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Maintenance and repair of concrete structures —

Part 4: Execution of repairs

Entretien et réparation des structures en béton —

Partie 4: Exécution des réparations

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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*.

This second edition cancels and replaces the first edition (ISO 16311-4:2014) which has been technically revised.

The main changes are as follows:

— the title has been changed due to clarification of the definition of the term;

— some relevant reference standards have been clarified;

— some editorial corrections have been made.

A list of all parts in the ISO 16311 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.

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Introduction

This document defines and specifies site application of products and systems and quality control of repairs. The execution of maintenance and repair of concrete structures is an important and integral part of the complex process of repair, and this document specifies how it is carried out. This document incorporates rules for the use of maintenance and repair materials and systems. Maintenance and repair methods applying traditional concrete construction work are listed in this document. Maintenance and repair methods applying electrochemical methods, e.g. cathodic protection, re-alkalisation of carbonated concrete, and chloride extraction, are listed in this document.

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Maintenance and repair of concrete structures —

Part 4: Execution of repairs

1 Scope

This document provides requirements for substrate condition before and during application, including structural stability, storage of materials, the preparation, and application of products and systems for repair of concrete structures, including quality control and qualifications of personnel, maintenance, health and safety, and the environment.

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 1920-2, *Testing of concrete — Part 2: Properties of fresh concrete*

ISO 1920-3, *Testing of concrete — Part 3: Making and curing test specimens*

ISO 1920-4, *Testing of concrete — Part 4: Strength of hardened concrete*

ISO 1920-5, *Testing of concrete — Part 5: Density and water penetration depth*

ISO 1920-6, *Testing of concrete — Part 6: Sampling, preparing and testing of concrete cores*

ISO 1920-7, *Testing of concrete — Part 7: Non-destructive tests on hardened concrete*

ISO 2394, *General principles on reliability for structures*

ISO 2409, *Paints and varnishes — Cross-cut test*

ISO 2808:2019, *Paints and varnishes — Determination of film thickness*

ISO 3274, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Nominal characteristics of contact (stylus) instruments*

ISO 4624, *Paints and varnishes — Pull-off test for adhesion*

ISO 4628-1, *Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 1: General introduction and designation system*

ISO 4628-2, *Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 2: Assessment of degree of blistering*

ISO 4628-3, *Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 3: Assessment of degree of rusting*

ISO 4628-4, *Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 4: Assessment of degree of cracking*

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ISO 4628-5, *Paints and varnishes — Evaluation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 5: Assessment of degree of flaking*

ISO 4628-6, *Paints and varnishes — Evaluation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 6: Assessment of degree of chalking by tape method*

ISO 5091 (all parts), *— Structural intervention of existing concrete structures using cementitious materials*

ISO 6935-2, *Steel for the reinforcement of concrete — Part 2: Ribbed bars*

ISO 8501-1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 8502-2, *Preparation of steel substrates before application of paints and related products — Tests for the assessment of surface cleanliness — Part 2: Laboratory determination of chloride on cleaned surfaces*

ISO 8502-3, *Preparation of steel substrates before application of paints and related products — Tests for the assessment of surface cleanliness — Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)*

ISO 8502-4, *Preparation of steel substrates before application of paints and related products — Tests for the assessment of surface cleanliness — Part 4: Guidance on the estimation of the probability of condensation prior to paint application*

ISO 13822, *Bases for design of structures — Assessment of existing structures*

ISO 14654, *Epoxy-coated steel for the reinforcement of concrete*

ISO 14657, *Zinc-coated steel for the reinforcement of concrete*

ISO 16311-1, *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 16311-3:2014, *Maintenance and repair of concrete structures — Part 3: Design of repairs and prevention*

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

ISO 21920-3, *Geometrical product specifications (GPS) — Surface texture: Profile — Part 3: Specification operators*

ISO 22965-1, *Concrete — Part 1: Methods of specifying and guidance for the specifier*

ISO 22965-2, *Concrete — Part 2: Specification of constituent materials, production of concrete and compliance of concrete*

ISO 22966, *Execution of concrete structures*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16311-1, ISO 2394, ISO 13822 and ISO 19338 and the following 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/

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3.1
bond
adhesion of the applied product or system to the substrate

Note 1 to entry: The bond requirements for a given repair can range from negligible to firmly adherent.

