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Structural intervention of existing concrete structures using cementitious materials —

Part 3: Bottom-surface (soffit) underlaying

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

Partie 3: Recouvrement de la surface inférieure (soffite)

Reference number
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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 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 way. For the first way, the cementitious layer is attached either on 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 cementitious layer. The ISO 5091 series serves as the first ISO standard for the intervention by attaching 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.

Generally, polymer hydraulic cement mortar (PCM) is used as the underlaying material. This is because PCM bonds well with the existing members and has large tensile strain at cracking, and makes the penetration of degradation factors less likely. As reinforcing materials, reinforcing steel, welded wire mesh, FRP grid are used.

Bottom-surface (soffit) underlaying has evolved as a strengthening method for fatigue of RC decks. drawing attention because of examples of applications like the one shown in Figure 1. The members that are currently repaired or strengthened using this method include RC decks, tunnel linings, box culverts, waterways and beams. In this document, the latest information about the design and construction of the bottom-surface (soffit) underlaying method using underlaying materials has been collected and the best possible standards are presented.

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 3:
Bottom-surface (soffit) underlaying

1 Scope

This document specifies the standards for design and construction using the bottom-surface (soffit) underlaying method. Bottom-surface (soffit) underlaying is a method whereby reinforcing materials are placed on the bottom surface of the slabs or beams whose performance is lower than required and the improvement of durability, serviceability, safety and other performance of the members is achieved by the integrity between the reinforcing materials and existing members.

This document specifies structural intervention of existing concrete structures using cementitious materials design and execution principles, and strategies for defects and on-going deterioration including, but not limited to:

a) mechanical actions, e.g. fatigue, impact, overloading, movement caused by settlement, blast, vibration, and seismic actions;

b) chemical and biological actions from environments, e.g. sulfate attack, alkali-aggregate reaction;

c) physical actions, e.g. freeze–thaw, thermal cracking, moisture movement, salt crystallization, fire, and erosion;

d) reinforcement corrosion;

e) original construction defects that remained unaddressed from the time of construction.

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 5091-1:2023, *Structural intervention of existing concrete structures using cementitious materials — Part 1: General principles*

ISO 22966, *Execution of concrete structures*

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
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.

3.2
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.

3.3
filling material
material injected to fill the gap between a reinforcing material, such as intermediate penetrating tie, and concrete

3.4
filling property
degree of filling of cracks and adhesion of crack filling material to substrate

3.5
reinforcing material
steel or FRP material used to sustain, restore or improve the mechanical performance of a structure

3.6
polymer hydraulic cement mortar
hydraulic composition made cementitious materials and fine aggregate modified by the addition of a polymer

3.7
FRP grid
resin-impregnated FRP reinforcing materials formed into a grid shape

3.8
design response value
value of structural response obtained by numerical analysis on design process, such as sectional force and deformation

3.9
design limit value
design value for quantified limit state on design process, such as strength of element, allowable crack width

3.10
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 study of the existing structure for which to consider intervention using the bottom-surface (soffit) underlaying method shall be as set forth in ISO 5091-1:2023, Clause 4.

4.2 Investigation

4.2.1 Investigation using documents, records

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 ISO 5091-1:2023, 4.2.1.

4.2.2 On-site investigation

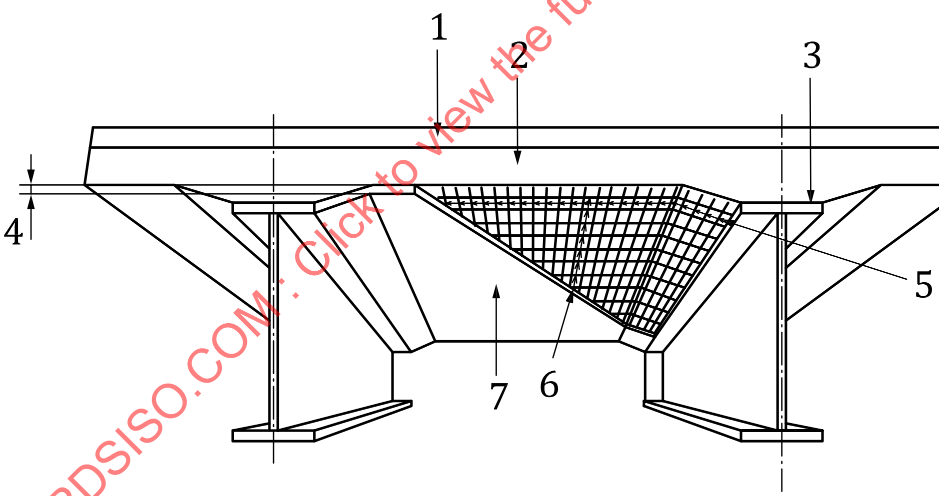
The on-site study on degradation, damage and initial defects of the existing concrete structure shall be conducted in accordance with ISO 5091-1:2023, 4.2.2.

The work environment and other relevant conditions of the site shall be checked in advance.

5 Intervention design

5.1 General

When repairing or strengthening a concrete structure using bottom-surface (soffit) underlaying as shown in Figure 1, it shall be verified by means of an appropriate method that the structure fulfils the required performance for the required period. Also, the environment for the intervention construction, constructability, post-intervention maintainability and economy shall be taken into consideration.



