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Structural intervention of existing concrete structures using cementitious materials —

Part 1: General principles

Intervention structurelle sur les structures en béton existantes utilisant des matériaux cimentaires —

Partie 1: Principes généraux

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 7, *Maintenance and repair of concrete structures*.

A list of all parts in the ISO 5091 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

As a repairing and strengthening method, attaching of a cementitious material layer to surface of existing concrete structures has been widely accepted. Since the cementitious layer does not have enough tensile strength, tension reinforcement is generally placed in the cementitious layer. There are two types of attaching. For the first way, the cementitious layer is attached either on the top surface or bottom surface of horizontal concrete members, especially slabs, while, for the second way, the cementitious layer is attached to jacket vertical concrete members, especially columns. There has not been any ISO standard on design, execution and maintenance for this method with attaching a cementitious layer. The ISO 5091 series serves as the first ISO standard for the intervention by attaching a cementitious material layer with tension reinforcement inside.

At the same time, the ISO 5091 series is the first ISO standard developed for a specific intervention method, which conforms to the umbrella code, ISO 16311, especially ISO 16311-3 and ISO 16311-4.

The ISO 5091 series consists of four parts. ISO 5091-1 provides the issues common to all three parts, while ISO 5091-2, 3 and 4 provide the issues specific to each attaching way of cementitious material layers.

The ISO 5091 series can serve as a practical standard for construction industry, such as client, design consultant and general contractor, to apply the structural intervention with externally attached cementitious layer. Additional technical information, which is not provided explicitly in the ISO 5091 series, needs to be provided in each application case with consideration of the provisions of the ISO 5091 series.

Structural intervention of existing concrete structures using cementitious materials —

Part 1: General principles

1 Scope

This document specifies the standards for design, construction and maintenance following completion of intervention to be applied for performing intervention work using cementitious materials to improve the performance of existing concrete structures. The intervention dealt with in this document 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.

This document covers the overlaying, underlaying and jacketing methods using cementitious materials.

The intervention with cementitious materials is covered in ISO 16311-1, Clause 4.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16311-1:2014, *Maintenance and repair of concrete structures — Part 1: General principles*

ISO 16311-2, *Maintenance and repair of concrete structures — Part 2: Assessment of existing concrete structures*

ISO 16311-3, *Maintenance and repair of concrete structures — Part 3: Design of repairs and prevention*

ISO 16311-4:2014, *Maintenance and repair of concrete structures — Part 4: Execution of repairs and prevention*

ISO 19338, *Performance and assessment requirements for design standards on structural concrete*

ISO 10406-1, *Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods — Part 1: FRP bars and grids*

ISO 10406-2, *Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods — Part 2: FRP sheets*

ISO 10406-3, *Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods — Part 3: CFRP strips*

ISO 22966, *Execution of concrete structures*

ISO 679, *Cement — Test methods — Determination of strength*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
top-surface overlaying
method in which the thickness of the structural element associated with the top surface of the existing concrete members is increased using cementitious materials, which will generally be reinforced

Note 1 to entry: The technique enhances the performance (e.g. strength, stiffness) of the existing concrete structure and is applicable to highway bridge decks, etc.

3.2
bottom-surface (soffit) underlaying
method in which the thickness of the structural element associated with the bottom surface of the existing concrete is increased using cementitious materials, which will generally be reinforced

Note 1 to entry: The technique enhances the performance (e.g. strength, stiffness) of the existing concrete structure and is applicable to highway bridge decks, tunnel linings, box culverts/waterway structures, beams, etc.

3.3
jacketing
method in which additional cementitious materials and associated reinforcement are added to the periphery of the existing concrete member to increase its strength, stiffness and/or ductility

Note 1 to entry: It is applicable to columns, bridge piers, rigid-frame pier beams, etc.

3.4
bonding product
material, such as a primer or adhesive, that is applied to bond concrete and mortar

Note 1 to entry: The grouting material for bonding concrete and reinforcing material is also included in this term.