3.2
cement grout
mixture of cement, water, and, in some cases, admixtures

3.3
cementitious repair products and systems
hydraulic or polymer hydraulic mortars, concretes and grouts

3.4
dew point
temperature at which water vapour condenses

3.5
mortars
concrete
hydraulic, polymer hydraulic, and polymer mortar and concrete

3.6
pre-formed hole
hole or slot formed or cut in concrete into which reinforcement or other fixing is to be anchored

3.7
quality plan
programme to ensure that the activities of a process are undertaken to comply with the intended design

3.8
sprayed mortar or concrete
mortar or concrete applied under pressure through a nozzle delivered through pipes

3.9
wet on wet
application of a cementitious mortar or concrete onto the surface of a similar material which has set but not hardened

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4 Structural stability during execution of repairs

Safety and stability before, during and after repair shall be maintained in accordance with ISO 16311-3.

Any period required for gain of strength of the repair products and systems shall be a part of the duration of the repair.

5 General requirements

Consideration shall be given to the chemical, electrochemical and physical condition of the substrate and any contaminants, the ability of the structure to accept loading, movement and vibration during repair, ambient conditions and the characteristics of the materials contained in the structure and those of repair products and systems.

The following requirements shall be met.

— The achievement of the required condition of the substrate regarding cleanliness, roughness, cracking, tensile and compressive strength, chloride or other contaminant and their penetration, depth of carbonation, moisture content, temperature, and degree of corrosion of reinforcement.

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— The achievement of the compatibility of the original concrete and reinforcement with repair products and systems and compatibility between any different products and systems, including avoiding the risk of creating conditions which can cause corrosion.

— The achievement of the specified properties of products and systems when applied and in their hardened condition regarding the fulfilment of their purpose for repair of the structure.

— The achievement of the required storage and application conditions regarding ambient temperature, humidity and dew point, wind force and precipitation, and any temporary protection which is needed.

6 Methods of repair

The remedies and methods of repair, given in ISO 16311-3:2014, Table 1, are described below, excluding those methods specified in standards valid in the place of use.

The preparation of substrate, application of products and systems, quality control, and maintenance for each method shall comply with Clauses 7, 8, 9 and 10.

The relevant subclauses are given in Table 1 for each method together with any deviations, additions, necessary precautions and limitations.

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Table 1 — Table for each method together with any deviations, additions, necessary precautions and limitations

Repair remedies and methods		Preparation See subclauses	Application See subclauses	Quality control See subclauses
Method	**Methods to satisfy remedy 1 – Protection against ingress** The following methods satisfy the remedy of reducing or preventing the ingress of adverse agents, e.g. water, other liquids, vapour gas such as carbon dioxide, chemicals such as chlorides and biological agents.			
1.1	**Hydrophobic impregnation** This method applies a product to prevent or reduce the passage of water by lining the surface pores with material with hydrophobic properties.	7.1, 7.2.1, 7.2.2	8.1, 8.2.7	9.1, 9.2
1.2	**Impregnation** This method is to apply liquid products which penetrate the concrete and block the pore system.	7.1, 7.2.1, 7.2.2	8.1, 8.2.7	9.1, 9.2
1.3	**Coating** This method applies a product to the surface of the concrete to prevent the passage of agents.	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.7	9.1, 9.2
1.4	**Surface bandaging of cracks** The method seals cracks in the concrete to prevent the passage of deleterious agents. Refer to A.3.	7.1, 7.2.1, 7.2.2	[a] 8.1, 8.2.1, 8.2.2, 8.2.5, 8.2.6	9.1, 9.2
1.5	**Filling of cracks** This method fills cracks to protect against ingress.	7.1, 7.2.1, 7.2.2	[a] 8.1, 8.2.1, 8.2.2, 8.2.5, 8.2.6	9.1, 9.2
1.6	**Transforming cracks into joints** This method makes use of existing cracks as an integral part of the structure. Refer to A.3.	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.6	9.1, 9.2
1.7	**Erecting external panels** This method installs barrier panels to protect or encapsulate the deteriorating substrate.	System dependent	System dependent	System dependent
1.8	**Applying membranes** This method installs proprietary systems to protect or encapsulate the concrete substrate.	System dependent	System dependent	System dependent
Method	**Methods to satisfy remedy 2 – Moisture control** The following methods satisfy the remedy of adjusting and maintaining the moisture content in the concrete between a specified range of values.			
2.1	**Hydrophobic impregnation** This method applies a product to reduce the penetration of water and other agents into the treated concrete by lining the surface pores with materials with hydrophobic properties.	7.1, 7.2.1, 7.2.2	8.1, 8.2.7	9.1, 9.2
2.2	**Impregnation** This method applies liquid products which penetrate the concrete and block the pore system.	7.1, 7.2.1, 7.2.2	8.1, 8.2.7	9.1, 9.2
2.3	**Coating** This method applies a product to the surface of the concrete to prevent the passage of water or water vapour.	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.7	9.1, 9.2
2.4	**Erecting external panels** (refer to method 1.7)	System dependent	System dependent	System dependent
2.5	**Electrochemical treatment** This method applies an electro-osmotic pulse to reduce water content of the concrete. Refer to A.3.	System dependent	System dependent	System dependent

