. Some permanent and variable actions increase after intervention. These actions need to be taken into consideration appropriately according to the target structure, and they differ depending on the members for which intervention is performed, the purpose of intervention and the construction method. It is necessary to separate and consider the actions on the repaired or strengthened structure in their respective states, as well as to synthesize responses rationally.

The environment of the structure shall be grasped to verify environmental actions. The environment of each individual structure for which the intervention design is performed differs in temperature, sunlight exposure, humidity, water supply and other factors including the concentration and supply of substances, and it is not rare that these structures are under severe conditions. Also, substances that cause deterioration, such as chloride ions, may diffuse from the existing structure to the repaired or strengthened parts. For these reasons, it is necessary to grasp the environment of the existing structure and appropriately take into consideration the environmental actions after intervention.

(2) It is conventionally common practice to measure and verify the characteristic values acting on the structure before performing the intervention design. These measured values refer to those determined by appropriate means such as statistical processing of multiple measurement results. Such measured values may be used as characteristic values if doing so enables the condition of the actual structure to be verified concretely and makes rational design possible. When such characteristic values are adopted, the action factors used for design actions shall be relaxed or tightened from those shown in Table C5.1.2.

CHAPTER 6　PERFORMANCE VERIFICATION FOR THE REPAIRED OR STRENGTHENED STRUCTURE

6.1 General

(1) The performance verification for the repaired or strengthened structure shall be performed in principle by establishing limit states relative to durability, safety, serviceability and restorability either for a structure during the design service life or for each of its structural members and checking that the structure or structural members having the structural details assumed in the design, such as shape, dimensions and reinforcement arrangement, do not reach any limit state.

(2) The verification of the limit states of the repaired or strengthened structure shall be performed in principle by establishing appropriate verification indices and comparing their limit values and response values.

(3) In principle, for the performance verification for the repaired or strengthened structure, mathematical models based on the mechanisms of the materials and structure shall be used or demonstrations shall be conducted through experiments or by other means. The intervention method shall be considered on the assumption that it meets the specifications proven through experiments or by other means to be suitable for the target structure.

(4) In general, the performance verification for the repaired or strengthened structure shall be performed using Equation 6.1.1.

$$\gamma_i S_d / R_d \leq 1.0 \tag{6.1.1}$$

where S_d: Design response value

R_d: Design limit value

γ_i: Structure factor, which in general may be set to 1.0 to 1.2.

[Commentary]　It has been decided that the limit states of the repaired or strengthened structure shall be established relative to durability, safety, serviceability and restorability, as with existing structures. For the verification, the performance requirements for the repaired or strengthened structure need to be established appropriately. The performance after intervention is realized jointly by the existing members and repaired or strengthened members, and it shall be evaluated while taking into consideration the properties of the individual members, the combinations of actions and failure modes. Also, it is especially important that the effect of intervention be proven through experiments or by other means prior to the evaluation. In the case of a civil engineering structure, it is difficult to reproduce the actual actions at the actual scale of the structure through experiments, which makes it necessary to conduct load experiments and other tests by using a modeled specimen. Since the dimensions, section properties, reinforcement arrangement details and so forth of the modeled specimen are different, it is important that the results of these experiments take into consideration the various differences in the experiment conditions. Therefore, the verification for the actual structure should be performed by complementing the experiments with an analysis model or analysis method having proven estimation accuracy for the experiment results. The performance verification for the repaired or strengthened structure may be performed in accordance with Chapter 4 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements” when appropriate consideration has been given to the features of the selected intervention method.

The performance verification for the repaired or strengthened structure shall be performed in principle taking into consideration the changes in performance over time due to environmental actions and other factors. Note that this chapter specifies how to verify the performance of the repaired or strengthened structure without considering the degradation in materials during the design service life on the assumption that the requirements for the consideration on durability described in Section 6.3 are met.

6.2 Calculation of Response Values

6.2.1 General

(1) In principle, response value calculation shall involve performing a structural analysis by means of an analysis model of proven reliability and accuracy, which is obtained by modeling the actions and structure according to the shape of the structure, the support conditions, the states of actions and the limit states to be considered, and calculating such response values as sectional force, stress level, crack width, deflection and so forth according to verification indices.

(2) When the response values of the repaired or strengthened structure are calculated, changes in those values over time shall be taken into consideration in principle. If material degradation due to environmental actions can be ignored as set forth in Section 6.3, the response values may be calculated without considering changes over time caused by these actions.

[Commentary] (1) The calculation of the response values used for the verification of the limit states of the individual performance requirements of the repaired or strengthened structure must appropriately reflect the combined properties of the existing members and repaired or strengthened members. When the response values are calculated by means of a non-linear analysis or other advanced analysis method, it is necessary to ensure a certain level of accuracy.

6.2.2 Modeling

(1) The range and dimension of analysis shall be established and the actions and structure shall be modeled according to the response properties of the structure deriving from the actions.

(2) In modeling, the analysis range consisting of the structure, members, bonded parts, ground, boundary elements and so on shall be established according to the range in which responses occur.

(3) If an analysis range including ground is established, modeling shall be performed so that the influence of that range is taken into consideration appropriately.

[Commentary] When modeling a structure, it is necessary to establish an analysis range that covers the entire range in which responses occur due to actions. If the influence of such coverage is small or if such influence can be allowed for by boundary conditions, the analysis range may be divided into structural elements for modeling purposes.

6.2.3 Structural analysis

(1) For structural analysis, a structural analysis method must be used that meets the action and structural modeling needs and makes verification indices available. If verification indices cannot be obtained directly from structural analysis, a structural analysis method may be used that enables conversion to verification indices by appropriate means.

(2) As for structural members, the influence of non-linearity shall be taken into consideration according to the response. A structural member may be regarded as a linear one if it is evident that the non-linearity of the member does not affect verification indices, such as sectional force, or that conservative and rational evaluation results are obtained.

(3) Structural analysis for the verification of cross-sectional and fatigue failures of the repaired or strengthened structure or for the verification of restorability should preferably take into consideration the influence of the peeling and floating of the existing members and strengthened members.

[Commentary] (1) For structural analysis, an analysis method shall be selected according to the action and structural modeling. Also, in order to perform structural performance verification, it is desirable that verification indices be able to be obtained directly from structural analysis. Therefore, where possible, a structural analysis method that enables verification indices to be obtained directly needs to be selected. If the response values of verification indices cannot be obtained directly from structural analysis, it is necessary to convert the response values of indices obtained from the analysis to the design response values of verification indices by appropriate means.

The verification does not necessarily require that the same structural model and analysis theory be used for all limit states. A structural model and an analysis theory appropriate for each individual limit state may be used. Also, it is necessary to select a structural analysis factor γ_a according to the analysis theory used to calculate the response values.

(2) Since the rigidity of the repaired or strengthened structure changes due to such factors as the occurrence of cracks, the non-linearity of the materials of the members needs to be taken into consideration appropriately. In general, the mechanical model for materials mentioned in Chapter 4 may be used for material non-linearity.

(3) The verification of cross-sectional failure of the repaired or strengthened structure assumes that the integrity of the existing and strengthened members is guaranteed. The possible failure modes of the repaired or strengthened structure include peeling failure of the repaired or strengthened members in addition to bending failure and shear failure. Here, it is desirable that the structural analysis for the repaired or strengthened structure involve considering the influence of the peeling and floating of the repaired or strengthened members appropriately, in addition to the structural analysis specified in "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". In that case, the structural analysis factor γ_a may be set to 1.0 by specifying the structural details of the intervention method.

6.2.4 Calculation of design response values

Design response values shall be calculated by converting the response values obtained as mentioned in Section 6.2.3 to verification indices through the use of an appropriate method.

[Commentary] For the modeling of the repaired or strengthened structure, there are two methods. One uses fiber-model-based sectional forces for calculation, and the other uses the finite element method to calculate stress, strain, etc. as response values. If stress and strain are used as verification indices or the response values of stress and strain are converted to verification indices by means of the finite element method, it is necessary to conduct a thorough study because there are currently various restrictions.

6.3 Durability Verification

6.3.1 General

(1) It must be verified that the repaired or strengthened structure sustains the required durability throughout the design service life. Note that there is the need to check that the integrity of the existing parts and repaired or strengthened parts is guaranteed based on the intervention design.

(2) It shall be checked in accordance with "Standard Specifications for Concrete Structures-2017, Design" that the required performance of the repaired or strengthened structure is not impaired by steel corrosion or cement-based material degradation. If these factors are combined, its influence shall be taken into consideration.

[Commentary] (1) If the evaluation reveals that a change may occur in the structure prematurely before the end of the design service life specified in the intervention design, making it impossible to guarantee the target durability (re-degradation), an appropriate design needs to be considered again. In this case, proper measures are required that take into full consideration how the re-degradation has occurred.

The performance characteristics of the repaired or strengthened structure are achieved by the integrity of the existing parts and repaired or strengthened parts, which is also true for durability. Therefore, the verification assumes that the bonded parts between the existing parts and repaired or strengthened parts do not suffer peeling, floating or any other condition that impairs the integrity.

The integrity of the existing parts and repaired or strengthened parts is affected by not only external forces and vibration but also a vast range of other factors, including indirect actions on cement-based materials and bonding materials (time-dependent deformation such as shrinkage or creep), degradation of cement-based materials (freezing and thawing or alkali-aggregate reaction), problems with the construction method (inappropriate chipping, surface preparation or primer) and incompatibility between cement-based materials and bonding materials. The involvement of water in the interface has a particularly great impact on the integrity of the bonded parts, and grasping the condition of water supply to the repaired or strengthened members is extremely important for appropriate maintenance.

Therefore, in the intervention design, it is of primary importance to eliminate the factors that affect the integrity of the existing parts and repaired or strengthened parts through careful examinations of the design contents and construction method and, if necessary, preventive measures for the interface (e.g., use of bonding materials) shall be considered. It is also important to select cement-based materials and bonding materials having the specified levels of strength, durability and water-tightness and sufficient constructability. The use of a water absorption adjustment material (primer) suppresses the occurrence of dry-out (which causes the moisture in the repaired or strengthened parts to transfer to the existing parts) at the bonded parts, making the hydration organization dense and contributing to ensuring the integrity.

One index used to check that the integrity of the existing parts and repaired or strengthened parts will be sustained for a long period of time is the bonding strength of the cement-based materials and bonding materials, which is measured after the history of loads due to environmental actions is given in a stimulatory manner. Since the bonding strength is a strength property at the bonded parts, further studies are needed as to other indices of bond durability (energy and elongation capacity).

The available indices of the bonding strength measured after the history of loads due to environmental actions is given in a stimulatory manner include the bond durability (after repeating 10 heating and cooling cycles) set forth in JIS A 1171 “Test methods for polymer modified mortar”, the bonding strength after various environmental loads (high humidity, underwater, repeated drying and wetting and repeated heating and cooling) set forth in “Test methods of patching repair materials in concrete structures” of JSCE and, in the case of bonding materials, the bonding strength after the history of hot water loads and the water immersion tensile fatigue test set forth in NEXCO test method 434 “Performance test methods of epoxy resin adhesive for overlaid concrete”.

(2) The degradation of the repaired or strengthened structure needs to be predicted comprehensively, taking into consideration the degradation process unique to intervention. Also, given the cases of re-degradation due to macro-cell corrosion, it is necessary to give due consideration to the performance of the entire structural system even if the applied intervention is partial.

The techniques for evaluating the durability of cement-based materials used for intervention are not organized well enough compared to those for concrete. Therefore, the technique by which to divide the period during which durability can be guaranteed into long, medium and short terms in accordance with “Standard Specifications for Concrete Structures-2013, Maintenance” is also effective. If it is difficult to ensure the required durability with the cement-based materials alone, the application of the surface protection method (Concrete Library 119, Recommendation for Concrete Repair and Surface Protection of Concrete Structure, 2005.4), the electric corrosion prevention method (Concrete Library 107, Recommendation for Design and Construction of Electrochemical Corrosion Control Method, 2011.11) or the like may be considered.

6.3.2 Verification related to steel corrosion

The required performance of the repaired or strengthened structure must not be impaired by steel corrosion due to carbonation, chloride ion penetration, etc. during the design service life under the given environmental conditions. Generally, item (1) below shall be verified first and then items (2) and (3) shall be verified in principle. Appropriate limit values shall be set respectively according to the conditions of the structure pursuant to Part 2 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods".

(1) The crack width on the surface shall be less than the limit value of the crack width for steel corrosion.

(2) The amount of steel corrosion due to carbonation and water penetration shall be less than the limit value.

(3) The chloride ion concentration at the position of the steel shall not reach the limit concentration for the occurrence of steel corrosion during the design service life.

[Commentary] (1) Appropriate values shall be set as the limit values of the crack width for steel corrosion of the repaired or strengthened structure according to the conditions of the structure pursuant to "Standard Specifications for Concrete Structures-2017, Design".

(2) In evaluating the progress of carbonation in the repaired or strengthened members, it is important to appropriately grasp the in-service environmental conditions. Generally, carbonation progresses rapidly in a relatively dry condition. However, subsequent steel corrosion requires the involvement of water, and the progress of carbonation tends to be accelerated in a place that is prone to the repetition of drying and wetting. Therefore, steel corrosion due to carbonation is prone to occur on the bottom surfaces of overhanging decks and main girders of an over-road bridge, places near girder edges, etc. From the viewpoint of water supply, these places are significantly affected by exposure to rainwater and inappropriate drainage (e.g., water leaks from expansion joints). Inappropriate waterproofing and throating are equally detrimental.

(3) To predict the condition of chloride ion penetration, it is common to use the equation based on the diffusion theory represented by the analytical solution derived from Fick's diffusion equation assuming constant surface concentration, which is adopted in "Standard Specifications for Concrete Structures-2017, Design". When making a clear distinction between the existing parts and repaired or strengthened parts, reference may be made to the method pursuant to the specifications set forth in "Concrete Library 119, Recommendation for Concrete Repair and Surface Protection of Concrete Structure, 2005.4" among others. In addition, more advanced methods such as one that uses numerical analysis can be used as well. Also, if necessary, consideration should be given appropriately, based on test data and other reliable reference information, to the impact of cracks on chloride ion penetration from the outside, the impact of internal salt permeating reversely from deep inside the covering of the existing parts, the impact of rust-proofing agent (e.g., lithium nitrite) and salt absorbing material mixed with cement-based materials to prevent salt damage, the impact of bonding materials on mass transfer resistance at the interface between the existing parts and repaired or strengthened parts (for example, the cured coating of epoxy resin adhesive exhibits low moisture permeability) and so on.

Many cement-based materials used for intervention, a typical example being polymer cementitious mortar, have high resistance to the penetration of chloride ions (degradation factor) compared to ordinary concrete. Depending on the thickness of the covering and other conditions, however, it may be necessary to conduct an appropriate study taking into consideration the location, members and other aspects of the structure. If the structure is in an environment subject to particularly severe salt damage due to the proximity to the seashore, anti-freezing agent being sprayed in large quantities, etc., preventive measures (such as use of epoxy-coated reinforcing steel bars and simultaneous use of a surface protection method or electric corrosion prevention method) shall be taken as needed. If the use of a sacrificial anode material, the application of an electric corrosion prevention method, etc. are deemed to be necessary, attention needs to be paid to the electrical resistivity of the cement-based materials to be used.

6.3.3 Verification related to degradation of cement-based materials

(1) In principle, the verification related to the freezing damage to cement-based materials shall be performed in two separate stages of (i) verification of internal damage and (ii) verification of surface damage (scaling) in accordance with Part 2 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods".

(i) If degradation occurs in the cement-based materials inside the repaired or strengthened structure, a verification of internal damage shall be performed. This verification does not need to be performed if the structure is of an ordinary type and the characteristic value of the relative dynamic modulus of elasticity of the cement-based materials observed in the freezing-thawing test is 90% or more.

(ii) If freezing damage is sustained by the cement-based materials on the surface of the repaired or strengthened structure, a verification of surface damage (scaling) shall be performed.

(2) The verification related to chemical erosion shall be performed in accordance with Part 2 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods".

[Commentary] <u>(1)</u> The characteristic value of the relative dynamic modulus of elasticity of the cement-based materials shall be determined based on that specified in Method A (In-water freeze-thaw test method) of JIS A 1148 "Method of test for resistance of concrete to freezing and thawing". It is generally said that Method A uses stricter conditions than those of Method B (Test method for freezing in air and thawing in water). At present, in order to evaluate the resistance of cement-based materials to surface damage (scaling), the methods specified in overseas standards ASTM C672 and RILEM TC117-FDC shall be employed.

The degradation of cement-based materials due to freezing and thawing tends to become obvious at places where freezing and thawing actions are repeated many times (e.g., members directly exposed to sunlight and wind and those prone to temperature changes) as well as at places prone to water supply (e.g., exposure to rainwater, inappropriate drainage and water leaks). Degradation due to freezing damage is caused by environmental actions peculiar to snowy, cold regions. It is known that, under conditions where anti-freezing agents are sprayed in large quantities and there is a supply of chloride ions, scaling is accelerated. It has been pointed out that, once scaling occurs on the top surface of reinforced concrete decks due to freezing and thawing actions, degradation and damage, such as pop-outs and turning into gravel, are induced, thus reducing the effective section thickness and lowering the fatigue durability.

If water enters the interface of the bonded parts and freezing and thawing actions are exerted with the interface submerged in water, the integrity of the existing parts and repaired or strengthened parts may be impaired. If the repaired or strengthened parts are prone to degradation due to freezing and thawing, it is important to carefully remove degraded parts and achieve appropriate waterproofing and drainage designs during the surface preparation at the time of construction. If it is difficult to ensure resistance to freezing and thawing with the cement-based materials alone, the application of the surface protection method needs to be considered as well.

(2) Since chemical erosion can be caused by numerous causal substances for degradation in many different ways, it is difficult to evaluate its impact on cement-based materials in a uniform manner. One sure way is to verify the performance by conducting exposure tests in the actual environment. This involves calculating the erosion rate of cement-based materials from the exposure period and checking that degradation does not reach the limit depth of the structure during the design service life.

As for degradation in the sewage environment caused by sulfuric acid (derived from sulfur-oxidizing bacteria) and organic acid, specific and useful information can be found in the "Technical Manual: Corrosion Control Measures for Sewerage Concrete Structure" of the Japan Sewage Works Agency.

6.4 Safety Verification

6.4.1 General

In principle, the safety verification of the repaired or strengthened structure shall generally involve checking that the limit states of cross-sectional and fatigue failures are not reached.

[Commentary] The method set forth herein is the standard one for verifying that the repaired or strengthened structure sustains the required safety during the design service life. In addition to the verification described in this section, the requirements specified in the individual method-specific sections need to be fulfilled.

6.4.2 Verification related to cross-sectional failure

6.4.2.1 General

(1) There are a period during which the repaired or strengthened structure responds to permanent actions that have been exerted since before intervention and a period during which the structure responds to both permanent and variable actions that increase after intervention. The responses of the repaired or strengthened structure shall be separated and considered in their respective states and synthesized rationally.

(2) The verification of the performance of members repaired or strengthened in accordance with "Standard Specifications for Concrete Structures-2017, Design" must involve verifying the integrity of the existing members and repaired or strengthened members. Such verification may be omitted in the case of an intervention method proven to guarantee integrity by complying with the specified structural details, materials used and construction methods.

(3) The safety verification shall be performed by checking that none of the structural members reaches the limit state of cross-sectional failure under design actions.

[Commentary] (1) The intervention effect expected of the existing structure through intervention applies only to increments in loads acting on the repaired or strengthened structure. It is therefore necessary to consider the responses before and after intervention and verify them in combination.

(2) The integrity of the existing members and repaired or strengthened members shall be guaranteed in principle, and the performance of members repaired or strengthened in accordance with "Standard Specifications for Concrete Structures-2017, Design" shall be verified. Depending on the intervention method or target structure, the design is done so that the integrity of the existing members and repaired or strengthened members is guaranteed on condition of strict compliance with the structural details, materials used and construction methods. Reference should be made to the structural details, materials used and construction methods specified in the individual method-specific sections. The preconditions for the verification should preferably be taken into consideration appropriately.

6.4.2.2 Verification related to bending moment and axial force

(1) The axial load-carrying capacity of the members jacketed with reinforcing materials may be calculated using a method that appropriately takes into consideration the reinforcing effect of the reinforcing materials.

(2) When the design cross-sectional strength of the repaired or strengthened members is calculated relative to the member cross section or unit width according to the direction of action of the sectional force, "Standard Specifications for Concrete Structures-2017, Design, General Requirements" shall govern. As for the sectional force acting on the repaired or strengthened members, the sectional force borne by the existing members and that borne by the composite members comprising the existing and repaired or strengthened members shall be taken into consideration appropriately. Note that this verification assumes that the integrity of the existing members and repaired or strengthened members is guaranteed. The stress-strain curve of concrete and steel shall be determined in accordance with "Standard Specifications for Concrete Structures-2017, Design, General Requirements". The stress-strain curve of continuous fiber reinforcing materials shall be determined in accordance with "Standard Specifications for Hybrid Structures-2014, Design, Standard Methods". As for overlaying materials, an appropriate stress-strain curve for each individual intervention method shall be used in principle.

[Commentary] (2) Giving lateral confinement by placing tie reinforcement or the like in the existing structure by means of an intervention method improves the cross-sectional performance of the repaired or strengthened structure. The confinement effect, however, is affected by many factors such as the material, shape, pitch and volume ratio of the confining steel and the gradient and rate of strain of confined concrete. It is therefore desirable to check that experiment results appropriate for the intervention method concerned have been obtained and to use a stress-strain curve based on those results.

6.4.2.3 Verification related to shear force

(1) The safety verification related to the shear force of the repaired or strengthened members must be performed taking into consideration the type of member (bar member, surface member, etc.), boundary conditions of members, the application states of loads, the direction of action of shear force and so forth. Note that this verification assumes that the integrity of the existing members and overlaying members is guaranteed.

(2) For bar members, a shear capacity calculation method appropriate for the load bearing mechanism taking into consideration the boundary conditions of members and the application states of loads must be used. The effect of the repaired or strengthened members may be added to the shear capacity borne by the repaired or strengthened members using a calculation method proven through experiments or

by other means.

(3) For surface members, the load surface is separated from the free end or the opening of the member and the eccentricity of the load is small, the punching shear capacity must be calculated with appropriate consideration given to the effect of reinforcing materials.

[Commentary] (1) and (2) Since the behavior and failure mechanism of members under the action of shear force differ depending on the type of member and the direction of action of shear force, the safety verification needs to be performed by means of a method that takes these factors into consideration. Also, among the failure mechanisms unique to the repaired or strengthened structure is peeling failure of the existing and overlaying members, which makes it necessary to perform the verification set forth in Section 6.4.2.4 as well. Since the shear capacity borne by the repaired or strengthened members differs depending on the intervention method and the type of the target structure, it is desirable to confirm the intervention effect through experiments or by other means and give consideration in an appropriate way.

6.4.2.4 Verification related to the integrity of overlaying members

The verification related to the integrity of overlaying members must involve checking that the occurrence of peeling of overlaying materials or splitting cracks in the covering concrete of existing members does not lead to the corresponding failure under the design actions.

[Commentary] The performance verification of the repaired or strengthened members assumes that the integrity of the existing members and repaired or strengthened members is guaranteed in principle, and it shall be performed in accordance with "Standard Specifications for Concrete Structures-2017, Design". Among the failure modes unique to the repaired or strengthened structure is peeling failure of the repaired or strengthened members. Depending on the intervention method and the type of the target structure, the safety verification may need to be performed taking into consideration peeling strength as well as design cross-sectional strength.

6.4.3 Verification related to fatigue failure

(1) The verification of fatigue safety shall check flexural strength and shear capacity for beams and flexural strength and punching shear capacity for slabs. In general, the performance verification for columns may be omitted.

(2) The characteristic values of fatigue strength of the materials comprising the section shall be determined based on the fatigue strength found through testing that takes into consideration the types, shapes and dimensions of the materials, magnitude and frequency of stress application, environmental conditions and so on.

(3) The fatigue capacity of the repaired or strengthened structure shall be calculated taking into consideration the fatigue property and peeling fatigue failure of the repaired or strengthened members appropriately in addition to the fatigue property of the existing members.

[Commentary] (1) The verification of the limit state of cross-sectional failure related to the fatigue of the repaired or strengthened members also assumes that the integrity of the existing and repaired or strengthened members is guaranteed in principle, and it shall be performed with regard to the fatigue failure of the main and shear reinforcement subject to repeated tensile stress.

(2) As the fatigue property of the materials used for intervention, the design fatigue strength shall

be determined through testing in principle taking into consideration the conditions of use, environmental conditions, etc. appropriately.

(3) The fatigue capacity of the repaired or strengthened structure assumes in principle that the integrity of the existing members and repaired or strengthened members is guaranteed and shall be based on the design fatigue strength of each material used. Also, it shall be calculated taking into consideration the peeling fatigue failure of the repaired or strengthened members appropriately. It has been revealed that the punching shear fatigue capacity is reduced significantly under the repeated action of moving loads, as on highway bridge decks, compared to the case where the load point is fixed. In such a case, the capacity needs to be estimated through experiments or by other appropriate means.

6.5 Serviceability Verification

6.5.1 General

(1) It must be verified that the repaired or strengthened structure sustains the required serviceability throughout the design service life.

(2) The serviceability verification shall be performed by checking that none of the members of the repaired or strengthened structure reaches the limit state of serviceability under design actions in accordance with "Standard Specifications for Concrete Structures-2017, Design".

(3) In principle, the physical quantities appropriate for the purpose of use of the repaired or strengthened structure shall be established as verification indices.

[Commentary] It shall be examined that the repaired or strengthened structure or members will sustain sufficient functions suitable for the purpose of use, such as comfort, during the design service life by means of an appropriate method that takes into consideration the effect of the relevant intervention method as a precondition for the verification. The integrity of the existing parts and repaired or strengthened parts needs to be guaranteed.

6.5.2 Stress level limit

To prevent excessive deformation or harmful cracking from occurring while the repaired or strengthened structure is in service, care must be exercised to ensure that the level of stress that load and environmental actions cause on the members of the repaired or strengthened structure does not exceed the limit value of the appropriate stress level determined from serviceability.

[Commentary] As the limit value of the stress level applicable when the repaired or strengthened structure or members are in service, that specified in Section 10.2 of "Standard Specifications for Concrete Structures-2017, Design, General Requirements" is recommended. Here, the stress level refers to that obtained by totaling the stress level due to the permanent actions before intervention and the stress level due to the permanent and variable actions after intervention. While preconditions differ depending on the intervention method, the calculation of the level of stress of each constituent element applied to the member section may be based on the hypotheses mentioned below, assuming that the integrity of the existing parts and repaired or strengthened parts is guaranteed in principle. If the integrity between the concrete and repaired or strengthened parts is not secured, the individual stress levels shall be calculated by means of an appropriate method.

(i) Fiber strain is proportional to the distance from the neutral axis of the cross section.

(ii) Concrete, steel and materials used for intervention are elastic.

(iii) The tensile stress of concrete is negligible.

(iv) The stress−strain curve of the concrete, steel and materials used for intervention is as set forth in Section 4.4 of these guidelines.

6.5.3 Verification related to appearance

The appearance verification of the repaired or strengthened structure shall use (1) crack width and (2) displacement or deformation as verification indices and check that the design response values resulting from load and environmental actions satisfy the design limit values determined from serviceability.

(1) The crack width on the surface of the repaired or strengthened structure may be calculated in accordance with "Standard Specifications for Concrete Structures-2017, Design", assuming that the integrity of the existing parts and repaired or strengthened parts is guaranteed. The limit value for the crack width relative to appearance shall be established according to how frequent the surface of the structure is seen by users, the psychological impact on users and so on.

(2) The displacement or deformation of the repaired or strengthened structure may be calculated in accordance with "Standard Specifications for Concrete Structures-2017, Design", assuming that the integrity of the existing parts and repaired or strengthened parts is guaranteed.

[Commentary] The crack width on the repaired or strengthened structure or members can be evaluated, using the reinforcement stress level calculated with the intervention effect taken into consideration, by means of Equation 2.3.3 in Section 2.3.4 of Part 4 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". Note that, when the integrity of the existing parts and repaired or strengthened parts is secured, cracking on the repaired or strengthened members is different from that on the members before intervention in terms of the degree of distribution. It is therefore important to evaluate the crack spacing taking into consideration the effect of the relevant intervention method appropriately. The increase in the steel stress level shown in Equation 2.3.3 shall be calculated taking into consideration both the stress status of the concrete and steel before and after intervention and the status of occurrence of cracking.

In general, deformation arising in a normal state of use is considered to be within the range of infinitesimal deformation, which is also true for the repaired or strengthened structure or members. Therefore, the displacement or deformation verification may be omitted for normal load actions.

6.5.4 Verification related to vibration

The vibration verification of the repaired or strengthened structure shall check that the comfort in use is not affected by vibration in accordance with "Standard Specifications for Concrete Structures-2017, Design", assuming that the integrity of the existing parts and repaired or strengthened parts is guaranteed.

[Commentary] If resonance is considered likely to result because intervention has changed the natural period of members, making it similar to the period of variable actions, an appropriate measure should be taken.

6.5.5 Verification related to water-tightness

The water-tightness verification of the repaired or strengthened structure shall be performed for each structural member in accordance with "Standard Specifications for Concrete Structures-2017, Design", assuming that the integrity of the existing parts and repaired or strengthened parts is guaranteed. As the verification index, transmissibility shall be used in principle.

[Commentary] A verification related to water-tightness shall be performed with relation to the intervention of a structure that is required to be water-tight. The verification shall be performed for each repaired or strengthened part, instead of for the entire structure, and transmissibility shall be used in principle as the index. In the case of a repaired or strengthened structure or members, it is important to increase the water-tightness of the bonded parts between the existing and repaired or strengthened parts. When waterproofing, drainage or some other construction-related measure is taken for those members that are required to be water-tight, it is necessary to evaluate its effects appropriately.

6.6 Restorability Verification

6.6.1 General

The seismic performance that the repaired or strengthened structure must possess shall be determined by considering it comprehensively from the viewpoints of safety, serviceability and restorability against seismic actions. Note that this verification assumes that the integrity of the existing members and overlaying members is guaranteed and that the preconditions for the verification mentioned in Section 6.6.2 are met strictly.

[Commentary] The seismic performance that the repaired or strengthened structure must possess may be determined in accordance with seismic performance 1 to 3 set forth in Part 5 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". The verification of the seismic performance of the repaired or strengthened structure shall be performed appropriately, taking into consideration the target structure and the scope of application of the intervention method, so that the expected seismic performance can be achieved.

6.6.2 Structural details related to seismic performance

As for structural details related to seismic performance, it is rational to establish specifications suitable for the target structure through experiments or by other means.

[Commentary] For structural details of an intervention method, it is important that it has been proven through experiments or by other means that the repaired or strengthened structure is capable of achieving the expected seismic performance. If it is impossible to conduct experiments due to restrictions on test equipment, structural details should preferably be established through appropriately modeled experiments.

6.7 Structural Details

The fundamental structural concept necessary for the design of reinforced concrete structures shall be established in accordance with "Standard Specifications for Concrete Structures-2017, Design".

[Commentary] Regarding structural details of a repaired or strengthened structure, reference should be made to the method-specific sections for the general requirements that are the preconditions for the verification for each construction method.

CHAPTER 7 CONSTRUCTION

7.1 General

The construction for intervention must be performed by formulating an appropriate construction plan so as to ensure that the quality assumed in the design is secured and that the repaired or strengthened structure fulfills the required performance.

[Commentary] In order for the repaired or strengthened structure to fulfill the required performance throughout the design service life, it is necessary to perform the construction while securing the quality assumed in the design. In the construction for intervention, it is important to implement appropriate construction control and quality control taking into consideration the properties of the materials used and the restrictions on construction.

7.2 Construction Plan

(1) Before performing the construction for intervention, a prior study shall be conducted on the target structure and results shall be reflected in the intervention construction plan.

(2) In order to perform the construction for intervention appropriately, the construction plan shall be formulated taking into consideration the structural conditions of the existing structure, environmental conditions and construction conditions.

[Commentary] (1) The prior study shall involve grasping information about design documents, the history of previous intervention, the status of damage to the structure, etc. In construction using cement-based materials, a problem with the existing structure, such as water leaks, affects the bonding property and strength manifestation of the cement-based materials. Therefore, the information obtained through the prior study shall be reflected in the construction plan, such as repairing damaged parts in advance, so that the intended intervention performance can be achieved.

(2) In intervention using cement-based materials, mechanized construction is adopted for base coating of the existing concrete as well as for overlaying and jacketing intervention. This makes it necessary to select the machinery and construction method appropriate for the structure's shape, location and environmental conditions. Therefore, when formulating a construction plan, it is important to ensure that the plan is appropriate for the shape, environment and construction conditions of the target structure.

7.3 Construction

(1) Cement-based materials shall be handled appropriately with care exercised about the construction conditions and environment.

(2) Construction must be performed appropriately so that the existing concrete and repaired or strengthened parts are integrated to form a composite structure.

(3) Cement-based materials shall be applied appropriately with care exercised about the construction conditions and environment.

(4) After construction for intervention, appropriate curing shall be performed to ensure the intended effect is obtained.

[Commentary] (1) In construction using cement-based materials, materials are stored, mixed, placed and cured at the site. Therefore, environmental conditions such as temperature, humidity, wind and airborne salt considerably influence strength manifestation and intervention effect. Therefore, the storage, mixing and application of cement-based materials shall be handled appropriately.