3.5
filling material
material injected to fill the gap between a reinforcing material, such as intermediate penetrating tie, and concrete

3.6
intermediate penetrating tie
reinforcing member, generally made of steel or fibre-reinforced polymer (FRP), that is installed inside the drilled hole and glued into the concrete substrate to improve the ductility and shear strength of bridge piers

3.7
very high early strength cement
type of cement with a typical mix proportion that develops a compressive strength as high as 20 N/mm^2 to 30 N/mm^2 within 2 h to 3 h of placement

3.8
reinforcing material
steel or FRP material used to sustain, restore or improve the mechanical performance of a structure

3.9
polymer hydraulic cement mortar
hydraulic composition made cementitious materials and fine aggregate modified by the addition of a polymer

3.10
overlaying material
cementitious material, potentially reinforced, added on the top surface of an existing concrete structure for the purpose of making an intervention to enhance the performance of that structure

3.11
underlaying material
cementitious material, potentially reinforced, added on the bottom surface (soffit) of an existing concrete structure for the purpose of making an intervention to enhance the performance of that structure

3.12
design response value
value of structural response obtained by numerical analysis on design process, such as sectional force and deformation

3.13
design limit value
design value for quantified limit state on design process, such as strength of element, allowable crack width

3.14
cross section failure
loss or decrease of load carrying capacity of structural member due to the excessive action more than which is more than cross sectional strength, such as flexure, shear and axial strength

3.15
maintainability
ability of a structure to meet service objectives with a minimum expenditure of maintenance effort under service conditions in which maintenance and repair are performed

4 Investigation of existing structure

4.1 General

The existing structure for which intervention is to be considered shall be investigated in detail to obtain the information necessary for intervention design and construction. The necessary information for intervention is additional to and/or different from the information obtained from assessment of existing structure as maintenance activities, which shall be obtained from ISO 13822 and ISO 16311-1 and ISO 16311-2.

4.2 Investigation

4.2.1 Investigation using documents, records

When an investigation is conducted using documents, records, etc., the climatic conditions, environmental conditions, geographical conditions and other relevant conditions of the local site shall be understood in detail from the following viewpoints:

— formulation of material and structural plans;

— formulation of a construction plan;

— maintenance following completion of intervention.

Generally, the workability and hardening characteristics of cementitious materials greatly change depending on the construction environment, such as temperature. It is therefore necessary to take into account the climate of the local site during the period when construction is planned to be performed. Also, for intervention using cementitious materials, the restrictions of the local site regarding the construction space as well as the carry-in and installation of materials and equipment needs to be understood before a specific construction plan is formulated.

4.2.2 On-site investigation

On the site, an investigation shall be conducted to check degradation, damage and initial defects of the existing concrete structure from the following viewpoints:

— securing of integrity between the existing parts and strengthening parts;

— prediction of durability and degradation after intervention.

In obtaining the expected effect of intervention using cementitious materials, integrity between the repairing or strengthening parts and existing structure is important. For ensuring integrity, it is necessary to take measures based on the understanding of degradation, such as carbonation of the surface of the existing structure, damage such as cracks, splash 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 understand the cause and degree of degradation.

5 Intervention design

5.1 General

In intervention design, a rational structural plan shall be formulated, and structural details shall be established based on that plan so that intervention restores the performance of the existing structure to the required level and that the structure after intervention fulfils the required performance throughout the remaining design service life. The required performance shall be determined according to ISO 19338.

5.2 Structural plan

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 fulfils the required performance throughout the design service life.

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 field measurements and other activities shall be taken into consideration.

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 compatibility between the existing parts and strengthening parts is particularly important for preventing the structure after intervention from experiencing early performance degradation.

The intervention methods and materials are selected to ensure that maintenance work such as inspections and performance evaluations can be efficiently conducted on the structure after intervention. The costs required for corrective measures shall be minimized through the selection. Changes that can occur in the structure after the intervention need be detected.