[a] Concrete at the edges of cracks shall be prepared and repaired in accordance with Clauses 7 and 8. Subclauses 8.2.2 and 8.2.5 apply only to cementitious grouts.

[b] Subclauses 8.2.1 and 8.2.5 apply only to cementitious grouts.

[c] Coating to concrete which prevents repassivation shall be removed and the concrete shall be cleaned, roughened and removed where necessary.

[d] Concrete shall be removed only to the depth to which it has been cracked or loosened. Embedded reinforcement shall be cleaned in accordance to 7.3.1 and 7.3.2.

[e] Hydraulic mortar or concrete shall be used.

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Table 1 *(continued)*

Repair remedies and methods		Preparation See subclauses	Application See subclauses	Quality control See subclauses
Method	**Methods to satisfy remedy 3 – Concrete restoration** The following methods satisfy the remedy of restoring the original concrete of a member of the structure to the originally specified shape and function. Restoring the concrete structure by replacing part of it.			
3.1	**Hand-applied localized patches**	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4	8.1, 8.2.1, 8.2.2, 8.2.5	9.1, 9.2
3.2	**Recasting components with concrete or mortar**	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4 and ISO 22966	8.1, 8.2.1, 8.2.2, 8.2.5, ISO 22965-1, ISO 22965-2 and ISO 22966	9.1, 9.2
3.3	**Spraying concrete or mortar**	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4 and ISO 22966	8.1, 8.2.1, 8.2.2, 8.2.5 and ISO 22966	9.1, 9.2
3.4	**Replacing structural members**	ISO 2394	ISO 22966	9.1, 9.2
Method	**Methods to satisfy remedy 4 – Structural strengthening** The following methods satisfy the remedy of increasing or restoring the structural load bearing capacity of a member of the concrete structure.			
4.1	**Adding or replacing embedded or external reinforcing bars**	7.1, 7.3.1, 7.3.2, 8.2.1, 8.3.2	8.1, 8.2.8, 8.3.1, 8.3.3 and ISO 22966	9.1, 9.2
4.2	**Adding reinforcement anchored in pre-formed or drilled holes**	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.8, 8.3.1, 8.3.3	9.1, 9.2
4.3	**Bonding plate reinforcement** This method bonds the strengthening plates externally to a member of the concrete structure.	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4	8.1, 8.2.1, 8.2.6, 8.2.9	9.1, 9.2
4.4	**Adding mortar or concrete** This method bonds additional mortar or concrete to the concrete structure.	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4	8.1, 8.2.1, 8.2.2, 8.2.3, 8.2.4, 8.2.5	9.1, 9.2
4.5	**Injecting cracks, voids or interstices** This method injects the concrete with appropriate fluid.	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.2, 8.2.5, 8.2.6	9.1, 9.2
4.6	**Filling cracks, voids, or interstices**	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.2, 8.2.5, 8.2.6	9.1, 9.2
4.7	**Prestressing (post-tensioning) or FRP strengthening**	ISO 2394	ISO 22966	9.1, 9.2
Method	**Methods to satisfy remedy 5 – Increasing physical resistance** The following methods satisfy the remedy of increasing resistance to physical or mechanical attack.			
5.1	**Coating** This method increases the physical resistance with a coating.	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.7	9.1, 9.2
5.2	**Impregnation** This method applies liquid products which penetrate the concrete.	7.1, 7.2.1, 7.2.2	8.1, 8.2.7	9.1, 9.2
5.3	**Adding mortar or concrete** This method bonds additional mortar or concrete to the concrete structure.	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4	8.1, 8.2.1, 8.2.2, 8.2.3, 8.2.4, 8.2.5	9.1, 9.2

[a] Concrete at the edges of cracks shall be prepared and repaired in accordance with Clauses 7 and 8. Subclauses 8.2.2 and 8.2.5 apply only to cementitious grouts.