(2) Construction for intervention exerts its effect when the existing structure and repaired or strengthened parts are integrated to form a composite structure. Therefore, to enable the existing concrete to be integrated with the repaired or strengthened parts, it is necessary to apply base coating to the concrete surface and perform overlaying or jacketing construction using cement-based materials by means of an appropriate construction method.

(3) In hot or cold weather, external environmental factors affect the strength manifestation of cement-based materials, as with concrete. Therefore, before performing construction, it shall be checked that the average daytime temperature is 5°C or higher in the winter or 25°C or lower in the summer in accordance with “Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction”. If the temperature is outside these ranges, construction shall be performed in accordance with Chapter 12 “Cold Weather Concrete” and Chapter 13 “Hot Weather Concrete”.

(4) Cement-based materials need to be cured appropriately until they exhibit the specified strength. Those parts repaired or strengthened with cement-based materials have a thickness that is thin relative to the surface area when compared to the concrete structure. Therefore, when subjected to temperature change, wind, direct sunlight, etc. after the completion of construction, they are prone to suffer cracking. For this reason, it has been decided that, after construction for intervention, appropriate curing should be performed to ensure the intended effect is obtained.

7.4 Inspection

A structure repaired or strengthened with cement-based materials shall be inspected according to an inspection plan.

[Commentary] For the inspection of a structure repaired or strengthened with cement-based materials, an inspection plan shall be formulated and the structure shall be inspected by means of an appropriate method in accordance with “Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Inspection” (Chapter 7 Construction Inspection, Chapter 8 Inspection of Concrete Structures and Chapter 9 Inspection Records). The inspection shall be conducted upon reception of intervention materials, in each phase of intervention and upon completion of the structure.

CHAPTER 8　RECORDS

Basically, the records on intervention-related studies, diagnoses, designs, performance verifications, intervention, materials used, etc. shall be as set forth in "Standard Specifications for Concrete Structures-2013, Maintenance, Standard Methods". Particularly, the items concerning initial defects, acting external forces, action environments and the degree and progress of damage and degradation, including cracking and steel corrosion, must be recorded.

[Commentary] The records on studies, diagnoses, designs, performance verifications, intervention, materials used, etc. shall be as set forth in Chapter 8 of "Standard Specifications for Concrete Structures-2013, Maintenance, Standard Methods". In performing intervention for a concrete structure, records on initial defects, acting external forces and action environments that change over time such as traffic volumes and uses of land in surrounding areas, progress of cracking and steel corrosion for damage and degradation classification and the history of measures taken are especially important. Also, records on intervention methods adopted, materials used, construction conditions and the like should be kept for future maintenance. Since the construction for intervention using cement-based materials is easily affected by the environment, it is necessary to record the environmental conditions during construction such as temperature and humidity. To ensure that the post-intervention degradation in performance over time can be grasped in a systematic manner, inspections after measures are taken shall be recorded. Furthermore, it is desirable to record those intervention methods not adopted during inspections, diagnoses and performance verifications as well. This provides information about the social background and other matters relevant to the maintenance of the target structure at the time.

CHAPTER 9　MAINTENANCE

The personnel responsible for the maintenance of a structure shall formulate a maintenance plan in accordance with "Standard Specifications for Concrete Structures-2013, Maintenance, Standard Methods" and indicate the method of diagnosis, which comprises inspection, prediction, performance evaluation, judgment of whether measures are necessary, etc., as well as the measure selection method, recording method and so on, according to the maintenance category of the structure after intervention and the estimated degradation mechanism. The maintenance plan shall be reviewed as necessary.

[Commentary] It shall be decided that, in principle, the personnel responsible for the maintenance of a structure after intervention should formulate a maintenance plan in accordance with "Standard Specifications for Concrete Structures-2013, Maintenance, Standard Methods". In formulating a maintenance plan, it is necessary to determine the period of maintenance based on the planned service life of the structure considered in the design phase of intervention. If the planned service life is unclear, the design service life may be considered the planned service life.

When formulating a plan for post-intervention maintenance, the characteristics of the methods and materials adopted for intervention in particular should be fully understood and attention should be paid to the members and properties deemed prone to change.

In the case of a structure after intervention, it is good practice to formulate a maintenance plan as early as in the planning and design phases of intervention, verify the adequacy of the plan by collecting the information about the structure in the initial diagnosis performed after intervention and finalize the maintenance plan while reviewing its content according to circumstances. In such cases as when the result of degradation prediction based on inspection results is different from the initial prediction, it is important to review the maintenance plan that has been in place as necessary. Furthermore, since the service life of the structure after intervention is long, it is highly likely that the performance requirements for the structure may change with the change in the lifestyles and needs of people, distribution systems, society, etc. The maintenance plan may need to be reviewed in line with such a change.

Guidelines for Structural Intervention of Existing Concrete Structures Using Cement-Based Materials - Method-Specific Section (Top-Surface Overlaying)

CHAPTER 1 GENERAL PROVISIONS

1.1 Scope

These guidelines specify the standards for design and construction using the top-surface overlaying method, which increases the thickness of existing concrete members by integrating cement-based materials onto the top surface of the members so as to improve the safety, serviceability, durability and other properties of a concrete structure. The requirements not mentioned in the Top-Surface Overlaying section shall be as set forth in the Common section and relevant standard specifications for concrete structures.

[Commentary] Top-surface overlaying is a construction method that increases the thickness of existing concrete members by placing and integrating cement-based materials onto the top surface of the members so as to improve the safety, serviceability, durability and other properties of a concrete structure.

Typical structures to which top-surface overlaying is applied as an intervention method are highway bridge reinforced concrete decks (hereinafter decks) that are subject to the repeated action of relatively large variable loads. The method is mainly applied to improve the safety and other properties of decks that have degraded due to fatigue resulting from the repeated action of traffic loads. It may also be applied to improve durability and functionality for such purposes as to respond to design load changes taking place as vehicles become larger and protect the top surface of decks against degradation due to anti-freezing agent. Examples of application other than those for decks include overlaying reinforcement of the top surface of footings aimed at improving the seismic performance of bridge piers whose existing footings have insufficient flexural load-carrying capacity for ground motions. While the Top-Surface Overlaying section is not necessarily confined to a specific type of structure, it mainly covers the standard design and construction methods for top-surface overlaying of decks.

For top-surface overlaying to produce the specified effect, it is indispensable to integrate the existing members with the cement-based materials of the overlaying parts. In some cases, after the top surface of decks are cut and cleaned, short fiber reinforced concrete is placed while adhesive is applied in order to achieve integrity. The primary reason for using short fiber reinforced concrete on the overlaying parts is to improve the flexural resistance, tensile resistance, shear resistance and cracking resistance of the concrete. For example, since the cross section layer of the top-surface overlaying parts is relatively thin, there are fears of cracking occurring due to initial drying or occurring and progressing due to active loads. Mixing short fiber is expected to suppress the progress of cracking. Also, in intermediate support points and overhanging decks of continuous girder bridges, reinforcing materials such as reinforcing steel and continuous fiber reinforcing materials are used to improve the negative flexural load-carrying capacity. In top-surface overlaying for footings, the thickness is greater than for decks. In the case of mass concrete, therefore, a measure needs to be taken to protect against thermal cracking due to hydration heat of cement.

These guidelines describe a specific method of verifying the performance of a structure repaired or strengthened by means of top-surface overlaying based on the currently available latest technologies. Note, however, that the verification method described herein does not cover all kinds of verification. For necessary information, reference must be made to the relevant standard specifications and other documents. In the future, as purposes for intervention diversify and advances in technology are made, many different methods are expected to be proposed.

Given that members subject to intervention are mostly decks at present, the standard methods are described herein that are considered the latest information on design and construction of top-surface overlaying using short fiber reinforced concrete on overlaying parts. As technology advances, new materials and design and construction methods are developed and methods for evaluating the post-intervention structural performance with sufficient accuracy are established, making it possible to apply top-surface overlaying for intervention parts and members other than decks, use materials other than short fiber reinforced concrete, employ interface treatment methods other than cutting, cleaning and adhesive, etc., it is not necessarily required to adhere to what is set forth in these guidelines.

The fundamentals of the design and construction of concrete structures in general are described in “Standard Specifications for Concrete Structures-2017, Design” and “Standard Specifications for Concrete Structures-2017, Materials and Constructions”. The guidelines complement these standard specifications. Also, when top-surface overlaying is applied to decks, the intervention design based on these guidelines is complemented by “Manual for Top-Surface Overlaying Design and Construction, 1995” (Express Highway Research Foundation of Japan), “Concrete Library 95, Guidelines for Retrofit of Concrete Structures, Draft, 1999.9” (Japan Society of Civil Engineers), “Manual for Maintenance of Highway Bridge Decks, 2012.6” (Japan Society of Civil Engineers), “Guidelines on Construction Management of Structures, 2017” (East Nippon Expressway Co., Ltd., Central Nippon Expressway Co., Ltd. and West Nippon Expressway Co., Ltd.) and “Second Edition for Design Procedures, Part for Maintenance of Bridges, 2017” (East Nippon Expressway Co., Ltd., Central Nippon Expressway Co., Ltd. and West Nippon Expressway Co., Ltd.).

1.2 Terms and Definitions

The definitions of the terms used in the Top-Surface Overlaying section shall be as defined in Chapter 1 of the Common section.

CHAPTER 2 STUDY OF THE EXISTING STRUCTURE

2.1 General

The study of the existing structure for intervention using the top-surface overlaying method shall be as set forth in Chapter 2 of the Common section.

[Commentary] Intervention using the top-surface overlaying method needs to be designed by grasping the condition of the existing structure through a prior study, and plans for construction, construction management and inspections need to be formulated based on the results of the design. The study work of the existing structure shall be as set forth in Chapter 2 of the Common section and involve a study using documents, records, etc. and an on-site study. It is necessary to check the condition of the structure, environmental conditions and conditions of use, as well as to grasp the restrictions and problems on intervention, through these studies.

2.2 Study

2.2.1 Study using documents, records, etc.

The study of the existing structure using documents, records, etc. for top-surface overlaying shall be as set forth in Section 2.2.1 of the Common section.

[Commentary] In order to check the performance that the existing structure possesses, it is necessary to grasp such information as the dimensions of members, steel arrangement and materials used, based on design documents and as-built drawings. Information such as the traffic volume on the target road and the percentage of large vehicles should also be obtained as needed. If intervention has already been performed, maintenance records need to be inspected. It is important to check the location and environmental conditions of the structure in advance in order to identify construction restrictions and problems.

2.2.2 On-site study

The on-site study for considering the application of top-surface overlaying shall be as set forth in Section 2.2.2 of the Common section.

[Commentary] If the existing structure has any physical degradation such as cracks, the integrity between the existing structure and cement-based materials may be impaired. Also, if the existing structure has steel corrosion due to intrusion of anti-freezing agent, scaling caused by freezing and thawing actions, cracking or turning into sand resulting from alkali silica reaction or the like, intervention using top-surface overlaying may not be fully effective unless the degraded parts are removed. It is therefore necessary to check changes in the existing structure in advance by means of periodical inspection records and other relevant information, as well as to check the necessary items on the site. It is good practice to judge whether the existing structure needs intervention or not, the scale of intervention and so on by taking into consideration the performance level and design service life of the structure required to be achieved by the intervention based on results of the on-site study. In order to ensure smooth construction work with top-surface overlaying on the site, it is important to check the storage space and arrangement of construction machines and materials, traffic restrictions and so forth in the prior study phase.

CHAPTER 3 INTERVENTION DESIGN

3.1 General

The intervention plan for considering the application of top-surface overlaying shall be as set forth in Chapter 3 of the Common section.

[Commentary] With top-surface overlaying, the effect of intervention is greatly influenced by the degradation status of the existing structure. Therefore, the structural plan for degraded part removal, patching repair, concrete replacement, etc. needs to be formulated based on the correct judgment of the degradation status to ensure that the performance level and design service life of the structure required from the intervention are achieved.

In structural details, a bonding method must be established that ensures the integrity between the existing parts and overlaying parts so that the intervention effect of top-surface overlaying is obtained. Specifically, an appropriate base coating method and, if necessary, a method of maintaining integrity for a specified period of time by means of adhesive or other bonding materials shall be considered. Also, when asphalt pavement is placed on top of the overlaying parts, it is important from the perspective of post-intervention durability to provide a water-resistant layer and consider a plan for blocking and draining water intruding into decks.

3.2 Structural Plan

The structural plan for considering the application of top-surface overlaying shall be as set forth in Section 3.2 of the Common section.

[Commentary] When top-surface overlaying is selected, it is necessary to take economy into consideration in addition to the impact of construction work on the surrounding environment, maintainability after intervention and so forth. The intervention method by top-surface overlaying is often adopted for decks, and it is common to strengthen decks with short fiber reinforced concrete after appropriate treatment of a placement interface on the top surface of the existing decks. When the method is used for decks, a grasp must be gained in advance as to the cracking and efflorescence in the existing reinforced concrete decks, the degradation of concrete due to traffic loads, repeated freezing and thawing, alkali silica reaction, etc., the status of concrete covering peeling resulting from reinforcing steel corrosion caused by salt damage mainly due to sprayed anti-freezing agent, the status of the concrete covering turning into sand as a result of water intruding into such corroded parts, an so on. In designing intervention work, appropriate decisions must be made on the method to remove degraded concrete, the materials and method for patching repair, whether partial concrete replacement is necessary and the range of replacement, the construction method of top-surface overlaying, etc. before starting construction with top-surface overlaying, taking these circumstances into consideration. Materials for patching repair for the top surface of decks are required to shrink little, be excellent in cracking resistance and following capability, have Young's modulus equal to or smaller than that of the existing concrete, etc.

In the top-surface overlaying plan, it is necessary to consider specific intervention measures according to the performance requirements specified for the structure. Based on the evaluation of the impact of the degradation and damage of the existing structure on its structural performance, specific measures need to be planned according to structural conditions to ensure that the functionality and required performance of the target structure are fulfilled throughout the design service life.

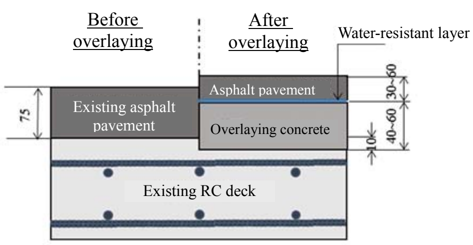
In intervention, the location and environmental conditions of the target structure have a significant impact on the construction work. For example, when top-surface overlaying is applied to decks, intervention involves prolonged traffic restrictions and, therefore, the range of construction needs to be planned taking this into consideration.

In recent years, there have been reports of post-intervention peeling and re-degradation of overlaying parts of decks reinforced with the top-surface overlaying method. The reason for such peeling and re-degradation is considered to be that the bonding between the existing decks and overlaying parts is impaired by rainwater intruding from construction joints, cracks, etc. thereby making it impossible for them to resist loads together. Therefore, the intrusion of water into the inside of decks needs to be completely prevented and it is important to apply waterproofing and ensure water drainage on the waterproof top surface. In order to ensure that the repaired or strengthened structure sustains its performance as mentioned above, it is necessary to take measures to prevent re-degradation while taking into consideration the post-intervention environment and maintenance as well.

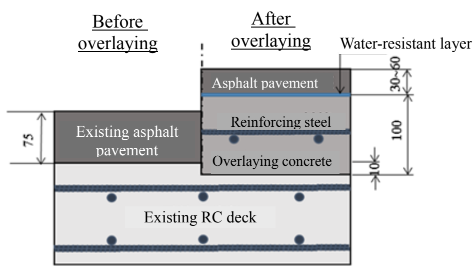
3.3 Structural Details

The structural details for considering the application of top-surface overlaying shall be as set forth in Section 3.3 of the Common section. An increase in the self-weight due to the overlay must also be considered appropriately.

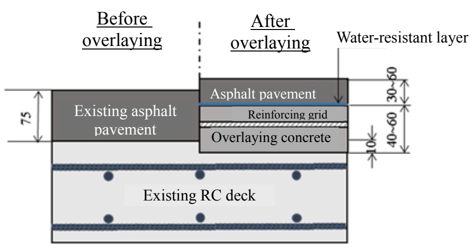
[Commentary] In order for a structure repaired or strengthened with top-surface overlaying to fulfill the required performance, the existing parts and overlaying parts need to function together as a composite structure. Fig. C3.3.1 shows examples of the cross section of decks to which



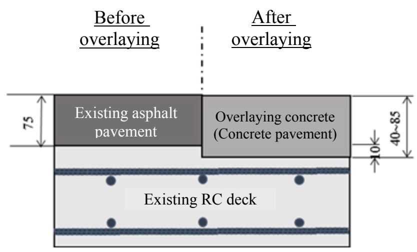
Construction method: Top-surface overlaying
Pavement: Asphalt



Construction method: Steel reinforced top-surface overlaying
Pavement: Asphalt



Construction method: Grid (e.g., CFRP grid) reinforced top-surface overlaying
Pavement: Asphalt



Construction method: Top-surface overlaying
Pavement: Concrete

Fig. C3.3.1 Examples of the cross section of decks to which top-surface overlaying is applied

top-surface overlaying is applied. Generally, after the existing deck is cut by 10 mm, its top surface is shot-blasted and steel fiber reinforced concrete is placed while applying adhesive as necessary in order to bond the existing deck and overlaying part. Regarding placement interface treatment, whether to use adhesive and how to apply it shall be decided rationally taking into consideration the circumstances of the construction site. Generally, asphalt pavement is placed on top of the steel fiber reinforced concrete of the overlaying part and a water-resistant layer needs to be provided between the overlaying part and pavement. This is particularly important for preventing the degradation of decks from occurring or accelerating in the presence of water. For example, water accumulating in decks accelerates fatigue-caused damage or degradation, and chloride ions that penetrate into decks with water promote steel corrosion.

If the rigidity of the existing part is vastly different from that of the overlaying part, the strength, Young's modulus and other properties of the existing concrete and overlaying materials need to be considered fully because a sufficient strengthening effect may not be obtained depending on the bonding method. Also, since the layer of the overlaying part is as thin as 50 mm, the confinement from the existing member is great in terms of shrinkage and creep deformation. It is therefore necessary to thoroughly consider the volume change characteristics of short fiber reinforced concrete and the suppression effect of the progress of cracking.

If overlaying results in the entire cross section of the member becoming thicker, an increase in dead loads due to the self-weight needs to be considered as well.

CHAPTER 4 MATERIALS

4.1 General

The materials used for top-surface overlaying must be of proven quality to ensure that the required performance is fulfilled for a necessary period of time.

[Commentary] Since applying top-surface overlaying to highway bridge decks generally involves traffic restrictions, it is required to minimize the time before the structure is put back into service. Therefore, cement-based materials need to exhibit the required strength in a short time and provide sufficient workability to meet the construction speed among other things. It is also necessary to select materials that ensure the integrity of the existing and overlaying parts is maintained for a long period of time.

4.2 Materials in the Existing Structure

The characteristic values and design values of the materials in the existing structure shall be as set forth in Section 4.2 of the Common section.

[Commentary] The characteristic values and design values of strength in the existing structure used for the intervention design shall be determined based on the study and inspection results in accordance with Section 4.2 of the Common section. As for decks, cases of concrete degradation and steel corrosion deemed due to sprayed anti-freezing agent have become increasingly visible in recent years. When setting the material properties of the existing structure based on documents, records, etc. in accordance with Section 5.2 of “Standard Specifications for Concrete Structures-2017, Design, General Requirements”, the material factors should be determined taking into consideration the impact of these problems. On the other hand, when the functionality of the existing structure is restored using patching repair materials or the like prior to top-surface overlaying, the material properties of the repair materials should be considered appropriately according to their impact.

4.3 Materials Used in Repaired or Strengthened Parts

4.3.1 Cement-based materials

The cement-based materials used for top-surface overlaying shall be as set forth in Section 4.3.2 of the Common section. Water, cement, aggregate, short fiber, mineral admixture and chemical admixture, cement mixing polymer, and others used for the cement-based materials must be those compliant with the relevant JIS standards or those proven to have the required levels of quality based on existing test results or through confirmation tests.

[Commentary] The cement-based materials used for top-surface overlaying include concrete, short fiber reinforced concrete, polymer cementitious mortar, polymer cementitious concrete and expansive concrete, and they are used alone or in combination.

As the cement used for the cement-based materials, the type of cement appropriate for the required performance and purpose needs to be selected. In top-surface overlaying for decks, a different type of cement is generally used according to the number of days for which traffic restrictions can be imposed. In cases where quick construction is required, ultrarapid hardening cement is used that achieves the target strength at a material age of 3 hours. The available types of ultrarapid hardening cement include pulverized clinker whose main component is calcium aluminate, Portland cement mixed with an appropriate amount of finely pulverized calcium sulfoaluminate and cement whose main component is magnesium phosphate. While there is no established JIS standard for ultrarapid hardening cement, the material has a track record as a type of cement used for overlaying parts in top-surface overlaying. When traffic restrictions can be imposed for 10 days or so, high early strength Portland cement is usually used.

As for aggregate, a material compliant with JIS A 5005 “Crushed stone and manufactured sand for concrete” or JIS A 5308 “Ready-mixed concrete” is used in general. If the overlaying member thickness is thin, coarse aggregate whose maximum size is less than 20 mm may be used.

When the cement-based materials are required to improve the crack dispersion performance or mechanical performance, short fiber reinforced concrete is used. In top-surface overlaying for decks, steel fiber reinforced concrete is used widely mainly for the purpose of improving the punching shear capacity of the strengthened members. Steel fibers in general use are those compliant with JSCE-E 101. The aspect ratio and length of steel fibers in use are 40 to 80 and 30 mm, respectively. Commonly used short fibers other than steel fibers include synthetic fibers, such as polyvinyl alcohol (PVA) and polypropylene, and aramid fibers made by bundling aramid single fibers with epoxy resin.

If shrinkage cracking of cement-based materials presents a problem, an expansive material may be used as mineral admixture. Typically, an expansive material compliant with JIS A 6202 “Expansive additive for concrete” is used. Or information about concrete using an expansive material, reference should be made to Chapter 5 “Expansive Concrete” of “Standard Specifications for Concrete Structures-2017, Materials and Constructions, Special Concrete”. What is important for an expansive material to exhibit its shrinkage-compensating effect is the timing of expansive hydrate generation and skeleton formation of the cement hardened body. When ultrarapid hardening cement is combined with an expansive material, the skeleton of the cement hardened body is formed early and, therefore, there are cases in which an expansive material that generates expansive hydrate early is used.

When cement-based materials are required to have substance penetration resistance, polymer cementitious mortar or polymer cementitious concrete is used as appropriate for the scale of construction. Since the nature of the hardened body of polymer cementitious mortar or concrete varies depending on the amount and type of polymer used, it is necessary to use an appropriate material according to the required performance.

4.3.2 Reinforcing materials

The reinforcing materials used for top-surface overlaying shall be as set forth in Section 4.3.3 of the Common section.

[Commentary] In top-surface overlaying for decks, grid-shaped steel and continuous fiber reinforcing materials may be used as reinforcements in addition to reinforcing steel.

4.3.3 Bonding materials

The bonding materials used for top-surface overlaying shall be as set forth in Section 4.3.5 of the Common section.

[Commentary] In top-surface overlaying for decks, adhesive may be used on the placement interface for the purpose of achieving integrity between cement-based materials and existing decks. The bonding strength of the placement interface obtained when adhesive is used is affected by environmental conditions such as temperature, humidity and wind, as well as by construction conditions such as the moisture state of the existing concrete. Therefore, an appropriate material needs to be selected taking these factors into consideration. Also, the material is required to ensure a usable time appropriate for the construction procedure, shrink little and maintain the bonding property on a long-term basis.

4.3.4 Waterproof materials

The waterproof material to be used for top-surface overlaying must be selected so as to fulfill the required performance, taking into consideration the construction conditions and environment, variations in quality, etc.

[Commentary] In the case of decks, it is common to provide a water-resistant layer between the asphalt pavement and overlaying members in order to prevent degradation factors, such as water and anti-freezing agent, from intruding into decks. The performance requirements for the material used in the water-resistant layer include waterproof property, durability, constructability, quality stability and environmental safety. For information about the performance requirements and verification methods, reference should be made to “Guideline of Waterproofing System for Bridge Decks 2016, 2016.11” (Japan Society of Civil Engineers).

4.3.5 Pavement materials

With regard to the pavement material to be placed after top-surface overlaying for highway bridge decks, its performance of bonding with the waterproof material must be taken into consideration.

[Commentary] If the bonding between the pavement material and waterproof material is insufficient, the required waterproof performance may not be able to be obtained. For information about the characteristics of pavement materials including the water-resistant layer, reference should be made to “Guideline of Waterproofing System for Bridge Decks 2016, 2016.11” (Japan Society of Civil Engineers).

4.4 Characteristic Values and Design Values of Materials Used for Repaired or Strengthened Parts

4.4.1 General

The characteristic values and design values of the materials used for top-surface overlaying shall be as set forth in Section 4.4 of the Common section.

4.4.2 Cement-based materials

The characteristic values and design values of the cement-based materials used for top-surface overlaying shall be as set forth in Section 4.4.2 of the Common section.

[Commentary] For top-surface overlaying, special concrete such as steel fiber reinforced concrete is often used from the viewpoints of the bonding with existing members, the suppression of cracking and so on. Therefore, if the concrete exhibits mechanical properties different from those of normal-strength concrete, its characteristic values and design values need to be determined through appropriate testing. For example, steel fiber has almost no impact on the characteristic values of compressive strength and Young's modulus of steel fiber reinforced concrete as long as its mix rate is appropriate. Therefore, these values can be considered the same as those of normal-strength concrete. However, since the compressive toughness, flexural strength and toughness, tensile strength and shear strength are greater than those of normal-strength concrete with the same compressive strength, these values need to be established through appropriate testing based on JCI-SF "Codes Concerning Test Methods for Steel Fiber-Reinforced Concrete", JSCE-G 551 1983 (SFRC guidelines) "Test method for compressive strength and compressive toughness of steel fiber reinforced concrete", JSCE-G 552 1983 (SFRC guidelines) "Test method for bending strength and bending toughness of steel fiber reinforced concrete", JSCE-G 553 1983 (SFRC guidelines) "Test method for shear strength of steel fiber reinforced concrete" and so on. It has been reported from previous research that the flexural fatigue strength of steel fiber reinforced concrete is greater than that of normal-strength concrete. At present, however, there is no established equation for calculating fatigue strength according to the steel fiber type or fiber mix rate. As for concrete that uses short fiber other than steel fiber, there is even less fatigue data and, therefore, it is desirable to calculate the S-N curve through testing and determine the characteristic value of fatigue strength.

The characteristic values and design values of the cement-based materials used for top-surface overlaying need to be determined based on the strength identified by a test conducted at an appropriate material age, according to the purpose of use of the structure, when the main loads act, the construction plan and so on.

4.4.3 Reinforcing materials

The characteristic values and design values of the reinforcing materials used for top-surface overlaying shall be as set forth in Section 4.4.3 of the Common section.

4.4.4 Bonding materials

A bonding material that ensures the integrity between the existing and overlaying parts for a necessary period of time must be selected and used appropriately based on a full understanding of its properties.

[Commentary] The bonding material is required to have material properties that ensure the overlaying parts are bonded throughout the design service life. It is therefore necessary to check through appropriate testing that the integrity between the existing and overlaying parts can be achieved with the bonding material. The placement interface of the actual structure is likely to be in a complex stress status because of loads, surrounding environmental actions, condition of the existing structure, etc. Also, there may be composite actions of degradation factors. In the evaluation, it is desirable to check the performance of the bonding material by means of a technique whereby the influence of these factors can be taken into consideration appropriately.

Table C4.4.1 shows an example of a method that evaluates the performance of adhesive based on the property of bonding between old and new concrete. According to this table, the tensile bond strength is required to be 1.0 N/mm^2 or more as the performance of adhesive when submerged in hot water and given a tensile fatigue load. At present, it is difficult to explain theoretically about whether the fact that the integrity between the existing and overlaying parts is ensured is equivalent to the fact that the tensile bond strength is 1.0 N/mm^2 or more. This criterion value is widely adopted, however, based on past records showing that, when the tensile bond strength determined through testing is 1.0 N/mm^2 or more, there is generally no problem with the integrated existing and overlaying parts. It is desirable that appropriate tensile bond strength and evaluation test method be established according to the quality of construction and environmental conditions.

Note also that long-term integrity between the existing and overlaying parts cannot be achieved with tensile bond strength alone. The bonding material should change little in the tensile bond property over time and be able to follow deformation, resistant to peeling and durable to actions of degradation factors among other things. It is important to take these factors into consideration when selecting the bonding material.

Table C4.4.1 An example of a performance evaluation test method for adhesive (NEXCO test method 434: Performance test methods of epoxy resin adhesive for overlaid concrete)

Item	Criterion value	Test method
Durability of bonding between old and new concrete	After application of specified loads, the bonding strength of the interface between old and new concrete shall be 1.0 N/mm^2 or more.	Bonding strength before load application
		Bonding strength after application of hot water load[1)]
		Bonding strength after application of a specified load[2)]

1) Submerged in hot water whose temperature is 50°C for 10 days.

2) Application of tensile fatigue in a water-filled condition (amplitude: 0.6 N/mm^2, frequency: 10 Hz, number of cycles: 4.80 million)

CHAPTER 5　ACTIONS

5.1 General

The actions used for performance verification of the intervention method using top-surface overlaying shall be as set forth in Chapter 5 of the Common section.

5.2 Actions for Intervention Design

The actions for intervention design that are used for performance verification of the intervention method using top-surface overlaying shall be as set forth in Section 5.2 of the Common section.

[Commentary] When top-surface overlaying is applied to decks, the permanent actions to be considered in intervention design are dead loads of the existing parts and dead loads of the overlaying parts. These dead loads are borne by the existing parts until the overlaying parts are hardened and bonded. Once the overlaying parts are hardened, the loads are borne by the composite section of the existing and overlaying parts. Variable actions occurring after intervention are borne by the composite section of the existing and overlaying parts. These actions need to be taken into consideration appropriately according to the structure.

CHAPTER 6 PERFORMANCE VERIFICATION FOR THE REPAIRED OR STRENGTHENED STRUCTURE

6.1 General

(1) The performance of a structure repaired or strengthened with top-surface overlaying shall be verified by means of the method specified in this chapter.

(2) When intervention is performed using top-surface overlaying, the verification shall assume that the composite section formed as the existing and overlaying parts are integrated offers resistance to external forces.

(3) When the composite section formed after intervention as the existing and overlaying members are integrated is verified, cracks and other types of damage, residual deformation and stress, corrosion factors, etc. on the existing members must be taken into consideration appropriately.

[Commentary] (1) The performance of a structure repaired or strengthened with a selected construction method must be evaluated by means of an appropriate method in order to verify that it fulfills the required performance. This chapter specifies how to evaluate the safety and serviceability of a structure repaired or strengthened with top-surface overlaying by means of the currently available technologies.

(2) As a precondition for the verification, the integrity between the existing and overlaying parts needs to be achieved through the appropriate treatment of the placement interface and the appropriate application of cement-based materials. Normally, it is necessary to check whether the shear bond stress, deformation and others of the placement interface satisfy the limit values. In the application to decks, however, the existing parts and overlaying parts are considered to be integrated when the tensile bond strength of the placement interface is 1.0 N/mm^2 or more, based on past records. Note that, if an appropriate method of integration is employed or the performance is verified by means of a reliable method, it is not necessarily required to adopt the method described herein.

(3) When the performance of a repaired or strengthened structure is evaluated, as well as the properties of the overlaying parts, cracks and other types of damage, residual deformation and stress, amount of chloride ions and depth of carbonation that are steel corrosion factors, etc. on the existing parts need to be taken into consideration as necessary.

If the thickness of the overlaying parts is large and the increment in dead loads is substantial, it is desirable to verify the stress level of members including the impact of the dead loads. In top-surface overlaying for decks, the impact that the increment in dead loads has on main girders is generally small. When the stress level is verified, it is common to consider that resistance to the dead loads of the overlaying and existing parts is offered by the existing section taking cutting into account while resistance to the post-dead loads after hardening (pavement, etc.) and live loads is offered by the composite section formed as the overlaying and existing parts are integrated.

6.2 Calculation of Response Values

6.2.1 General

The response values of a structure repaired or strengthened with top-surface overlaying shall be calculated as set forth in Section 6.2 of the Common section.

6.2.2 Modeling of the structure

A structure repaired or strengthened with top-surface overlaying shall be modeled as set forth in Section 6.2.2 of the Common section.

6.2.3 Structural analysis

The structural analysis of a structure repaired or strengthened with top-surface overlaying shall be performed as set forth in Section 6.2.3 of the Common section.

6.2.4 Calculation of design response values

The design response values of a structure repaired or strengthened with top-surface overlaying shall be calculated as set forth in Section 6.2.4 of the Common section.

6.3 Durability Verification

6.3.1 General

The durability of a structure repaired or strengthened with top-surface overlaying shall be verified as set forth in Section 6.3 of the Common section.

6.3.2 Verification related to steel corrosion

When a structure repaired or strengthened with top-surface overlaying is verified to check for steel corrosion due to salt damage, an appropriate value of chloride ion concentration on the concrete surface shall be established if salt damage due to anti-freezing agent has an impact as an environmental action.