5.3 Structural details

The bonding method of reinforcing materials shall be selected appropriately to ensure that the structure after intervention achieves the required level of performance.

In the verification of the serviceability and safety of the structure after intervention, it is assumed that the existing parts and strengthening parts are integrated to resist external forces. A bonding method that ensures sufficient integrity for the structure after intervention should be considered.

The reinforcing materials to be used and the structural properties of the strengthening parts shall be selected so that the structure after intervention sustains the required load-carrying capacity and stiffness.

Specifically, it should be carefully examined whether the weight of the strengthening part is transferred to the existing structure or is borne by the strengthening part itself. It is important to set the stiffness ratio of the existing parts and strengthening parts appropriately and to control the load sharing ratio and resistance mechanism.

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

6 Materials

6.1 General

The materials used for intervention shall be of proven quality.

The quality of the materials used for intervention shall be checked using 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 Clause 6. The properties of the materials in the existing structure subject to intervention can 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 properties and partial safety factors for materials of the existing concrete members shall be determined appropriately considering this fact. Materials not specified herein may be used as long as they fulfil the required performance in accordance with the intent of Clause 6.

6.2 Materials in existing structure

The design values of the materials in the existing structure shall be determined based on the results of inspections.

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 the results of inspections separately from the characteristic values of the material physical properties, those values may be used. In general, however, there are few sample test values from inspections, which make it difficult to identify the distribution of test values. In this case, therefore, an overall judgment of inspections is made to estimate the characteristic values of material physical properties.

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 decrease. 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 is noted that the bond property, fatigue property, elongation characteristics, etc. have altered.

The partial safety factors for materials of the materials in the existing structure shall be determined in accordance with the relevant standard which was applied for the design of existing structure when it was constructed. 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 partial safety factors for materials may be determined appropriately taking into consideration the environmental conditions and other factors.

The characteristic value of the concrete in the existing structure is known from inspections, thus resulting in less uncertainty. By considering this, the partial safety factors for materials can be reduced.

6.3 Materials used in repairing or strengthening parts

6.3.1 General

The quality of the materials used in repairing or strengthening parts can 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 shall be taken into consideration as necessary. Table 1 provides examples of types of materials used for intervention.

Table 1 — Examples of the types of materials used for intervention

Cementitious materials	Reinforcing materials	Filling materials	Bonding products
— Normal-strength concrete — High-strength concrete — Fibre-reinforced mortar/concrete — Plasticized concrete — High-fluidity concrete — Expansive concrete — Polymer hydraulic cement mortar/concrete	— Reinforcing steel — Prestressing steel — FRP reinforcing materials	— Non-shrink grout — Non-shrink mortar — Expansive concrete	— Primer — Adhesive (resin-based, cement-based) — Anchor — Anchor grouting material

6.3.2 Cementitious materials

The quality of cementitious materials can 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 thermophysical 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.

The quality requirements for these cementitious materials vary depending on the type and level of performance required for the repaired or strengthened structure. Currently, the materials used for overlaying, underlaying or jacketing differ depending on the target method, and the materials of the appropriate types and quality are used.

It is necessary that cementitious materials shrink little, attain design strength quickly and have excellent cracking resistance, flexural property and shear property. Also, they shall have excellent fatigue resistance when used with top-surface overlaying or bottom-surface (soffit) underlaying employed to strengthen bridge decks. With bottom-surface (soffit) underlaying, whereby cementitious materials are applied to the bottom surface, these materials shall have particularly excellent bonding strength to ensure integrity with existing concrete members.

Here, the generally used cementitious materials are described, but this is not meant to prevent the use of other materials. In general, with top-surface overlaying, steel fibre-reinforced concrete using high early strength cement, such as very high early strength cement or ultra-rapid hardening cement, is used. With bottom-surface (soffit) underlaying, polymer hydraulic cement 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 with a slump of approximately 18 cm or high-workability concrete with slump flow greater than 550 mm is used, in some cases, together with an expansive additive, which expands upon setting and hardening to reduce shrinkage.