Key

1 pavement
2 RC deck
3 main girder
4 underlaying
5 distribution reinforcement
6 main reinforcement
7 bottom-surface (soffit) underlaying

Figure 1 — Example of application of bottom-surface (soffit) underlaying for deck strengthening

5.2 Structural plan

The structural plan for a structure repaired or strengthened with bottom-surface (soffit) underlaying shall be as set forth in ISO 5091-1:2023, 5.2. The repaired or strengthened structure shall fulfil the required levels of durability, safety, serviceability and restorability throughout the design service life. Also, the intervention shall be planned taking into consideration the causes of degradation and damage of the existing members subject to bottom-surface (soffit) underlaying.

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.

5.3 Structural details

The structure of bottom-surface (soffit) underlaying shall ensure the integrity between the existing and underlaying parts in the repaired or strengthened members to avoid brittle failure.

The structure of bottom-surface (soffit) underlaying shall ensure that reinforcing materials are securely anchored to the existing parts to reduce the risk of peeling.

The structure of bottom-surface (soffit) underlaying shall prevent retention of water in the interface between the existing and underlaying parts to avoid degradation of the interface or a decrease in adhesion.

The reinforcing materials used for bottom-surface (soffit) underlaying shall have a certain level of tensile stiffness that allows the reinforcing materials to behave with the existing parts as one. The reinforcing materials used for bottom-surface (soffit) underlaying shall not have excessive tensile stiffness against the existing parts.

If the tensile stiffness of the reinforcing materials is excessive, care shall be taken because the forces transferred through the interface between the existing and underlaying parts as well as the anchoring parts of the reinforcing materials become great, potentially leading to peeling or some other problem.

6 Materials

6.1 General

The materials used for bottom-surface (soffit) underlaying shall be of proven quality to ensure that the required performance is fulfilled for a necessary period.

6.2 Materials in existing structure

The characteristic values of material strength, partial safety factor for materials and design values of the materials in the existing structure that are used for the design shall be determined in accordance with ISO 5091-1:2023, 6.2.

6.3 Materials used in repairing or strengthening parts

6.3.1 General

The quality of the materials used in the parts repaired or strengthened with bottom-surface (soffit) underlaying shall be as set forth in ISO 5091-1:2023, 6.3.

6.3.2 Cementitious materials

The underlaying materials used for bottom-surface (soffit) underlaying shall have a bonding property and durability sufficient to integrate the existing parts with added 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.

The underlaying materials shall have performance equal to or greater than the resistance against permeation of the existing members against environmental factors.

6.3.3 Reinforcing materials

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

6.3.4 Bonding products

The bonding products used in the interface between the existing and underlaying parts shall ensure the specified bonding property.

The bonding products shall prevent the degradation in the bonding property of the underlaying and existing parts. The bonding products shall be those proven to be compatible with the materials used in both the underlaying and existing parts and have sufficient durability.

6.4 Characteristic values and design values of materials for repaired or strengthened parts

6.4.1 General

The characteristic values and design values of the materials used for bottom-surface (soffit) underlaying shall be as set forth in ISO 5091-1:2023, 6.4.

6.4.2 Cementitious materials

The cementitious materials used for bottom-surface (soffit) underlaying shall be as set forth in ISO 5091-1:2023, 6.4.2. The characteristic values of strength and other properties need to be determined under the temperature condition appropriate for the usage environment.

6.4.3 Reinforcing materials

The reinforcing materials used for bottom-surface (soffit) underlaying shall be as set forth in ISO 5091-1:2023, 6.4.3.

6.4.4 Bonding products

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

7 Actions

7.1 General

The actions used for performance verification of intervention using the bottom-surface (soffit) underlaying method shall be as set forth in ISO 5091-1:2023, Clause 7.

7.2 Actions for intervention design

In the intervention design, the actions that can occur on the existing structure and repaired or strengthened parts shall be considered in accordance with ISO 5091-1:2023, 7.2.

8 Performance verification for repaired or strengthened structure

8.1 General

The items to be verified for the concrete members repaired or strengthened with bottom-surface (soffit) underlaying shall be established appropriately so as to fulfil the required performance of the repaired or strengthened structure.

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

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 shall therefore be taken into consideration appropriately.

8.2 Calculation of response values

8.2.1 General

The response values of a structure repaired or strengthened with bottom-surface (soffit) underlaying shall be calculated as set forth in ISO 5091-1:2023, 8.2.

8.2.2 Modelling of structure

A member repaired or strengthened with bottom-surface (soffit) underlaying may be modelled as a beam or slab according to the shape and action direction through the use of finite element modelling or modelling with linear element.

When an out-of-plain force acts on a slab repaired or strengthened with bottom-surface (soffit) underlaying, 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.

In the case of finite element modelling, the constitutive law for the existing members take into consideration the changes in the existing members. For the interface between the existing and underlaying parts, an appropriate constitutive law shall be adopted according to the materials used.

In the case of modelling with structural stick model of beam and column elements s, in principle, the skeleton curve shall be obtained using a fibre model or one proven through experiments or other means shall be employed.