[b] Subclauses 8.2.1 and 8.2.5 apply only to cementitious grouts.

[c] Coating to concrete which prevents repassivation shall be removed and the concrete shall be cleaned, roughened and removed where necessary.

[d] Concrete shall be removed only to the depth to which it has been cracked or loosened. Embedded reinforcement shall be cleaned in accordance to 7.3.1 and 7.3.2.

[e] Hydraulic mortar or concrete shall be used.

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Table 1 *(continued)*

Repair remedies and methods		Preparation See subclauses	Application See subclauses	Quality control See subclauses
5.4	**Applying membranes** This method installs proprietary systems to protect or encapsulate the concrete substrate.	System dependent	System dependent	System dependent
Method	**Methods to satisfy remedy 6 – Increasing resistance to chemicals** The following methods increase the resistance of the concrete surface to deterioration by reducing the penetration of chemical agents.			
6.1	**Coating** This method increases the physical resistance with a coating.	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.7	9.1, 9.2
6.2	**Impregnation** This method applies liquid products that penetrate the concrete.	7.1, 7.2.1, 7.2.2	8.1, 8.2.7	9.1, 9.2
6.3	**Adding mortar or concrete** This method bonds additional mortar or concrete to the concrete structure.	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4	8.1, 8.2.1, 8.2.2, 8.2.3, 8.2.4, 8.2.5	9.1, 9.2
Method	**Methods to satisfy remedy 7 – Preserving or restoring passivity** The following methods satisfy the remedy of creating chemical conditions in which the surface of the reinforcement is maintained at or is returned to a passive condition.			
7.1	**Increasing cover to reinforcement with additional cementitious mortar or concrete, or applying coatings** These methods increase cover or provide surface coatings to prevent penetration of the de-passivating agents: — Concrete or mortar overlays — Coatings	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4 7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.2, 8.2.3, 8.2.4, 8.2.5 8.1, 8.2.1, 8.2.7	9.1, 9.2 9.1, 9.2
7.2	**Replacing contaminated or carbonated concrete** This method replaces carbonate concrete with uncontaminated mortar or concrete.	7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4	8.1, 8.2.1, 8.2.2, 8.2.5	9.1, 9.2
7.3	**Electrochemical re-alkalisation of carbonated concrete**	System dependent	System dependent	9.1, 9.2
7.4	**Re-alkalisation of carbonated concrete by diffusion**	[c, d] 7.1, 7.2.1, 7.2.2, 7.2.3, 7.2.4	[e] 8.1, 8.2.1, 8.2.2, 8.2.3, 8.2.4, 8.2.5	9.1, 9.2
7.5	**Electrochemical chloride extraction**	System dependent	System dependent	System dependent and 9.1, 9.2
7.6	**Applying membranes (preserving passivity only)** This method installs proprietary systems to protect or encapsulate the concrete substrate, thereby maintaining passivity.	System dependent	System dependent	System dependent
Method	**Methods to satisfy remedy 8 – Increasing resistivity** The following method satisfies the remedy of increasing the electrical resistivity of the concrete by limiting moisture content.			
8.1	**Hydrophobic impregnation** This is a method to reduce water content and as a result increase the electrical resistance of concrete.	7.1, 7.2.1, 7.2.2	8.1, 8.2.7	9.1, 9.2
8.2	**Impregnation** This method applies liquid products that penetrate the concrete.	7.1, 7.2.1, 7.2.2	8.1, 8.2.7	9.1, 9.2

[a] Concrete at the edges of cracks shall be prepared and repaired in accordance with Clauses 7 and 8. Subclauses 8.2.2 and 8.2.5 apply only to cementitious grouts.

[b] Subclauses 8.2.1 and 8.2.5 apply only to cementitious grouts.

[c] Coating to concrete which prevents repassivation shall be removed and the concrete shall be cleaned, roughened and removed where necessary.