In principle, high-quality cementitious materials shall be selected, and an optimal mix proportion shall be determined by performing trial mixing utilizing an appropriate mixing design method to minimize the change in quality over time after hardening.

When appropriate testing and analysis have confirmed that the compressive strength and other material properties of cementitious materials, which have been created with an appropriate mixing design through the use of materials of proven quality will exhibit almost no change over time, the material properties at the time of strengthening construction may be used as those for the verification.

With the overlaying, underlaying and jacketing methods, since cementitious materials are often placed on the outer surface of the structure, protection or some other appropriate measure is taken to prevent changes in the cementitious materials over time. When changes in the material properties over time can be prevented through appropriate protection, the material properties at the time of strengthening construction shall be used as those for the verification.

6.3.3 Reinforcing materials

The quality of reinforcing materials used together with cementitious 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 thermophysical properties.

Reinforcing materials include reinforcing steel materials, such as reinforcing steel used with cementitious materials and prestressing steel, and bar- or grid-shaped FRP reinforcing materials. They also include steel used to anchor and connect these materials.

The reinforcing steel materials need to fulfil the quality requirements outlined in the relevant standards. The quality of the reinforcing steel materials is 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 shall be checked to confirm that they possess mechanically reliable material properties including strength, strain capacity, Young's modulus and coefficient of linear expansion. The partial safety factors for materials 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.

FRP reinforcing materials, which are made by encasing continuous fibres, such as aramid, glass and carbon, with matrix resin can be used as a substitute for reinforcing steel and prestressing steel. The difference in physical properties of FRP reinforcing materials depending on the type and amount of fibre used, cross-sectional shape and surface condition should be considered.

6.3.4 Filling materials

The filling materials shall have the required fluidity and be able to attach the repairing or strengthening members firmly to the existing concrete members. A test should be conducted in advance to determine the mix proportion and other properties.

If the filling materials are required to transfer stress induced by the weight, live load and other actions of members, they shall have sufficient strength to fulfil the required performance.

6.3.5 Bonding products

As the bonding products used to bond the repairing or strengthening members and existing concrete members, those proven to meet the specified quality and performance requirements shall be selected.

The adhesive is necessary 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. 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 are taken into consideration when selecting the material.

The integrity between the existing concrete members and repairing or strengthening members depends not only on the specifications and quality of the bonding product 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 determined that the specified performance requirements cannot be met, there arises the need to consider restoring the existing concrete members to a sound condition.

The bonding products that ensure integrity throughout the design service life shall be selected through full consideration of the actions to be exerted on the repaired or strengthened structure and bonded parts.

The requirements for the bonding products 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. As for resin-based adhesives, those excelling in energy absorption until the deformation limit show better integrity in a long-term performance than those with higher strength properties. However, it should be considered that their bonding strength and other physical properties vary depending on temperature and its history.

6.4 Characteristic values and design values of materials

6.4.1 General

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 using a specified test method and ensure that the probability of the test values falling below them is at a specified level.

The partial safety factors for materials of the intervention materials shall be determined in accordance with ISO 19338. If the partial safety factors for materials are specified separately for the material to be used, those specified values may be adopted.

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

6.4.2 Cementitious materials

The characteristic values of cementitious materials shall be determined in accordance with ISO 679. As for cementitious materials not covered by ISO 679, their characteristic values shall be determined through appropriate testing.

In intervention construction, cementitious materials whose material properties are vastly different from those of normal-strength concrete can be used from the viewpoints of the bonding with existing concrete, crack suppression property and so on. In such a case, the characteristic values of the cementitious materials shall be determined based on the tests specified in the relevant standards as well as the quality certificates issued by the material manufacturers.

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 hydraulic cement mortar, the characteristic values of the material shall be determined under the temperature condition considering the environment in its service life.