Since a member repaired or strengthened with bottom-surface (soffit) underlaying has a combination of different material properties, such as existing reinforcing steel and reinforcing material or existing concrete and underlaying material, the skeleton curve used for modelling with structural stick model of beam and column elements should be obtained using a fibre model or through experiments.

8.2.3 Structural analysis

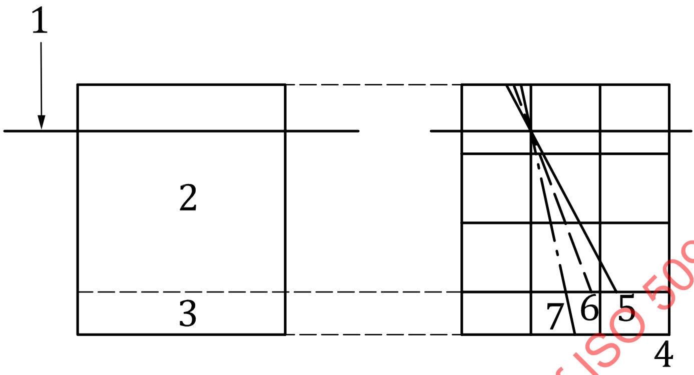
The structural analysis of a structure repaired or strengthened with bottom-surface (soffit) underlaying shall be performed as set forth in ISO 5091-1:2023, 8.2.3.

8.2.4 Calculation of design response values

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

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 totalled.

NOTE Figure 2 shows an example in which the existing stress of the existing members is calculated using a fibre model. The responses to the loads acting on the strengthened members are calculated considering the obtained strain as the residual strain.



Key

1 neutral axis

2 existing part

3 underlaying part

4 strain

5 response to preload

6 response to post-load

7 response after integration

Figure 2 — Strain when used after strengthening

The flexural crack width of a member repaired or strengthened with bottom-surface (soffit) underlaying may be calculated using Formula (1). A.2 may be used for evaluating the crack spacing in the underlaying part surface.

$$w = S_{sf} \cdot (\varepsilon_s - \varepsilon_c) \quad (1)$$

where

w is the crack width (mm);

S_{sf} is the crack spacing (mm);

μ_s is the average strain of reinforcing material between cracks;

μ_c is the average strain between cracks on underlaying part surface.

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

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

b) The influence of the crack widths resulting from underlaying material shrinkage, creep, etc. shall be taken into consideration.

8.3 Durability verification

The durability of a structure repaired or strengthened with bottom-surface (soffit) underlaying shall be verified as set forth in ISO 5091-1:2023, 8.3.

8.4 Safety verification

8.4.1 General

The safety of a member repaired or strengthened with bottom-surface (soffit) underlaying shall be verified as set forth in ISO 5091-1:2023, 8.4.

8.4.2 Verification related to failure

8.4.2.1 General

The verification related to failure shall be generally performed with respect to axial force, bending moment, shear force and torsion.

When calculating the design strength, it shall be checked that the integrity between the existing and underlaying parts is ensured.

8.4.2.2 Verification related to bending moment and axial force

When subject to bending moment and axial force, the design capacity after the intervention can be calculated in accordance with ISO 5091-1:2023, 8.4.1.2.

It shall be checked that the underlaying parts do not peel off near the cross-section under study when the design load is acting. A.2 may be used for checking the peeling failure of the underlaying parts.

8.4.2.3 Verification related to shear force

a) The safety verification related to the shear force 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.

b) The design shear capacity of beams and the design punching shear capacity of slabs that are borne by concrete may be calculated taking into account the effect of the anchored reinforcing materials placed in the underlaying parts. A.3 may be used for checking the design shear capacity of beams and the design punching shear capacity of slabs strengthened with bottom surface (soffit) underlaying.

If the reinforcing materials of the underlaying parts are not anchored at the edges, it shall be checked that the peeling of the underlaying 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. A.4 may be used for checking the peeling failure of the underlaying parts or the splitting cracking of the covering concrete of the existing parts.

8.4.2.4 Verification related to torsional moment

If the action of torsional moment is not negligible, a safety study shall be performed by means of an appropriate method.

8.4.3 Verification related to fatigue failure

The safety verification related to fatigue failure shall check flexural strength and shear capacity for beams and flexural strength and punching shear capacity for slabs.

The safety verification related to fatigue peeling failure of underlaying materials shall be considered by means of an appropriate method. A.5 may be used for checking the fatigue peeling failure of the underlaying materials.

The verification related to fatigue failure shall be performed by conducting numerical analyses, experiments and the other appropriate method to take into consideration the changes in responses due to the movement of loads, when the influence of the movement of loads is not negligible. A.6 may be used for checking the fatigue failure due to the movement of loads in the strengthened members.

8.5 Serviceability verification

8.5.1 General

The serviceability of a member repaired or strengthened with bottom-surface (soffit) underlaying shall be verified as set forth in ISO 5091-1:2023, 8.5.

8.5.2 Verification related to appearance

The verification related to appearance shall be performed taking into consideration how frequently the underlaying bottom surface is seen by users and the levels of uneasiness and unpleasantness that cracks, dirt and other appearance problems give to users.