[d] Concrete shall be removed only to the depth to which it has been cracked or loosened. Embedded reinforcement shall be cleaned in accordance to 7.3.1 and 7.3.2.

[e] Hydraulic mortar or concrete shall be used.

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Table 1 *(continued)*

Repair remedies and methods		Preparation See subclauses	Application See subclauses	Quality control See subclauses
8.3	**Coating** This method increases the physical resistance with a coating.	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.7	9.1, 9.2
Method	**Methods to satisfy remedy 9 – Cathodic control** The following methods satisfy the remedy of creating conditions in which potentially cathodic areas of reinforcement are unable to drive an anodic reaction.			
9.1	**Limiting oxygen content (at the cathode) by saturation or surface coating** Saturation. Surface coating.	7.1, 7.2.1, 7.2.2 7.1, 7.2.1, 7.2.2	The concrete shall be continuously saturated with water. 8.1, 8.2.1, 8.2.7	9.1, 9.2 9.1, 9.2
Method	**Method to satisfy remedy 10 – Cathodic protection**			
10.1	**Applying an electrical current to achieve a protective electrochemical potential**			9.1, 9.2
Method	**Methods to satisfy remedy 11 – Control of anodic areas** The following methods satisfy the remedy of creating conditions in which potentially anodic areas of reinforcement are unable to take part in the corrosion reaction.			
11.1	**Active coating of the reinforcement** This is a method which provides either: — coatings to provide an alkaline environment; — coatings which function as inhibitors of electrochemical action; — coatings provide sacrificial galvanic reaction.	7.1, 7.3.1, 7.3.2	8.1, 8.3.1	9.1, 9.2
11.2	**Barrier coating of the reinforcement** This is a method providing a barrier to prevent pore water containing chlorides or other contaminants from reaching the reinforcement.	7.1, 7.3.1, 7.3.2	8.1, 8.3.1	9.1, 9.2
11.3	**Applying corrosion inhibitors in or to concrete** Corrosion inhibitors are applied as a surface treatment or are added to repair products and systems. Refer to A.3 for additional information.	7.1, 7.2.1, and 7.2.2.	8.1,8.2.6.	9.1, 9.2
11.4	**Installation of discrete galvanic anodes** This method is intended to counteract the incipient anode effect that occurs at the perimeter of localized concrete patch repairs.	7.1, 7.3.1, 7.3.2	8.1, 8.3.1	9.1, 9.2

[a] Concrete at the edges of cracks shall be prepared and repaired in accordance with Clauses 7 and 8. Subclauses 8.2.2 and 8.2.5 apply only to cementitious grouts.

[b] Subclauses 8.2.1 and 8.2.5 apply only to cementitious grouts.

[c] Coating to concrete which prevents repassivation shall be removed and the concrete shall be cleaned, roughened and removed where necessary.

[d] Concrete shall be removed only to the depth to which it has been cracked or loosened. Embedded reinforcement shall be cleaned in accordance to 7.3.1 and 7.3.2.

[e] Hydraulic mortar or concrete shall be used.

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7 Preparation of substrate

7.1 General

The preparation of the substrate of concrete and reinforcement shall be suitable for the required condition of the repair work, so that the products and systems can be properly applied, and shall be carried out in such a way as to produce repair which is in accordance with this document, ISO 16311-2 and ISO 16311-3. The requirements for preparation are given in the following subclauses and are related to the methods of repair in Table 2.

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Table 2 — Preparation of substrate

Preparation process	Subclause no. (background information in Annex A)	References	Method no. in Table 1							
			Hydrophobic impregnation and impregnation	Surface coating	Filling cracks, voids or interstices	Application of mortar and concrete	Adding reinforcing steel bars	Installing bonded rebars in pre-formed holes	Plate bonding	Coating reinforcement
			1.1, 1.2, 2.1, 2.2, 5.2, 6.2, 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4, 7.6, 9.1, 11.1, 11.2
General	7.1		X	X	X	X	X	X	X	X
Preparation of concrete substrate										
General	7.2.1	ISO 16311-3	X	X	X	X		X	X	
Cleaning	7.2.2		X	X	X	X		X	X	
Roughening	7.2.3					X			X	
Concrete removal	7.2.4	ISO 16311-3				X			X	
Preparation of reinforcement										
General	7.3.1	ISO 16311-3					X	X		X
Cleaning	7.3.2	ISO 8501-1					X	X		X

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7.2 Preparation of concrete

7.2.1 General

Weak, damaged and deteriorated concrete and, where necessary, sound concrete shall be removed in accordance with the repair remedy and method chosen from ISO 16311-3.