[Commentary] In general, a water-resistant layer and asphalt pavement are placed on top of the overlaying parts. However, there are cases where salt from sprayed anti-freezing agent intrudes into the overlaying and existing concrete parts due to the degradation of the parts where cracking may occur, such as intermediate support points and girder edges or the water-resistant layer or for some other reason. The value of surface chloride ion concentration to be used when verifying salt damage due to anti-freezing agent is shown in “Technical Guidelines on Precast Prestressed Concrete Slabs for Renewal” of the Japan Prestressed Concrete Institute. Fig. C6.3.1 shows the relationship between the surface chloride ion concentration and the amount of anti-freezing agent sprayed.

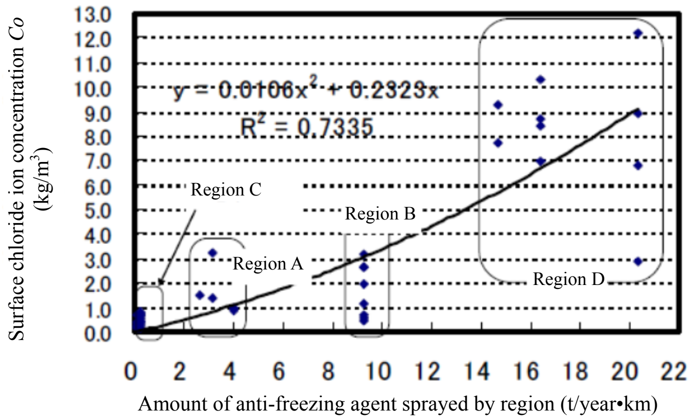


Fig. C6.3.1 Relationship between the surface chloride ion concentration and the amount of anti-freezing agent sprayed[1)]

References

1) Nobuo Kuwahara, Yasuhiro Umemura and Hideaki Sakai: "A Study on Prediction of Chloride Ion Infiltration into the Expressway Slab", Proceedings of the Japan Concrete Institute, Vol. 32, No. 1, pp. 791-796, 2010

6.4 Safety Verification

6.4.1 General

The safety of a structure repaired or strengthened with top-surface overlaying shall be verified as set forth in Section 6.4 of the Common section.

6.4.2 Verification related to cross-sectional failure

6.4.2.1 General

The verification of cross-sectional failure shall be performed in accordance with Section 6.4 of the Common section, while the verification method specific to top-surface overlaying shall be as set forth in Section 6.4.

6.4.2.2 Verification related to bending moment and axial force

The verification related to bending moment and axial force shall be performed as set forth in Section 6.4.2.2 of the Common section.

[Commentary] When the flexural load-carrying capacity of repaired or strengthened concrete members is calculated, it is assumed that the existing members and overlaying members behave as one without peeling away from each other. Therefore, when the overlaying parts to be bent are located in the tension zone, the tension-side concrete shall be ignored. When the existing parts are located in the compression zone, the flexural load-carrying capacity needs to be calculated using the design strength of the existing concrete. When the overlaying parts are located in the the compression zone, the strength and Young's modulus of the overlaying parts do not match those of the existing concrete and, therefore, it is desirable to calculate the flexural load-carrying capacity using the design strength of the cement-based materials of the overlaying parts obtained in accordance with Section 4.4.

6.4.2.3 Verification related to shear force

The safety verification related to shear force shall be performed as set forth in Section 6.4.2.3 of the Common section. Note that this verification assumes that the existing members and overlaying members are integrated. The design shear capacity of bar members shall be as set forth in "Standard Specifications for Concrete Structures-2017, Design, Standard Methods", appropriately taking into consideration the effect of reinforcing materials used in top-surface overlaying. When the load surface is separated from the free end or the opening of the member and the eccentricity of the load is small, the punching shear capacity shall be as set forth in "Standard Specifications for Concrete Structures-2017, Design, Standard Methods", appropriately taking into consideration the effect of reinforcing materials used in top-surface overlaying.

[Commentary] Considering decks to which top-surface overlaying is applied as an example, it is necessary to give due consideration when deciding on the type of member and boundary conditions and perform the safety verification related to shear capacity with care, because the application states of loads are generally moving loads and shear failure occurs after the decks ultimately become like girders.

When the shear capacity of repaired or strengthened bar members is calculated, it is assumed that the existing parts and overlaying parts behave as one without peeling away from each other. Therefore, the design shear capacity V_{cd} of bar members without shear reinforcement shall be calculated with regard to the cross section including the overlaying parts in accordance with Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". If the strength of the concrete used in the overlaying parts is greater than that of the existing parts, the evaluated shear capacity will be on the safe side when V_{cd} is calculated using the compressive strength of the existing concrete for the overlaying parts. It has been decided that, when there is shear reinforcement in the existing members, the design shear capacity V_{yd} should be expressed as the sum of the contribution of the shear reinforcement V_{sd} and V_{cd} in accordance with Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods".

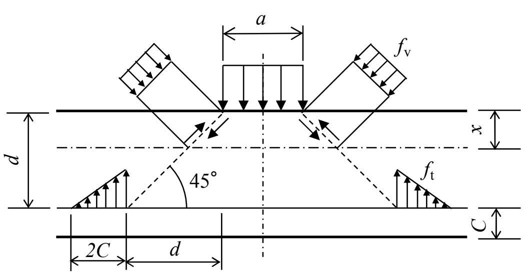
It is desirable that the punching shear capacity of repaired or strengthened surface members be calculated using the design strength of the cement-based materials in the overlaying parts, with regard to the cross section including the overlaying parts, in accordance with Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". Note, however, that if the strength level considerably differs between the existing parts and overlaying parts, the verification needs to be performed carefully by making checks through experiments or by other means.

At present, the surface members to which top-surface overlaying is applied are mainly decks. To calculate the punching shear capacity of relatively thin members like decks, Equation C6.4.1 can be applied that is based on the failure modes derived from experiments as well as on the punching shear failure model shown in Fig. C6.4.1. Note that, even when Equation C6.4.1 is used, the verification also needs to be performed carefully by checking the punching shear capacity of the decks to which top-surface overlaying has been applied through experiments or by other means. While it is desirable that Equation C6.4.1 be calculated for the cross section including the overlaying parts, using the design strength of the cement-based materials in the overlaying parts, consideration must be given to the following. Since the equation for calculating the shear strength of concrete f_v is based on results obtained when normal-strength concrete is used, it cannot be applied when steel fiber reinforced concrete is used in the overlaying parts. However, since the shear strength of steel fiber reinforced concrete is generally greater than that of the existing deck concrete, the evaluated punching shear capacity will be put on the safe side if it is calculated using the design compressive strength of the existing deck concrete. In fact, the decks to which top-surface overlaying has been applied are likely to be subject to advanced degradation or damage, such as cracks in the existing parts, and it is therefore safe to use the design strength of the existing deck concrete for the verification related to punching shear capacity.

$$P_{0d} = \left[f_v \{ 2(a+2x_m)x_d + 2(b+2x_d)x_m \} + f_t \{ 2(a+2d_m)C_d + 2(b+2d_d+4C_d)C_m \} \right] / \gamma_b \quad \text{(Equation C6.4.1)}$$

where:

- P_{0d} : Design punching shear capacity (N)
- a, b : Side lengths of the loading plate in the main reinforcement and distribution reinforcement directions (mm)
- x_m, x_d : Neutral axis depths when the tension-side concrete of the cross section at right angles to the main reinforcement and distribution reinforcement is ignored (mm)
- d_m, d_d : Effective heights of the tension-side main reinforcement and distribution reinforcement (mm)
- C_m, C_d : Covering depths of the tension-side main reinforcement and distribution reinforcement (mm)
- f_v : Shear strength of concrete (N/mm^2), $f_v = 0.656 f'_{cd}{}^{0.606}$
- f_t : Tensile strength of concrete (N/mm^2), $f_t = 0.269 f'_{cd}{}^{0.667}$
- f'_{cd} : Design compressive strength of concrete (N/mm^2)
- γ_b : In general, this may be set to 1.3.



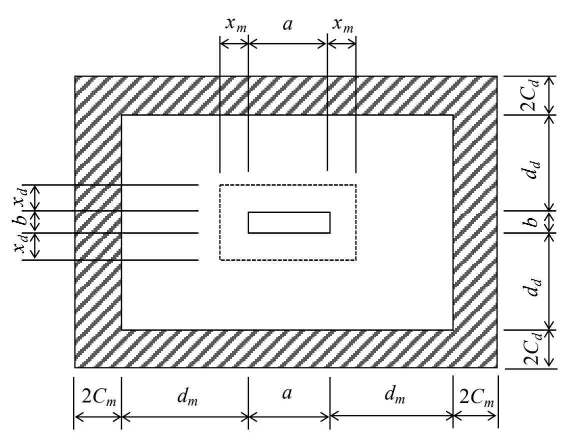


Fig. C6.4.1 Punching shear failure model and the corresponding stress distribution and range

6.4.2.4 Verification related to torsional moment

If the action of torsional moment cannot be ignored, a safety verification shall be performed by means of an appropriate method.

[Commentary] When the torsional capacity after intervention is calculated, it is assumed that the existing members and the cement-based materials in the overlaying parts behave as one without peeling away from each other and the calculation shall be performed in accordance with Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". Since there is almost no research on the behavior of torsional moment of members repaired or strengthened with top-surface overlaying, performance should be checked through appropriate experiments.

6.4.3 Verification related to fatigue failure

6.4.3.1 Verification related to flexural fatigue capacity

It must be verified that the members repaired or strengthened with top-surface overlaying are safe against flexural fatigue under load and environmental actions.

[Commentary] In the safety verification related to the flexural fatigue capacity of top-surface overlaying members (decks and beams) placed on a surface subject to the repeated action of tensile stress, the fatigue strength of concrete and steel may be calculated in accordance with Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". It is desirable to perform a flexural fatigue verification for the overlaying parts on an as-needed basis in such cases as when negative bending moment acts on top-surface overlaying decks. If no data is available about the fatigue strength of the cement-based materials used for top-surface overlaying, the flexural fatigue capacity needs to be calculated by means of an appropriate method such as experiments, an experiment-based evaluation method or non-linear finite element analysis. Since a fatigue test generally takes time, it is allowed to perform the verification using an S-N curve created from existing research data. In that case, however, care needs to be exercised by assuming a life with a survival probability of 95%, defining the point of time when the progress of cracking suddenly accelerates as the service limit life, etc. Calculating the flexural fatigue capacity of actual members requires appropriately grasping the present level of damage, the level of repeated flexural stress that acts, etc. It is extremely difficult to accurately establish these conditions in a test. A verification through a fatigue test with limited conditions should be regarded as an index of the extension of the fatigue life of members repaired or strengthened with top-surface overlaying and as an evaluation of the effect of top-surface overlaying.

6.4.3.2 Verification related to the punching shear fatigue capacity of surface members

It must be verified that the surface members repaired or strengthened with top-surface overlaying are safe against punching shear fatigue under load and environmental actions.

[Commentary] When the punching shear fatigue capacity of repaired or strengthened surface members is calculated, it is assumed that the existing members and overlaying members behave as one without peeling away from each other.

When top-surface overlaying is applied to decks, the punching shear fatigue capacity is reduced significantly as the decks are subject to the repeated action of moving wheel loads, compared to the case where the load point is fixed. Therefore, the capacity needs to be estimated by means of an appropriate method such as experiments, an experiment-based evaluation method or non-linear finite element analysis. It is known that, in actual decks, several penetrating cracks ultimately form in the direction perpendicular to the bridge axis, leaving the decks connected only by distribution reinforcement, which makes it appear as if girders of a certain width are lined up. When considering the fatigue life of decks, therefore, the widely used equation for calculating the punching shear capacity of girder-like decks shall be employed to estimate the fatigue life from the repetition of wheel loads on the decks repaired or strengthened with top-surface overlaying. The fatigue life can be estimated by Equation C6.4.2 in a dry condition or by Equation C6.4.3 in a water-filled condition.

$$\log\left(\frac{P}{P_{sxd}}\right) = -0.07835\log N + \log 1.52$$ (Equation C6.4.2)

$$\log\left(\frac{P}{P_{sxd}}\right) = -0.07835\log N + \log 1.23$$ (Equation C6.4.3)

$$P_{sxd} = P_{sx}/\gamma_b$$ (Equation C6.4.4)

$$P_{sx} = 2B\left(f_v x_m + f_t C_m\right)$$ (Equation C6.4.5)

where:

	P	:	Wheel load (N)
	P_{sxd}	:	Design punching shear capacity of the girder-like deck (N)
	N	:	Number of repetitions
	P_{sx}	:	Punching shear capacity of the girder-like deck (N)
	B	:	Girder width of the girder-like deck (= $b + 2d_d$)
	b	:	Side length of the loading plate in the bridge axis direction (mm)
	x_m	:	Neutral axis depth of the cross section of the main reinforcement (mm)
	d_d	:	Effective height of the distribution reinforcement (mm)
	C_m	:	Covering depth of the tension-side main reinforcement (mm)
	f_v	:	Shear strength of concrete (N/mm^2), $f_v = 0.656 f'^{\,0.606}_{cd}$
	f_t	:	Tensile strength of concrete (N/mm^2), $f_t = 0.269 f'^{\,0.667}_{cd}$
	f'_{cd}	:	Design compressive strength of concrete (N/mm^2)
	γ_b	:	In general, this may be set to 1.3.

Note that there have been few reports on the experimental verification related to the punching shear fatigue capacity of decks repaired or strengthened with top-surface overlaying and, therefore, the verification needs to be performed carefully. As with the calculation of the punching shear capacity, the equation for calculating the shear strength of concrete f_v is obtained from normal-strength concrete. Therefore, when steel fiber reinforced concrete is used as the cement-based materials for the overlaying parts and the neutral axis is located inside the top-surface overlaying parts, the shear strength of steel fiber reinforced concrete should be used. In general, however, since the shear strength of the concrete used for the overlaying parts is greater than that of normal-strength concrete, the evaluated punching shear capacity will be put on the safe side if it is calculated using the design strength of normal-strength concrete. In actual top-surface overlaying decks, if the existing parts are wet or subject to freezing and thawing actions, it is likely that the degradation of concrete will progress in the existing parts in the form of cracking, steel corrosion, etc., resulting in lower fatigue capacity. In light of this problem, it is safer to use the design strength of normal-strength concrete for the verification related to punching shear capacity.

Also, since the track equipment and others differ depending on the wheel load running tester, simple comparison of experiment results is not possible and it is therefore difficult to readily unify the S-N curves. For this reason, these S-N curves should be regarded as the intervention effect on the target members by the top-surface overlaying method, that is, an index of the extension of the fatigue life.

6.5 Serviceability Verification

6.5.1 General

The serviceability of a structure repaired or strengthened with top-surface overlaying shall be verified as set forth in Section 6.5 of the Common section.

6.5.2 Stress level limit

The stress level limit of a structure repaired or strengthened with top-surface overlaying shall be as set forth in Section 6.5.2 of the Common section.

[Commentary] In a structure repaired or strengthened with top-surface overlaying, the stress level in the existing section taking cutting into account shall be calculated with relation to the permanent loads that have been exerted since before intervention. As for the permanent and variable loads that increase after intervention, the stress level in the composite section formed as the existing and overlaying parts are integrated shall be calculated. The verification should be performed using the stress level obtained by totaling them.

6.5.3 Verification related to appearance

The appearance verification of a structure repaired or strengthened with top-surface overlaying shall use the crack width as the verification index and check that the design response values resulting from load and environmental actions satisfy the design limit values determined from serviceability in accordance with Section 6.5.3 of the Common section.

[Commentary] The flexural crack width of members repaired or strengthened with top-surface overlaying shall be calculated, using the stress level calculated for the composite section formed as the existing and overlaying parts are integrated, in accordance with Part 4 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". Note that, since there is little knowledge, the crack width should be checked through appropriate experiments.

6.6 Restorability Verification

6.6.1 General

The restorability of a structure repaired or strengthened with top-surface overlaying shall be verified as set forth in Section 6.6 of the Common section.

[Commentary] When top-surface overlaying is applied to decks, it is necessary to ensure the functionality required after an earthquake and check that the structure can prevent the falling of the superstructure.

6.6.2 Structural details related to seismic performance

Structural details related to seismic performance shall be as set forth in Section 6.6.2 of the Common section.

6.7 Structural Details

6.7.1 Thickness of the top-surface overlaying parts

The top-surface overlaying parts shall have a sufficient covering thickness to achieve the specified durability within a range that ensures the necessary intervention effect and constructability.

[Commentary] The thickness of overlaying cement-based materials needs to be determined, taking into consideration the maximum size of coarse aggregate and construction accuracy, in order to ensure constructability and integrity with the existing members. Also, the overlaying parts must have a covering thickness that takes into consideration drying shrinkage and intrusion of degradation factors such as chloride ions.
For example, "Second Edition for Design Procedures, Part for Maintenance of Bridges, 2015-7" (East Nippon Expressway Co., Ltd., Central Nippon Expressway Co., Ltd. and West Nippon Expressway Co., Ltd.) states that, when reinforcing materials are not used, aggregate whose maximum size is 20 mm shall be used, construction accuracy is required for concrete compaction, leveling, etc. for deck unevenness and the minimum thickness of cement-based materials shall be 50 mm taking into consideration the influence of drying shrinkage and other factors. If the overlaying member thickness is thinner than 50 mm, concrete or mortar with coarse aggregate whose maximum size is 13 mm may be used. In such a case, the use of admixture should be considered to improve the bonding property and deformation following capability of polymer and other materials. When reinforcing steel is used for the overlaying parts, the design thickness of the overlaying parts shall be 100 mm in principle, combining the space between the existing concrete and reinforcing steel (30 mm), the thickness of the upper surface covering of reinforcing steel (30 mm) and reinforcing steel diameter.

When continuous fiber reinforcing materials are used for the overlaying parts, the covering may be reduced because there will be no corrosion due to chloride ion penetration or some other factor. Therefore, the thickness is the same as that employed for the top-surface overlaying method that does not involve the placement of reinforcing steel.

6.7.2 Covering

The covering for top-surface overlaying must be determined taking into consideration the bonding strength of cement-based materials and reinforcing materials, construction error and the durability of the structure.

[Commentary] A covering shall be provided whose thickness is more than the value obtained by adding construction error to the diameter of reinforcing steel, and the thickness must be determined taking into consideration the past records and whether fiber is mixed among other things. Also, the unevenness on the surface of the existing concrete members resulting from base coating should be taken into consideration.

6.7.3 Placement of reinforcing materials

In top-surface overlaying, reinforcing materials must be placed taking into consideration the space between reinforcing materials and the space between the existing concrete surface and reinforcing materials in order to ensure that the reinforcing materials achieve the specified strengthening performance and constructability.

[Commentary] The space between the existing concrete surface and reinforcing steel and the space between reinforcing steels need to be determined taking into consideration the maximum size of coarse aggregate and the length of short fiber. These spaces need to be more than four-thirds times the maximum size of coarse aggregate and more than the length of short fiber. In top-surface overlaying for decks, the space between the existing concrete and reinforcing materials is often set to 30 mm based on the fact that it should be more than four-thirds times the maximum size of coarse aggregate as well as the filling property of concrete and the length of short fiber. The space between the reinforcing materials and existing concrete is important not only to ensure constructability but also to integrate the reinforcing materials and cement-based materials for attaining the mechanical performance.

6.7.4 Joints for reinforcing materials

Joints for the reinforcing materials used in the overlaying parts must ensure the transfer of stress without breaking at the joint part.

[Commentary] In top-surface overlaying for decks, lap joints are generally used as joints for steel materials. If divided construction is affected, the construction work may be performed using joints whose length is 20 times or more the reinforcing steel diameter. This is based on the fact that the confinement effect of steel fiber reinforced concrete used in top-surface overlaying contributes to the integrity of lap joints. If lap joints of the specified length are not available, mechanical joints need to be used.

CHAPTER 7 CONSTRUCTION

7.1 General

(1) The construction for top-surface overlaying must be performed according to a construction plan.

(2) Engineers with sufficient knowledge and experience in the construction for top-surface overlaying must be present at the site and the construction work must be performed under the direction of those engineers.

(3) If the construction plan cannot be followed in the actual construction for top-surface overlaying, appropriate measures must be taken to ensure the performance required at the time of design under the direction of the responsible engineer.

[Commentary] (1) What is essential in construction is that the construction work is performed economically and efficiently by means of an appropriate construction method, assuming that the safety of work is guaranteed. The construction for top-surface overlaying consists of many different types of work, such as preparation, base coating, assembly of reinforcing materials, manufacture of cement-based materials and transportation, placement, compaction and finish. When construction work is performed, therefore, it is desirable to achieve sufficient coordination with other related types of work as well in order to ensure efficient construction. Fig. C7.1.1 shows an example of the construction procedure.

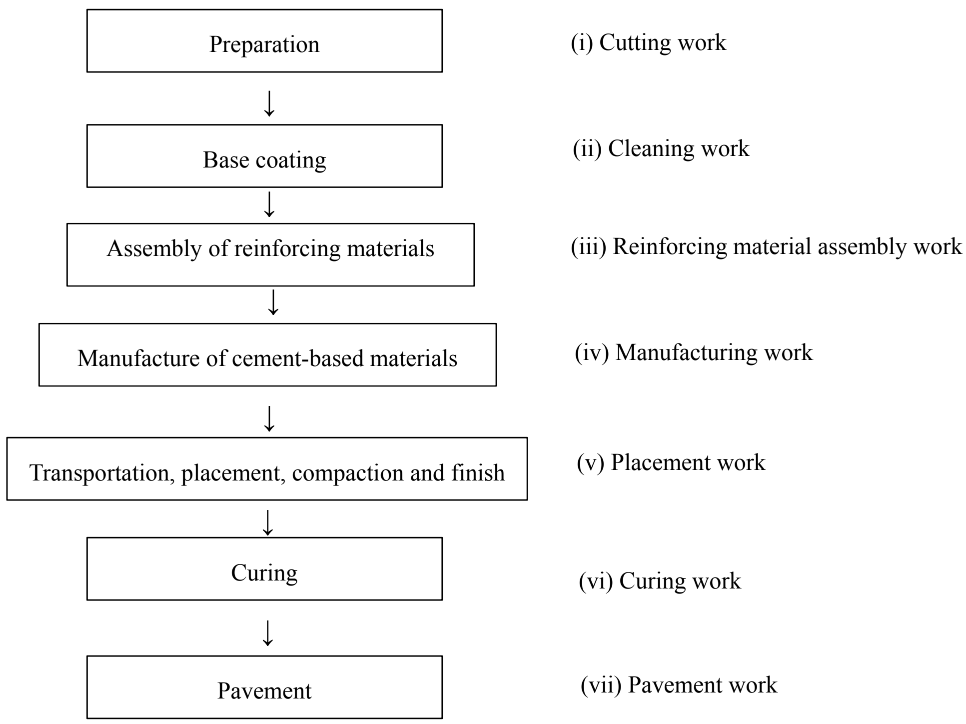


Fig. C7.1.1 Example of the construction procedure for top-surface overlaying (decks)

(2) In general, whether construction succeeds or fails greatly depends on human factors such as the experience and qualities of constructing parties involved. It is therefore desirable that engineers

with sufficient knowledge and experience in the construction for top-surface overlaying be present at the site and that the construction work be performed under the direction of those engineers.

(3) During the actual construction, it is not rare that a situation not expected in the design phase occurs and, therefore, the construction work may not necessarily be able to be performed according to the construction plan. If it is difficult to follow the construction plan at the time of construction, appropriate measures must be taken to ensure the performance required under the direction of the responsible engineer.

7.2 Prior Study and Construction Plan

(1) The existing concrete structure to which to apply top-surface overlaying must be fully studied in advance to check differences from design documents, the status of damage and so on.

(2) A construction plan must be formulated and a construction plan document must be created to perform the construction for top-surface overlaying appropriately. When formulating a construction plan, the structural conditions of the existing structure, environmental conditions of the site, construction conditions and other relevant factors must be taken into consideration.

[Commentary] (1) The prior study in top-surface overlaying is aimed at studying design documents, determining the planned height, grasping construction quantities, ensuring smooth construction, etc. When decks are the target, the study involves visually checking for cracking and efflorescence from under the decks. Also, core samples must be collected from the road surface to measure the pavement thickness, reinforcing steel covering, etc.

(2) When formulating a construction plan for top-surface overlaying, it is important to create an appropriate construction plan according to the conditions of the site. When decks are the target, an example of the construction procedure is as shown in Fig. C7.1.1. The items to note are described below.

(i) Cutting work: If the existing deck surface is uneven, part of the asphalt pavement may be left unremoved when a large-size cutter is used. In such a case, the remaining asphalt pavement shall be removed through human labor or with a small-size cutter. Also, care needs to be exercised because the top reinforcement of the existing decks may be damaged while cutting. If the top reinforcement is damaged, supplementary reinforcement must be placed.

(ii) Cleaning work: Steel shot blasting is difficult to perform in rainy weather. Depending on the process, necessary equipment such as a road surface dryer shall be prepared. After cleaning, the deck surface shall be cured with fire-retardant sheets or other materials to protect it from work vehicles and the like.

(iii) Reinforcing material assembly work: Appropriate spaces between reinforcing materials and between reinforcing materials and existing concrete shall be secured.

(iv) Manufacturing work: Cement-based materials shall be manufactured with a mix proportion that ensures the required strength, durability, water-tightness and workability.

(v) Placement work: In the site, construction machines, such as dedicated concrete finishing machines, and a work area where materials can be loaded and unloaded are necessary. When adhesive is used to increase the bonding strength between the existing and overlaying parts, short fiber reinforced concrete shall be placed while adhesive is applied. When polymer cementitious mortar or other cement-based material is used for overlaying, a process of increasing the bonding strength between the existing and overlaying parts shall be performed by means of a method appropriate for the material used, such as primer application.

(vi) Curing work: A curing agent that hinders the bonding with the water-resistant layer shall not be used.

(vii) Pavement work: Before pavement work, waterproofing shall be applied to the placement surface of top-surface overlaying. Waterproofing requires not only providing a water-resistant layer on top of the overlaying parts but also considering the installation of drainage facilities. When asphalt pavement is placed, it may be necessary to replace the expansion device, perform smoothing at the earthmoving part, etc. depending on changes in the road height.

7.3 Mix Proportion of Cement-Based Materials

The mix proportion of cement-based materials must be designed, taking into consideration the construction conditions and environment, variations in the quality of the materials used, etc., so that the materials fulfill the required performance.

[Commentary] This section describes the points to note regarding how to design a mix proportion necessary to ensure the integrity between the existing and overlaying parts when cement-based materials are placed on the top-surface overlaying parts of certain members.

(i) Design material age and strength: Since the design strength of cement-based materials in top-surface overlaying assumes the integrity between the existing and overlaying parts, a strength equal to or greater than that of the concrete of the existing parts is required. The material age at which the design strength is established is often set to 3 hours when ultrarapid hardening cement is used or 7 days when high early strength Portland cement is used. When determining the water-cement ratio that satisfies the design strength at the specified material age, trial mixing needs to be performed using the cement-based materials that are actually used for top-surface overlaying in order to find the relationship between the water-cement ratio and strength. Polymer cementitious mortar is premixed in many cases. By mixing it with an amount of water proven to ensure performance, polymer cementitious mortar having the specified performance can be obtained.

(ii) Maximum size of coarse aggregate: It is common to use coarse aggregate whose maximum size is 20 mm. If there are restrictions on the thickness of the top-surface overlaying work or the covering of or space between reinforcing materials, the maximum size of coarse aggregate may be set to a value smaller than 20 mm.

(iii) Slump: When top-surface overlaying is applied to decks, construction is performed mainly by machines and, therefore, stiff-consistency concrete with a slump of 5 cm is used. By contrast, when construction is performed through human labor, the slump is often set to 8 cm or so.

(iv) Air content: Generally, air content is often set to 2 to 3% when ultrarapid hardening cement is used at the site plant or around 4.5% when high early strength Portland cement prepared by a mixer at a ready mixed concrete plant is used.

(v) Mineral admixture quantity: When an expansive material is used for shrinkage compensation or crack prevention, the unit quantity must be established so as to achieve the required performance. As low additive expansive materials have come into common use in recent years, 20 kg/m^3 (expansive material type 20) is becoming the standard as the unit quantity applied for shrinkage compensation in place of the conventional unit quantity of 30 kg/m^3 (expansive material type 30).

(vi) Chemical admixture quantity: The quantity of high performance water reducing agent to be used shall be checked through trial mixing. To determine the polymer-cement ratio when using polymer, premixed polymer cementitious mortar with proven performance should be used. If polymer is added, the appropriate quantity of polymer to be used needs to be determined separately through testing. When short fiber is used, the short fiber mix rate needs to be determined taking into consideration the strengthening effect and constructability of short fiber. The fiber mix rate of steel fiber reinforced concrete is often set to 1.0 to 1.3 vol. %.

7.4 Preparation

Before intervention is performed with top-surface overlaying, preparation work shall be done as necessary.

[Commentary] Before top-surface overlaying is performed, preparation work needs to be done, including the treatment of degradation of the existing concrete, the carry-in of materials and the installation of construction machines. When top-surface overlaying is applied to decks, the pavement materials such as asphalt, water-resistant layer and tack coat need to be cut and removed in advance because they impair the integrity between the existing members and overlaying members. Generally, as much as 10 mm of the existing concrete members is cut from the top surface. Examples of the preparation work likely to be needed when top-surface overlaying is applied to decks are as follows.

(i) Removal of degraded parts of concrete

(ii) Carry-in and accumulation of raw cement materials (when mixing is performed at the site)

(iii) Building of a site plant (when mixing is performed at the site)

(iv) Consideration of the method of transporting concrete at the site

(v) Carry-in, installation, etc. of machines and facilities such as dedicated concrete finishing machines

7.5 Base Coating

Dirt such as oil and fat on the surface and vulnerable layers must be removed so that the overlaying and existing members can achieve the specified bonding property. Also, patching repair and other repair measures must be taken for the construction parts.

[Commentary] If the existing concrete for which top-surface overlaying is to be performed is degraded, the property of bonding with cement-based materials may be inhibited. It is therefore necessary to conduct a study in advance by means of an appropriate method to identify the degraded concrete parts and remove the range of concrete that affects the bonding. Forms of concrete degradation include peeling, honeycombs, rust fluid and cracking. The range of concrete subject to partial replacement needs to be determined taking into consideration both the paved surface and bottom surface of decks. Also, it is necessary to remove the parts of concrete that contain more chloride ions than allowed or the degraded parts turning into sand. The degraded parts may be removed through human labor, blasting, water jetting, etc. Depending on the condition of the base, a water blast method (water jet, high-pressure cleaning, etc.) may be employed to remove oil, fat and other dirt, vulnerable layers and cement paste and expose the sound surface (surface texturing). In top-surface overlaying for decks, shot blasting is commonly used for base coating. If necessary, patching repair is done for the parts from which concrete has been removed. In general, polymer cementitious mortar with a higher bonding property that shrinks little is often used to achieve the integrity with the existing decks. Also, from the viewpoint of the capability to follow deformation from the existing concrete, the patching repair material may be required to have a Young's modulus value equal to or lower than that of the existing concrete. For information about the patching repair method, reference should be made to "Concrete Library 119, Recommendation for Concrete Repair and Surface Protection of Concrete Structure, 2005.4".

Since the existing concrete members to be repaired with top-surface overlaying are on the top surface, there are fewer construction restrictions than in other methods such as bottom-surface overlaying. Note, however, that if there are many parts that need partial concrete replacement, the restrictions become severe as access by vehicles to those parts is blocked, the construction time is insufficient, etc. Therefore, it is desirable to take necessary measures such as performing partial concrete replacement as separate work in advance.

7.6 Assembly of Reinforcing Materials

Individual reinforcing materials must be jointed and anchored by means of the method specified according to the type of reinforcing material.

[Commentary] When reinforcing materials are used, they shall be jointed and anchored pursuant to the jointing method of each individual material. Also, it is important to put spacers at appropriate locations that are made of materials appropriate for the locations where they are used in order to ensure that the covering of reinforcing materials and the space from the existing members are within the allowable error margin. The unevenness on the surface of the existing concrete members resulting from base coating should be taken into consideration.

7.7 Manufacture of Cement-Based Materials

Cement-based materials must be manufactured so as to achieve the required quality.

[Commentary] Cement-based materials shall be manufactured in principle in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction". Since the usable time and curing time of ultrarapid hardening concrete used in top-surface overlaying for decks are short, it is difficult to manufacture the concrete at a ready mixed concrete plant and transport it by agitating truck. Therefore, ultrarapid hardening concrete is generally manufactured in an on-site concrete plant car capable of supplying, measuring and mixing raw materials stored in a location near the construction site on an as-needed basis. When concrete is manufactured at an on-site concrete plant as mentioned above, it is necessary to ensure that the cement-based materials achieve the required quality. There are two types of large-size on-site concrete plant car: continuous mixer and batch mixer. Mixing cement-based materials at a certain speed while transporting them to the site stabilizes the spreading and compaction work by the concrete finishing machine. This is extremely important for attaining a high level of quality for construction using the top-surface overlaying method.

As for steel fiber reinforced concrete using high early strength Portland cement, there have been previous cases in which the concrete was manufactured at a ready mixed concrete plant and transported by agitating truck or dump truck. In some cases, concrete is manufactured by putting steel fibers into a mixer at a plant while, in other cases, steel fibers are put into an agitating truck at the site.

7.8 Transportation, Placement, Compaction and Finish

(1) For the transportation of cement-based materials, a method that gives consideration to the separation of materials and a drop in fluidity must be selected.

(2) Cement-based materials must be unloaded and placed such that the separation of the materials does not occur.