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 general, cracks that occur in a structure repaired or strengthened with bottom-surface (soffit) underlaying are much smaller than 0,2 mm in width, and the verification related to the crack width may be omitted.

8.5.3 Verification related to displacement and deformation

When the purpose of bottom-surface (soffit) underlaying is to increase the stiffness of members, the verification shall be performed using displacement and deformation as indices to check that the requirements for use are met.

While bottom-surface (soffit) underlaying 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 stiffness. For example, in order to check that the functional performance requirements regarding trafficability, which is the performance to provide a comfortable ride quality, and walkability, which is the performance to provide a comfortable walking experience, of bridges and other structures are met, it is advisable to establish appropriate limit values for deflection and bend angle of the members strengthened with bottom-surface (soffit) underlaying.

8.6 Restorability verification

The restorability of a member repaired or strengthened with bottom-surface (soffit) underlaying shall be verified as set forth in ISO 5091-1:2023, 8.6.

8.7 Structural details

8.7.1 Thickness of bottom-surface (soffit) underlaying parts

The thickness of the bottom-surface (soffit) underlaying parts shall be determined taking into consideration the surface treatment and surface unevenness adjustment of existing members, placement error of reinforcing materials, influence of covering thickness construction error and integrity. An example of the construction section observed when bottom-surface (soffit) underlaying is applied to bridge decks and shown in Annex A.

8.7.2 Cover

The covering thickness for bottom-surface (soffit) underlaying shall be equal to or greater than the value that ensures the mechanical performance and durability required for the intervention using the bottom-surface (soffit) underlaying method.

8.7.3 Space between reinforcing materials

The space between reinforcing materials shall be determined taking into consideration the filling property of underlaying materials.

NOTE 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.

8.7.4 Joints for reinforcing materials

When the reinforcing materials used in the underlaying parts have joints, it shall be ensured that stress is transferred at the joint part without failure of the joint part.

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 relevant standard specifications in each country.

8.7.5 Anchoring and securing methods of reinforcing materials

Reinforcing materials shall be anchored to the underlaying or existing parts to integrate the materials with the parts.

Reinforcing materials shall be secured so that they sustain durability both during and after construction and are not subject to deformation or vibration.

9 Construction

9.1 General

The construction for intervention with bottom-surface (soffit) underlaying shall be in principle performed in accordance with the provisions set forth in ISO 5091-1:2023, Clause 9 as well as in this clause. Bottom-surface (soffit) underlaying shall be in principle performed by applying underlaying materials through either spraying or trowelling, and there are two spraying methods: wet spraying and dry spraying. An example of the construction procedure for bottom-surface (soffit) underlaying is shown in Annex A.

Engineers with sufficient knowledge and experience in the construction for bottom-surface (soffit) underlaying shall be assigned to the site and the construction work shall be performed under the direction of those engineers.

NOTE Particularly, the construction technique for spraying underlaying materials is important for ensuring quality in bottom-surface (soffit) underlaying. It is desirable to assign engineers qualified through spraying managing engineer qualification systems run by relevant organizations or qualified spraying technicians.

9.2 Prior investigation and construction plan

A prior investigation shall be conducted before construction to grasp the condition of the existing structure to be repaired or strengthened with bottom-surface (soffit) underlaying.

It is also required to grasp the status of cracking in the existing members, whether free lime and rust staining are present or not, the corrosion status of reinforcing steel and the level of damage such as concrete flaking 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 (soffit) underlaying method. Water leaks and running water not only reduce the durability of the concrete structure substantially but are likely to cause re-degradation after the intervention. If there is any water leak or running water, therefore, it is necessary to consider installing water stop and drainage facilities and drip inducer as well.

An appropriate construction plan shall be formulated, and a construction plan document shall be created, taking into consideration the construction and environmental conditions, to construct the repaired or strengthened concrete structure shown in design documents.

When formulating a construction plan, care shall be taken to ensure:

— a reasonable process plan is created taking into consideration the time zones during which work can be done;

— a sufficient workspace is secured;

— the necessary amounts of materials of proven quality are procured;

— constructing parties with necessary skills and sufficient experience are assigned.

Also, to perform construction safely, care shall be taken to ensure:

— measures to provide safety for constructing parties are specified;

— measures to provide safety for third parties are specified;

— measures to prevent the destruction of additive and other related facilities;

— a system is in place to respond to accidents swiftly;

— a waste disposal method is specified.

Formulating the construction plan shall involve considering the actual work methods and the management methods to ensure the implementation of those methods.

The construction procedure for bottom-surface (soffit) underlaying roughly consists of the processes mentioned below. When formulating a construction plan, the actual work methods and management methods in the individual work processes shall be clearly defined.

a) Surface treatment

b) Assembly of reinforcing materials

c) Surface preparation

d) Storage, mixing and transportation of underlaying materials

e) Execution of underlaying

f) Curing

Also, considering the restrictions such as the work environment of the construction site and work time, a quality control method shall 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 shall 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 shall be changed accordingly.

9.3 Surface treatment

In base coating, dirt such as oil and grease on the surface of the existing members and vulnerable layers shall be removed so that the parts repaired or strengthened with bottom-surface (soffit) underlaying and existing members are integrated. Also, harmful cracks, flaking, peeling and water leaks shall be treated appropriately.