If necessary, cleaning shall be carried out after roughening or concrete removal to comply with 7.2.2 unless water-based methods are used, which can make this unnecessary.

Micro-cracked or delaminated concrete, including that caused by the techniques of cleaning, roughening, or removal which reduces bond or structural integrity, shall be subsequently removed or remedied. The finished surface shall be visually inspected and tested by tapping with a hammer to detect loose concrete.

7.2.2 Cleaning

For those methods which require cleaning, the following requirements shall be met:

a) the substrate shall be free from dust, loose material, surface contamination, and materials which reduce bond or prevent suction or wetting by repair materials;

b) unless cleaning is carried out immediately before application of repair materials, the cleaned substrate shall be protected from further contamination.

7.2.3 Roughening

For those methods which require roughening, the following requirement shall be met.

The texture of the roughened surface shall be appropriate for the products and systems to be applied and shall be specified.

7.2.4 Concrete removal

For those methods which require the removal of concrete, the following requirements shall be met.

a) The extent of the removal shall be appropriate to the repair remedy and method chosen from those given in ISO 16311-3.

b) Removal shall be kept to a minimum.

c) Removal shall not reduce structural integrity beyond the ability of the structure to perform its function. Temporary shoring and bracing can be necessary.

d) The depth of carbonation and the concentration profiles of chloride or other contamination in the concrete shall be established and taken into account.

e) The extent of the removal of the concrete shall be in accordance with the method chosen and shall be specified. It shall take into account the following:

   1) the penetration resistance of the concrete against gases and fluids;

   2) the nature and concentration of the contamination before and after the repair and its anticipated effect on the design service life of the repaired structure;

   3) the depth of the contamination;

   4) the depth of the carbonation;

   5) the corrosion activity of the reinforcement;

   6) cover to reinforcement;

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7) the need for compaction of the repair material;

8) the need for bond to the substrate;

9) the need for treatment of reinforcement.

7.3 Preparation of reinforcement

7.3.1 General

Before repair systems are applied, the required condition of the existing and any new reinforcement shall be prepared in accordance with the specification and the remedy and method chosen from ISO 16311-3, and the required structural performance. The extent of any cleaning, coating, removal, or replacement shall be specified taking into account the possible need for corrosion prevention and the need to provide the specified bond between the repair products and systems and the reinforcement.

7.3.2 Cleaning

For those methods which require cleaning of the reinforcement, the following requirements shall be met.

a) Rust, scale, mortar, concrete, dust and other loose and deleterious material which reduce bond or contribute to corrosion, shall be removed.

b) The whole circumference of the exposed reinforcement shall be uniformly cleaned, except where structural considerations prevent it.

c) Unless the cleaning is carried out immediately before application of protection products and systems, the cleaned substrates shall be protected against further contamination.

d) Reinforcement shall be cleaned without causing damage to it or damage to or contamination of the adjacent concrete or environment.

e) Where exposed reinforcement is contaminated with chloride or other material which can cause corrosion, the whole of the circumference of the contaminated reinforcement shall be cleaned by water washing to remove the chlorides and other contaminants, unless electrochemical methods of repair are to be used (see A.6.3).

f) For method 11.2 (given in Table 1), the degree of cleaning shall be to Sa 21/2 in accordance with ISO 8501-1, or compliant with relevant standards and guideline in the area of use. For method 11.1 and other methods, except method 11.2, where reinforcement is to be coated, the degree of cleaning shall be specified and shall be suitable for the coating to be applied. The specification, method and choice of cleaning shall take into account bar congestion, contact between bars, proximity to concrete substrate and other factors which prevent access for cleaning (see A.6.3).

8 Application of products and systems

8.1 General

The application of the products and systems shall be suitable for the substrate and structure to which it is applied and to produce repair which is in accordance with ISO 16311-2, ISO 16311-3 and ISO 22965-1, ISO 22965-2 and ISO 22966.

Products shall be stored before use so that their properties shall not be impaired.