(3) Compaction shall be performed using a vibrator promptly after cement-based materials are placed. Prior to compaction using a vibrator, the areas around the mold and construction joints shall be compacted fully by means of a simple device or other tool.

(4) The surface shall be finished so that the specified shape, size and quality are achieved.

It is important to plan these processes so that they can be performed consecutively. Appropriate methods for placement, compaction and finish shall be selected in principle based on an understanding of the properties of the materials and the characteristics of the structure.

[Commentary] Cement-based materials shall be transported, placed, compacted and finished in principle in accordance with “Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction”. In top-surface overlaying for decks, when adhesive is used to increase the bonding strength between the existing decks and the short fiber reinforced concrete of the overlaying parts, the concrete shall be placed while adhesive is applied to the surface of the existing parts. Typically, the unit placement area is the span in the bridge axis direction and the full width in the width direction. Since stiff-consistency steel fiber reinforced concrete with a slump of about 5 cm is often used and the thickness of the overlaying members is relatively thin, a dedicated concrete finishing machine is used for compaction. Note that, at the start and end of compaction with the dedicated concrete finishing machine, the spreading work needs to be done through human labor using a mold vibrator. The dedicated concrete finishing machine is required to have a vibration property that ensures the integrity between the existing members and cement-based materials, in addition to proper flatness of the finished surface. A machine with proven performance should be used.

7.9 Curing

The method and period of curing must be determined to ensure that temperature and humidity are kept at the levels necessary for hardening for a certain length of time and to prevent the detrimental effects of drying, sudden temperature change, etc., as well as the effects of vibration and deformation.

[Commentary] The curing method and period for cement-based materials shall be determined in principle in accordance with “Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction”. It is necessary to note that, when a film curing agent is used in top-surface overlaying for decks, the bonding with waterproof materials may be affected depending on the type of agent or the amount of agent sprayed.

7.10 Pavement

(1) Since waterproofing can have great impact on durability, materials must be selected, based on an understanding of the structure, construction time, compatibility with cement-based materials and other relevant conditions, so that the specified waterproof performance is achieved.

(2) As for asphalt pavement, care must be exercised in determining the transportation time of materials and selecting the machines to be used in order to ensure that the specified quality can be achieved at various outdoor air temperatures.

(3) When the surface of the overlaying members is used as concrete pavement, it needs to meet the performance requirements of pavement.

[Commentary] (1) In recent years, there have been reports of cases of the degradation rate being accelerated significantly by the water supply or the intrusion of anti-freezing agent. As for top-surface overlaying, cases have been reported of water entering the bonding interface between the existing concrete and cement-based materials from construction joints, exerting a load repeatedly and thus impairing their integrity. Therefore, a waterproof measure is important for decks to which top-surface overlaying is applied. A waterproof measure should not only cover waterproof materials but encompass drainage facilities and pavement as well. Waterproof materials are classified into two types: sheet and film. Waterproof materials should be selected based on an understanding of their characteristics and constituent materials. Since construction work is difficult to perform at deck edges such as railings, wheel guards and expansion devices, particular care needs to be exercised in selecting materials. It is also necessary to select waterproof materials that bond well to asphalt and cement-based materials. Care needs to be exercised because, depending on the combination of the curing agent used when placing cement-based materials and the waterproof materials, the required bonding performance may not be achieved. For information about waterproof materials, reference should be made to “Guideline of Waterproofing System for Bridge Decks 2016, 2016.11” (Japan Society of Civil Engineers).

(2) For information about construction of asphalt pavement, reference should be made to “Standard Specifications for Pavements-2014”.

(3) In some cases of the intervention of decks for which increases in dead loads are limited, after the pavement on the decks is removed, the top surface is overlaid with cement-based materials as thick as the pavement and the surface of the overlaying members is used as the concrete pavement as is. In such cases, the member surface needs to achieve the skid resistance and finished shape required for pavement. Also, since a water-resistant layer cannot be provided between the overlaying and existing members, it is necessary to select a structure and materials that give due consideration to the entry of water to the existing members. For information about construction of concrete pavement, reference should be made to “Standard Specifications for Pavements-2014”.

7.11 Quality Control

(1) Quality control must be implemented appropriately in each phase of construction to

ensure that a concrete structure with the required quality is created using the top-surface overlaying method.

(2) Quality control is a voluntary activity by constructing parties, and constructing parties themselves must plan a method whereby the expected effect can be obtained and perform this activity appropriately.

(3) Quality control records must be retained for a specified period of time after handing over so that they can be used for quality assurance of the constructed structure as well as for quality control in future construction work.

[Commentary] Constructing parties shall perform construction according to a construction plan to build a top-surface overlaying structure that fulfills the required performance, as well as ensure that the specified level of quality is achieved in each phase of construction by implementing quality control with an appropriate method for appropriate items such as cement-based materials, reinforcing materials, machines and facilities and construction methods. Note that quality control not only involves conducting various tests and collecting a large amount of data, but it should be implemented on necessary items as frequently as necessary. Also, in addition to conducting actual tests, another method of checking quality based on test results is to refer to test reports of manufacturers as with JIS products.

Constructing parties must formulate a secure, efficient and economical quality control plan based on a construction plan and perform construction according to this quality control plan. Since results of quality control may be used in place of results of inspections by the ordering party in each phase of construction, it is desirable that, where practical, quality control be implemented using a reliability-guaranteed method supported by existing technical knowledge and the like.

If quality control results reveal any signs of significant variations in quality, the cause of those variations must be examined and appropriate measures must be taken to keep variations within the predetermined control range. If any anomaly occurs or there is any doubt as to quality, appropriate measures shall be taken promptly under the direction of the responsible engineer. Since quality control records often include control data indicating how construction work is performed, it is desirable to retain these records for a specified period of time after handing over so that they can be used for quality assurance of the constructed structure as well as for quality control in future construction work.

7.12 Inspection

(1) A structure to which top-surface overlaying is applied shall be in principle inspected in each phase of construction and upon completion of construction under the responsibility of the ordering party.

(2) Constructing parties shall conduct necessary inspections in each phase of construction based on a construction plan. The standard inspections to be conducted by constructing parties are the material receiving inspection, manufacturing equipment inspection, ready mixed concrete receiving inspection and reinforcing material receiving inspection.

[Commentary] (1) In order to ensure that the intervention with top-surface overlaying is performed as specified in design documents, an inspection shall be conducted in each phase of construction to check that the content of work performed is appropriate. Also, in the intervention with top-surface overlaying, it is important that the existing concrete members and the overlaying members made from cement-based materials behave as an integrated composite section. It is therefore desirable to conduct destructive tests such as a bonding strength test and nondestructive tests using the impact echo method, tapping sound, etc. as inspections for the repaired or strengthened structure in order to check for gaps and other anomalies between the existing and overlaying members.

CHAPTER 8 RECORDS

Information concerning the intervention of a structure must be recorded by means of an appropriate method and retained for a necessary period of time. The method of recording shall be as set forth in Chapter 8 of the Common section.

[Commentary] Records of studies, design, performance verification, construction, materials used, quality control, etc. regarding the intervention with top-surface overlaying shall be in principle handled as set forth in Chapter 8 of the Common section.

CHAPTER 9　MAINTENANCE

The maintenance of a structure repaired or strengthened with top-surface overlaying shall be as set forth in Chapter 9 of the Common section.

[Commentary] The maintenance of a structure repaired or strengthened with top-surface overlaying shall be in principle as set forth in Chapter 9 of the Common section. There have been reports of cases of peeling or re-degradation of the overlaying and existing parts in the decks repaired or strengthened with top-surface overlaying. Therefore, maintenance needs to be performed to prevent re-degradation, taking into consideration the post-intervention environment and the condition of the structure.

Guidelines for Structural Intervention of Existing Concrete Structures Using Cement-Based Materials - Method-Specific Section (Bottom-Surface Overlaying)

CHAPTER 1 GENERAL PROVISIONS

1.1 Scope

These guidelines specify the standards for design and construction using the bottom-surface overlaying method. Bottom-surface overlaying is a method whereby reinforcing materials are placed on the bottom surface of the surface members or bar members whose performance is lower than required and the integrity between the reinforcing materials and existing members is achieved with overlaying materials so as to improve the durability, serviceability, safety and other properties of the members.

[Commentary] Bottom-surface overlaying is a method that improves the flexural property, shear property and fatigue property by placing reinforcing materials on the bottom surface (tension side) of surface or bar members and integrating them with the existing members. Overlaying materials play a part in integrating reinforcing materials with the existing members, lap-jointing and anchoring reinforcing materials and guaranteeing durability of reinforcing materials. Generally, polymer cementitious mortar (hereinafter PCM) is used as the overlaying material. This is because PCM bonds well with the existing members and has great tensile strain for cracking, thus making the penetration of degradation factors less likely. As reinforcing materials, reinforcing steel, welded wire mesh, FRP grid, and the like are used.

Bottom-surface overlaying has evolved as a strengthening method for fatigue of RC decks, drawing attention because of examples of application like the one shown in Fig. C1.1.1. The members that are currently repaired or strengthened using this method include RC decks, tunnel linings, box culverts, waterways and beams. In these guidelines, the latest information about the design and construction of the bottom-surface overlaying method using overlaying materials has been collected and the best possible standards are presented. Matters not mentioned herein shall be as set forth in the Common section.

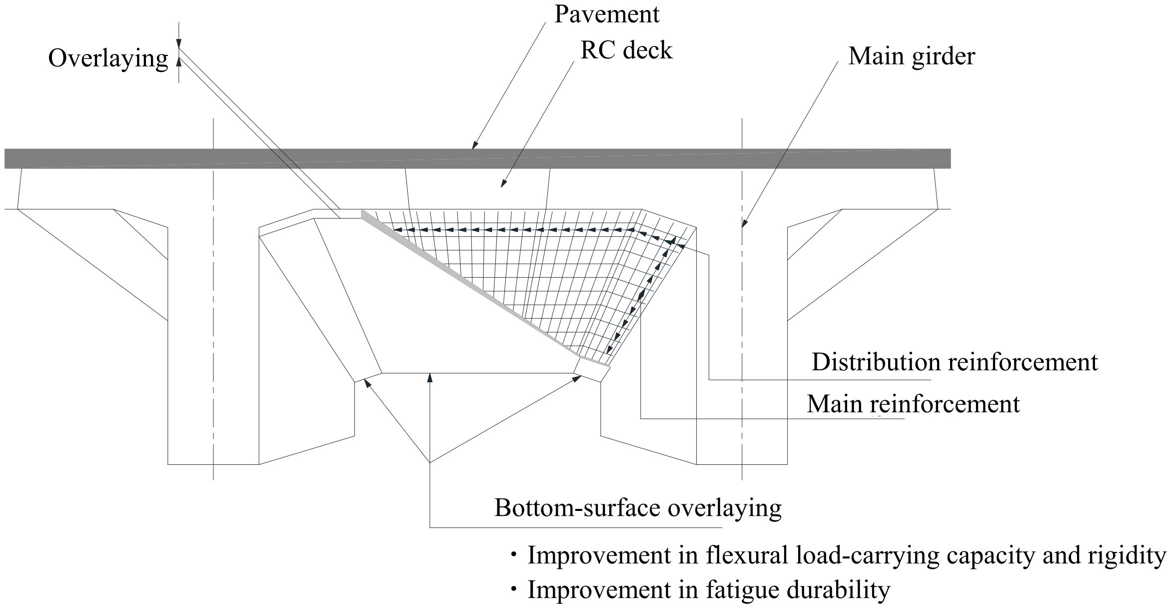


Fig. C1.1.1 Example of application of bottom-surface overlaying for deck strengthening

1.2 Terms and Definitions

The definitions of the terms used in the Bottom-Surface Overlaying section shall be as defined in Chapter 1 of the Common section.

CHAPTER 2　STUDY OF THE EXISTING STRUCTURE

2.1 General

The study of the existing structure for which to consider intervention using the bottom-surface overlaying method shall be as set forth in Chapter 2 of the Common section.

2.2 Study

2.2.1 Study using documents, records, etc.

When the climatic conditions, environmental conditions and geographical conditions of the local site are studied using documents, records, etc., the study shall be conducted in accordance with Section 2.2.1 of the Common section.

2.2.2 On-site study

(1) The on-site study on degradation, damage and initial defects of the existing concrete structure shall be conducted in accordance with Section 2.2.2 of the Common section.

(2) The work environment and other relevant conditions of the site must be checked in advance.

[Commentary]　(1) It is necessary to check that the shape, size and other characteristics of the existing members subject to bottom-surface overlaying are consistent with the documents and records. In the study, the steel materials of the existing members need to be checked in terms of size, arrangement, etc. through a nondestructive inspection, chipping inspection or the like as necessary. Also, the degree of degradation and the progress of damage of the existing members subject to bottom-surface overlaying shall be grasped through checking for changes in appearance (cracks, water leaks, free lime, rust fluid, floating, peeling, exposed reinforcing steel, etc.), measurement of chloride ion content, checking of the carbonation depth, covering depth and degree of steel corrosion, etc. At the same time, the causes of degradation and damage must be presumed based on the surrounding environment (coastal lines, traffic conditions, climatic conditions, etc.), the characteristics of damage, the flow of rainwater, water leaks, vibration generated when large vehicles pass and so forth.

(2) It is necessary to check the status of the approach route for work vehicles, work machines, etc. as well as whether the storage space and temporary structures such as scaffoldings can be set up.

CHAPTER 3 INTERVENTION DESIGN

3.1 General

When repairing or strengthening a concrete structure using bottom-surface overlaying, it must be verified by means of an appropriate method that the structure fulfills the required performance for the required period of time. Also, the environment for the intervention construction, constructability, post-intervention maintainability and economy must be taken into consideration.

[Commentary] Bottom-surface overlaying is applied for purposes such as flexural strengthening and shear strengthening of structural members by providing thin reinforcing overlaying layers. One feature of this method is that the increase in weight due to intervention is small. When it is used for box culverts, tunnels, waterways, etc., there is only a small reduction in the inner section. When structural members such as bridge decks are repaired or strengthened using bottom-surface overlaying, a verification related to the punching shear failure of the decks needs to be performed. In the case of waterways or box culverts, it is necessary to verify ordinary design loads such as earth pressure and water pressure. Even for tunnels and waterways, a verification related to level 2 ground motions may be required. While the verification methods described in these guidelines do not cover all kinds of verification, the currently available latest technologies are presented herein. For the items necessary for verifications, reference must be made to the relevant standard specifications in addition to these guidelines.

Fig. C3.1.1 shows an example of the construction section observed when bottom-surface overlaying is applied to bridge decks. This example shows a method whereby reinforcing materials are placed and anchored along the existing members and the existing members and the added reinforcing materials are integrated using overlaying materials. There are also various other methods to achieve integrity with reinforcing materials.

Bottom-surface overlaying requires that overlaying materials protect reinforcing materials from corrosion as well. With the bottom-surface overlaying method using PCM, the thickness of overlaying parts is 30 mm or so in many cases. Therefore, overlaying materials can be applied to overlaying parts by either spraying or troweling. A rational application method should be selected taking into consideration the application environment and quantity.

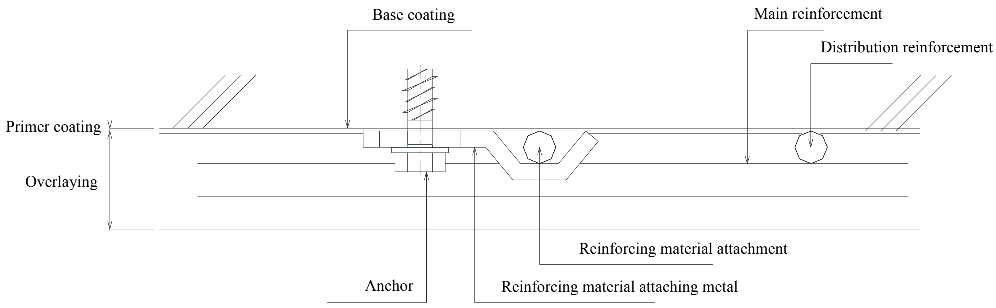


Fig. C3.1.1 Example of the construction section for bottom-surface overlaying

3.2 Structural Plan

The structural plan for a structure repaired or strengthened with bottom-surface overlaying shall be as set forth in Section 3.2 of the Common section.

[Commentary] The repaired or strengthened structure must fulfill the required levels of durability, safety, serviceability and restorability throughout the design service life. The performance requirements differ depending on the structure repaired or strengthened with bottom-surface overlaying. In flexural strengthening of existing members, the verification is mainly intended for serviceability, safety, etc. In fatigue strengthening of bridge decks, the punching shear capacity of the decks is required to be improved. In seismic strengthening of box culverts and tunnels, the verification is intended for restorability. Also, the intervention must be planned taking into consideration the causes of degradation and damage of the existing members subject to bottom-surface overlaying.

The restrictions on the bottom-surface overlaying construction must be taken into consideration. Either troweling or spraying can be selected as the method of applying overlaying materials. Also, there are two spraying methods: wet spraying and dry spraying. Each of these construction methods has unique characteristics and both advantages and disadvantages. It is desirable that an appropriate construction method be selected in the planning phase based on the construction environment, economy and so on.

Since thin members are used as overlaying materials in bottom-surface overlaying, the covering of reinforcing materials becomes relatively thin. This makes it possible for degradation factors to intrude more quickly in a severe corrosion environment. Therefore, the durability verification is a key point in maintenance and necessary measures must be considered.

3.3 Structural Details

(1) The structure of bottom-surface overlaying must ensure the integrity between the existing and overlaying parts in the repaired or strengthened members.

(2) The structure of bottom-surface overlaying must ensure that reinforcing materials are securely anchored to the existing parts.

(3) The structure of bottom-surface overlaying must prevent water from accumulating in the interface between the existing and overlaying parts.

(4) The reinforcing materials used for bottom-surface overlaying must have a degree of tensile stiffness that allows the reinforcing materials to behave with the existing parts as one.

[Commentary] (1) In bottom-surface overlaying, the loss of the integrity between the existing and overlaying parts in the repaired or strengthened members may result in the limit state of safety being reached. This failure is a vulnerability, which must be avoided.

(2) Anchoring reinforcing materials securely to the existing parts can reduce the risk of peeling.

(3) The accumulation of water near the interface between the existing and overlaying parts in the

members repaired or strengthened with bottom-surface overlaying may cause the degradation of the interface or a decrease in adhesion. Therefore, a measure to prevent such accumulation must be taken.

(4) The reinforcing materials used for bottom-surface overlaying must not have excessive tensile stiffness against the existing parts. If the tensile stiffness of the reinforcing materials is excessive, care needs to be exercised because the loads on the interface between the existing and overlaying parts as well as on the anchoring parts of the reinforcing materials become great, potentially leading to peeling or some other problem. It is desirable that the reinforcing materials be arranged as evenly as possible so that they behave with the existing parts as one. Therefore, it is advisable to use reinforcing materials having a small diameter and arrange them as densely as allowed for construction. For example, small-diameter reinforcing steel (D6 or D10) may be used as reinforcing materials and arranged at the pitch of 50 mm.

CHAPTER 4　MATERIALS

4.1 General

The materials used for bottom-surface overlaying must be of proven quality to ensure that the required performance is fulfilled for a necessary period of time.

[Commentary] Bottom-surface overlaying is a construction method whereby thin overlaying parts are applied on the bottom surface of the existing members. Considering this, it is necessary to select appropriate materials and methods.

4.2 Materials in the Existing Structure

The characteristic values of material strength, material factors and design values of the materials in the existing structure that are used for the design shall be determined in accordance with Section 4.2 of the Common section.

4.3 Materials Used in Repaired or Strengthened Parts

4.3.1 General

The quality of the materials used in the parts repaired or strengthened with bottom-surface overlaying shall be as set forth in Section 4.3 of the Common section.

4.3.2 Cement-based materials

(1) The overlaying materials used for bottom-surface overlaying must have a bonding property and durability sufficient to integrate the existing parts with added reinforcing materials.

(2) The overlaying materials must have performance equal to or greater than the shielding property of the existing members against environmental factors.

[Commentary] (1) The overlaying materials used for bottom-surface overlaying are required to achieve excellent bonding between the existing parts and reinforcing materials and have sufficient adhesion, gap filling property, etc. to guarantee the integrity between the existing parts and reinforcing materials. Generally, they need to be excellent in bonding strength, tensile strength and flexural strength and ensure the transfer of stress between the existing parts and reinforcing materials. Materials having Young's modulus and compressive strength that are the same as or similar to those of the existing members are suitable.

(2) In many cases, the covering of overlaying materials is thin relative to reinforcing materials and, therefore, the overlaying materials need to be impermeable to degradation factors that affect the overlaying parts and existing parts. Particularly, those having a low diffusion coefficient of chloride ions, a low carbonation rate and high resistance to freezing and thawing are preferred. Considering these performance requirements as well as uniform quality and economy, premixed PCM is often used as the overlaying material.

4.3.3 Reinforcing materials

Considering the performance requirements, reinforcing materials having appropriate tensile stiffness, design tensile strength and durability must be selected.

[Commentary] Reinforcing steel, welded reinforcing steel, FRP reinforcing steel and the like are used as reinforcing materials, and they are available in shapes of bars and grids.

4.3.4 Bonding materials

(1) The bonding materials used in the interface between the existing and overlaying parts must ensure the specified bonding property.

(2) The bonding materials must prevent the degradation in the bonding property of the overlaying and existing parts.

[Commentary] (1) The bonding materials include polymer dispersion, polymer cementitious mortar and resin adhesive selected for each individual method (material). They are used to improve the bonding property of the existing and overlaying parts.

(2) The bonding materials must be those proven to be compatible with the materials used in both the overlaying and existing parts and have sufficient durability.

4.4 Characteristic Values and Design Values of Materials

4.4.1 General

The characteristic values and design values of the materials used for bottom-surface overlaying shall be as set forth in Section 4.4 of the Common section.

4.4.2 Cement-based materials

The cement-based materials used for bottom-surface overlaying shall be as set forth in Section 4.4.2 of the Common section.

[Commentary] If the strength and other mechanical properties of a material change depending on temperature even in the temperature range under the normal usage environment of the structure, as with PCM, the characteristic values of strength and other properties need to be determined under the temperature condition appropriate for the usage environment.

4.4.3 Reinforcing materials

The reinforcing materials used for bottom-surface overlaying shall be as set forth in Section 4.4.3 of the Common section.

4.4.4 Bonding materials

As the design value of the bonding material, the characteristic value of the bonding strength obtained after integrating interfaces between the existing part and the overlaying part and between overlaying parts shall be used, instead of the characteristic value of the strength of the bonding material itself.

[Commentary] The bonding material must have material properties that ensure that the existing parts and overlaying parts are integrated throughout the design service life. The bonding material is used to integrate the existing parts, overlaying parts and interface between overlaying members through intervention. Therefore, the characteristic value of the strength obtained after integrating the old and new materials is necessary for the design. For this reason, it has been decided that the bonding strength obtained after the members are integrated should be used as the characteristic value, instead of the characteristic value of the bonding material itself. The characteristic value of the bonding material shall be determined through testing as necessary.

CHAPTER 5 ACTIONS

5.1 General

The actions used for performance verification of intervention using the bottom-surface overlaying method shall be as set forth in Chapter 5 of the Common section.

5.2 Actions to Be Considered for the Intervention Design

In the intervention design, the actions that may occur on the existing structure and repaired or strengthened parts shall be considered in accordance with Section 5.2 of the Common section.

CHAPTER 6 PERFORMANCE VERIFICATION FOR THE REPAIRED OR STRENGTHENED STRUCTURE

6.1 General

(1) The items to be verified for the concrete members repaired or strengthened with bottom-surface overlaying must be established appropriately so as to fulfill the required performance of the repaired or strengthened structure.

(2) When calculating the design limit values for the repaired or strengthened members, the influence of the cracks, strain, stress, corrosion factors and others that remain in the existing members must be taken into consideration.

[Commentary] (2) The existing members have been subject to various actions from the time they are constructed until they are repaired or strengthened, thus causing changes in them. These changes influence the calculation of the design limit values for the strengthened members and must therefore be taken into consideration appropriately.

6.2 Calculation of Response Values

6.2.1 General

The response values of a structure repaired or strengthened with bottom-surface overlaying shall be calculated as set forth in Section 6.2 of the Common section.

6.2.2 Modeling of the structure

(1) A member repaired or strengthened with bottom-surface overlaying may be modeled as a bar or surface member according to the shape and action direction through the use of finite element modeling or modeling with linear members.

(2) In the case of finite element modeling, the constitutive law for the existing members shall be as set forth in "Standard Specifications for Concrete Structures-2017, Design" taking into consideration the changes in the existing members. For the interface between the existing and overlaying parts, an appropriate constitutive law must be adopted according to the materials used.

(3) In the case of modeling with linear members, in principle, the skeleton curve shall be obtained using a fiber model or one proven through experiments or other means shall be employed.

[Commentary] (1) When a surface external force acts on a surface member repaired or strengthened with bottom-surface overlaying, the sectional force shall be in principle calculated with respect to two directions taking into consideration the support conditions and the action points of loads.

(3) Since a member repaired or strengthened with bottom-surface overlaying has a combination of different material properties, such as existing reinforcing steel and reinforcing material or existing concrete and overlaying material, it has been decided that the skeleton curve used for modeling with linear members should be obtained using a fiber model or through experiments.

6.2.3 Structural analysis

The structural analysis of a structure repaired or strengthened with bottom-surface overlaying shall be performed as set forth in Section 6.2.3 of the Common section.

6.2.4 Calculation of design response values

(1) The design response values to be used for the verification of a structure repaired or strengthened with bottom-surface overlaying shall be calculated taking into consideration the responses of the existing structure before intervention.

(2) The permanent loads that have been exerted since before intervention shall be calculated as responses on the existing section, and the permanent and variable loads that increase after intervention shall be calculated as responses on the composite section of the existing and strengthened sections. Then, these responses shall be totaled.

(3) The flexural crack width of a member repaired or strengthened with bottom-surface overlaying may be calculated using Equation 6.2.1.

$$w = S_{sf} \cdot (\varepsilon_s - \varepsilon_c)$$ **(Equation 6.2.1)**

where w : Crack width (mm)

S_{sf} : Crack spacing (mm)

ε_s : Average strain of reinforcing material between cracks

ε_c : Average strain between cracks on overlaying part surface

(4) The crack spacing S_{sf} of a member repaired or strengthened with bottom-surface overlaying needs to be calculated appropriately, assuming the integrity between the overlaying and existing parts.

(5) The average strain between cracks may be calculated based on the hypotheses mentioned below.

(i) The crack width of a member strengthened with bottom-surface overlaying shall be calculated using the average strain of the reinforcing material in the overlaying layer and the average strain on the overlaying material surface. The average strain shall take into consideration the effect of tension stiffening.

(ii) The influence of the widths of cracks resulting from overlaying material shrinkage, creep, etc. shall be taken into consideration.

[Commentary] (1) In many cases, intervention is performed as a measure to improve the performance of the existing members that has degraded or to address increasing actions. At the time when intervention is performed, the existing members are subject to sectional force and stress due to self-weight and other permanent loads. Also, residual displacement, cracking and so on exist in damaged or degraded members. It is therefore necessary to calculate the responses of the existing members combined with the overlaying parts by correctly combining the responses observed before being combined with the overlaying parts and those observed after being combined.

(2) Generally, a certain level of stress exists in the compressive parts of reinforcing steel or concrete of the existing members as they support dead loads such as decks and pavements. This stress level must be considered for the design. The dead loads of the overlaying parts are supported by the existing members until the overlaying materials are hardened and integrated. Fig. C6.2.1 shows an example in which the existing stress of the existing members is calculated using a fiber model and the responses to the loads acting on the strengthened members are calculated considering the obtained strain as the residual strain.

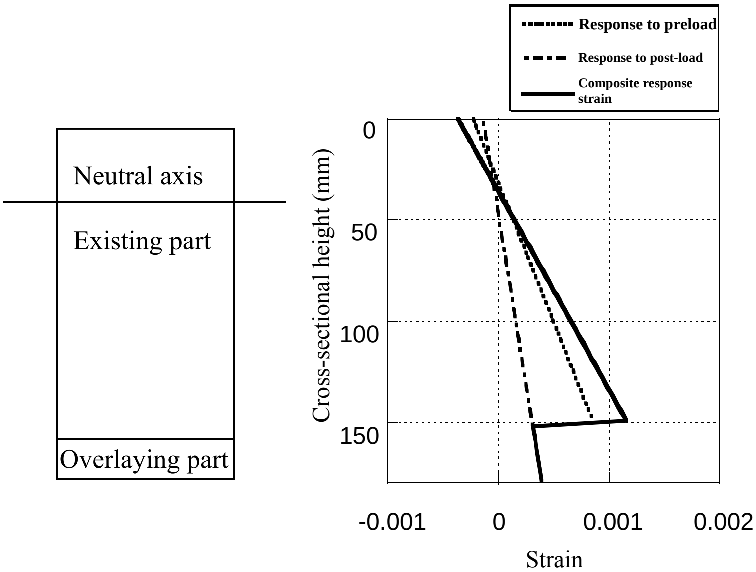


Fig. C6.2.1 Strain when used after strengthening

(3) The crack width of the members repaired or strengthened with bottom-surface overlaying varies in a complex way depending on the stress level and cracking of the existing members before strengthening, physical property differences between the overlaying materials and concrete after strengthening, differences in reinforcing materials and so on. It is assumed that cracks in the overlaying parts are propagated from the existing parts. Therefore, the crack width after strengthening refers to the width of cracks that occur in overlaying parts.

(4) The average crack spacing on the overlaying part surface is estimated by Equation C6.2.1.

$$S_{sf} = k_1 \cdot \min(S_{cs}, S_{os}) \qquad \text{(Equation C6.2.1)}$$

where $k_1 = \dfrac{h_b + h_u}{2 \cdot h_b}$

$$S_{cs} = \frac{3 \cdot f_{ct} \cdot \left(A_{ct} + A_{ot} \dfrac{E_o}{E_c} \right)}{\sum O_c \cdot \tau_{bcm} + \sum O_o \cdot \tau_{bom}}$$

$$S_{os} = \frac{3 \cdot f_{ot} \cdot \left(A_{ct} \dfrac{E_c}{E_o} + A_{ot} \right)}{\sum O_c \cdot \tau_{bcm} + \sum O_o \cdot \tau_{bom}}$$

$$A_{c(o)t} = b \cdot \min\left(h_{c(o)\max}, h_{c(o)tc}, h_{c(o)tt}\right)$$

$$h_{c(o)\max} = \sqrt{\frac{A_{sc(o)} \cdot f_{yc(o)}}{f_{c(o)t}}}$$

$$h_{c(o)tc} = \frac{1}{2} h_{c(o)\max} + h_{c(o)} - d_{s(o)}$$

$$h_{ctt} = h_c - x_{gc}$$

$$h_{ott} = t$$

$$\tau_{bc(o)m} = 5.5 \cdot \left(\frac{f'_{c(o)}}{20} \right)^{0.25}$$

k_1 : Coefficient for considering strain distribution

S_{cs} , S_{os} : Assumed spacing of cracks that occur in the existing part and overlaying part respectively (mm)

A_{ct} , A_{ot} : Cross-sectional area of the cement-based material that affects the tension stiffness of the existing part and overlaying part (mm^2)

τ_{bcm} , τ_{bom} : Bonding strength of the cement-based material of the existing part and overlaying part against the reinforcing material (N/mm^2)

t : Thickness of the overlaying part (mm)

x_{gc} : Distance from the compressive edge to the neutral axis (mm)

h_b : Distance from the neutral axis to the overlaying bottom surface (mm)

h_u : Distance from the neutral axis to the upper edge that affects the tension stiffness of the existing member (mm)

f_{ct} , f_{ot} : Tensile strength of the cement-based material of the existing part and overlaying part (N/mm^2)

Generally, the design tensile strength $f_{c(o)td}$ may be used.

E_c , E_o : Young's modulus of the cement-based material of the existing part and overlaying part (N/mm^2)

O_c , O_o : Perimeter of the reinforcing material of the existing part and overlaying part (mm)

f'_c , f'_o : Compressive strength of the cement-based material of the existing part and overlaying part (N/mm^2)

Generally, the design compressive strength $f'_{c(o)d}$ may be used.