6.4.2.1 Strength

The values of the strength properties of a cementitious 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 tends to be required to go into service quickly and under ambient conditions. 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.

When fibre or polymer is used, the tensile strength and other strength properties of a cementitious 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 fibre 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, the test method is preferable to take their effects into consideration.

6.4.2.2 Fatigue strength

The flexural fatigue strength of fibre-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 fibre. It is therefore desirable to accumulate data on fatigue through testing, obtain the fatigue strength curve (S-N curve) and determine the characteristic value of fatigue strength.

6.4.2.3 Stress-strain curve

An appropriate stress-strain curve for a cementitious 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 cementitious material can be assumed to be linear based on the characteristic value of Young's modulus. As for fibre reinforced concrete, deformation performance in post-peak compressive strength or tensile strength is improved. When investigating deformation, toughness or other property before the ultimate limit state is reached, it is desirable to determine an appropriate stress-strain curve.

6.4.2.4 Fracture energy

The fracture energy of a cementitious material generally increases in proportion to the amount of fibre or polymer used. The fracture energy corresponds to the area below the tension softening curve consisting of the crack width and transferred tensile stress.

6.4.2.5 Young's modulus

Young's modulus of mortar is generally smaller than that of concrete. Also, Young's modulus of a cementitious material that uses polymers tends to be slightly smaller than that of a cementitious material that does not use polymers.

6.4.2.6 Poisson’s ratio

Poisson’s ratio of a cementitious material can be 0,2 within the range of elasticity.

6.4.2.7 Thermophysical properties

The coefficient of linear thermal expansion of a cementitious material that uses polymers tends to be greater than that of a cementitious material that does not use polymers. The coefficient of linear thermal expansion of the generally used polymer hydraulic cement mortar can be $15 \times 10^{-6}/^{o}C$. Also, the coefficient of thermal expansion varies depending on the rock type of aggregate. Thermal conductivity, specific heat and thermal diffusion coefficient shall be determined based on experiments or available previous data.

6.4.2.8 Shrinkage

The characteristic value of shrinkage of a cementitious material can be obtained by conducting a test according to ISO 1920-8. The shrinkage of cementitious materials in the repairing or strengthening members shall 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.

6.4.2.9 Creep

The characteristic value of creep of a cementitious material can be obtained according to ISO 1920-9. 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 cementitious materials in the repairing or strengthening members shall be calculated considering these factors.

6.4.2.10 Carbonation rate

This value can be obtained in accordance with the method specified in the relevant standard.

6.4.2.11 Chloride diffusion coefficient

When a cementitious material uses polymers, the chloride diffusion coefficient tends to be considerably smaller than that of normal-strength concrete. Therefore, the test method shall be selected, taking into consideration such factors as whether the test can be applied or not and the required test period.

6.4.2.12 Relative dynamic modulus of elasticity for the freezing-thawing test

This value can be obtained in accordance with the method specified in the relevant standard.

6.4.3 Reinforcing materials

The characteristic values and design values of steel shall be determined by the relevant ISO standards or domestic standard. As for materials not covered by the ISO standard, their characteristic values and design values shall be determined through appropriate testing.

The characteristic values and design values of FRP reinforcing materials shall be as set forth in ISO 10406-1, ISO 10406-2, ISO 10406-3. As for materials not covered by them, their characteristic values and design values shall be determined through testing.

6.4.4 Bonding products

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

In securing the load-carrying performance required for a composite structure that integrates the repairing or strengthening members and existing concrete members, the bond strength and shear strength obtained when cementitious materials are bonded to the concrete are used as the values of strength properties of the bonding product, instead of its mere material strength.

When the relative displacement, separation and other changes in the repairing or strengthening members and existing concrete members are allowed, the strength and deformation properties of the bonding product itself are be taken into consideration.

7 Actions

7.1 General

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.