If the surface of the existing members has construction defects such as honeycombs, noticeable degradation, cracks, water leaks, etc., the existing members shall be repaired using an appropriate method such as patching repair, crack injection or water leak prevention.

9.4 Assembly of reinforcing materials

The reinforcing materials used for bottom-surface (soffit) underlaying shall be placed at the specified positions precisely.

Reinforcing materials shall 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 shall be assembled correctly at the positions specified in design documents.

Reinforcing materials shall 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 shall be assembled correctly at the positions specified in design documents.

If epoxy-coated reinforcing steel bars are used in a saline environment due care shall be taken so that the epoxy coating is not damaged during assembly.

The reinforcing materials used for bottom-surface (soffit) underlaying shall be securely anchored to existing members using concrete anchors or the like. The reinforcing materials used for bottom-surface (soffit) underlaying 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 underlaying.

The positions of the joints of reinforcing materials and the jointing method shall be in principle as specified in design documents. To joint reinforcing materials, an appropriate method shall be selected according to the type of reinforcing material, cross-sectional dimensions, 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 shall be in principle as specified in design documents.

9.5 Surface preparation

For the work of surface preparation, bonding products appropriate for the underlaying materials used shall be selected.

9.6 Storage, mixing and transportation of underlaying materials

Underlaying materials shall be stored properly.

Underlaying 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.

For the transportation of underlaying materials, a method shall be selected that ensures the capability of transportation for required amount of materials with the required level of quality. For the transportation of underlaying materials, the pump capacity, pipe diameter and length and spraying equipment appropriate for the bottom-surface (soffit) underlaying method and the selected underlaying materials shall be selected.

9.7 Execution of underlaying

Underlaying materials shall be applied using the method determined for each material.

For those materials which are applied to underlaying, the following requirements shall be met.

If the spray thickness is large, the underlaying material shall be divided into an appropriate number of layers according to the thickness when sprayed.

NOTE The allowable spray thickness per layer differs depending on the type of spraying method and the spraying direction. In general, when the underlaying 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.

When the spray surface is finished, the underlaying material shall be sprayed up to the finished surface and the surface shall be smoothed with a metal trowel.

During construction, temperature management shall be accomplished using a thermometer installed at the construction site. Before performing construction work, the average daytime temperature shall be checked. If the temperature is outside acceptable ranges, construction shall be performed in accordance with ISO 22966.

9.8 Curing

The underlaying materials applied with bottom-surface (soffit) underlaying shall be cured such that they are not subject to sudden temperature changes, drying or other detrimental action, such as vibration and deformation until they achieve the specified strength.

A sudden change in temperature after the application of the underlaying 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 drying shrinkage. It is therefore necessary to exercise due care to prevent cracking from occurring at places where the underlaying materials have been applied and, if necessary, to employ an appropriate curing technique such as mist curing or film curing.

9.9 Quality control

Quality control shall be implemented for specified items in each phase of construction so as to check that the structure constructed and strengthened with bottom-surface (soffit) underlaying has the required level of quality. Quality control that shall be implemented are as follows.

a) Quality control of reinforcing materials

b) Mixing management

c) Mix proportion management

d) Strength management

9.10 Inspection

A structure constructed with bottom-surface (soffit) underlaying shall be in principle inspected according to an inspection plan under the responsibility of the ordering party of the structure. The inspection shall be performed by means of an appropriate method.

It is desirable to conduct destructive tests such as a bond strength test and non-destructive tests using the impact echo method, tapping sound, etc. as inspections for the repaired or strengthened structure to check for gaps and other anomalies between the existing and underlaying members.

10 Records

Information concerning the intervention of a structure shall be recorded by means of an appropriate method and retained for a necessary period. The method of recording shall be as set forth in ISO 5091-1:2023, Clause 10.

11 Maintenance

The maintenance of a structure repaired or strengthened with bottom-surface (soffit) underlaying shall be as set forth in ISO 5091-1:2023, Clause 11.

There have been reports of cases of peeling or re-degradation of the underlaying and existing parts in the decks repaired or strengthened with bottom-surface (soffit) underlaying. The possible causes of peeling include cracking due to abnormal shrinkage of the underlaying parts and the impact of water intrusion from the top surface of the existing structure. Particularly, if there is water entering after completion, there is a concern of early degradation occurring on the bonding interface and, therefore, it is desirable to drain the water promptly. Therefore, maintenance needs to be performed to prevent re-degradation, taking into consideration the post-intervention environment and the condition of the structure.