$h_{c(o)\max}$: Maximum height of the effective tension zone of the cement-based material of the existing part and overlaying part (mm)

$h_{c(o)tc}$: Height of the effective tension zone taking into consideration the restrictions on the covering of the existing part and overlaying part (mm)

$h_{c(o)tt}$: Height of the maximum tension zone of the existing part and overlaying part (mm)

$A_{sc(o)}$: Cross-sectional area of the reinforcing material of the existing part and overlaying part (mm^2)

$f_{vc(o)}$: Yield strength of the reinforcing material of the existing part and overlaying part (N/mm^2)

Generally, $f_y = \rho_m \cdot f_{yd}$, $\rho_m = 1.2$

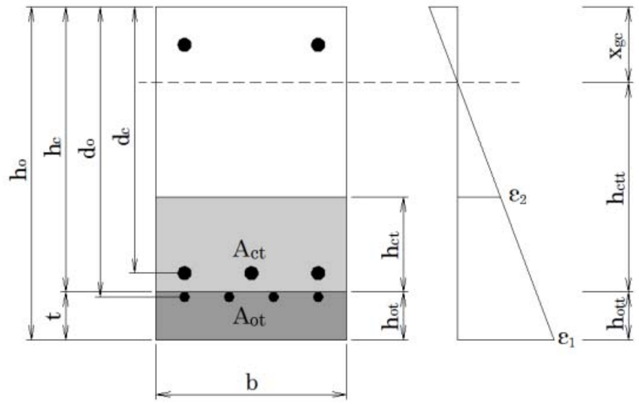


Fig. C6.2.2 Explanation of symbols

When applying Equation C6.2.1, it is necessary to calculate the crack spacing and average strain taking into consideration the stress and strain in the member caused by the loads that act when the member is strengthened with overlaying method. When there are no loads acting at the time of strengthening, Equation C6.2.1 may be applied as is. If there is any load acting at the time of strengthening, however, it is necessary to replace the strengths f_{ct}, f_{ot} of the existing part and overlaying part with the values obtained by subtracting the stress applied by the load to the existing part and overlaying part from the respective strengths f_{ct}, f_{ot}, as well as to replace the bonding strengths τ_{bcm} , τ_{bom} of the existing part and overlaying part with the values obtained by subtracting the bond stress applied by the load from the respective bonding strengths. If there are cracks at the time of strengthening or those cracks are repaired, the situation is different from the one in which there are no cracks to be exact. However, the impact of cracks or the repair thereof varies depending on the degree of cracking and is very complex to calculate. For simplicity, therefore, the equation may be calculated in the same way as when there are no cracks at the time of strengthening with the overlaying method. Equation C6.2.1 is a semi-empirical formula based on past experiment results, and these experiments assume a condition in which there are no cracks or no loads acting at the time of strengthening with the overlaying method. While the theoretical contents of this equation are also applicable under other conditions, it is necessary to further examine the applicability of the equation when there are cracks or loads acting at the time of strengthening.

To calculate the crack width, the average strain of the reinforcing material of the existing part shall be used for cracks in the existing part and the average strain of the reinforcing material of the overlaying part shall be used for cracks in the overlaying part. The average strain of the existing part is that under the loads including the loads that have been exerted since before strengthening, while the average strain of the overlaying part is that under the loads exerted after strengthening. Note that the average strain needs to be calculated taking into consideration the material properties of the existing concrete and overlaying parts, the material properties of the reinforcing materials of the existing and overlaying parts and the bonding property between the reinforcing materials and the surrounding concrete or overlaying materials. For simplicity, the strain of the reinforcing materials may be considered to be the average value obtained when assuming that each cross section is a cracking section, ignoring the strain of the concrete and overlaying materials. The influence of the existing concrete or overlaying materials shrinking due to drying, auto-shrinkage or for some other reason should be taken into consideration as when calculating the crack width of an ordinary concrete structure.

6.3 Durability Verification

The durability of a structure repaired or strengthened with bottom-surface overlaying shall be verified as set forth in Section 6.3 of the Common section.

6.4 Safety Verification

6.4.1 General

The safety of a member repaired or strengthened with bottom-surface overlaying shall be verified as set forth in Section 6.4 of the Common section.

6.4.2 Verification related to cross-sectional failure

6.4.2.1 General

(1) The verification related to cross-sectional failure shall be generally performed with respect to axial force, bending moment, shear force and torsion.

(2) When calculating the design cross-sectional strength, it must be checked that the integrity between the existing and overlaying parts is ensured.

[Commentary] (2) The shear capacity and flexural load-carrying capacity of the repaired or strengthened members are calculated assuming that the integrity between the existing and overlaying parts is guaranteed. If the reinforcing materials of the overlaying parts are excessive or reinforcement cannot be anchored, the overlaying materials may peel off or splitting failure may occur in the covering concrete of the existing parts.

6.4.2.2 Verification related to bending moment and axial force

(1) When subject to bending moment and axial force, the design cross-sectional strength after intervention may be calculated in accordance with Section 6.4.1.2 of the Common section.

(2) It must be checked that the overlaying parts do not peel off near the cross section under study when the design load is acting.

[Commentary] (1) The cross-sectional strength of a member relative to bending moment and axial force shall be calculated for the cross section or the unit width of the member according to the direction of action of the sectional force. This calculation may assume that the overlaying materials do not peel off and that the repaired or strengthened sections behave as one. It has been decided that the peeling of the overlaying parts should be considered separately.

(2) Depending on the size of the cross section of the existing parts or the amount of reinforcement of the overlaying parts, the peeling of the overlaying parts may occur before the ultimate state of the cross section is reached, resulting in a drop in the load bearing capacity. It has been decided, therefore, that this verification should involve checking the peeling of the overlaying parts separately. If a special study is not conducted through experiments or analyses, the method described below may be used.

When studying the peeling failure of the overlaying parts that occurs near the middle part of the span (see Fig. C6.4.1), it shall be checked using Equation C6.4.1 that the shear bond stress level of the interface of the overlaying parts is below the shear bond strength.

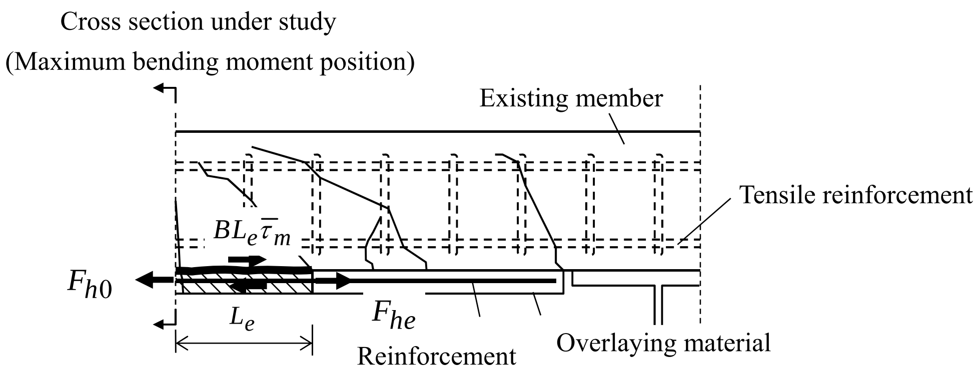


Fig. C6.4.1 Peeling of overlaying material near the middle part of the span

$$\gamma_i \frac{\bar{\tau}_m}{\tau_{mud}} \leq 1.0 \qquad \text{(Equation C6.4.1)}$$

where:

$$\bar{\tau}_m = \frac{F_{h0} - F_{he}}{B \cdot L_e}$$

$$F_{h0} = n \cdot A_r \cdot \sigma_{r0}$$

$$F_{he} = n \cdot A_r \cdot \sigma_{re}$$

$\bar{\tau}_m$: Design shear bond stress level of the overlaying part interface (N/mm²)

F_{h0} : Tensile force of reinforcing material of the cross section under study (N)

F_{he} : Tensile force of reinforcing material at the position separated by the effective bond length L_e from the cross section under study (N)

n : Number of reinforcing materials

A_r : Cross-sectional area per reinforcing material (mm^2)

σ_{r0} : Stress level of reinforcing material at the cross section under study (maximum bending moment position) (N/mm^2)

σ_{re} : Stress level of reinforcing material at the position separated by the effective bond length L_e from the cross section under study (N/mm^2)

B : Effective width of the member (unit width or girder width of the girder-like deck in the principal direction) (mm)

L_e : The effective bond length may be used as the crack spacing (mm).
It may be set to 150 mm if the crack spacing exceeds 150 mm.

τ_{mud} : Design shear bond strength of the overlaying part interface (N/mm^2)
If the base surface of the existing part is treated appropriately and the treatment depth is about 3 mm or less, it may be considered that $\tau_{mud} = 2.6\,\sigma_{mud}$.

σ_{mud} : Design tensile bond strength of the overlaying part interface determined through direct tensile testing (N/mm^2)

γ_i : Structure factor, which in general may be set to 1.1.

6.4.2.3 Verification related to shear force

(1) The safety verification related to the shear force must be performed taking into consideration the type of member (bar member, surface member, etc.), boundary conditions of members, the application states of loads, the direction of action of shear force and so forth.

(2) The design shear capacity of bar members and the design punching shear capacity of surface members that are borne by concrete may be calculated taking into account the effect of the anchored reinforcing materials placed in the overlaying parts.

(3) If the reinforcing materials of the overlaying parts are not anchored at the edges, it must be checked that the peeling of the overlaying parts or splitting cracking of the covering concrete of the existing parts does not occur at the edges under the action of the design load.

[Commentary] (1) Appropriate modeling of bar members or surface members must be performed according to the boundary conditions and application states of loads of the members strengthened with bottom-surface overlaying. In the case of a structure subject to planar application of a load such as earth pressure or water pressure, the member type may be considered to be bar members having the unit width. Also, when taking highway bridge decks as an example, the type of the existing members is girder-like surface members, which may be considered to be beams as well. According to the boundary conditions, the members can also be seen as beams fixed to the main girder at both edges. Also, the application states of loads are generally moving loads. Therefore, the safety verification related to shear force to be performed carefully.

(2) When members of box culverts, tunnels, etc. are strengthened with bottom-surface overlaying, the overlaying parts can be placed beyond the point of contrary flexure of moment, which makes the overlaying parts less prone to peel off. In this case, the effect of strengthening of the overlaying parts can be added to the shear capacity of the strengthened members although that effect is insignificant.

(i) Shear capacity of bar members

The design shear capacity of bar members without shear reinforcing materials may be calculated using Equation C6.4.2.

$$V_{cd} = \beta_{dr} \cdot \beta_{pr} \cdot \beta_n \cdot f_{vcd} \cdot b_w \cdot d_r / \gamma_b \qquad \text{(Equation C6.4.2)}$$

where $f_{vcd} = 0.20\sqrt[3]{f'_{cd}}$ (N/mm^2) but $f_{vcd} \leq 0.72$ (N/mm^2)

$\beta_{dr} = \sqrt[4]{1000 / d_r}$ but when β_{dr} > 1.5, it shall be set to 1.5.

$\beta_{pr} = \sqrt[3]{100\, p_{wr}}$ but when β_{pr} > 1.5, it shall be set to 1.5.

$\beta_n = 1 + 2M_0 / M_{ud}$ (when $N'_d \geq 0$) but when β_n > 2, it shall be set to 2.

$= 1 + 4M_0 / M_{ud}$ (when $N'_d < 0$) but when β_n < 0, it shall be set to 0.

$$d_r = \frac{E_{s1}A_{s1}d_1 + E_{s2}A_{s2}d_2}{E_{s1}A_{s1} + E_{s2}A_{s2}}$$: Converted effective height

$$p_{wr} = \frac{A_{s1} + (E_{s2}/E_{s1})A_{s2}}{b_w \cdot d_r}$$: Converted reinforcement ratio

N'_d : Design axial compressive force

M_{ud} : Design flexural load-carrying capacity when not considering the axial force

M_0 : Bending moment necessary to cancel the stress generated by the axial force at the tension edge corresponding to the design bending moment M_d

A_{s1} : Cross-sectional area of the tension reinforcing material of the existing beam (mm^2)

A_{s2} : Cross-sectional area of the tension reinforcing material of the overlaying part (mm^2)

d_1 : Distance from the upper edge to the center of the tension reinforcing material of the existing beam (mm)

d_2 : Distance from the upper edge to the center of the tension reinforcing material of the overlaying part (mm)

E_{s1} : Modulus of elasticity of the tension reinforcing material of the existing beam (N/mm^2)

E_{s2} : Modulus of elasticity of the tension reinforcing material of the overlaying part (N/mm^2)

b_w : Web width (mm)

γ_b : Member factor, which in general may be set to 1.3.

(ii) Shear capacity of surface members

The punching shear capacity V_{mpd} of surface members strengthened with bottom-surface overlaying was proposed to associate the fatigue capacity of RC decks with the punching shear capacity of the existing decks and strengthened decks.

Equation C6.4.3 assumes the resistance mechanism like the one shown in Fig. C6.4.2. It hypothesizes that the reinforcing materials of the overlaying parts increase the depth of the neutral axis and the shear resistance of concrete, as well as a mechanism whereby peeling resistance is provided by the bond stress of the overlaying materials and existing members and the bonding area, and verifies this hypothesis. In this figure, α_t is twice the thickness of the overlaying parts (α = 2). When the equation is applied to special decks whose reinforcement ratio or other property significantly deviates, a separate study is needed.

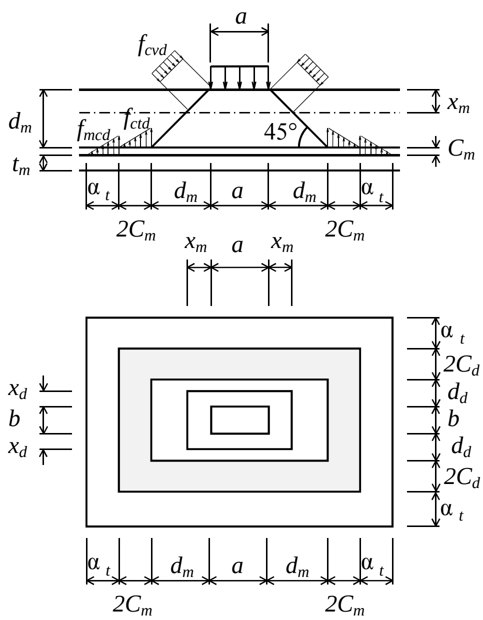


Fig. C6.4.2 Punching shear failure model

$$V_{mpd} = \Big[f_{cvd} \{ 2(a+2x_m)x_d + 2(b+2x_d)x_m \} + f_{ctd} \{ 2(a+2d_m)C_d + 2(b+2d_d+4C_d)C_m \} + f_{mcd} \{ 2(a+2d_m+4C_m)t_m + 2(b+2d_d+4C_d+4t)t_m \} \Big] / \gamma_b$$

(Equation C6.4.3)

where $f_{cvd} = 0.656 f'^{0.606}_{cd}$

$f_{ctd} = 0.269 f'^{0.667}_{cd}$

a, b : Side lengths of the loading plate in the main reinforcement and distribution reinforcement (mm)

x_m, x_d : Neutral axis depth taking reinforcement into consideration as well when the tension-side concrete of the cross section at right angles to the main reinforcement and distribution reinforcement is ignored (mm)

d_m, d_d : Effective heights of the tension-side main reinforcement and distribution reinforcement (mm)

C_m, C_d : Covering depths of the tension-side main reinforcement and distribution reinforcement (mm)

t_m : Thickness of the overlaying part (mm)

f_{cvd} : Design shear strength of existing concrete (N/mm^2)

f_{ctd} : Design tensile strength of existing concrete (N/mm^2)

f_{mcd} : Design bonding strength of the interface between the existing concrete and overlaying part (N/mm^2)

γ_b : Member factor, which in general may be set to 1.3.

(3) If the edges of the overlaying parts are not anchored after diagonal cracking occurs in the repaired or strengthened members, the peeling of the overlaying materials or splitting failure of the covering concrete of the existing parts may result. It is necessary to check that such local failures do not occur under the action of the design load. The safety verification related to these two failures may be performed using the methods described below.

(i) Study of the peeling of the overlaying material at the edge of the overlaying part

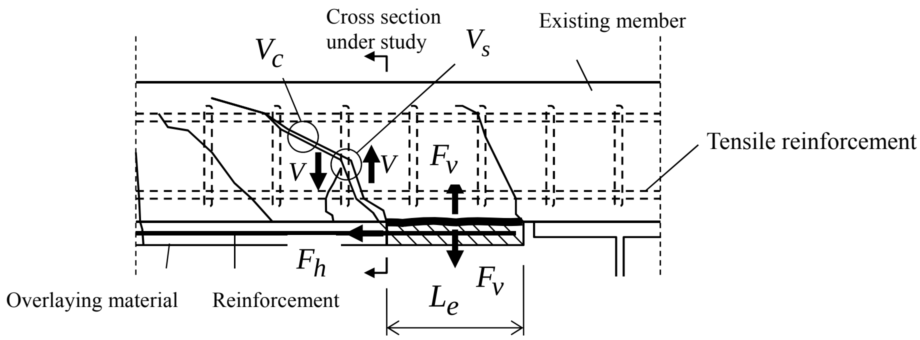


Fig. C6.4.3 Peeling of overlaying material at the edge of the overlaying part

When members with shear reinforcing materials placed in the existing parts are strengthened with bottom-surface overlaying, the safety verification related to the peeling failure at the edges of the overlaying parts may be performed using Equation C6.4.4 below. This verification can be omitted if the shear force for the verification is below the diagonal cracking shear force ($V_d < V_{cd}$).

$$\gamma_i \left\{ \left(\frac{\bar{\sigma}_m}{\sigma_{mud}} \right) + \left(\frac{\bar{\tau}_m}{\tau_{mud}} \right) \right\} \le 1.0$$

(Equation C6.4.4)

where $\bar{\sigma}_m = \dfrac{F_v}{B \cdot L_e}$

$F_v = V - V_s$

$V_s = k\,(V_d - V_{cd})$

$\bar{\tau}_m = \dfrac{F_h}{B \cdot L_e}$

$F_h = n \cdot A_r \cdot \sigma_r$

$\bar{\sigma}_m$: Design tensile bond stress level of the overlaying part interface (N/mm^2)

F_v : Vertical direction force of the interface (N)

V_d : Design shear force (N)

V_{cd} : Diagonal cracking shear force (N) of the member taking into consideration the effect of strengthening with the overlaying method, which may be calculated using Equation C6.4.2.

$k = 0.8$: Ratio of shear force of shear reinforcing materials to other shear forces after occurrence of diagonal cracking

B : Effective width of the member (unit width or girder width of the girder-like deck in the principal direction) (mm)

L_e : The effective bond length may be used as the crack spacing (mm). It may be set to 150 mm if the crack spacing exceeds 150 mm.

$\bar{\tau}_m$: Design shear bond stress of the overlaying part interface (N/mm^2)

F_h : Tensile force of reinforcing material of the cross section under study (N)

n : Number of reinforcing materials

A_r : Cross-sectional area of reinforcing material (mm^2)

σ_r : Stress level of reinforcing material of the cross section under study under the action of the design live load (N/mm^2)

Considering the moment shift, this shall be calculated using the bending moment at the position as far as the effective height from the cross section under study on the load action side.

σ_{mud} : Design tensile bond strength of overlaying material determined through direct tensile testing (N/mm^2)

τ_{mud} : Design shear bond strength of overlaying material (N/mm^2)

If the base surface of the existing part is treated appropriately and the treatment depth is about 3 mm or less, it may be considered that $\tau_{mud} = 2.6\,\sigma_{mud}$.

γ_i : Structure factor, which in general may be set to 1.1.

When shear reinforcing materials are not placed in the existing members, it is considered that peeling will occur at the edges of the overlaying parts as soon as shear cracking occurs. Therefore, the verification shall be performed as set forth in (2).

(ii) Study of splitting failure of covering concrete

When the bonding strength of the overlaying materials is high, a failure may occur if horizontal cracking develops rapidly from the intersection of diagonal cracking from an edge of the overlaying parts and the existing tensile reinforcement, resulting in the entire covering concrete peeling off (see Fig. C6.4.4). Unlike a failure due to bond splitting cracking caused by the bond action of deformed reinforcing bars, this failure arises from the action exerted as the local bending moment deriving from the tensile force of the reinforcing materials at the edge of the overlaying parts peels down the covering concrete. It is considered that the failure occurs when the tensile stress of the concrete caused by the local bending moment on the plane where the tensile reinforcement of the existing parts is placed reaches the tensile strength.

The verification may be performed using Equation C6.4.5.

$$\gamma_i \frac{M_{rs}}{M_{rud}} \le 1.0 \qquad \text{(Equation C6.4.5)}$$

where $M_{rs} = F_h \cdot z$

$$M_{rud} = \frac{1}{6} f_{ct}\,(B - n_s \varphi_s)\, L_e^{\,2} / \gamma_b$$

$$F_h = n \cdot A_r \cdot \sigma_r$$

M_{rud} : Design splitting cracking initiation moment (N·mm)

F_h : Tensile force of reinforcing material of the cross section under study taking the moment shift into consideration (N)

n : Number of reinforcing materials

A_r : Cross-sectional area of reinforcing material (mm^2)

σ_r : Tensile stress level of reinforcing material of the cross section under study (N/mm^2)

z : Distance between tensile reinforcement of the existing part and reinforcing material (mm)

f_{ct} : Tensile strength of concrete of the existing part (N/mm^2)

B : Effective width of the member (unit width or girder width of the girder-like deck in the principal direction) (mm)

n_s : Number of tensile reinforcement bars of the existing part

ϕ_s : Diameter of tensile reinforcement of the existing part (mm)

L_e : The effective bond length may be used as the crack spacing (mm).

It may be set to 150 mm if the crack spacing exceeds 150 mm.

γ_b : Member factor, which in general may be set to 1.3.

γ_i : Structure factor, which in general may be set to 1.1.

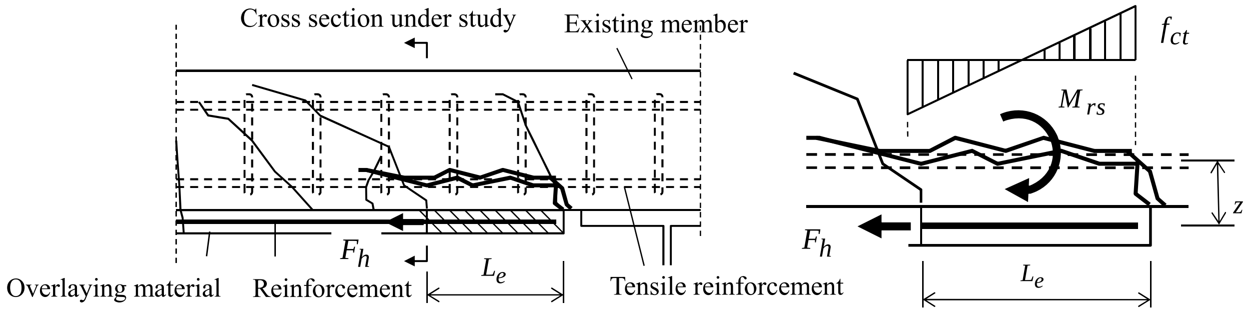


Fig. C6.4.4 Splitting failure of covering concrete

6.4.2.4 Verification related to torsional moment

If the action of torsional moment cannot be ignored, a safety study shall be performed by means of an appropriate method.

[Commentary] Since there is almost no research on the behavior of torsional moment of members repaired or strengthened with bottom-surface overlaying, little is known about it. If the action of torsional moment is substantial and its impact on the safety of the structure cannot be ignored, it should be checked through appropriate experiments or other means.

6.4.3 Verification related to fatigue failure

(1) The safety verification related to fatigue failure shall check flexural strength and shear capacity for bar members and flexural strength and punching shear capacity for surface members. When the influence of the movement of loads can be ignored, the verification may be performed in accordance with "Standard Specifications for Concrete Structures-2017, Design".

(2) The safety verification related to fatigue peeling failure of overlaying materials must be considered by means of an appropriate method.

(3) The verification related to fatigue failure performed when the influence of the movement of loads cannot be ignored must involve conducting analyses, experiments and the like to take into consideration the changes in responses due to the movement of loads, in addition to (1).

[Commentary] (1) The verification of failure assuming that overlaying materials do not peel off may be performed in accordance with "Standard Specifications for Concrete Structures-2017, Design" in general by calculating the design variable stress levels of the main reinforcement of the existing parts, reinforcing materials of the overlaying parts and concrete of the compressive edges. With regard to fatigue shear failure of the members strengthened with bottom-surface overlaying, reference may also be made to "Standard Specifications for Concrete Structures-2017, Design". Also, the design variable stress level or design variable sectional force and the equivalent number of repetitions may be verified as set forth in "Standard Specifications for Concrete Structures-2017, Design".

(2) It has been confirmed through experiments and others that, depending on the specifications of the existing parts or the amount of reinforcing materials used, the peeling failure of the overlaying parts precedes bending failure and shear failure when integrity is assumed. For a structure in which repeated actions are predominant, the peeling of the overlaying parts needs to be considered as well. While the peeling model shown in Section 6.4.2 of this Method-Specific (Bottom-Surface Overlaying) section may be used for the verification, the fatigue bonding strength of the overlaying part interface shall be checked through experiments in principle. When PCM is used as the overlaying material, the design fatigue strength shown below may be used.

$$\sigma_{brd} = \sigma_{mud}\,(1-\sigma_{b\min}/\sigma_{mud})\left(1-\frac{\log N}{21.0}\right)\Big/\gamma_m$$

(Equation C6.4.6)

where σ_{brd} : Design fatigue tensile bond strength of the overlaying part interface (N/mm^2)

$\sigma_{b\min}$: Tensile bond stress of the overlaying part interface under the action of permanent loads (N/mm^2)

σ_{mud} : Design tensile bond strength of overlaying material determined through direct tensile testing (N/mm^2)

N : Fatigue life

γ_m : Material factor, which in general may be set to 1.3.

$$\tau_{brd} = \tau_{mud}\,(1-\tau_{b\min}/\tau_{mud})\left(1-\frac{\log N}{20.4}\right)\Big/\gamma_m$$

(Equation C6.4.7)

where τ_{brd} : Design fatigue shear bond strength of the overlaying part interface (N/mm^2)

$\tau_{b\min}$: Shear bond stress of the overlaying part interface under the action of permanent loads (N/mm^2)

τ_{mud} : Design shear bond strength of overlaying material (N/mm^2)

(3) The mechanism of fatigue damage by moving wheel loads on highway bridge decks and the effect of strengthening can be evaluated based on previous experiments. Equation C6.4.8 is a proven equation for calculating the fatigue capacity of RC decks that is derived from a number of experiments. The fatigue life of decks strengthened with PCM can be evaluated using Equation C6.4.8. *Psxd* in this equation may be calculated using Equation C6.4.9, which expresses the punching shear capacity and which is obtained by modifying Equation C6.4.3 taking into consideration the influence of the girder width of the girder-like deck.

$$\log\left(\frac{P_d}{P_{sxd}}\right) = -0.07835 \log N + \log 1.52$$

(Equation C6.4.8)

where P_d : Design load (wheel load)

N : Fatigue life

$$P_{sxd} = 2B\,(f_{cvd} \cdot x_m + f_{ctd} \cdot C_m + f_{mcd} \cdot t_m)/\gamma_b$$

(Equation C6.4.9)

where $B = b + 2d_d$

P_{sxd} : Design punching shear capacity of the girder-like RC deck (N)

B : Girder width of the girder-like deck (mm)

b : Side length of the design load in the bridge axis direction (mm)

d_d : Effective height of the distribution reinforcement (mm)

x_m : Neutral axis depth taking reinforcement into consideration as well when the tension-side concrete of the cross section at right angles to the distribution reinforcement is ignored (mm)

C_m : Covering depth of the tension-side main reinforcement (mm)

t_m : Thickness of the PCM overlaying part (mm)

f_{cvd} : Design shear strength of concrete (N/mm^2)

f_{ctd} : Design tensile strength of concrete (N/mm^2)

f_{mcd} : Design bonding strength of the interface between the concrete and PCM overlaying part (N/mm^2)

γ_b : Member factor, which in general may be set to 1.0.

It has been confirmed that deck strengthening by means of bottom-surface overlaying using PCM is also effective for fatigue degraded decks designed in accordance with “Specifications for Highway Bridges” published in 1964 and that decks can be strengthened to the level specified in “Specifications for Highway Bridges” of 1996. Also, studies have been conducted on changes in actually strengthened decks over time, showing that the drop in deck rigidity is slight even 20 years after strengthening. Note that Equation C6.4.8 is an experimental one obtained using wheel load running testers. To calculate the fatigue life of an actual bridge, it is necessary to grasp the current damage level, past and future traffic volumes and so on. Therefore, this equation should be considered to provide an index for prolonging the service life of the target decks through strengthening.

6.5 Serviceability Verification

6.5.1 General

The serviceability of a member repaired or strengthened with bottom-surface overlaying shall be verified as set forth in Section 6.5 of the Common section.

6.5.2 Verification related to appearance

The verification related to appearance shall be performed taking into consideration how frequent the overlaying bottom surface is seen by users and the levels of uneasiness and unpleasantness that cracks, dirt and other appearance problems give to users.

[Commentary] The verification related to appearance may be omitted for an underground or underwater structure that is rarely seen by users or other third parties. In the case of viaducts and river bridges in urban areas, which is frequently seen by third parties (residents and users of nearby facilities), cracks and other appearance problems of the overlaying parts may give a sense of uneasiness or unpleasantness. The limit value for the crack width relative to appearance may be considered to be 0.2 mm or so. In general, cracks that occur in a structure repaired or strengthened with bottom-surface overlaying are much smaller than 0.2 mm in width, and the verification related to the crack width may be omitted.

6.5.3 Verification related to displacement and deformation

When the purpose of bottom-surface overlaying is to increase the rigidity of members, the verification shall be performed using displacement and deformation as indices to check that the requirements for use are met.

[Commentary] While bottom-surface overlaying is mainly aimed to improve the load bearing capacity and fatigue life of existing members, it should be checked that the required performance is fulfilled, by using displacement and deformation as indices, when the method is also aimed at improvement in rigidity. For example, in order to check that the functional performance requirements regarding trafficability and walkability of bridges and other structures are met, it is advisable to establish appropriate limit values for deflection and corner folding size of the members strengthened with bottom-surface overlaying.

6.6 Restorability Verification

The restorability of a member repaired or strengthened with bottom-surface overlaying shall be verified as set forth in Section 6.6 of the Common section.

6.7 Structural Details

6.7.1 Thickness of the bottom-surface overlaying parts

The thickness of the bottom-surface overlaying parts must be determined taking into consideration the base coating and surface unevenness adjustment of existing members, placement error of reinforcing materials, influence of covering construction error and integrity.

[Commentary] The thickness of the bottom-surface overlaying parts shall be the thickness from the prepared surface to the surface of the covering of reinforcing materials and overlaying materials. The design thickness of the bottom-surface overlaying parts must be determined taking these factors into consideration. If the overlaying parts become extremely thick, a problem such as the peeling of the reinforcing layer may result. Therefore, the maximum thickness needs to be determined carefully. In some cases, for example, the maximum thickness of the bottom-surface overlaying parts is set to 70 mm, considering past records and constructability.

The thickness of the overlaying parts influences an increase in dead loads on repaired or strengthened members, resistance to intrusion of degradation factors, drainage performance for water entering from existing members and integrity between existing and overlaying parts. It is necessary to consider these influential factors in a well-balanced manner.

When continuous fiber reinforcing materials are used for the overlaying parts, the covering may be reduced because there will be no corrosion due to chloride ion penetration or some other factor.

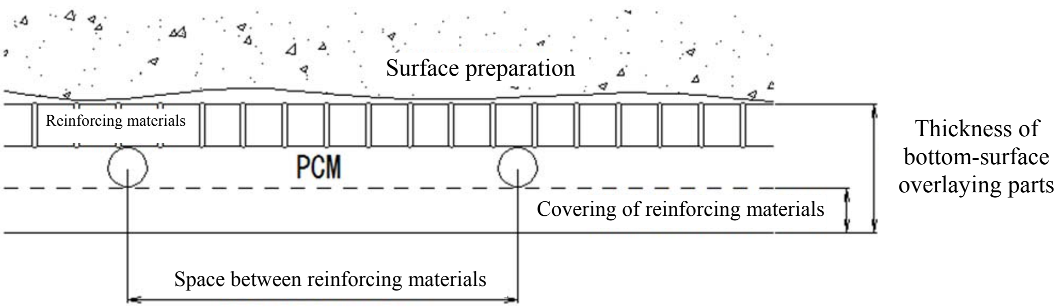


Fig. C6.7.1 Example of the construction section for bottom-surface overlaying

6.7.2 Covering thickness

The covering thickness for bottom-surface overlaying must be equal to or greater than the value that ensures the mechanical performance and durability required for the intervention using the bottom-surface overlaying method.

[Commentary] In bottom-surface overlaying, when PCM is used as overlaying materials, the anchorage performance and joint performance of reinforcing materials can be achieved with a thin covering because the tensile strength of PCM is high. Also, since the carbonation rate of PCM is extremely low, a covering thickness greater than the diameter of reinforcing materials at the outermost edge has been conventionally used. However, the environment in which a structure is installed differs case by case and the covering thickness must be considered for each individual environment. Particularly, in an environment with high chloride ion concentration or where fire resistance is required, careful consideration is necessary. Also, there are cases in which the covering thickness is 10 mm or so and, in these cases, a slight construction error may lead to a significant covering shortage. Therefore, care needs to be exercised in terms of design.

6.7.3 Space between reinforcing materials

The space between reinforcing materials must be determined taking into consideration the filling property of overlaying materials.

[Commentary] When reinforcing steel is used as reinforcing materials, the space between reinforcing steel bars ranges from 50 mm to 100 mm for small-diameter and large-diameter bars. When PCM is used as overlaying materials, the net space should be set to 50 mm or so, considering the filling property of PCM, although it also depends on the thickness of reinforcing steel. As for the arrangement of reinforcing materials, reinforcing steel as thin as possible shall be closely spaced. This is because even shear force acts on the bonding interface with existing members and a smaller flexural rigidity of reinforcing steel makes the steel less prone to peel from existing members. As a result, the overlaying parts can be made thinner, leading to economical design.

6.7.4 Joints for reinforcing materials

When the reinforcing materials used in the overlaying parts have joints, it must be ensured that stress is transferred at the joint part without breaking the joint part.