A design action shall be determined by multiplying the characteristic value of the action by the partial safety factor for action.

Types of actions considered shall be in accordance with ISO 19338.

In principle, combinations of design actions shall be set with consideration of the relevant standard. In general, the combinations of design actions shall be determined as shown in Table 2.

The characteristic values of actions shall be determined individually concerning the limit states for each performance requirement to be considered.

In principle, the partial safety factor for action by which to multiply the characteristic value of the action to determine the design action shall be chosen in accordance with the relevant standard.

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

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 2 — Combinations of design actions

Required performance	Limit state	Combination to be considered
Durability	All limit states	Permanent action + variable action
Safety	Failure, such as cross section 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

7.2 Actions for intervention design

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

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 the intervention. These actions shall 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 understood to verify environmental actions. The environment of each 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, possibly diffuse from the existing structure to the repairing or strengthening parts. For these reasons, it is necessary to see the environment of the existing structure and appropriately take into consideration the environmental actions after the intervention.

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. When measured values are not available, the partial safety factor used for design actions shown in Table A.2 shall be used.

8 Performance verification for repaired or strengthened structure

8.1 General

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 or each of its structural members during the design service life 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 limit state.

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.

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.

The performance after the intervention is realized jointly by the existing members and repairing or strengthening 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 before 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 loading experiments and other tests by using a modelled specimen. It is important that the results of these experiments take into consideration the differences in the experimental conditions.

The performance verification for the repaired or strengthened structure is performed in accordance with a design standard applied to new structures without intervention when appropriate consideration has been given to the features of the selected intervention method.

The performance verification for the repaired or strengthened structure is be performed in principle taking into consideration the changes in performance over time due to environmental actions and other factors. Clause 8 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 8.3 are met.

The performance verification in Clause 8 can be conducted in accordance with the relevant standard. The available standards are shown in Table A.1.

In general, the performance verification for the repaired or strengthened structure shall be performed using Formula (1).

$$\gamma_i S_d \,/\, R_d \leq 1{,}0 \qquad (1)$$

where

S_d is the design response value;

R_d is the design limit value;

γ_i is the partial safety factor for structure, which is generally set to 1,0 to 1,2.

8.2 Calculation of response values

8.2.1 General

In principle, response value calculation shall involve performing a structural analysis using an analysis model of proven reliability and accuracy, which is obtained by modelling 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.

When the response values are calculated using a non-linear analysis or other advanced analysis methods, it is necessary to ensure a certain level of accuracy.

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 8.3, the response values may be calculated without considering changes over time caused by these actions.

8.2.2 Modelling

The target object and dimension of analysis shall be established, and the actions and structure shall be modelled according to the response properties of the structure deriving from the actions.

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

If an analysis object including ground is established, modelling shall be performed so that the influence of that area and boundary condition are taken into consideration appropriately.

8.2.3 Structural analysis

For structural analysis, a structural analysis method that corresponds to the type of action and structural modelling shall be used to obtain verification indices. If verification indices are not calculated directly from structural analysis, a structural analysis method may be used that enables conversion to verification indices by appropriate means.

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.

Structural analysis for the verification of cross section failure and fatigue failures of the repaired or strengthened structure or for the verification of restorability shall take into consideration the influence of the peeling and flaking of strengthening members from the existing members.

8.2.4 Calculation of response values

Response values shall be calculated by converting the response values obtained as mentioned in 8.2.3 to verification indices using an appropriate method.

For the modelling of the repaired or strengthened structure, there are two methods. One uses fibre-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 the modelling contains uncertainties such as assumption of boundary condition for partial model.

8.3 Durability verification

8.3.1 General

It shall be verified that the repaired or strengthened structure sustains the required durability throughout the design service life. There is the need to check that the integrity of the existing parts and repairing or strengthening parts is guaranteed based on the intervention design.

NOTE The available indices of the bonding strength measured after the history of loads due to environmental actions are given in an accelerating manner as shown in Annex A.