Annex A
(informative)

Examples of design and execution procedure

A.1 Example of the arrangement of reinforcing materials

The average crack spacing on the underlaying part surface is estimated by Formula (A.1). An explanation of the symbols is provided in Figure A.1.

$$S_{sf} = k_1 \cdot min(S_{cs}, S_{os}) \tag{A.1}$$

where

$$k_1 = \frac{h_b + h_u}{2 \cdot h_b}$$

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

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

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

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

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

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

$$h_{ott} = t$$

$$\tau_{bc(o)m} = 5{,}5 \cdot \left(\frac{f'_{c(o)}}{20} \right)^{0{,}25}$$

k_1 is the coefficient for considering strain distribution;

S_{cs}, S_{os} is the assumed spacing of cracks that occur in the existing part and underlaying part respectively (mm);

A_{ct}, A_{ot} is the cross-sectional area of the cementitious material that affects the tension stiffness of the existing part and underlaying part (mm^2);

τ_{bcm}, τ_{bom} is the bond strength of the cementitious material of the existing part and underlaying part against the reinforcing material (N/mm^2);

t is the thickness of the underlaying part (mm);

x_{gc} is the distance from the extreme compression fibre to the neutral axis (mm);

h_b is the distance from the neutral axis to the underlaying bottom surface (mm);

h_u is the distance from the neutral axis to the upper edge that affects the tension stiffness of the existing member (mm);

f_{ct}, f_{ot} is the tensile strength of the cementitious material of the existing part and underlaying part (N/mm^2);

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

E_c, E_o is the Young's modulus of the cementitious material of the existing part and underlaying part (N/mm^2);

O_c, O_o is the perimeter of the reinforcing material of the existing part and underlaying part (mm);

f_c', f_o' is the compressive strength of the cementitious material of the existing part and underlaying part (N/mm^2);

Generally, the design compressive strength $f_{c(o)d}'$ can be used.

$h_{c(o)max}$ is the maximum height of the effective tension zone of the cementitious material of the existing part and underlaying part (mm);

$h_{c(o)tc}$ is the height of the effective tension zone taking into consideration the restrictions on the covering of the existing part and underlaying part (mm);

$h_{c(o)tt}$ is the height of the maximum tension zone of the existing part and underlaying part (mm);

$A_{sc(o)}$ is the cross-sectional area of the reinforcing material of the existing part and underlaying part (mm^2);

$f_{vc(o)}$ is the yield strength of the reinforcing material of the existing part and underlaying part (N/mm^2);

Generally, $f_y = \rho_m \cdot f_{yd}$, $\rho_m = 1{,}2$.

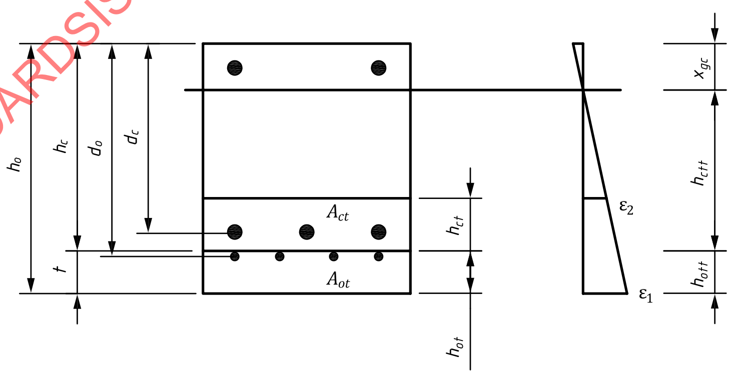


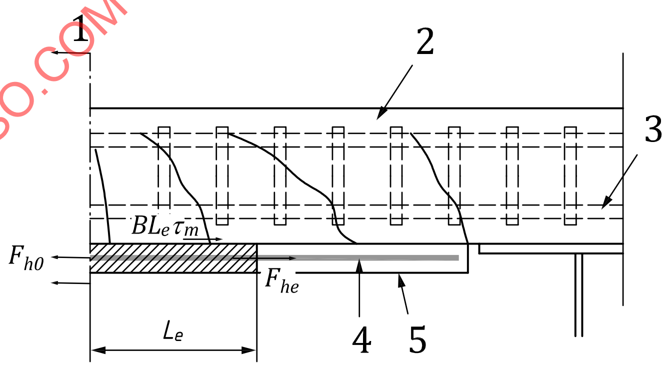
Figure A.1 — Explanation of symbols

When applying Formula (A.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 underlaying method. When no loads are acting at the time of strengthening, Formula (A.1) can be applied as is. If there is any load acting at the time of strengthening, however, it is necessary to replace the strengths of the existing part and underlaying part with the values obtained by subtracting the stress applied by the load to the existing part and underlaying part from the respective strengths, as well as to replace the bond strengths, of the existing part and underlaying part with the values obtained by subtracting the bond stress applied by the load from the respective bond 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 formula can be calculated in the same way as when there are no cracks at the time of strengthening with the underlaying method. Formula (A.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 underlaying method. While the theoretical contents of this formula are also applicable under other conditions, it is necessary to further examine the applicability of the formula 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 needs to be used for cracks in the existing part and the average strain of the reinforcing material of the underlaying part needs to be used for cracks in the underlaying 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 underlaying 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 underlaying parts, the material properties of the reinforcing materials of the existing and underlaying parts and the bonding property between the reinforcing materials and the surrounding concrete or underlaying materials. For simplicity, the strain of the reinforcing materials can 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 underlaying materials. The influence of the existing concrete or underlaying materials shrinking due to drying, autogenous shrinkage or for some other reason needs to be taken into consideration when calculating the crack width of an ordinary concrete structure.