[Commentary] When the specifications of the joints of reinforcing materials are not clearly indicated and reinforcing steel is used as reinforcing materials, the joints shall meet the specifications of reinforcing steel joints set forth in "Standard Specifications for Concrete Structures-2017, Design" or "Recommendations for Design, Fabrication and Evaluation of Anchorages and Joints in Reinforcing Bars [2007]". When reinforcing materials other than reinforcing steel are used, the joint specifications for the reinforcing materials used shall govern. Still, the dimensions, filling property and constructability of the overlaying parts must be checked as well. When adopting reinforcing materials whose specifications are determined in terms of the joint location, jointing method, etc. in bottom-surface overlaying, it is advisable to comply with the specifications of the materials.

6.7.5 Anchoring and securing methods of reinforcing materials

(1) Reinforcing materials must be anchored to the overlaying or existing parts to integrate the materials with the parts.

(2) Reinforcing materials must be secured so that they sustain durability both during and after construction and are not subject to deformation or vibration.

[Commentary] (1) The reinforcing materials used for the overlaying parts must be anchored completely to the overlaying parts or existing members so as to fully achieve their strength.

(2) It is important that reinforcing materials be secured when overlaying materials are applied as well and not subject to vibration or the like. The general method of securing reinforcing materials is to secure the materials to the existing members by means of metal fittings and concrete anchors. If the adopted method has specifications for anchoring and securing of reinforcing materials, it is advisable to comply with those specifications.

CHAPTER 7 CONSTRUCTION

7.1 General

(1) The construction for intervention with bottom-surface overlaying shall be in principle performed in accordance with the provisions set forth in Chapter 7 of the Common section as well as in this chapter.

(2) Engineers with sufficient knowledge and experience in the construction for bottom-surface overlaying must be assigned to the site and the construction work must be performed under the direction of those engineers.

[Commentary] (1) Bottom-surface overlaying shall be in principle performed by applying overlaying materials through either spraying or troweling, and there are two spraying methods: wet spraying and dry spraying. Fig. C7.1.1 shows an example of the construction procedure for bottom-surface overlaying. Assuming that the structure is appropriately designed to meet its performance requirements, the figure shows the processes necessary to construct the intervention target concrete structure specified in design documents by using the bottom-surface overlaying method. It is important to thoroughly study and grasp the environment of the existing concrete structure to be repaired or strengthened with bottom-surface overlaying, as well as the status of damage, and to take pre-intervention and post-intervention measures as needed. In principle, a construction plan shall be formulated based on design documents, overlaying parts shall be constructed while exerting appropriate quality control and then investigations shall be performed to check that the repaired or strengthened structure has been built according to design documents. Also, construction records must be stored appropriately to ensure appropriate post-intervention maintenance.

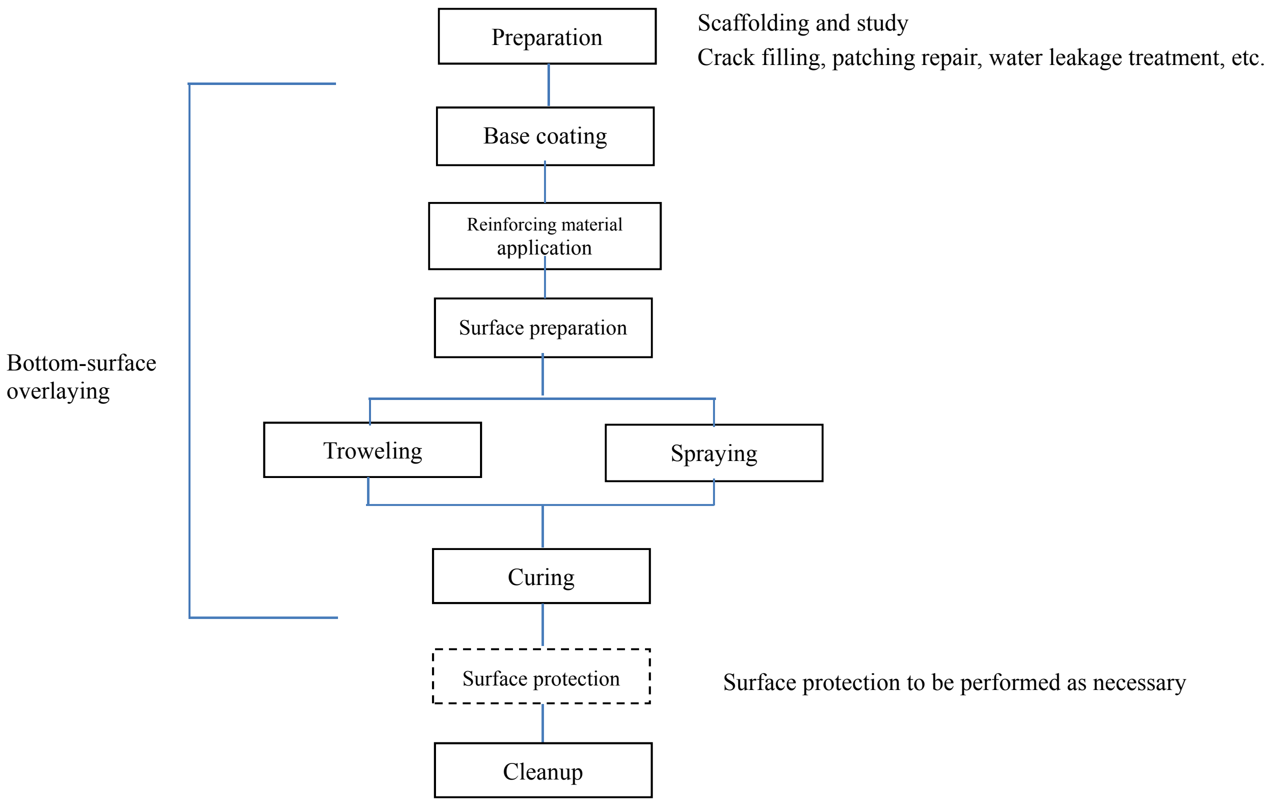


Fig. C7.1.1 Example of the construction procedure for bottom-surface overlaying

(2) In general, whether construction succeeds or fails may depend on human factors such as the experience and qualities of constructing parties involved. Therefore, the construction work shall be performed under the direction of engineers with sufficient knowledge and experience in the construction for bottom-surface overlaying. Particularly, the construction technique for spraying overlaying materials is important for ensuring quality in bottom-surface overlaying. It is therefore desirable to assign engineers qualified through spraying managing engineer qualification systems run by relevant organizations or qualified spraying technicians.

7.2 Prior Study and Construction Plan

(1) A prior study shall be conducted before construction to grasp the condition of the existing structure to be repaired or strengthened with bottom-surface overlaying.

(2) An appropriate construction plan must be formulated and a construction plan document must be created, taking into consideration the construction and environmental conditions, to construct the repaired or strengthened concrete structure shown in design documents.

(3) Formulating the construction plan must involve considering the actual work methods and the management methods to ensure the implementation of those methods.

[Commentary] (1) A prior study shall involve examining the design documents of the existing structure and checking the strength of concrete, the status of reinforcement arrangement, etc. as necessary. It is also required to grasp the status of cracking in the existing members, whether free lime and rust fluid are present or not, the corrosion status of reinforcing steel and the level of damage such as concrete floating and peeling, as well as to fill cracks, remove degraded parts, perform patching repair and take other measures as necessary before construction using the bottom-surface overlaying method. Water leaks and running water not only reduce the durability of the concrete structure substantially but are likely to cause re-degradation after intervention. If there is any water leak or running water, therefore, it is necessary to consider installing water stop and drainage facilities and throating equipment as well. The prior study and measures shall be as set forth in “Standard Specifications for Concrete Structures-2013, Maintenance”.

(2) In order to ensure that the repaired or strengthened structure has the performance properties (durability, serviceability, safety, etc.) defined in the intervention design, it is necessary to formulate an appropriate construction plan and perform construction work properly according to that construction plan. In intervention with bottom-surface overlaying, the conditions of the local site, such as the location and status of use of the existing structure, and the environmental conditions of the construction site significantly affect the certainty and safety of construction. It is therefore necessary to formulate a construction plan, comprehensively taking into consideration the securing of quality appropriate for the conditions of the local site, the safety, economy and period of construction work and the environmental burden, by reflecting the results of the prior study.

When formulating a construction plan, care must be exercised to ensure:

- That a reasonable process plan is created taking into consideration the time zones during which work can be done;
- That a sufficient work space is secured;
- That the necessary amounts of materials of proven quality are procured; and
- That constructing parties with necessary skills and sufficient experience are assigned.

Also, in order to perform construction safely, care must be exercised to ensure:

- That measures to provide safety for constructing parties are specified;
- That measures to provide safety for third parties are specified;

・That measures to prevent the destruction of additive and other related facilities;
・That a system is in place to respond to accidents swiftly; and
・That a waste disposal method is specified.

(3) The construction procedure for bottom-surface overlaying roughly consists of the processes mentioned below. When formulating a construction plan, the actual work methods and management methods in the individual work processes must be clearly defined.

(i) Base coating
(ii) Reinforcing material application
(iii) Surface preparation
(iv) Storage, mixing and transportation of overlaying materials
(v) Application of overlaying materials
(vi) Curing

Also, considering the restrictions such as the work environment of the construction site and work time, a quality control method must be specified to ensure the processes corresponding to the construction items and the required performance in the design. If any change in construction work becomes necessary during construction, the construction plan must be changed to ensure that the relevant requirements, such as the construction requirements and the performance requirements of the structure, are met. If the construction plan is changed, the construction plan document must be changed accordingly.

7.3 Base Coating

In base coating, dirt such as oil and fat on the surface of the existing members and vulnerable layers must be removed so that the parts repaired or strengthened with bottom-surface overlaying and existing members are integrated. Also, harmful cracks, floating, peeling and water leaks must be treated appropriately.

[Commentary] In principle, base coating shall be performed using water jetting, vacuum blasting, sand blasting, wire brushing or other appropriate method and involve removing oil, fat and other dirt, vulnerable layers and cement paste and exposing the sound surface (surface texturing). If the surface of the existing members has construction defects such as honeycombs, noticeable degradation, cracks, water leaks, etc., the existing members must be repaired using an appropriate method such as patching repair, crack filling or water leak prevention.

7.4 Reinforcing Material Application

(1) The reinforcing materials used for bottom-surface overlaying must be placed at the specified positions precisely.

(2) The reinforcing materials used for bottom-surface overlaying must be securely anchored to existing members using concrete anchors or the like.

(3) The positions of the joints of reinforcing materials and the jointing method must be in principle as specified in design documents.

[Commentary] (1) Reinforcing materials must be processed using an appropriate method that does not affect the material quality so that they have the correct size and shape determined in the design, and they must be assembled correctly at the positions specified in design documents. If epoxy-coated reinforcing steel bars are used in a salty environment, due care must be exercised so that the epoxy coating is not damaged during assembly.

(2) The reinforcing materials used for bottom-surface overlaying shall be securely anchored using metal fittings or other tools appropriate for the individual reinforcing materials so that there will be no space between the existing parts and reinforcing materials. Other methods may be used in which reinforcing materials are embedded in grooves on the surface of the existing parts and fastened with adhesive or in which reinforcing materials are clamped with tapered anchors first and then resin is injected after overlaying.

(3) To joint reinforcing materials, an appropriate method must be selected according to the type of reinforcing material, cross sectional size, stress status, joint positions, joint performance requirements and so on. In the design phase, therefore, the joint positions and jointing method are specified in design documents giving due consideration to these factors. For this reason, the joint positions and jointing method must be in principle as specified in design documents. If the need arises to provide joints for reinforcing materials not specified in design documents during the construction phase, Section 6.7 "Structural Details" and "Standard Specifications for Concrete Structures-2017, Design" shall govern.

7.5 Surface Preparation

For the work of surface preparation, bonding materials appropriate for the overlaying materials used must be selected.

[Commentary] For many overlaying materials used for bottom-surface overlaying, dedicated bonding materials for surface preparation are determined on a product-by-product basis. Selecting surface preparation work appropriate for the overlaying materials used ensures that the specified bonding strength is achieved. Therefore, surface preparation must be done giving due care about the usable time and placement time of bonding materials, which differ from product to product.

7.6 Storage, Mixing and Transportation of Overlaying Materials

(1) Overlaying materials shall be stored as set forth in "Standard Specifications for Concrete Structures-2017, Materials and Constructions".

(2) Overlaying materials shall be mixed using the specified mix proportion, which is determined for each material, in the specified order of material entry at the specified mixer capacity in the specified mixing time.

(3) For the transportation of overlaying materials, a method must be selected that ensures that the required amount of materials can be transported with the required level of quality.

[Commentary] (1) Overlaying materials must be stored appropriately in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction (Section 5.2.1 Storage facilities)". When PCM is used as an overlaying material and a fluid emulsion is used as a chemical admixture, they must be stored so that they do not freeze. Once a fluid emulsion freezes, its material properties change. Therefore, if a fluid emulsion freezes, it must not be used.

(2) In general, the mix proportion of overlaying materials is determined for each individual material relative to the specified performance. Therefore, the mix proportion determined for each

overlaying material in use must be used. If the overlaying materials used for bottom-surface overlaying are handled in a procedure different from the determined one that covers the order of material entry, mixer capacity, mixing time, etc., their flow behavior, spraying behavior, strength manifestation and so on may be affected. For this reason, when overlaying materials are mixed, the mixing methods determined for the individual overlaying materials used must be adopted and appropriate equipment must be used.

(3) For the transportation of overlaying materials, the pump capacity, pipe diameter and length and spraying equipment appropriate for the bottom-surface overlaying method and the selected overlaying materials must be selected.

7.7 Application of Overlaying Materials

(1) Overlaying materials must be applied using the method determined for each individual material.

(2) If the spray thickness is large, the overlaying material must be divided into an appropriate number of layers according to the thickness when sprayed.

(3) When the spray surface is finished, the overlaying material must be sprayed up to the finished surface and the surface must be smoothed with a metal trowel.

(4) In the summer or winter, the overlaying material shall be applied in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions".

[Commentary] (1) Depending on the overlaying materials used, bonding materials are not used for surface preparation and, instead, water may be sprayed to prevent water absorption from mortar to the surface of the existing members (dryout). In this case, the surface of the existing members must be sufficiently prewetted before bottom-surface overlaying is performed. When bottom-surface overlaying is performed with the wet spraying method, the overlaying material is pumped to the spraying position and then the specified amount of material is sprayed to the existing members. Therefore, the overlaying material needs to have the specified fluidity. For this reason, it is necessary to conduct a consistency test or the like to check fluidity before spraying. The available test methods to check fluidity include J funnel test, mortar flow test, mini-slump test and maximum shear force test. Depending on the properties of the overlaying material used, troweling work may be performed by human power if the material is difficult to spray, the amount of material to be applied is small or the spraying equipment is difficult to install. When troweling work is performed, the overlaying material must be pressed down with care using a metal trowel to ensure that the overlaying material is filled between the reinforcing materials and exiting members.

(2) The allowable spray thickness per layer differs depending on the type of spraying method and the spraying direction. In general, when the overlaying material is sprayed upwardly, the maximum spray thickness is 30 mm or so for the wet spraying method and 100 mm or so for the dry spraying method. Therefore, if the allowable spray thickness is exceeded, the overlaying material must be sprayed in multiple layers. In general, considering the filling property of the overlaying material, it is advisable to spray a layer of overlaying material up to the reinforcing material and, after the first layer of overlaying material hardens, spray the overlaying material to the covering. If the placement surface between layers is not treated appropriately, it may cause peeling in the future. Therefore, the placement surface between layers must be treated appropriately so as to prevent the peeling of mortar pieces. Generally, the bonding material employed for surface preparation is used. If the placement surface is wet, however, the overlaying material may be placed without applying any bonging material.

(3) When the wet spraying method is used for spraying, the overlaying material shall be sprayed up to the surface and then the surface shall be smoothed by human power using a metal trowel. Note that, in the case of the dry spraying method, the overlaying material hardens quickly and, therefore, the surface must be finished swiftly while adjusting the area to be finished.

(4) During construction, temperature management shall be accomplished using a thermometer installed at the construction site. Before performing construction work, it shall be checked that the average daytime temperature is 5°C or higher in the winter or 25°C or lower in the summer in accordance with “Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction”. If the temperature is outside these ranges, construction shall be performed in accordance with “Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction” (Chapter 12 Cold Weather Concrete and Chapter 13 Hot Weather Concrete).

7.8 Curing

The overlaying materials applied with bottom-surface overlaying must be cured such that they are not subject to sudden temperature changes or drying.

[Commentary] The overlaying materials applied with bottom-surface overlaying must be cured appropriately until they achieve the specified strength. A sudden change in temperature after the application of the overlaying materials or, in particular, blowing wind in the winter or direct sunlight causes the surface to dry rapidly, making it prone to cracking due to plastic shrinkage or dry shrinkage. It is therefore necessary to exercise due care to prevent cracking from occurring at places where the overlaying materials have been applied and, if necessary, to employ an appropriate curing technique such as mist curing or film curing.

7.9 Quality Control

Quality control must be implemented for specified items in each phase of construction so as to check that the structure constructed and strengthened with bottom-surface overlaying has the required level of quality.

[Commentary] In construction using the bottom-surface overlaying method, process management, quality control and safety management are important. Of these, quality control is an act of securing quality that is performed in every phase of construction in order to ensure that the strengthening through bottom-surface overlaying is consistent with the intended purpose. Quality control must involve controlling the quality of reinforcing materials, managing the mixing of overlaying materials and accomplishing mix proportion management and strength management.

(i) Quality control of reinforcing materials

When JIS reinforcement is used as reinforcing materials, the properties shall be checked based on the quality records created during production at the plant. As for FRP grids, the tensile strength and Young's modulus in tension shall be checked based on the quality records created during production at the plant.

(ii) Mixing management

During the mixing of overlaying materials, the mixer, pump, compressor and others must be managed to ensure that they operate normally while mixing the materials.

(iii) Mix proportion management

Overlaying materials achieve the required fluidity, pumpability and thickening property and excellent strength when they are mixed with the specified mix proportion using an appropriate mixing method. The properties of overlaying materials before hardening slightly change depending on the outdoor air temperature and other environmental conditions. Therefore, when the mixing is started (morning or afternoon) or the mix proportion is changed, it is advisable to manage the quality of overlaying materials before hardening by checking the mix proportion and flow behavior as well as the temperature of the materials being mixed, outdoor air temperature and so on.

(iv) Strength management

The quality of overlaying materials shall be checked before being carried in, based on the quality records created during production at the plant. At the site, the compressive strength, flexural strength and bonding strength of overlaying materials shall be checked in appropriate construction quantities.

7.10 Inspection

A structure constructed with bottom-surface overlaying shall be in principle inspected according to an inspection plan under the responsibility of the ordering party of the structure.

[Commentary] The inspection must be performed by means of an appropriate method in accordance with “Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Inspection” (Chapter 7 Construction Inspection, Chapter 8 Inspection of Concrete Structures and Chapter 9 Inspection Records). Particularly, when bottom-surface overlaying is performed using the wet spraying method, the spraying thickness and covering thickness are small and, therefore, an inspection must be conducted to ensure that these thicknesses are appropriate.

CHAPTER 8　RECORDS

Records of studies, design, performance verification, construction, materials used, quality control, etc. regarding the intervention with bottom-surface overlaying shall be handled as set forth in Chapter 8 of the Common section.

[Commentary]　Records of studies, design, performance verification, construction, materials used, quality control, etc. regarding the intervention with bottom-surface overlaying shall be in principle handled as set forth in Chapter 8 of the Common section.

CHAPTER 9　MAINTENANCE

The maintenance of a structure repaired or strengthened with bottom-surface overlaying shall be as set forth in Chapter 9 of the Common section.

[Commentary] The maintenance of a structure repaired or strengthened with bottom-surface overlaying shall be in principle as set forth in Chapter 9 of the Common section. Since the bottom-surface overlaying method applies overlaying materials on the bottom surface of an existing structure, care needs to be exercised about the danger of the overlaying materials peeling off. The possible causes of peeling include cracking due to abnormal shrinkage of the overlaying parts and the impact of water entering from the top surface of the existing structure. Particularly, if there is water entering after completion, there is fear of early degradation occurring on the bonding interface and, therefore, it is desirable to drain the water promptly. If floating or other similar problem is found, it is advisable to restore the bonding property of the floating part by filling cracks or using other appropriate means.

Guidelines for Structural Intervention of Existing Concrete Structures Using Cement-Based Materials - Method-Specific Section (Jacketing)

CHAPTER 1　GENERAL PROVISIONS

1.1 Scope

The Jacketing section specifies the standard requirements regarding design, construction and maintenance to be applied for structural intervention using the jacketing method, which places reinforcing materials such as reinforcing steel or FRP grids around the periphery of existing concrete bar members and jackets these members with cement-based materials. The requirements not mentioned in the Jacketing section shall be as set forth in the Common section.

[Commentary]　Jacketing is a construction method that restores or improves mechanical performance, such as flexural load-carrying capacity, shear capacity and toughness, as well as durability and other performance properties, by placing reinforcing steel or FRP grids around existing concrete bar members or in the grooves on the concrete surface and jacketing the entire periphery of the members with cement-based materials, such as concrete or polymer cementitious mortar, so that the materials integrate with the existing concrete members. Generally, when concrete is used as the jacketing material, the concrete jacketing method is adopted whereby concrete is placed in set up molds, or when polymer cementitious mortar or other type of mortar is used as the jacketing material, the mortar jacketing method is adopted whereby the thickness of members is increased by spraying or troweling. Jacketing is often employed for seismic strengthening mainly of column members such as bridge piers and beam members of rigid-frame piers. The Jacketing section specifies the standard requirements regarding design, construction and maintenance to be applied for structural intervention of existing concrete structures using the jacketing method. The requirements not mentioned in the Jacketing section shall be as set forth in the Common section.

Note that the Jacketing section also covers cases of intervention in which the jacketing method is used to repair or strengthen concrete structures such as reinforced concrete bridge piers damaged by seismic actions. When a damaged concrete structure is repaired or strengthened using the jacketing method, the status of damage such as concrete cracking and peeling shall be grasped through a prior study and crack filling, patching repair and other measures shall be taken in advance as necessary.

1.2 Terms and Definitions

The definitions of the terms used in the Jacketing section shall be as defined in Chapter 1 of the Common section.

CHAPTER 2 STUDY OF THE EXISTING STRUCTURE

2.1 General

(1) The study of the existing structure for which to consider intervention using the jacketing method shall be conducted as set forth in Chapter 2 of the Common section.

(2) When an earthquake-affected structure is repaired or strengthened using the jacketing method, the status of damage of that structure must be studied in detail.

[Commentary] (2) Jacketing is often employed for seismic strengthening of vertical members such as reinforced concrete bridge piers. In some cases, it is also used for intervention of earthquake-affected structures. An earthquake-affected structure may have been afflicted with different types of damage including cracking of concrete, peeling of covering concrete, crushing of concrete, buckling and fracture of reinforcing steel and so on. Depending on the status of damage, it may be necessary to take measures such as crack filling, patching repair, restoration of deformation of reinforcement and replacement of reinforcement before intervention using the jacketing method. These types of damage may significantly impact the mechanical performance of the existing structure and the repaired or strengthened structure. Therefore, when an earthquake-affected structure is repaired or strengthened using the jacketing method, it is necessary to grasp the status of damage through a study, evaluate the impact that these types of damage have on the performance of the structure by means of an appropriate method and ensure that the intervention design and construction plan reflect the evaluation results.

2.2 Study

2.2.1 Study using documents, records, etc.

(1) A study using documents, records, etc. shall be conducted in accordance with Section 2.2.1 of the Common section.

(2) Details of the materials used in the target existing structure and the structural specifications must be grasped from the design documents created at the time of construction, the design documents for the intervention work performed before the consideration of intervention and so on.

[Commentary] (2) When the existing structure is repaired or strengthened using the jacketing method, it is important to grasp the materials used and the structural specifications, such as the cross sectional size and reinforcement arrangement, for evaluating the performance of the existing structure and verifying the performance of the repaired or strengthened structure.

2.2.2 On-site study

(1) The on-site study on the existing structure shall be conducted in accordance with Section 2.2.2 of the Common section.

(2) The on-site study on an earthquake-affected structure must involve studying the status of damage caused by the earthquake in detail.

[Commentary] (1) Obtaining the expected effect of intervention through the use of the jacketing method requires ensuring the integrity between the existing structure and the jacketing parts. It is therefore advisable to grasp the status of degradation and damage on the surface and inside of the existing structure through the on-site study.

(2) An earthquake-affected structure may have been afflicted with different types of damage including cracking of concrete, peeling of covering concrete, crushing of concrete, buckling and fracture of reinforcing steel and so on. Therefore, when an earthquake-affected structure is repaired or strengthened using the jacketing method, the status of damage must be studied in detail by means of an appropriate method. The methods commonly used in the on-site study are visual inspection and tapping inspection.

The performance evaluation method based on changes in the appearance of a damaged structure is specified in Chapter 3 of “Standard Specifications for Hybrid Structures-2014, Maintenance, Specifications”. It is advisable to grade changes in the appearance, taking into consideration the degree of damage to the concrete, steel, etc. and changes in the mechanical performance, and evaluate the structural performance according to the grading of the appearance changes. In the structural performance evaluation based on the appearance changes, the grades of structural performance must be established on mechanical grounds taking into full consideration the degree of each graded appearance change and the impact of the change region on structural performance. Appearance changes may be classified into the following three grades.

Grade I: No or minor damage

Grade II: Moderate damage

Grade III: Severe damage

The mechanical resistance of the change region should be classified into the following 4 levels.

Level a: Resistance remaining intact

Level b: Slightly degraded resistance

Level c: Significantly degraded resistance

Level d: No resistance

As for reinforced concrete bridge piers damaged by an earthquake, the methods of inspecting the damaged bridge piers and determining the degree of damage are set forth in the “Guideline for Earthquake Disaster Mitigation Measures for Roads (Part for Seismic Damage Restoration) (Japan Road Association)”. In the case of reinforced concrete bridge piers, both the position and degree of damage are important. It is therefore necessary to study each bridge pier to determine whether it is damaged at its base or in its middle part (where the main reinforcement is cut off). This study needs to be conducted in both the bridge axis direction and the direction perpendicular to the bridge axis. How damage occurs in reinforced concrete bridge piers differs between bending failure and shear failure. In general, damage progresses as described below, respectively.

・Bending failure
  ① Concrete cracking (horizontal cracking)
  ② Covering concrete peeling
  ③ Buckling of axial reinforcement
  ④ Fracture of axial reinforcement or crushing of core concrete

・Shear failure
  ① Concrete cracking (horizontal or diagonal cracking)
  ② Spread of concrete cracking

③ Covering concrete peeling

④ Exposure of axial reinforcement

⑤ Fracture of tie reinforcement or crushing of core concrete

In order to grasp the degree of damage, therefore, it is important to study the actual damage to reinforced concrete bridge piers to determine which of the above-mentioned stages corresponds to the damage.

CHAPTER 3　INTERVENTION DESIGN

3.1 General

In the intervention design using the jacketing method, a rational structural plan must be formulated and structural details must be established based on that plan so that the structure after intervention fulfills the required performance throughout the remaining design service life.

[Commentary]　In the intervention design, it is assumed that the structure after intervention fulfills the required performance throughout the remaining design service life. In the case of intervention using the jacketing method, which is often applied to members that significantly affect the seismic performance of the structure, the intervention must be designed with particular care to ensure that the repaired or strengthened structure achieves the required seismic performance.

There are cases in which repairing or strengthening a structural member using the jacketing method may induce damage to other members in the event of an earthquake. When planning the intervention, therefore, consideration must be given to ensure that the entire structure fulfills the performance.

If the intervention target structure is already damaged, the damage may affect the performance of the repaired or strengthened structure. Therefore, the impact of the existing damage of the structure shall be evaluated, based on the results of the study of the existing structure set forth in Chapter 2, and then practical measures shall be planned according to circumstances in which the structure is placed, to ensure that the target structural performance is achieved throughout the design service life. When an earthquake-affected structure is repaired or strengthened using the jacketing method, it is necessary to take appropriate measures for the members damaged by the earthquake first. The intervention plan shall be considered with this in mind.

3.2 Structural Plan

(1) In the intervention plan using the jacketing method, the intervention method shall be selected, taking into consideration the structural properties, materials, construction method, maintenance method, economy, etc., so as to ensure that the required performance is fulfilled under the environmental conditions of the structure.

(2) The intervention plan using the jacketing method must take into consideration the restrictions on construction.

(3) In the intervention plan using the jacketing method, consideration must be given to facilitate the maintenance of the repaired or strengthened structure, factoring in the structure's importance, design service life, service conditions, environmental conditions, maintainability, etc.

[Commentary]　(1) There are two methods to achieve intervention by jacketing members with cement-based materials: concrete jacketing and mortar jacketing. Generally, the concrete jacketing method is more economical and has been in wider use. In the case of a structure installed in a river, however, the impediment ratio of river flow needs to be taken into consideration and there may be restrictions such as a severe clearance limit due to a narrow space from the adjacent structure. In such a case, if the concrete jacketing method is used for which the standard jacketing thickness is 250 mm or so, the cross sectional size of members become large, potentially making it impossible to meet the restrictions on construction or service. By contrast, the standard jacketing thickness of the mortar jacketing method is 100 mm or less and the change in the cross sectional size of strengthened members can be reduced. Therefore, the mortar jacketing method may be selected to meet the restrictions such as those mentioned above. Among the mortar materials used for jacketing, polymer cementitious mortar is highly durable with a low diffusion coefficient of chloride ions, a low carbonation rate, etc. and used in an environment such as a coastal or seaside area. As mentioned above, a specific intervention method must be selected, taking into consideration the structural properties, materials, construction method, maintenance method, economy, etc., so as to ensure that the required performance is fulfilled under the environmental conditions of the structure.

In the design phase, the public safety in the surrounding area that may be impacted by an accident such as the peeling of the covering concrete of the concrete members repaired or strengthened using the jacketing method shall be verified in principle with established limit states assuming that such concrete peeling does not occur. If it is feared that this assumption may be exceeded, measures should be taken to prevent a public disaster from happening. There are two possible cases of peeling of the jacketing part: ① peeling of the surface of the jacketing part (the covering of the reinforcing material of the jacketing part); and ② peeling of the jacketing part due to the separation at the interface between the jacketing part and the existing part. In the design phase, it may be considered that the public safety requirements regarding the peeling of the jacketing part and other public disaster risks for users of the structure, third parties, etc. are met if the requirements set forth in Section 6.3 “Durability Verification” are met.

(2) In intervention, the impact of the location and environmental conditions of the target structure on the construction work and the impact of the construction work on the surrounding environment are both significant. In the case of the intervention of a structure installed in a river, for example, it is necessary to take into consideration the environmental impacts on animals, plants, water quality and so forth. When the structure subject to intervention is located in a steep valley, it is uneconomical to carry in large construction machines. Construction work in a cold region requires care about the handling of cement-based materials, such as cold weather concrete measures in the winter and hot weather concrete measures in the summer. Given these factors, the intervention plan must take into consideration the restrictions on construction.

(3) There are cases in which it is difficult to ensure durability for the structure that is to be repaired or strengthened using the jacketing method, as with a structure in a river that may become submerged under water or a structure close to the sea. In order to ensure that the repaired or strengthened structure achieves and sustains its expected performance, it is necessary to take measures to prevent re-degradation while taking into consideration the post-intervention environment and maintenance as well. In the design phase, therefore, a method that facilitates post-intervention maintenance must be selected, factoring in the structure’s importance, design service life, service conditions, environmental conditions, maintainability, etc.

3.3 Structural Details

(1) In intervention using the jacketing method, structural details must be determined so as to ensure the integrity between the existing members and jacketing parts.

(2) The members to be repaired or strengthened using the jacketing method, the range of intervention, the arrangement of reinforcing materials around the periphery of the existing members, the thicknesses of reinforcing material covering and jacketing material, etc. must be established appropriately so that the performance requirements of the structure are met.

(3) If the flexural load-carrying capacity needs to be improved, the reinforcement placed around the periphery must be anchored securely enough to the existing parts.

(4) If the toughness needs to be improved, it is advisable to consider placing intermediate penetrating reinforcing materials according to the cross-sectional shape of the existing structure.

[Commentary] (1) In order to ensure that the seismic performance and other performance requirements of a structure are fulfilled by performing intervention using the jacketing method, it is important that the existing parts and jacketing parts function as an integrated structure. Therefore, the materials, construction method and cross-sectional structure that enable the integrity of these parts need to be selected.

(2) The members to be jacketed and the range of jacketing must be selected appropriately so that the seismic performance and other performance requirements of the structure are met. Also, to ensure the required shear capacity, flexural load-carrying capacity and toughness, reinforcing materials such as axial reinforcement or lateral confinement reinforcement shall be placed around the periphery of the existing members. In addition, based on the environment in which the existing structure is placed, the thicknesses of reinforcing material covering and jacketing material of the jacketing parts must be determined taking into consideration durability and constructability.

(3) If the flexural load-carrying capacity of the existing structure needs to be improved, the architecture shall be such that the placed reinforcement can be anchored appropriately to the existing structure. When the column members of bridge piers or the like are strengthened through jacketing, axial reinforcement needs to be anchored appropriately to the footings.

(4) If the cross-sectional shape of the members subject to intervention is flat with a long side-to-short side ratio of greater than 1:3, as with wall type piers, placing intermediate penetrating reinforcing materials is effective in improving the toughness of the strengthened members. It is therefore advisable to consider placing intermediate penetrating reinforcing materials as necessary, taking into account the cross-sectional shape, size and other factors of the existing structure.

CHAPTER 4   MATERIALS

4.1 General

The materials used for jacketing must be of proven quality to ensure that the required performance is fulfilled for a necessary period of time.