It shall be checked in accordance with design standards for new structures without repair/strengthening that the required performance of the repaired or strengthened structure is not impaired by steel corrosion or cementitious material degradation. If these factors are combined, their influence shall be taken into consideration.

8.3.2 Verification related to steel corrosion

The required performance of the repaired or strengthened structure shall not be impaired by steel corrosion due to carbonation, chloride ion penetration, etc. during the design service life under the given environmental conditions. item a) below shall be verified first and then items b) and c) shall be verified in principle. Appropriate limit values shall be set respectively according to the conditions of the structure.

a) The crack width on the surface shall be less than the limit value of the crack width for steel corrosion. 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 design standards for new structures without repair/strengthening.

b) The corrosion rate due to carbonation and water penetration shall be less than the limit value.

c) 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.

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 many design standards. Making a clear distinction between the existing parts and repairing or strengthening parts needs to be made by the appropriate method, including advanced methods such as one that uses numerical analysis can be used as well. Also, if necessary, consideration is 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 cementitious materials to prevent salt attack, the impact of bonding products on mass transfer resistance at the interface between the existing parts and repairing or strengthening parts (e.g. the cured coating of epoxy resin adhesive exhibits low moisture water and gas permeability) and so on.

8.3.3 Verification related to degradation of cementitious materials

In principle, the verification related to the frost damage to cementitious materials shall be performed in two separate stages of a) verification of internal damage and b) verification of surface damage (scaling).

a) Verification of internal damage: if degradation occurs in the cementitious 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 cementitious materials observed in the freezing-thawing test is 90 % or more.

b) Verification of surface damage: if frost damage is sustained by the cementitious materials on the surface of the repaired or strengthened structure, a verification of surface damage (scaling) shall be performed.

The characteristic value of the relative dynamic modulus of elasticity of the cementitious materials shall be determined based on that specified in Method A (in-water freeze-thaw test method) of ISO 13823. It is generally said that Method A uses stricter conditions than those of Method B (test for freezing in air and thawing in water). At present, to evaluate the resistance of cementitious materials to surface damage (scaling), different methods shall be employed (see an example in A.3 of Annex A).

The verification related to chemical attack shall be performed.

8.4 Safety verification

8.4.1 General

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

8.4.2 Verification related to failure

8.4.2.1 General

There is 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 separately considered in their respective states.

The verification of the performance of members repaired or strengthened in accordance with ISO 16311-1, ISO 16311-2, ISO 16311-3, ISO 16311-4 and relevant standard shall involve verifying the integrity of the existing members and repairing or strengthening members. Such verification may be omitted in the case of an intervention method proven to guarantee integrity by conforming to the specified structural details, materials used and construction methods.

The safety verification shall be performed by checking that none of the structural members reaches the limit state of failure under design actions.

8.4.2.2 Verification related to bending moment and axial force

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

When the design 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, ISO 16311-3 and relevant design standards shall apply. 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 repairing or strengthening members shall be taken into consideration appropriately. This verification assumes that the integrity of the existing members and repairing or strengthening members are guaranteed. The stress-strain curve of concrete and steel shall be determined in accordance with ISO 16311-3 and relevant design standards. The stress-strain curve of FRP reinforcing materials shall be determined in accordance with ISO 10406-1 ISO 10406-2, ISO 10406-3. As for overlaying, underlaying and jacketing materials, an appropriate stress-strain curve for each intervention method shall be used in principle.

8.4.2.3 Verification related to shear force

The safety verification related to the shear force of the repaired or strengthened members shall be performed taking into consideration the type of member (e.g. beam, slab), boundary conditions of members, the application states of loads, the direction of action of shear force and so forth. This verification assumes that the integrity of the existing members and overlaying, underlaying or jacketing members are guaranteed.