A.2 Evaluation method for peeling failure

When studying the peeling failure of the underlaying parts that occurs near the middle part of the span (see Figure A.2), it needs to be checked using Formula (A.2) that the shear bond stress level of the interface of the underlaying parts is below the shear bond strength.



Key

1 cross section under study (maximum bending moment position)

2 existing member

3 existing tensile reinforcement

4 reinforcement

5 underlaying material

Figure A.2 — Peeling of underlaying material near the middle part of the span

$$\gamma_i \frac{\bar{\tau}_m}{\tau_{mud}} \leq 1{,}0 \tag{A.2}$$

where:

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

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

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

$\bar{\tau}_m$ is the design shear bond stress of the underlaying part interface (N/mm^2);

F_{h0} is the tensile force of reinforcing material of the cross-section under study (N);

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

n is the number of reinforcing materials;

A_r is the cross-sectional area per reinforcing material (mm^2);

σ_{r0} is the stress of reinforcing material at the cross-section under study (maximum bending moment position) (N/mm^2);

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

B is the effective width of the member (unit width or girder width of the girder-like deck in the principal direction) (mm);

L_e is the effective bond length that may be used as the crack spacing (mm);

It can be set to 150 mm if the crack spacing exceeds 150 mm.

τ_{mud} is the design shear bond strength of the underlaying 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 can be considered that $\tau_{mud} = 2{,}6\,\sigma_{mud}$.

σ_{mud} is the design tensile bond strength of the underlaying part interface determined through direct tensile testing (N/mm^2);

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

A.3 Evaluation method for the design shear capacity of beams and the design punching shear capacity of slabs

A.3.1 Shear capacity of beams

The design shear capacity of beams without shear reinforcing materials can be calculated using Formula (A.3):

$$V_{cd} = \beta_{dr} \cdot \beta_{pr} \cdot \beta_n \cdot f_{vcd} \cdot b_w \cdot d_r / \gamma_b \tag{A.3}$$

where

$f_{vcd} = 0{,}20\sqrt[3]{f'_{cd}}$ (N/mm^2) but $f_{vcd} \leq 0{,}72$ (N/mm^2);

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

$\beta_{dr} = \sqrt[4]{1\,000 / d_r}$ but when β_{dr} > 1,5, it needs to be set to 1,5;

$\beta_{pr} = \sqrt[3]{100 p_{wr}}$ but when β_{pr} > 1,5, it needs to be set to 1,5;

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

$d_r = \dfrac{E_{s1}A_{s1}d_1 + E_{s2}A_{s2}d_2}{E_{s1}A_{s1} + E_{s2}A_{s2}}$: converted effective height;

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

N'_d is the design axial compressive force;

M_{ud} is the design flexural load-carrying capacity when not considering the axial force;

M_0 is the 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} is the cross-sectional area of the tension reinforcing material of the existing beam (mm^2);

A_{s2} is the cross-sectional area of the tension reinforcing material of the underlaying part (mm^2);

d_1 is the distance from the upper edge to the centroid of the tension reinforcing material of the existing beam (mm);

d_2 is the distance from the upper edge to the centroid of the tension reinforcing material of the underlaying part (mm);

E_{s1} is the modulus of elasticity of the tension reinforcing material of the existing beam (N/mm^2);

E_{s2} is the modulus of elasticity of the tension reinforcing material of the underlaying part (N/mm^2);

b_w is the web width (mm);

γ_b is the partial safety factor for member, which is generally set to 1,3.

A.3.2 Shear capacity of slabs

The punching shear capacity of slabs strengthened with bottom-surface (soffit) underlaying was proposed to associate the fatigue capacity of RC decks with the punching shear capacity of the existing decks and strengthened decks.

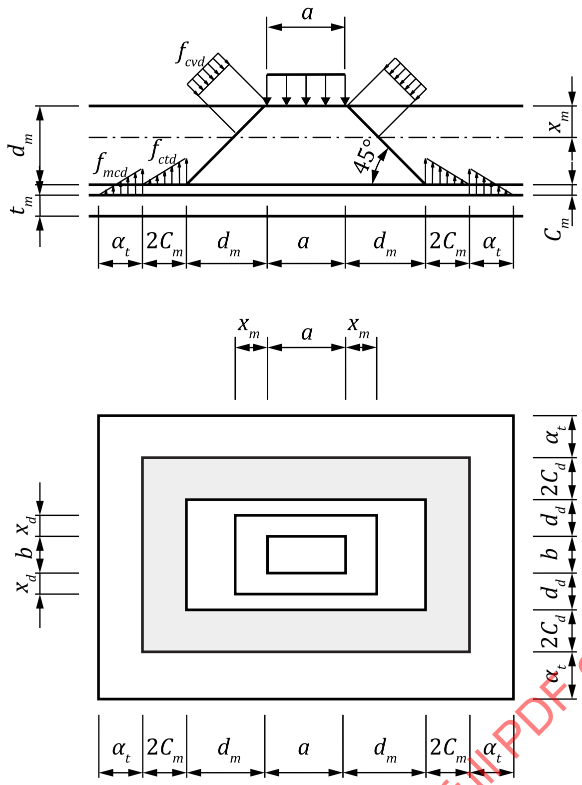


Figure A.3 — Punching shear failure model

Formula (A.4) assumes a resistance mechanism like the one shown in Figure A.3. It hypothesizes that the reinforcing materials of the underlaying 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 underlaying materials and existing members and the bonding area and verifies this hypothesis. In this figure, αt is twice the thickness of the underlaying parts (α = 2). When the formula is applied to special decks whose reinforcement ratio or other properties are out of range, an additional study is needed.