Access for the work shall be adequate so that products and systems can be prepared and applied in accordance with this document.

Protection shall be provided so that preparation, application and subsequent curing shall be carried out in accordance with this document.

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Before and during application of the products and systems, the substrate temperature and moisture content, and the characteristics of the environment, for example, temperature, relative humidity, dew point, rate of change of moisture content, as influenced by precipitation and wind, shall be considered.

Mixing of products and systems shall be in accordance with ISO 22965-1, ISO 22965-2 and ISO 22966, or shall be specified.

The thickness of layers of products and systems shall comply with this document or be specified.

The bond of the repair material with the substrate and between layers of repair material shall be not less than the bond strength specified.

The requirements for application are given in the following subclauses and are related to the methods of repair in Table 3.

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Table 3 — Application of products and systems

Application process	Subclause no. (background information in Annex A)	References	Method no. in Table 1							
			Hydrophobic impregnation and impregnation	Surface coating	Filling cracks, voids or interstices	Application of mortar and concrete	Adding reinforcing steel bars	Installing bonded rebars in pre-formed holes	Plate bonding and FRP strengthening	Coating reinforcement
			1.1, 1.2, 2.1, 2.2, 5.2, 6.2, 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4, 7.6, 9.1, 11.1, 11.2
	8.1		X	X	X	X	X	X	X	X
Defects in concrete and structural strengthening										
Bonding	8.2.1	ISO 22965-2		X	X	X		X	X	
Hand applied mortar and concrete	8.2.2	ISO 22966			X[a]	X[a]				
Sprayed mortar or concrete	8.2.3					X[a]				
Cast mortar or concrete	8.2.4	ISO 22966				X[a]				
Curing	8.2.5	ISO 22966			X[a]	X				
Cracks and joints	8.2.6	ISO 16311-3			X				X[a]	
Surface coatings and hydrophobic impregnation and impregnation	8.2.7		X	X		X[a]				
Anchoring	8.2.8	ISO 22966					X	X		
Plate bonding and FRP Strengthening	8.2.9	ISO 8501-1							X	
Defects caused by reinforcement corrosion										
Coating reinforcement	8.3.1						X			X
Removal	8.3.2						X			
Replacement	8.3.3	ISO 22966 ISO 9635-2					X			

[a] Where relevant.

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8.2 Structural strengthening to restore member capacity — methods

8.2.1 Bonding

Bonding requirements shall be specified, and the applied mortar and concrete shall comply with ISO 22966 or guidelines valid in the place of use.

Any water required for wetting the substrate shall comply with the purity requirements for mixing water of ISO 22965-2, or the requirements given in national standards and be as specified by the execution specification.

8.2.2 Hand applied mortar and concrete

Where non-proprietary cementitious products or systems are used without a bonding primer, the concrete substrate shall be well pre-wetted but free from water on the surface at the time of the application. The condition of the substrate shall be specified where a bonding primer is used and shall comply with the proprietary product manufacturer's requirements, if applicable.

Repair mortar shall be worked into the prepared substrate and shall be compacted without inclusion of entrapped air pockets and in such a way that the required strength is achieved, and the reinforcement is protected against corrosion.

It shall be decided whether the repair mortar or concrete is to be built up in layers to prevent sagging or slumping. The layer thickness, time between application of layers, and other requirements, shall be specified. Where the application of layers is interrupted, and layers cannot be applied wet on wet, surface treatment for bonding to the previous layer shall be in accordance with 7.2.2, 7.2.3 and 8.2.1.

8.2.3 Sprayed repair mortar or concrete

Sprayed concrete and sprayed mortar used as repair material shall comply with ISO 22966 or the requirements given in national standards and be as specified by the execution specification.

The need for pre-wetting of the substrate shall be considered. It depends upon its condition and the composition of the products and systems used.

Sprayed concrete and mortar shall be placed without the formation of voids and loose rebound material and in such a way that the required strength is achieved, and the reinforcement is protected against corrosion.

Overspray and loose rebound material shall be removed from surrounding areas and from the substrate before sprayed concrete or mortar is applied.

Where sprayed concrete or mortar is to be applied in more than one layer and, where the work is not applied wet on wet, intermediate surfaces shall comply with 7.2.2 and 8.2.1.