For beams and columns, a shear capacity calculation method appropriate for the load-carrying mechanism taking into consideration the boundary conditions of members and the application states of loads shall be used. The effect of the repairing or strengthening members can be added to the shear capacity borne by the repairing or strengthening members using a calculation method proven through experiments or by other means.

Since the behaviour 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 shall be performed by means of a method that considers these factors. Also, among the failure mechanisms unique to the repaired or strengthened structure is the peeling failure of the repairing or strengthening member from existing member, which makes it necessary to perform the verification set forth in 8.4.2.4 as well.

For plane 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 shall be calculated with appropriate consideration given to the effect of reinforcing materials.

8.4.2.4 Verification related to the integrity of overlaying, underlaying or jacketing members

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

8.4.3 Verification related to fatigue failure

The verification of fatigue safety shall check flexural strength and shear capacity for beams and flexural strength and punching shear capacity for plane members. In general, the performance verification for columns can be omitted.

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.

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

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 shall be estimated through experiments or by other appropriate means.

8.5 Serviceability verification

8.5.1 General

It shall be verified that the repaired or strengthened structure sustains the required serviceability throughout the design service life.

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 ISO 16311-3 and relevant design standards.

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

8.5.2 Stress level limit

To prevent excessive deformation or harmful cracking from occurring while the repaired or strengthened structure is in service, care shall be taken 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 in terms of serviceability. As the limit value of the stress level when the repaired or strengthened structure or members are in service, what is specified in ISO 19338 and relevant design standards can be referred.

8.5.3 Verification related to appearance

The appearance verification of the repaired or strengthened structure shall use crack width and displacement or deformation as verification indices and check that the calculated values resulting from loads and environmental actions satisfy the design limit values determined from serviceability.

The crack width on the surface of the repaired or strengthened structure can be calculated in accordance with ISO 19338 and relevant design standards, assuming that the integrity of the existing parts and repairing or strengthening parts are guaranteed. The limit value for the crack width relating to appearance shall be established according to how frequently the surface of the structure is seen by users, the psychological impact on users and so on.

The displacement or deformation of the repaired or strengthened structure can be calculated in accordance with ISO 19338 and relevant design standards, assuming that the integrity of the existing parts and repairing or strengthening parts are guaranteed.

8.5.4 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 ISO 19338 and relevant design standards, assuming that the integrity of the existing parts and repairing or strengthening parts is guaranteed.

8.5.5 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 ISO 19338 and relevant design standards, assuming that the integrity of the existing parts and repairing or strengthening parts is guaranteed. As the verification, water and gas permeability shall be used in principle.

8.6 Restorability verification

8.6.1 General

The seismic performance that the repaired or strengthened structure shall possess shall be determined by considering it comprehensively from the viewpoints of safety, serviceability and restorability against seismic actions in accordance with ISO 19338. Note that this verification assumes that the integrity of the existing members and overlaying, underlaying or jacketing members is guaranteed and that the preconditions for the verification mentioned in 8.6.2 are met strictly.

8.6.2 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.

8.7 Structural details

The fundamental structural concept necessary for the design of reinforced concrete structures shall be established in accordance with ISO 16311-3 and relevant design standards.

9 Execution

9.1 General

The construction for intervention shall 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 fulfils the required performance.

The construction for intervention shall be conducted in accordance with ISO 16311-4:2014, Clauses 7, 8 and 9.

9.2 Construction plan

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

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.

9.3 Construction

Cementitious materials shall be handled appropriately with care taken about the construction conditions and environment.

Construction shall be performed appropriately so that the existing concrete and repairing or strengthening parts are integrated to form a composite structure.

Cementitious materials shall be applied appropriately with care taken about the construction conditions and environment in accordance with ISO 22966.

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

9.4 Inspection

A structure repaired or strengthened with cementitious materials shall be inspected according to an inspection plan as set forth in ISO 22966.

10 Records

Basically, the records on intervention-related investigations, diagnoses, designs, performance verifications, intervention, materials used, etc. shall be as set forth in ISO 16311-4. Particularly, the