$$
\begin{aligned}
V_{mpd} = [& f_{cvd}\{2(a+2x_m)x_d + 2(b+2x_d)x_m\} \\
& + f_{ctd}\{2(a+2d_m)C_d + 2(b+2d_d+4C_d)C_m\} \\
& + f_{mcd}\{2(a+2d_m+4C_m)t_m + 2(b+2d_d+4C_d+4t)t_m\}]/\gamma_b
\end{aligned} \tag{A.4}
$$

where

$f_{cvd} = 0{,}656 f_{cd}'^{\,0{,}606}$

$f_{ctd} = 0{,}269 f_{cd}'^{\,0{,}667}$

a, b is the side lengths of the loading plate in the main reinforcement and distribution reinforcement (mm);

x_m, x_d is the 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 is the effective heights of the tension-side main reinforcement and distribution reinforcement (mm);

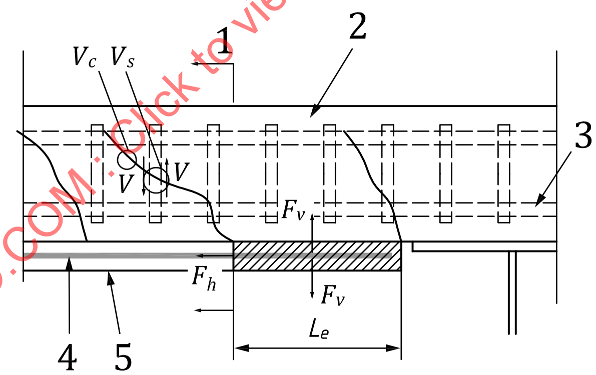
c_m, c_d	is the covering depths of the tension-side main reinforcement and distribution reinforcement (mm);
t_m	is the thickness of the underlaying part (mm);
f_{cvd}	is the design shear strength of existing concrete (N/mm^2);
f_{ctd}	is the design tensile strength of existing concrete (N/mm^2);
f_{mcd}	is the design bonding strength of the interface between the existing concrete and underlaying part (N/mm^2);
γ_b	is the partial safety factor for member, which is generally set to 1,3.

A.4 Evaluation method for the peeling failure of the underlaying parts and the splitting cracking of the covering concrete of the existing parts

A.4.1 General

If the edges of the underlaying parts are not anchored after diagonal cracking occurs in the repaired or strengthened members, the peeling of the underlaying materials or splitting failure of the covering concrete of the existing parts can result (see Figure A.4). 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 can be performed using the methods described below.

A.4.2 Study of the peeling of the underlaying material at the edge of the underlaying part



Key

1 cross section under study
2 existing member
3 existing tensile reinforcement
4 reinforcement
5 underlaying material

Figure A.4 — Peeling of underlaying material at the end of the underlaying part

When members with shear reinforcing materials placed in the existing parts are strengthened with bottom-surface (soffit) underlaying, the safety verification related to the peeling failure at the edges of the underlaying parts can be performed using Formula (A.5). This verification can be omitted if the shear force for the verification is below the diagonal cracking shear force ($V_d < V_{cd}$).

$$\gamma_i \left\{ \left(\frac{\bar{\sigma}_m}{\sigma_{mud}} \right) + \left(\frac{\bar{\tau}_m}{\tau_{mud}} \right) \right\} \leq 1,0 \qquad \text{(A.5)}$$

where

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

$F_v = V - V_s$

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

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

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

$\bar{\sigma}_m$ is the design tensile bond stress level of the underlaying part interface (N/mm^2);

F_v is the vertical direction force of the interface (N);

V_d is the design shear force (N);

V_{cd} is the diagonal cracking shear force (N) of the member taking into consideration the effect of strengthening with the underlaying method, which may be calculated using Formula (A.3);

$k = 0{,}8$ is the ratio of shear force of shear reinforcing materials to other shear forces after the occurrence of diagonal cracking;

B is the effective width of the member (unit width or girder width of the girder-like deck in the principal direction) (mm);

L_e is the effective bond length can be used as the crack spacing (mm);

It can be set to 150 mm if the crack spacing exceeds 150 mm.

$\bar{\tau}_m$ is the design shear bond stress of the underlaying part interface (N/mm^2);

F_h is the tensile force of reinforcing material of the cross-section under study (N);

n is the number of reinforcing materials;

A_r is the cross-sectional area of reinforcing material (mm^2);

σ_r is the stress 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 needs to 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} is the design tensile bond strength of underlaying material determined through direct tensile testing (N/mm^2);

τ_{mud} is the design shear bond strength of underlaying 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 can be considered that $\tau_{mud} = 2{,}6\,\sigma_{mud}$.

γ_i is the partial safety factor for structure, which is generally 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 underlaying parts as soon as shear cracking occurs. Therefore, the verification needs to be performed as set forth in Formula (A.1).