[Commentary] The jacketing method is often used to improve the seismic performance of an existing structure. In such a case, materials need to be selected to ensure the integrity between the existing parts and jacketing parts so that the structure repaired or strengthened through jacketing fulfills the seismic performance and other performance requirements for a necessary period of time.

4.2 Materials in the Existing Structure

(1) The characteristic values of material strength, design values and material factors of the materials in an existing structure shall be determined in accordance with Section 4.2 of the Common section.

(2) The characteristic values of material strength, design values and material factors of the materials in an earthquake-affected structure shall be determined appropriately taking into consideration the degree of the existing damage, the type of measure taken for the damage, etc.

[Commentary] (2) When intervention is targeted at an earthquake-affected structure, the materials in the existing structure may have incurred severe damage, such as yielding or buckling of reinforcing steel, cracking of concrete or crushing of core concrete, and the impact of that damage must be evaluated appropriately. If any measure such as cracking repair or patching repair has been taken for such damage prior to intervention through jacketing, the characteristic values, design values and material factors of the materials in the existing part must be determined, appropriately taking into consideration the influence of that measure as necessary.

4.3 Materials Used in Repaired or Strengthened Parts

4.3.1 General

The quality of the materials used in the parts repaired or strengthened through jacketing shall be as set forth in Section 4.3 of the Common section.

[Commentary] Jacketing is a construction method to improve the mechanical performance of members by integrating the reinforcing materials placed around the periphery of the existing structure and the cement-based materials placed for jacketing. As the materials used for jacketing, therefore, it is required to select those proven not only to achieve the specified mechanical properties but also to meet the quality requirements in terms of the bonding property required to ensure the integrity between the existing concrete and jacketing parts, workability for jacketing and so forth.

Table C4.3.1 shows the classification of the materials used for jacketing. The cement-based materials are divided into concrete used for concrete jacketing and mortar, such as polymer cementitious mortar, used for mortar jacketing. As reinforcing materials, continuous fiber reinforcing materials such as reinforcing steel, prestressed concrete steel and FRP grids are used. The bonding materials are applied or grouted to bond concrete members, concrete and mortar or concrete and reinforcing materials. Here, they refer to the following materials.

- Primer used to improve the bonding strength of the existing concrete and mortar
- Anchor grouting material used to anchor axial reinforcement or other reinforcing materials to footings
- Adhesive used to bond reinforcing materials and existing concrete. It is mainly used for a construction method that requires reinforcing materials to be embedded and fastened in grooves cut on the existing concrete covering or for bonding intermediate penetrating reinforcing materials.

The filling materials are grouted to fill the gap between reinforcing materials, such as intermediate penetrating steel, and concrete in order to prevent steel corrosion without expecting the intermediate penetrating reinforcing materials to be bonded.

Table C4.3.1 Types of materials used for jacketing

<table>
<tr><th>Construction method</th><th>Cement-based materials</th><th>Reinforcing materials</th><th>Bonding materials</th><th>Filling materials</th></tr>
<tr><td>Concrete jacketing</td><td>・Concrete</td><td>・Reinforcing steel
・Prestressed concrete steel bar
・Continuous fiber reinforcing materials</td><td rowspan="2">・Primer
・Anchor grouting material
・Adhesive</td><td rowspan="2">・Non-shrink grout
・Mortar</td></tr>
<tr><td>Mortar jacketing</td><td>・Mortar</td><td>・Reinforcing steel
・Continuous fiber reinforcing materials</td></tr>
</table>

4.3.2 Cement-based materials

(1) The cement-based materials used for jacketing shall be selected in accordance with Section 4.3.2 of the Common section.

(2) In principle, as the concrete used for concrete jacketing, high-quality materials having the required level of workability appropriate for construction through jacketing shall be selected and an appropriate mix proportion shall be established by performing trial mixing so as to minimize the change in quality over time after hardening.

(3) As the mortar used for mortar jacketing, materials with proven quality and safety for which an appropriate mix proportion is established must be used according to the type of spraying or troweling work.

[Commentary] (1) The cement-based materials mentioned here refer to concrete and mortar used for jacketing. The quality of cement-based materials is indicated not only by the compressive strength but by various other material properties as well. The strength properties are indicated by static strength, such as compressive strength, tensile strength, flexural strength and bonding strength, and fatigue strength. For the jacketing method, the compressive strength and bonding strength are important material properties. Also, in addition to Young's modulus and Poisson's ratio, indices of mechanical properties, including toughness and cracking resistance, may be required as deformation properties for the jacketing method. It is necessary that the cement-based materials used for jacketing have little drying shrinkage, attain practical strength quickly and have the required cracking resistance, flexural property and shear property. Cement-based materials of proven quality must be selected to ensure that the repaired or strengthened structure fulfills the required performance.

(2) In general, concrete used for the concrete jacketing method is either provided as ready mixed

concrete or mixed at the site. The quality of fresh concrete from the time mixing is complete until the concrete is laid changes over time and affects not only constructability but the material properties of the hardened concrete. Therefore, it is necessary to establish the mixing conditions so that the properties required for the hardened concrete are attained and to perform trial mixing in order to check the quality by means of the slump, air content, compressive strength and other material properties. With concrete jacketing, because it is important to make sure no voids are created in the overlaying parts, high-fluidity concrete, such as plasticized concrete with a slump of approximately 18 cm, may be used. An expansive material may be also used to prevent shrinkage cracking due to the confinement of the existing members. In addition, it is important to select good quality materials to avoid degradation such as alkali silica reaction.

When appropriate testing and analysis have confirmed that the compressive strength and other material properties of the concrete, which have been created with an appropriate mixing design through the use of good quality materials, will exhibit almost no change over time, the material properties at the time of verification may be used as those for intervention construction.

With the jacketing method, reinforcing materials, such as reinforcing steel, are placed on the outer surface of the existing structure. It is therefore advisable to make the reinforcement covering of the jacketing concrete sufficiently thick or, if necessary, provide the jacketing parts with surface protection so as to ensure that the reinforcing materials change as little as possible over time. When changes in the material properties over time can be prevented through appropriate protection, the material properties at the time of verification may be used as those for intervention construction.

In selecting the materials to be used and determining the mixing design, reference should be made to the following standard specifications, guidelines, etc.

・Standard Specifications for Concrete Structures-2017, Design, Standard Specifications for Concrete Structures-2017, Materials and Constructions (Japan Society of Civil Engineers)

・Concrete Library 119, Recommendation for Concrete Repair and Surface Protection of Concrete Structure, 2005.4 (Japan Society of Civil Engineers)

・Second Edition for Design Procedures, Part for Maintenance of Bridges, 2017 (East Nippon Expressway Co., Ltd., Central Nippon Expressway Co., Ltd. and West Nippon Expressway Co., Ltd.)

・Guidelines on Construction Management of Structures, 2017 (East Nippon Expressway Co., Ltd., Central Nippon Expressway Co., Ltd. and West Nippon Expressway Co., Ltd.)

(3) Mortar used for the mortar jacketing method is applied to the periphery of existing members through spraying or troweling work. There are two types of spraying mortar: dry spraying mortar and wet spraying mortar.

With the dry spraying method, in general, cement, aggregate and reinforcing fibers, such as steel fibers, are mixed without adding water (or by adding an amount of water sufficient to achieve the saturated surface-dry condition of aggregate) to manufacture dry mixed mortar, which is sprayed after being pumped with compressed air and mixed at the spray nozzle with either a specified amount of water or a mixture of water and cement mixing polymer and, depending on circumstances, accelerating agent.

The wet spraying method pumps mortar, mixed with a specified amount of water in a mixer, introduces compressed air before the mortar reaches the nozzle discharge port and then sprays the mortar. The wet spraying method uses two types of cement mortar: polymer cement mortar, including cement mixing polymer mentioned in JIS A 6203 “Polymer dispersions and redispersible polymer powders for cement modifiers", and cement mortar that does not contain polymers. As spraying mortar, polymer cement mortar is used in many cases. Also, it is common to use a premixed material made up of cement, fine aggregate, admixture such as cement mixing polymer or fiber, etc.

As the materials for dry or wet spraying, those proven to meet the quality and safety requirements for spraying mortar according to the relevant JIS standard, Japan Society of Civil Engineers standard or other appropriate test method must be used. Table C4.3.2 shows typical examples of the composition of the materials used in spraying mortar.

In selecting the materials to be used and determining the mixing design, reference should be made to the following standard specifications, guidelines, etc.

・Concrete Library 123, Recommendation for Sprayed Mortar for Repair and Strengthening of Existing Structures, 2005.7 (Japan Society of Civil Engineers)

・Design and Construction Guidelines for Seismic Retrofitting of Viaduct Piers by Spraying Mortar (Railway Technical Research Institute)

Table C4.3.2 Typical examples of the composition of the materials used in spraying mortar

Materials		Materials for dry spraying	Materials for wet spraying
Cement		Ultrarapid hardening cement (high early strength Portland cement or normal Portland cement to be used depending on circumstances)	In addition to the types of cement specified in JIS R 5210, 5211 and 5213, alumina cement may be used.
Fine aggregate		Dry natural fine aggregate*1	Dry natural fine aggregate and lightweight aggregate
Fiber		Steel fiber and organic fiber	Mainly organic fiber
Admixture	Cement mixing polymer*2	Polymer dispersion	Polymer dispersion and redispersible polymer powder
	Water reducing agent	-	May be used.
	Water retention agent	-	Used in many cases.
	Accelerant	-	May be used when thickening is required for construction in cold weather.
	Retarder	-	May be used for construction in hot weather.
	Accelerating agent	May be used*3.	May be used.
	Expansive material	-	Used in many cases.
	Fine powder	May be used.	Used in many cases.
Water		Tap water shall be used normally.	

*1: Mainly mechanically stabilized prepacked aggregate

*2: In the case of polymer cementitious mortar

*3: When high early strength Portland cement or normal Portland cement is used

4.3.3 Reinforcing materials

The reinforcing materials used for jacketing shall be selected in accordance with Section 4.3.3 of the Common section.

[Commentary] The reinforcing materials used for jacketing include steel such as reinforcing steel, epoxy-coated reinforcing steel and prestressed concrete steel, as well as continuous fiber reinforcing materials such as FRP grids and bars. They also include steel used to anchor and connect these materials. The quality of steel materials shall be indicated by material properties including strength properties such as compressive strength and tensile strength and deformation properties such as Young's modulus, Poisson’s ratio and the stress-strain relationship. The reinforcing steel materials need to be checked to confirm that they possess mechanically reliable material properties including strength, elongation capacity, Young's modulus and coefficient of linear expansion. Steel materials that fulfill the quality requirements set forth in the relevant JIS standards should be used.

The continuous fiber reinforcing materials must be checked to confirm that they possess mechanically reliable material properties including strength, elongation capacity, Young's modulus and coefficient of linear expansion. Other strength properties of FRP grids include the strength property of grid crossings. The bonding between an FRP grid and the existing concrete largely depends on the bearing between the FRP grid and the polymer cementitious mortar placed in the grid cells. If the strength of the grid crossings is low, the crossings can break before bond failure occurs between the existing concrete and polymer cementitious mortar, resulting in the loss of the anchorage performance. Since the strength of the crossings is influenced by the properties and molding method of matrix resin, it needs to be checked based on the combination of these factors. Also, the durability of a continuous fiber reinforcing material varies depending on the types of continuous fiber and matrix resin. It is necessary to check the durability of the composite material after molding.

4.3.4 Bonding materials

(1) The bonding materials used for jacketing shall be selected in accordance with Section 4.3.5 of the Common section.

(2) A primer that meets the performance requirements must be selected so that stress is transferred between the existing concrete and the cement-based materials of the jacketing parts.

(3) An anchor grouting material that has the required strength and ensures the anchorage strength between the existing concrete and reinforcement must be selected.

(4) An adhesive having the required strength and capable of integrating the existing concrete and reinforcing materials must be selected.

[Commentary] (2) With the mortar jacketing method, a primer is generally applied before the jacketing of mortar to ensure the transfer of stress between the existing concrete and mortar. A primer of proven quality that ensures the bonding property of the existing concrete and mortar must be selected according to the type of the mortar used.

(3) An anchor grouting material is used to anchor column axial reinforcement of the jacketing parts to footings when the strengthening of reinforced concrete bridge piers through jacketing is aimed at improving the flexural load-carrying capacity. Therefore, a material of proven quality that has the required bonding strength and ensures the anchorage strength between the existing concrete and

reinforcement must be selected.

(4) The adhesive used for jacketing is intended to integrate the existing concrete and reinforcing materials. The cases in which it is used are when grooves are cut in the existing concrete and filled with adhesive to anchor main reinforcement and when the gap between concrete holes and continuous fiber reinforcing materials is filled with adhesive to integrate the existing concrete and jacketing concrete after the prestressing of the continuous fiber reinforcing materials used as intermediate penetrating reinforcing materials. Therefore, an adhesive of proven quality that has the required strength and ensures the integrity between the existing concrete and reinforcing materials must be selected. The adhesive must also meet the quality requirements related to construction, such as the viscosity and fluidity appropriate for the construction work at the site.

4.3.5 Filling materials

A filling material having the required filling property and fluidity that reliably fills the gap between the reinforcing materials and existing concrete must be selected.

[Commentary] It is important that the filling material reliably fill the gap between the reinforcing materials and existing concrete and have the required rust-proofness, while it is not necessarily required to integrate the reinforcing materials and existing concrete. A filling material having an appropriate filling property, fluidity and rust-proofness must be selected according to the interval between the reinforcing materials and concrete and the injection method.

4.4 Characteristic Values and Design Values of Materials

4.4.1 General

The characteristic values and design values of the materials used for jacketing shall be as set forth in Section 4.4 of the Common section.

4.4.2 Cement-based materials

The characteristic values and design values of the cement-based materials used for jacketing shall be as set forth in Section 4.4.2 of the Common section.

4.4.3 Reinforcing materials

The characteristic values and design values of the reinforcing materials used for jacketing shall be as set forth in Section 4.4.3 of the Common section.

4.4.4 Bonding materials

The characteristic values and design values of the bonding materials used for jacketing shall be as set forth in Section 4.4.4 of the Common section.

[Commentary] The bonding materials are used to integrate the existing concrete with the reinforcing materials and the cement-based materials in the jacketing parts. For this reason, the material strengths used for bonding material design are not those of the bonding materials themselves. Instead, it is advisable to determine the characteristic values by measuring the bonding strengths and deformation properties through appropriate testing according to the combination of the materials to be bonded. In general, in the case of a primer, the bonding strength and other characteristic values should be determined through testing by means of a test specimen created by bonding the concrete and the cement-based material in the jacketing part with a primer. Similarly, in the case of an anchor grouting material, a test specimen created by anchoring reinforcing steel into a hole in the concrete with an anchor grouting material should be used and, when an adhesive is used for reinforcing steel embedded in concrete grooves, a test specimen created by anchoring reinforcing steel in a groove in the concrete should be used.

CHAPTER 5 ACTIONS

5.1 General

The actions to be considered in the performance verification of a structure repaired or strengthened using the jacketing method shall be as set forth in Chapter 5 of the Common section.

[Commentary] The actions to be used for the performance verification of a structure repaired or strengthened using the jacketing method shall include all those that increase or decrease the stress on or deformation of the structure or members and that cause changes in material properties over time and shall be as set forth in Chapter 5 of the Common section.

5.2 Actions to Be Considered for the Intervention Design

The actions to be considered for the intervention design shall be as set forth in Section 5.2 of the Common section.

[Commentary] The actions that may occur on the existing structure and repaired or strengthened parts shall be considered appropriately in accordance with Section 5.2 "Actions to Be Considered for the Intervention Design" of the Common section. When intervention is performed for an existing structure, there are permanent actions that have been applied to that existing structure since before intervention, as well as permanent and variable actions that increase after intervention. The permanent actions involved when reinforced concrete bridge piers are repaired or strengthened using the jacketing method are the superstructure reaction force and self-weight of the bridge piers, and these permanent actions are borne by the existing structure. Regarding the burden of the permanent action of self-weight that increases after intervention through jacketing, appropriate judgment shall be made taking into consideration the structure of the jacketing parts and the construction method. One possible accidental action is the inertia force resulting from an earthquake, and it may be considered that this action is borne by the structure created by integrating the existing structure with the jacketing parts.

CHAPTER 6 PERFORMANCE VERIFICATION FOR THE REPAIRED OR STRENGTHENED STRUCTURE

6.1 General

(1) The items to be verified for the members repaired or strengthened through jacketing must be established appropriately so as to ensure that the structure meets its performance requirements after intervention.

(2) For members configured so that the existing concrete and jacketing parts behave as one, the verification may be performed in accordance with this chapter. If no integrity is ensured between the existing concrete and jacketing parts, the performance verification must be performed by means of an appropriate method, such as analyses and experiments, pursuant to the Common section.

[Commentary] (1) The performance verification for a repaired or strengthened structure shall be performed in accordance with this chapter, Chapter 6 of the Common section, "Standard Specifications for Concrete Structures-2017, Design, General Requirements" and Part 5 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods".

When members are repaired or strengthened using the jacketing method, their cross-sectional shape and rigidity are changed by jacketing and these members cannot be considered to be identical to the existing members. Therefore, limit states shall be established for the repaired or strengthened structure or structural members and the verification shall be performed to check that those limit states are not reached. This chapter specifies how to verify the durability, safety, serviceability and restorability of members repaired or strengthened using the jacketing method.

(2) When members are repaired or strengthened using the jacketing method, it can be considered that the existing concrete and jacketing parts jointly resist actions if the integrity between them is ensured. The verification method specified in this chapter assumes that the integrity between the existing concrete and jacketing parts is ensured. Specifically, this chapter describes the performance verification method that assumes that the integrity between the existing concrete and jacketing parts is ensured by jacketing the entire periphery of a bar member with a cement-based material over almost all of its entire length after applying the required base coating through appropriate construction work and performing appropriate treatment such as the application of primers to the interface and the placement of lateral reinforcement. If the existing concrete and jacketing parts cannot be thought to be integrated or, in other words, if it is necessary to take into consideration any separation or slip at the interface between the jacketing parts and existing concrete, the performance verification needs to be performed through appropriate analyses and experiments in accordance with the Common section, factoring in the effect of the separation or slip.

6.2 Calculation of Response Values

6.2.1 General

The response values of a structure repaired or strengthened through jacketing shall be calculated as set forth in Section 6.2 of the Common section.

[Commentary] The calculation of the response values used for the verification of the limit states of the individual performance requirements of the structure repaired or strengthened through jacketing must appropriately reflect the properties resulting from the existing parts being integrated with the jacketing parts in accordance with Section 6.2.2 of the Common section.

6.2.2 Modeling of the structure

(1) A structure repaired or strengthened through jacketing shall be modeled in accordance with Section 6.2.2 of the Common section according to the required performance of the structure. The safety verification shall be performed in accordance with “Standard Specifications for Concrete Structures-2017, Design, General Requirements”, and the verification of seismic performance shall be performed in accordance with Part 5 of “Standard Specifications for Concrete Structures-2017, Design, Standard Methods”.

(2) Members repaired or strengthened through jacketing shall be modeled appropriately, taking into consideration the cross-sectional shape after intervention, and the range of strengthening and anchorage length shall be taken into account.

(3) The materials of members repaired or strengthened through jacketing shall be modeled in accordance with the Common section, “Standard Specifications for Concrete Structures-2017, Design, General Requirements” and Part 5 of “Standard Specifications for Concrete Structures-2017, Design, Standard Methods”.

(4) A structure repaired or strengthened through jacketing shall be modeled appropriately based on inspection and diagnosis results, taking into consideration the degradation of and damage to the existing members.

[Commentary] (1) When modeling a structure repaired or strengthened through jacketing, the range and dimension of analysis shall be established and the actions and structure shall be modeled according to the response properties of the structure deriving from the actions, in accordance with Section 6.2.2 of the Common section. The jacketing method is often used to improve the seismic performance of an existing structure. In such a case, the safety verification shall be performed in accordance with “Standard Specifications for Concrete Structures-2017, Design, General Requirements” and the verification of seismic performance shall be performed in accordance with Part 5 of “Standard Specifications for Concrete Structures-2017, Design, Standard Methods”.

(2) The cross section of members repaired or strengthened through jacketing becomes thicker, making them different from the existing members in the shear span ratio, slenderness ratio, etc. Therefore, when the structure is modeled, the influence of these differences needs to be taken into consideration appropriately. If the edge of the reinforcing material is anchored in the middle of a member, it is necessary to take into consideration its influence on the member appropriately by ignoring the reinforcing material in the anchorage range or the like.

(3) The materials of members repaired or strengthened through jacketing shall be modeled in accordance with the Common section, “Standard Specifications for Concrete Structures-2017, Design, General Requirements” and Part 5 of “Standard Specifications for Concrete Structures-2017, Design, Standard Methods”. The characteristic values and stress-strain curve may differ from those of concrete depending on the type of cement-based material used in the jacketing parts. The influence on the cross section shall be checked through experiments, and the material shall be modeled appropriately. In the case of modeling with linear members, it is necessary to devise an effective method such as conducting the design using the skeleton curve obtained through experiments.

The modeling of the interface between the existing concrete and jacketing parts using the finite element method or the like shall be considered as necessary.

(4) The existing members may have concrete cracking, steel corrosion wastage or other problem due to aging degradation. In that case, such factors as the decrease in member rigidity and the reduction in the cross-sectional area of steel need to be taken into consideration when the materials are modeled. The existing members are also subject to variable actions caused by earthquakes, as well as to various types

of damage including covering concrete peeling, cracking, steel buckling and member plasticization in such cases as when they receive the impact from vehicles or dropping rocks. In that case, the materials also need to be modeled appropriately taking into consideration the reduction in the cross-sectional area, the decrease in member rigidity and so on.

In some cases, on the other hand, the degraded or damaged existing members may be repaired prior to jacketing by eliminating the residual displacement of the existing members, restoring the covering concrete, filling concrete cracks, placing additional steel for buckled reinforcement, etc. The influence of these repairs needs to be taken into consideration as well when the materials are modeled appropriately.

6.2.3 Structural analysis

The structural analysis of a structure repaired or strengthened through jacketing shall be performed as set forth in Section 6.2.3 of the Common section.

6.2.4 Calculation of design response values

The design response values of members repaired or strengthened through jacketing shall be calculated as set forth in Section 6.2.4 of the Common section.

[Commentary] The design response values of members repaired or strengthened through jacketing shall be calculated as set forth in Section 6.2.4 of the Common section, by converting the response values, obtained as mentioned in Section 6.2.3 “Structural analysis”, to verification indices through the use of an appropriate method.

6.3 Durability Verification

The durability of a structure repaired or strengthened through jacketing shall be verified as set forth in Section 6.3 of the Common section in order to check that the structure is not subject to changes over time, such as steel corrosion due to environmental actions and degradation of the existing concrete and the cement-based materials of the jacketing parts, or that the degree of such change remains minor.

[Commentary] The durability of a structure repaired or strengthened through jacketing shall be verified as set forth in the Common section in order to check that the structure is not subject to changes over time, such as steel corrosion of the existing and jacketing parts due to environmental actions and the degradation of the concrete of the existing parts and the cement-based materials of the jacketing parts, or that the degree of such change remains minor.

6.4 Safety Verification

6.4.1 General

In general, the safety of a structure repaired or strengthened through jacketing shall be verified by establishing a limit state for cross-sectional failure.

6.4.2 Verification related to cross-sectional failure

6.4.2.1 General

The verification related to cross-sectional failure shall be generally performed with respect to bending moment, axial force, shear capacity and torsion.

6.4.2.2 Verification related to bending moment and axial force

(1) The safety verification related to bending moment and axial force shall be performed taking into consideration the state of cross-sectional failure appropriately.

(2) The cross-sectional strength may be calculated assuming that the existing and jacketing parts are integrated as one and that multiple layers of reinforcing materials are placed.

(3) When strength is calculated in a verification such as the verification related to the limit state of cross-sectional failure of a member subject to bending moment, as well as to bending moment and axial force, the model shown in Section 2.4.2 of Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods" may be used for the stress-strain curve of concrete.

(4) The stress-strain curve of the cement-based materials used for the jacketing parts shall be as set forth in Section 4.4.2 of the Common section.

(5) When strength is calculated in a verification such as the verification related to the limit state of cross-sectional failure, the model shown in Section 2.4.2 of Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods" may be used for the stress-strain relationship of steel.

(6) The stress-strain curve of continuous fiber reinforcing materials shall be as set forth in Section 4.4.3 of the Common section.

[Commentary] (1) and (2) When the method has been proven through experiments to enable the existing concrete and jacketing parts to behave as one and anchorage is taken into consideration appropriately, the cross-sectional strength may be calculated assuming that the existing members and jacketing parts are integrated as one. Also, anchorage shall be taken into consideration at the edges of the reinforcing materials when the cross-sectional strength is calculated.

In the calculation of the cross-sectional strength of the bridge pier base, consideration can be given to the reinforcing materials only when the reinforcing materials of the jacketing parts are anchored to the bridge pier base.

The design cross-sectional strength shall be calculated based on the hypotheses mentioned below.

・Fiber strain is proportional to the distance from the neutral axis of the cross section.

・The tensile stress of the cement-based materials is negligible.

・Consideration is given to the compressive stress of the cement-based materials of the jacketing parts.

(3) The model shown in Section 2.4.2 of Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods" may be used for the stress-strain curve of the existing concrete that has not degraded. As for the degraded existing concrete, the influence of the degradation shall be taken into consideration appropriately. When the physical properties of the concrete of the

jacketing parts can be deemed to be identical to those of the existing concrete, the stress-strain curve of the existing concrete may be assumed.

(4) A stress-strain curve proven through experiments shall be used for the cement-based materials of the jacketing parts. Actually, however, many different types of cement-based materials are available while there are few formulated stress-strain curves. Also, when a cement-based materials other than concrete is used, many construction methods allow the section thickness to be reduced, in which case the impact on the cross section may be insignificant. When strength is calculated in a verification such as the verification related to the limit state of cross-sectional failure, the impact on the cross section shall be taken into consideration and, if the cement-based materials can be deemed to be the same as the existing concrete, the stress-strain curve of the existing concrete may be assumed.

(5) The model shown in Section 2.4.2 of Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods" may be used for the stress-strain curve of the steel of the existing and jacketing parts. If the steel of the existing parts has corrosion wastage or any other problem, its impact shall be taken into consideration appropriately.

(6) A stress-strain curve proven in accordance with JSCE-E 531 "Test method for tensile properties of continuous fiber reinforcing materials" may be used for continuous fiber reinforcing materials. In general, the stress-strain curve of continuous fiber reinforcing materials is linear until fracture and formulated by a linear relationship that passes through the origin.

6.4.2.3 Verification related to shear force

(1) In principle, the safety verification related to shear force shall be performed with respect to the design shear capacity V_{yd} and design diagonal compressive failure strength of the web concrete V_{wcd}, respectively, taking into consideration the state of cross-sectional failure appropriately.

(2) As for the shear reinforcement of the jacketing parts, only that wrapped around the entire periphery of the existing members is taken into consideration in principle.

(3) The design shear capacity V_{yd} may be calculated using Equation 6.4.1 below.

$$V_{yd} = V_{cd} + V_{sd} + V_{asd} \tag{6.4.1}$$

where V_{cd} : Design shear capacity of bar members that do not use shear reinforcing steel, which is calculated using Equation 6.4.2

$$V_{cd} = \beta_{dr} \cdot \beta_{pr} \cdot \left(f_{vcd} \cdot b_w + f_{avcd} \cdot b_{aw}\right) \cdot d_r / \gamma_b \tag{6.4.2}$$

$f_{vcd} = 0.20\sqrt[3]{f'_{cd}}$ **(N/mm²) where** $f_{vcd} \leq 0.72$ **(N/mm²)**

$\beta_{dr} = \sqrt[4]{1000/d_r}$ **(d_r : mm) but when** $\beta_{dr} > 1.5$**, it shall be set to 1.5.**

$\beta_{pr} = \sqrt[3]{100 p_{vr}}$ **but when** $\beta_{pr} > 1.5$**, it shall be set to 1.5.**

b_w **: Web width of the existing concrete (mm)**

d_r **: Effective height after strengthening;**

distance from the compressive edge of the concrete to the centroid of tensile reinforcement bars of reinforced concrete members of the existing and jacketing parts (mm)

$p_{vr} = A_{sr} / \left\{\left(b_w + b_{aw}\right) \cdot d_r\right\}$

A_{sr} **: Cross-sectional area of the tension-side steel (mm²)**

f'_{cd} **: Design compressive strength of the existing concrete (N/mm²)**

f_{avcd} **: Average shear strength of cement-based materials of the jacketing part (N/mm²)**

b_{aw} **: Web width of the jacketing part (mm)**

γ_b **: In general, this may be set to 1.3.**

V_{sd} **: Design shear capacity supported by the shear reinforcement of the existing members, which is calculated using Equation 6.4.3**

$$V_{sd} = \left[A_w f_{wyd} \left(\sin\alpha_s + \cos\alpha_s\right) / s_s\right] z_r / \gamma_b \tag{6.4.3}$$

A_w **: Total cross-sectional area of the shear reinforcement in interval** s_s **(mm²)**

f_{wyd} **: Design yield strength of the shear reinforcement. The upper limit is** $25 f'_{cd}$

(N/mm^2) or 800 N/mm^2 (whichever is the smaller value).

α_s **: Angle formed by the shear reinforcement and member axis**

s_s **: Shear reinforcement spacing (mm)**

z_r **: Distance from the position at which the force resulting from compressive stress is applied after strengthening to the centroid of tensile steel, which may be generally set to** $d_r/1.15$**.**

γ_b **: In general, this may be set to 1.1.**

V_{asd} **: Design shear capacity supported by the shear reinforcement of the jacketing part, which is calculated using Equation 6.4.4**

$$V_{asd} = \left[A_{aw} f_{awyd} \left(\sin\alpha_{as} + \cos\alpha_{as} \right) / s_{as} \right] z_r / \gamma_b \qquad \textbf{(6.4.4)}$$

A_{aw} **: Total cross-sectional area of the shear reinforcement in interval** s_{as} **of the jacketing part (mm^2)**

f_{awyd} **: Design yield strength of the shear reinforcement of the jacketing part. The upper limit is 345 N/mm^2.**

α_{as} **: Angle formed by the shear reinforcement of the jacketing part and member axis**

s_{as} **: Shear reinforcement spacing in the jacketing part (mm)**

γ_b **: In general, this may be set to 1.1.**

(4) The design diagonal compressive failure strength of the web concrete against shear V_{wcd} **may be calculated using Equation 6.4.5 below.**

$$V_{wcd} = f_{wcd} \cdot \left(b_w + b_{aw} \right) \cdot d_r / \gamma_b \qquad \textbf{(6.4.5)}$$

where $f_{wcd} = 1.25\sqrt{f'_{cd}}$ **but** $f_{wcd} \leq 9.8$ **(N/mm^2)**

γ_b **: In general, this may be set to 1.3.**

[Commentary] (1) As stated in Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods", the safety of bar members that are modeled as simple beams or cantilever beams shall be verified with respect to both design shear capacity V_{yd} and design diagonal compressive failure strength V_{wcd}. If the shear span ratio is small, however, the safety shall be verified with respect to design shear compressive failure strength V_{dd} in accordance with Section 2.4.2 of Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods".

(2) When not wrapped around the entire periphery, the shear reinforcement of the jacketing parts is not anchored completely and may fail to function effectively. Therefore, only the shear reinforcement wrapped around the entire periphery of the existing members shall be taken into consideration in principle.

(3) It has been decided that, assuming that the existing concrete and jacketing parts are integrated, the design shear capacity of bar members should be expressed as the sum of the contribution of capacity of the cement-based materials of the existing and jacketing parts V_{cd}, the contribution of capacity of the shear reinforcing steel of the existing parts V_{sd} and the contribution of capacity of the shear reinforcement of the jacketing parts V_{asd}. The design shear capacity of bar members that do not use shear reinforcing steel V_{cd} shall be calculated from the shear strength of the existing concrete f_{vcd} and the average shear strength of the cement-based materials of the jacketing parts f_{avcd}, and it has been decided that the effective height d_r should be up to the centroid of the reinforcement of the existing and jacketing parts.

In jacketing, the web width shall be twice the jacketing thickness of the jacketing parts. In the case of a circular or elliptical cross section, its size shall be calculated after being converted to that of a rectangular shape.

When continuous fiber reinforcing materials are used as shear reinforcement, the contribution of capacity of the shear reinforcement V_{asd} shall be calculated using Equation 6.3.4 in Chapter 6 of "Concrete Library 88, Recommendation for Design and Construction of Concrete Structure Using Continuous Fiber Reinforcing Materials", and its Young's modulus and effective strain need to be evaluated appropriately.

It has been decided that the upper limit of the design yield strength of the shear reinforcement of the jacketing part f_{awyd} is 345 N/mm^2. When high-strength reinforcement is used, this shall be verified through experiments or other means.

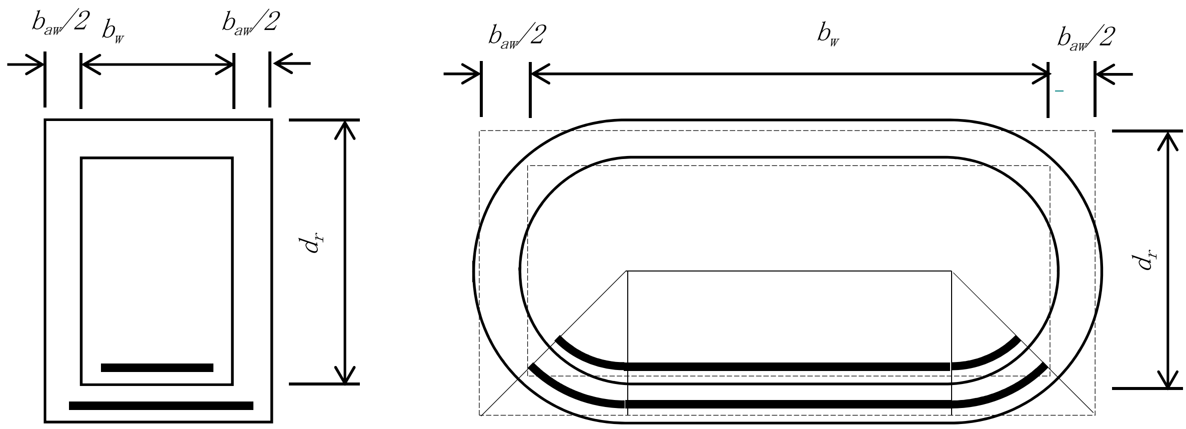


Fig. C6.4.1 Determining the web width in jacketing

6.4.2.4 Verification related to torsion

If the action of torsional moment cannot be ignored, a safety study shall be performed by means of an appropriate method.

[Commentary] If the action of torsional moment is substantial and its impact on the safety of the structure cannot be ignored, a safety verification must be performed with respect to torsion in accordance with Section 2.4.4 of Part 3 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods". The impact on the cement-based materials and reinforcing materials of the jacketing parts should be checked through appropriate analyses, experiments or other means.

6.5 Serviceability Verification

6.5.1 General

The serviceability verification for a structure repaired or strengthened through jacketing shall involve a verification related to appearance, a verification related to vibration and a verification related to displacement and deformation if necessary.

6.5.2 Verification related to appearance

The appearance of a structure repaired or strengthened through jacketing shall be verified as set forth in Section 6.5.3 of the Common section.

[Commentary] When a structure is repaired or strengthened through jacketing, the jacketing parts are frequently seen by users in many cases and cracks and dirty spots on the surface may make users uneasy or uncomfortable. The cement-based materials of the jacketing parts, in particular, are prone to thermal cracking or shrinkage cracking due to the confinement of the existing structure. If the crack width is noticeable or there are a large number of cracks, the structure is substantially affected and users feel uneasy. Therefore, the crack width shall be used as a verification index and the value shall be established, taking into consideration the psychological impact on users, in order to ensure that it does not pose any appearance problem.

Other sources of dirt, such as drained water and bird droppings, can also damage the appearance. As for these factors, appropriate measures should be considered separately.

6.5.3 Verification related to vibration

The verification related to vibration for a structure repaired or strengthened through jacketing shall be performed as set forth in Section 6.5.4 of the Common section and involve checking by means of an appropriate method that the vibration of the repaired or strengthened structure does not affect the comfort in use of the structure itself or any surrounding structure.

[Commentary] When a structure is repaired or strengthened through jacketing, the rigidity of the structure increases, resulting in a change in its natural period.If this makes the period of variable loads similar to the natural period of the structure, resonance may occur, possibly giving users a sense of unpleasantness. The impact of such vibration may also extend to surrounding structures and houses. Therefore, if intervention using the jacketing method greatly changes the natural period of the structure, the impact of such change must be checked by means of an appropriate method.

6.5.4 Verification related to displacement and deformation

The verification related to displacement and deformation shall involve checking by means of an appropriate method that the comfort in use is not affected by the displacement or deformation that occurs in a structure repaired or strengthened through jacketing.

[Commentary] Since the jacketing method is generally intended to improve the seismic performance and toughness, the displacement or deformation that occurs in a structure in a normal state of use is small. Therefore, the verification related to displacement and deformation may be omitted for normal load actions.

In the event of an earthquake of a high intensity, a certain degree of displacement and deformation is tolerated, even though the probability that such an earthquake will occur while the structure is in service is low. As for medium- and small-scale earthquakes, which are more likely to happen during the service life, it must be checked by means of an appropriate method that no significant displacement or deformation will arise.

6.6 Seismic Performance Verification

When a seismic performance verification is performed for members repaired or strengthened through jacketing, a level of seismic performance and a limit value of damage corresponding to that seismic performance level shall be established in advance.

[Commentary] Establishing the seismic performance of a structure shall involve taking into consideration the response properties of the structure corresponding to the assumed earthquake scale. In addition to the behavior during an earthquake, the impact of the damage of the structure on human lives and assets, secondary disaster prevention efforts, daily livelihoods and economic activities in the local community after the earthquake, difficulty in restoration and construction costs shall be considered comprehensively to establish seismic performance 1 to 3. Here, seismic performance 2 refers to a condition in which the structure can restore its functionality in a short time after an earthquake and meet the safety and serviceability requirements without the need for strengthening. Seismic performance 3 refers to a condition in which the structure as a whole does not collapse even if an earthquake has damaged the structure beyond repair, in which case no verification is performed with regard to the restorability after the earthquake.

A limit value shall be established according to the seismic performance, taking into consideration the topographical, geological and geotechnical features as well as the location among others. The limit value for seismic performance 2 shall be established within a range beyond the yield displacement or yield rotation angle of members up to the ultimate displacement or ultimate rotation angle. Specifically, in the case of general column members, the peeling of the covering concrete of jacketing parts, buckling of axial reinforcement or deformation of tie reinforcement occurs at a displacement close to ultimate displacement or ultimate rotation angle. As far as ordinary members are concerned, therefore, it is advisable to establish the limit value in the vicinity of the maximum load bearing capacity.

6.7 Structural Details

6.7.1 Arrangement of reinforcing materials and spacing of reinforcing steel

The arrangement of reinforcing materials and spacing of reinforcing steel must be determined taking into consideration the property of bonding between cement-based materials and reinforcing materials, the crack dispersion performance and the constructability of cement-based materials.

[Commentary] Reinforcing steel may be thought to have the required bonding property if it meets the requirements set forth in Section 2.2 “Spacing of Reinforcement” of Part 7 of “Standard Specifications for Concrete Structures-2017, Design, Standard Methods”. On the other hand, widening the arrangement spacing of reinforcing materials can reduce the crack dispersion performance of cement-based materials. When the crack dispersion performance is taken into consideration, the arrangement spacing of reinforcing materials should be kept below 200 to 300 mm, although it depends on the diameter of the reinforcing steel. In the case of FRP grids, the spacing should be kept below 200 mm.

Also, depending on the type of cement-based material, the construction method, such as placing, spraying or troweling, and the aggregate size differ. The arrangement of reinforcing materials and spacing of reinforcing steel shall be determined so that the specified bonding property is achieved without honeycombs forming around the reinforcing steel as a result of construction work.

6.7.2 Covering and jacketing thickness of reinforcing materials

The covering and jacketing thickness of reinforcing materials of the jacketing parts must be sufficient to ensure the performance of the repaired or strengthened structure with constructability taken into consideration.

[Commentary] With the concrete jacketing method, the minimum value of the reinforcing steel covering is equal to the covering that takes the bonding property and durability into consideration plus the construction error, pursuant to Part 7 of “Standard Specifications for Concrete Structures-2017, Design, Standard Methods”. In general, when the bonding property is taken into consideration, the jacketing concrete thickness is 250 mm or more. In many cases, however, this thickness is determined through a durability verification. Therefore, the covering of a structure in an extremely salty environment tends to become thicker than that of other structures. While a thicker covering can prevent the buckling of reinforcement and improve the deformation performance, it may make the covering concrete prone to peel off, leading to a sharp decline in strength. As far as the seismic performance is concerned, therefore, it is important to keep the covering from becoming excessively thick relative to the member thickness.

Polymer cementitious mortar and other cement-based materials have higher tensile strength than concrete, and some of them can achieve the required anchorage performance and joint performance of reinforcing materials with a thin covering. Also, many of these materials have more excellent properties than concrete, such as higher water-tightness, a lower diffusion coefficient of chloride ions and a lower carbonation rate. Therefore, the covering is often set to greater than the diameter of the reinforcing material. Care needs to be exercised, however, if the structure is in an extremely salty environment or requires fire resistance. Since the properties differ depending on the material used, it is necessary to take the material type into consideration when determining the covering.

Continuous fiber reinforcing materials have high corrosion resistance and, therefore, the covering can be made thinner. Taking the bonding property into consideration, it is necessary to check the required covering through experiments. There are cases in which the covering of an FRP grid is set to 10 mm or more or equal to or greater than the design thickness of the FRP grid.

6.7.3 Joints of lateral reinforcing materials

(1) When reinforcing steel is used as the lateral reinforcing material, joints that directly bond reinforcing steel shall be employed. Lap joints must not be used in principle.

(2) When a continuous fiber reinforcing material is used as the lateral reinforcing material, a method whose performance has been proven through experiments or other appropriate means must be used.

[Commentary] (1) When the thickness of the concrete sections of the jacketing parts is considered, it is difficult to anchor reinforcing materials with hooks and the use of joints is required. When tie reinforcement is anchored with lap joints, the joints may fail to exhibit sufficient joint strength due to peeling off of the covering concrete if members are greatly deformed. For tie reinforcement, therefore, joints that directly bond reinforcing steel shall be employed. In general, flare welding shall be used and the joint length shall be 10 times the diameter of reinforcing steel.

(2) Various types of joints are being studied for continuous fiber reinforcing materials. A method proven through experiments shall be used.

When FRP grids are used as a continuous fiber reinforcing material for strengthening bridge piers whose cross-sectional shape is rectangular or circular, U-shaped or semicircular FRP grids are created in advance and lap joints are used on the planar parts in many cases. When lap joints are used, they may fail to exhibit sufficient joint strength at the bridge pier base and other places where they serve as plastic hinges, due to peeling off of the covering concrete, as with reinforcing steel. Therefore, joints used in the range subject to plasticization, such as the bridge pier base, must have a structure, length and arrangement whose performance has been proven through experiments or other means.

6.7.4 Anchorage of axial reinforcement to footings

The post-installed anchors used for the anchorage of axial reinforcement to footings must be anchored in a way that ensures the yield strength of axial reinforcement.

[Commentary] Generally, the center-to-center space between anchors is 300 mm. Anchors shall be placed at intervals of 250 to 500 mm, avoiding the main reinforcement on top of the footings. Epoxy resin and non-shrink mortar are used as anchor grouting materials. Since the minimum anchorage length differs depending on the type of grouting material, a test-proven value needs to be adopted.

For example, the minimum anchorage length of epoxy resin is said to be 20 times the diameter of reinforcing steel. As for non-shrink mortar, Equation 2.5.1 in Section 2.5.3 of Part 7 of “Standard Specifications for Concrete Structures-2017, Design, Standard Methods” is used. The anchorage length of epoxy resin, which is shorter, is often used as the standard.

$$L = \alpha \frac{f_{yd}}{4 f_{bod}} \phi \qquad \text{(Equation C6.7.1)}$$

where ϕ : Diameter of reinforcing steel

f_{yd} : Design tensile yield strength of reinforcing steel

f_{bod} : Design bonding strength of concrete. Considering that γ_c is 1.3, this value may be calculated from f_{bok} in Equation C5.2.2 in “Standard Specifications for Concrete Structures-2017, Design, Standard Methods”. Note that $f_{bod} \le 3.2$ (N/mm^2).

Generally, the diameter of the drilled hole is equal to the diameter of reinforcing steel plus 10 mm.

6.7.5 Intermediate penetrating reinforcing materials

Considering the long side-to-short side ratio of existing members, intermediate penetrating reinforcing materials shall be placed as necessary.

[Commentary] Intermediate penetrating reinforcing materials are placed to increase the effect of confinement of the jacketing concrete parts and to improve the toughness of repaired or strengthened members. In general, intermediate penetrating reinforcing materials should be placed when strengthening bridge piers having a cross-sectional shape whose long side-to-short side ratio exceeds 1:3.

With the concrete jacketing method, it is standard to place intermediate penetrating reinforcing materials at intervals not exceeding the bridge axial cross-sectional width after intervention in the horizontal direction and at intervals of 300 mm or so in the height direction. In principle, when reinforcing steel is used as the intermediate penetrating reinforcing material, the steel shall be anchored with hooks. Possible alternative methods to be employed if the use of reinforcing steel is impractical include using prestressed concrete steel bars and shaped steel and anchoring them with bolts, as well as using aramid FRP rods as a continuous fiber reinforcing material to introduce tensioning force.

CHAPTER 7 CONSTRUCTION

7.1 General

(1) The construction for intervention with the jacketing method shall be in principle performed in accordance with Chapter 7 of the Common section as well as with this chapter.

(2) Engineers with sufficient knowledge and experience in the construction using the jacketing method must be assigned to the site and the construction work must be performed under the direction of those engineers.

[Commentary] (1) Methods of jacketing are roughly divided into concrete jacketing and mortar jacketing, and there are two mortar jacketing methods: spraying and troweling. Furthermore, two spraying methods are available: wet spraying and dry spraying. Fig. C7.1.1 shows an example of the construction procedure for jacketing. Assuming that the structure is appropriately designed to meet its performance requirements, the figure shows the processes necessary to construct the repaired or strengthened structure specified in design documents by using the jacketing method. In principle, the environment and damage status of the existing structure to be repaired or strengthened through jacketing shall be thoroughly studied and grasped, a construction plan shall be formulated based on design documents, jacketing parts shall be constructed while exerting appropriate quality control and then investigations shall be performed to check that the repaired or strengthened structure has been built according to design documents. Also, construction records must be stored appropriately to ensure appropriate post-intervention maintenance.

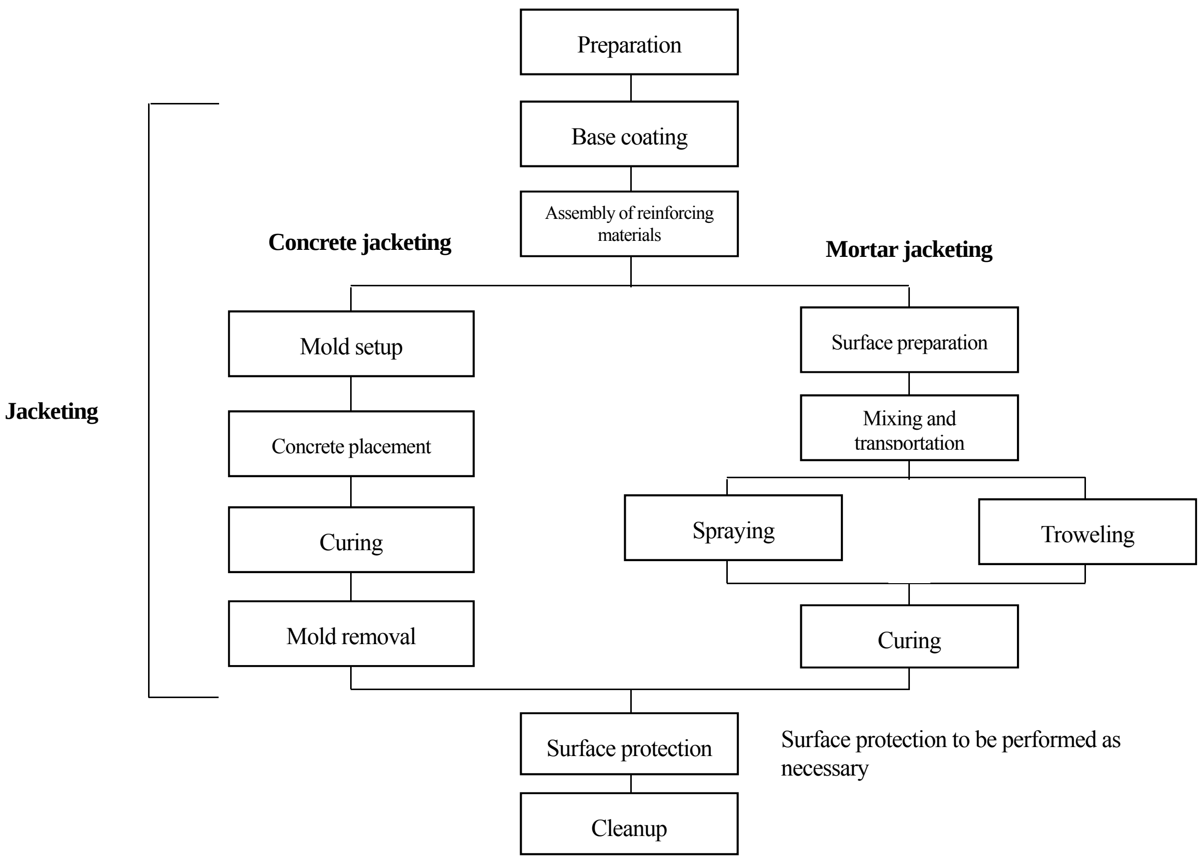


Fig. C7.1.1 Example of the construction procedure for jacketing

(2) In general, whether construction succeeds or fails may depend on human factors such as the experience and qualities of constructing parties involved. Therefore, the construction work shall be performed under the direction of engineers with sufficient knowledge and experience in the construction for jacketing. Particularly, the construction technique for spraying mortar is important for ensuring quality in jacketing. It is therefore desirable to assign engineers qualified through spraying managing engineer qualification systems run by relevant organizations or qualified spraying technicians.

7.2 Prior Study and Construction Plan

(1) A prior study shall be conducted before construction to grasp the condition of the existing structure to be repaired or strengthened through jacketing.

(2) An appropriate construction plan must be formulated and a construction plan document must be created, taking into consideration the construction and environmental conditions, to construct the repaired or strengthened structure shown in design documents.

(3) Formulating the construction plan must involve considering the actual work methods and the management methods to ensure the implementation of those methods.

[Commentary] (1) A prior study shall involve examining the design documents of the existing structure and checking the strength of concrete, the status of reinforcement arrangement, etc. at the site as necessary. It is also required to grasp the status of cracking in the existing members, whether free lime and rust fluid are present or not, the status of steel corrosion and the level of damage such as concrete floating and peeling, as well as to fill cracks, remove degraded parts, perform patching repair and take other measures as necessary before construction using the jacketing method. The prior study and measures shall be as set forth in “Standard Specifications for Concrete Structures-2013, Maintenance”.

(2) In order to ensure that the repaired or strengthened structure has the performance properties (safety, serviceability, seismic performance, durability, etc.) defined in the intervention design, it is necessary to formulate an appropriate construction plan and perform construction work properly according to that construction plan. In intervention through jacketing, the conditions of the local site, such as the location and status of use of the existing structure, and the environmental conditions of the construction site significantly affect the certainty and safety of construction. It is therefore necessary to formulate a construction plan appropriate for the conditions of the local site while reflecting the results of the prior study. The construction plan shall be formulated by reflecting the prior study results, comprehensively taking into consideration the securing of quality, the safety, economy and period of construction work and the environmental burden.

When formulating a construction plan, care must be exercised to ensure:

- That a reasonable process plan is created taking into consideration the time zones during which work can be done;
- That a sufficient work space is secured;
- That the necessary amounts of materials of proven quality are procured; and
- That constructing parties with necessary skills and sufficient experience are assigned.

Also, in order to perform construction safely, care must be exercised to ensure:

- That measures to provide safety for constructing parties are specified;
- That measures to provide safety for third parties are specified;
- That measures to prevent the destruction of additive and other related facilities;

・That a system is in place to respond to accidents swiftly; and

・That a waste disposal method is specified.

(3) The construction procedure for jacketing consists of the processes mentioned below. When formulating a construction plan, the actual work methods and management methods in the individual work processes must be clearly defined.

[Concrete jacketing]

① Base coating

② Assembly of reinforcing materials

③ Mold setup

④ Concrete placement

⑤ Curing

⑥ Mold removal

[Mortar jacketing]

① Base coating

② Assembly of reinforcing materials

③ Surface preparation

④ Storage, mixing and transportation of mortar materials

⑤ Mortar jacketing (spraying (wet or dry) or troweling)

⑥ Curing

Also, considering the restrictions such as the work environment of the construction site and work time, a quality control method must be specified to ensure the processes corresponding to the construction items and the required performance in the design. If any change in construction work becomes necessary during construction, the construction plan must be changed to ensure that the relevant requirements, such as the construction requirements and the performance requirements of the structure, are met. If the construction plan is changed, the construction plan document must be changed accordingly.

7.3 Base Coating

In base coating for jacketing, dirt such as oil and fat on the surface of the existing members and vulnerable layers must be removed so that the existing concrete and jacketing parts are integrated. Also, harmful cracks, floating, peeling and water leaks must be treated appropriately.

[Commentary] In principle, base coating shall be performed using water jetting, vacuum blasting, sand blasting, chipping or other appropriate method and involve removing oil, fat and other dirt, vulnerable layers and cement paste and exposing the sound surface (surface texturing). If the surface of the existing members has construction defects such as honeycombs, noticeable degradation, cracks, water leaks, etc., the existing members must be repaired using an appropriate method such as patching repair, crack filling or water leak prevention.

7.4 Reinforcing Material Application

(1) The reinforcing materials used for jacketing must be placed at the specified positions precisely.

(2) The reinforcing materials used for mortar jacketing must be securely anchored to existing members using concrete anchors or the like.

(3) The positions of the joints of reinforcing materials and the jointing method must be in principle as specified in design documents.

(4) When intermediate penetrating reinforcing materials are used, they must be placed at the specified positions according to design documents such that they do not damage the steel in the existing members.

[Commentary] (1) Reinforcing materials must be processed using an appropriate method that does not affect the material quality so that they have the correct size and shape determined in the design, and they must be assembled correctly at the positions specified in design documents. If epoxy-coated reinforcing steel bars are used in a salty environment, due care must be exercised so that the epoxy coating is not damaged during assembly. In the case of concrete jacketing, Chapter 10 of "Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction" shall govern.

(2) The reinforcing materials used for mortar jacketing shall be securely anchored using metal fittings or other tools appropriate for the individual reinforcing materials so that there will be no space between the existing members and reinforcing materials. Other methods may be used in which reinforcing materials are embedded in grooves on the surface of the existing members and fastened with adhesive.

(3) To joint reinforcing materials, an appropriate method must be selected according to the type of reinforcing material, cross sectional size, stress status, joint positions, joint performance requirements and so on. In the design phase, therefore, the joint positions and jointing method are specified in design documents giving due consideration to these factors. For this reason, the joint positions and jointing method must be in principle as specified in design documents. If the need arises to provide joints for reinforcing materials not specified in design documents during the construction phase, Section 6.7 "Structural Details", Section 8.5 of Part 5 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods" and Section 2.6 of Part 7 of "Standard Specifications for Concrete Structures-2017, Design, Standard Methods" shall govern.

(4) The commonly used intermediate penetrating reinforcing materials are reinforcing steel and prestressed concrete steel. Also, there are cases in which tensioning force is introduced to continuous fiber reinforcing materials and concrete is prestressed. When holes are bored in existing members by means of core boring or some other technique in order to place intermediate penetrating reinforcing materials, the positions of reinforcing steel must be checked in advance through a radar survey not to damage the existing reinforcing steel.

7.5 Construction for Concrete Jacketing

Mold setup, concrete placement, curing and mold removal for concrete jacketing must be performed by means of appropriate methods in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions".

[Commentary] Mold setup, concrete placement, curing and mold removal for concrete jacketing are the same as in the construction of a normal reinforced concrete structure and, therefore, they must be performed by means of appropriate methods in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions". Since the concrete placed for jacketing is structurally prone to cracking, an appropriate mixing design must be considered. Also, a sufficient amount of water must be sprayed over existing members immediately before the placement of concrete in order to prevent hardening failure that may occur as the moisture in the concrete is absorbed in the existing members.

7.6 Construction for Mortar Jacketing

7.6.1 Surface preparation

For the work of surface preparation, bonding materials appropriate for the mortar materials used must be selected.

[Commentary] For many mortar materials used for mortar jacketing, dedicated bonding materials for surface preparation are determined on a product-by-product basis. Selecting surface preparation work appropriate for the mortar materials used ensures that the specified bonding strength is achieved. Therefore, surface preparation must be done giving due care about the usable time and placement time of bonding materials, which differ from product to product.

7.6.2 Storage, mixing and transportation of mortar

(1) Mortar materials shall be stored as set forth in "Standard Specifications for Concrete Structures-2017, Materials and Constructions".

(2) Mortar shall be mixed using the specified mix proportion, which is determined for each material, in the specified order of material entry at the specified mixer capacity in the specified mixing time.

(3) For the transportation of mortar, a method must be selected that ensures that the required amount of mortar can be transported with the required level of quality.

[Commentary] (1) Mortar materials must be stored appropriately in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction (Section 5.2.1 Storage facilities)". When a fluid emulsion is used as a chemical admixture for mortar, it must be stored so that it does not freeze. Once a fluid emulsion freezes, its material properties change. Therefore, if a fluid emulsion freezes, it must not be used.

(2) In general, the mix proportion of mortar is determined for each individual material relative to the specified performance. Therefore, the mix proportion determined for each mortar in use must be used. If the mortar used for mortar jacketing is handled in a procedure different from the determined one that covers the order of material entry, mixer capacity, mixing time, etc., its flow behavior, spraying behavior, strength manifestation and so on may be affected. For this reason, when mortar is mixed, the mixing methods determined for the individual mortar used must be adopted and appropriate equipment must be used.

(3) For the transportation of mortar, the pump capacity, pipe diameter and length and spraying equipment appropriate for the jacketing method and the selected mortar must be selected.

7.6.3 Mortar jacketing

(1) For mortar jacketing, mortar must be applied using the method determined for each individual material.

(2) If the jacketing thickness is large, the material must be divided into an appropriate number of layers according to the thickness when applied.

(3) When the spray surface is finished, the jacketing material must be sprayed up to the finished surface and the surface must be smoothed with a metal trowel.

(4) In the summer or winter, mortar shall be applied in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction".

[Commentary] (1) Depending on the mortar used, bonding materials are not used for surface preparation and, instead, water may be sprayed to prevent water absorption from mortar to the surface of the existing members (dryout). In this case, the surface of the existing members must be sufficiently prewetted before mortar jacketing is performed. When mortar jacketing is performed with the wet spraying method, the mortar is pumped to the spraying position and then the specified amount of mortar is sprayed to the existing members. Therefore, the mortar needs to have the specified fluidity. For this reason, it is necessary to conduct a consistency test or the like to check fluidity before spraying. The available test methods to check fluidity include J funnel test, mortar flow test, mini-slump test and maximum shear force test. Depending on the properties of the mortar used, troweling work may be performed by human power if the mortar is difficult to spray, the amount of mortar to be applied is small or the spraying equipment is difficult to install. When troweling work is performed, the mortar must be pressed down with care using a metal trowel to ensure that the mortar is filled between the reinforcing materials and exiting members.

(2) The allowable spray thickness per layer differs depending on the spraying method and spraying direction. In general, when the material is sprayed horizontally, the maximum allowable spray thickness is 50 mm or so for the wet spraying method and 200 mm or so for the dry spraying method. When the material is sprayed upwardly, the maximum allowable spray thickness is 30 mm or so for the wet spraying method and 100 mm or so for the dry spraying method. Therefore, if the allowable spray thickness is exceeded, the material must be sprayed in multiple layers. In general, considering the filling property of mortar, it is advisable to spray a layer of mortar up to the height of the reinforcing material and, after the first layer of mortar hardens, spray mortar to the covering. If the placement surface between layers is not treated appropriately, it may cause peeling in the future. Therefore, the placement surface between layers must be treated appropriately so as to prevent the peeling of mortar pieces. Generally, the bonding material employed for surface preparation is used. If the placement surface is wet, however, the mortar may be placed without applying any bonging material.

(3) When the wet spraying method is used for spraying, mortar shall be sprayed up to the surface and then the surface shall be smoothed by human power using a metal trowel. Note that, in the case of the dry spraying method, the mortar hardens quickly and, therefore, the surface must be finished swiftly while adjusting the area to be finished.

(4) During construction, temperature management shall be accomplished using a thermometer installed at the construction site. Before performing construction work, it shall be checked that the average daytime temperature is 5°C or higher in the winter or 25°C or lower in the summer in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction". If the temperature is outside these ranges, construction shall be performed in accordance with "Standard Specifications for Concrete Structures-2017, Materials and

Constructions, Standard Methods for Construction" (Chapter 12 Cold Weather Concrete and Chapter 13 Hot Weather Concrete).

7.6.4 Curing

The mortar applied for jacketing must be cured such that it is not subject to sudden temperature changes, drying or other detrimental action.

[Commentary] The mortar applied for jacketing must be cured appropriately until it achieves the specified strength. A sudden change in temperature after jacketing or, in particular, blowing wind in the winter or direct sunlight causes the surface to dry rapidly, making it prone to plastic cracking as well as cracking due to dry shrinkage. It is therefore necessary to exercise due care to prevent cracking from occurring at places where the mortar has been applied and, if necessary, to employ an appropriate curing technique such as mist curing or film curing.

7.7 Surface Protection

After the construction of the jacketing parts is complete, surface protection work shall be performed as necessary.

[Commentary] Depending on the site environment, surface protection work may be performed to protect against carbonation and salt damage as well as against other types of damage due to driftwood and the like. Surface protection work should be performed in accordance with "Concrete Library 119, Recommendation for Concrete Repair and Surface Protection of Concrete Structure, 2005.4".

7.8 Quality Control

Quality control must be implemented for specified items in each phase of construction so as to check that the structure repaired or strengthened through jacketing has the required level of quality.

[Commentary] In construction using the jacketing method, process management, quality control and safety management are important. Of these, quality control is an act of securing quality that is performed in every phase of construction in order to ensure that the strengthening through jacketing is consistent with the intended purpose. Quality control must involve not only controlling the quality of reinforcing materials but, in the case of mortar jacketing, managing the mixing of mortar and accomplishing mix proportion management and strength management as well. In the case of concrete jacketing, the quality of concrete must be controlled by means of an appropriate method in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Construction" (Chapter 15 Quality Control).

① Quality control of reinforcing materials

When JIS reinforcement is used as reinforcing materials, the properties shall be checked based on the quality records created during production at the plant. As for FRP grids, the tensile strength and Young's modulus shall be checked based on the quality records created during production at the plant.

② Mixing management

During the mixing of mortar, the mixer, pump, compressor and others must be managed to ensure that they operate normally during manufacturing.

③ Mix proportion management

Mortar achieves the required fluidity, pumpability and thickening property and excellent strength when it is mixed with the specified mix proportion using an appropriate mixing method. The properties of mortar before hardening slightly change depending on the outdoor air temperature and other environmental conditions. Therefore, when the mixing is started (morning or afternoon) or the mix proportion is changed, it is advisable to manage the quality of mortar before hardening by checking the mix proportion and flow behavior as well as the temperature of the mortar being mixed, outdoor air temperature and so on.

④ Strength management

The quality of mortar materials shall be checked before being carried in, based on the quality records created during production at the plant. At the site, the compressive strength and bonding strength of the mortar shall be checked in appropriate construction quantities.

7.9 Inspection

A structure constructed using the jacketing method shall be in principle inspected according to an inspection plan under the responsibility of the ordering party of the structure.

[Commentary]　In the case of concrete jacketing, the inspection must be performed by means of an appropriate method in accordance with "Standard Specifications for Concrete Structures-2017, Materials and Constructions, Standard Methods for Inspection" (Chapter 7 Construction Inspection, Chapter 8 Inspection of Concrete Structures and Chapter 9 Inspection Records). Basically, the same applies to mortar jacketing, except that the inspection of the jacketing thickness is crucial because the jacketing thickness is as small as one-fifth that of concrete jacketing. Particularly, since the covering thickness is small, an inspection must be conducted to ensure that the thickness is appropriate.

CHAPTER 8 RECORDS

Records of studies, design, performance verification, construction, materials used, quality control, etc. regarding the intervention using the jacketing method shall be handled as set forth in Chapter 8 of the Common section.

[Commentary] Records of studies, design, performance verification, construction, materials used, quality control, etc. regarding the intervention using the jacketing method shall be in principle handled as set forth in Chapter 8 of the Common section. There are cases in which jacketing is applied for the intervention of a structure damaged by seismic force. In such cases, the existing structure may have damage noticeably greater than environmental degradation, such as cracking in the shear direction, peeling of the covering concrete of the plastic hinge and buckling of axial reinforcement. Therefore, when the intervention of a structure damaged by seismic force is performed using the jacketing method, it is important to store and maintain records about the status of damage to the existing structure prior to the intervention and the method of repairing the damage as well.

CHAPTER 9 MAINTENANCE

The maintenance of a structure repaired or strengthened through jacketing shall be as set forth in Chapter 9 of the Common section.

[Commentary] The maintenance of a structure repaired or strengthened through jacketing shall be in principle as set forth in Chapter 9 of the Common section. Structures repaired or strengthened through jacketing, such as bridge piers, may be located in extremely corrosion-prone places, such as in rivers and along seaside areas. In such cases, concrete surface protection or some other measure may be necessary to sustain the required durability and it is common that the concrete surface protection work involves treatment such as periodical repainting. Therefore, a maintenance plan should be formulated by incorporating the basic policy on the treatment required to sustain durability during the service life after the intervention as well as on when such treatment is to be given.

In the case of a structure built in a river, driftwood and other objects may collide with the structure during a flood, possibly damaging the covering parts of concrete or mortar that has been placed. Therefore, an inspection shall be performed after a flood and, upon discovery of damage, appropriate treatment shall be given.