No treatment shall be allowed to the surface of sprayed mortar or concrete, unless the sprayed mortar or concrete is non-structural, to avoid the possibility of reducing bond. If treatment is required to structural sprayed concrete or mortar, it shall be applied to the final layer which has not been applied wet on wet to the structural material.

8.2.4 Cast repair mortar or concrete

Where cementitious products or systems are used without a bonding primer, the concrete substrate shall be well pre-wetted but free from water on the surface at the time of application. The condition of the substrate shall be specified where a bonding primer is used.

Concrete shall be replaced in accordance with ISO 22966 and shall be specified to avoid segregation bleeding and loss of cement paste.

Formwork shall comply with ISO 22966.

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Formwork shall be fixed in place as soon as possible after the substrate has been prepared as specified in Clause 7. Openings in the formwork shall be protected to prevent entry of debris or contaminants.

Concrete intended for compaction by vibration, shall be compacted around the reinforcement and elsewhere without inclusion of entrapped air pockets and in such a way that the required strength is achieved, and the reinforcement is protected against corrosion.

Where casting is to be with flowing concrete intended to be compacted by gravity, the following shall also apply.

a) The substrate shall comply with Clause 7.

b) Formwork shall be watertight to the existing concrete and shall be free from obstructions to the free flow of concrete. It shall be designed to allow air and bleed water to escape.

c) The concrete shall be introduced into the formwork in such a way that the air and water can escape. It shall not be vibrated.

8.2.5 Curing

Where cementitious repair products and systems are used, curing is necessary and shall comply with ISO 22966, and shall be specified.

The method and period of any wet curing shall be specified taking into account the nature of the products and systems, the thickness of the repair and environmental conditions.

Curing compounds shall not be used where they adversely affect subsequently applied products and systems, e.g. electrochemical methods.

8.2.6 Cracks and joints

The position and size of cracks and joints (expansion, contraction, or termination), any movement in the substrate and of the effect on the stability, durability, and function of the structure and the risk of creating new cracks as a result of any treatment shall be accounted for when repairs are executed.

The treatment of cracks shall be in accordance with the repair remedy and method chosen from ISO 16311-3 and the following:

a) Cracks shall be cleaned in accordance with 7.2.2.

b) Cracks to be treated to restore structural integrity shall be filled with a bonding product or system.

c) Cracks to be treated to prevent the passage of agents shall be covered or filled.

d) Cracks to be treated to accommodate movement shall be repaired so that a joint is formed to extend through the full depth of any repair material and positioned to accommodate that movement. Joints shall be filled or covered with a flexible material for that purpose.

The treatment of joints shall ensure that the joint extends through any repair material so that the joint performance is maintained.

8.2.7 Surface coatings and other treatments

Smoothing coatings shall be applied and cured where necessary before surface coatings are applied to fill uneven surfaces and surface pores.

Coatings shall be applied within the specified maximum and minimum thickness.

The maximum and minimum temperature and moisture content of the substrate and the ambient temperature and humidity shall be specified and shall be appropriate to the surface coating hydrophobic impregnation or impregnation material.

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8.2.8 Anchoring

Anchoring reinforcement, independently of the existing reinforcement, to bond it to the substrate concrete shall be in accordance with ISO 22966 and any other relevant standards or guidelines valid in the place of use.

Anchors shall be installed in locations designed by the repair design. Undocumented cracks and interferences with other structural members shall be reported to the repair designer and owner.

The texture and cleanliness of the surface of anchor holes and grooves shall be in accordance with 7.2.2 and 7.2.3 and shall be appropriate to the anchoring material.

8.2.9 Plate bonding and fibre-reinforced polymer (FRP) strengthening

Plate bonding or fibre-reinforced polymer strengthening shall be carried out in accordance with ISO 5091 (all parts) or guidelines valid in the place of use.

The exposed surfaces of concrete to receive externally bonded reinforcement, shall be cleaned and roughened and voids treated to comply with 7.2.2 and 7.2.3. Weak, damaged, or deteriorated concrete shall be removed to comply with 7.2.4 prior to the application of bonded external reinforcement.

The conditions of the surface at the time of application of the bonding agent shall comply with 7.1, 7.2.1 and 7.2.2.

Replacement of removed concrete, filling of voids and treatment of cracks shall be in accordance with Clause 8.

The surface of the steel plates to be bonded, shall be free of any contaminants and shall be cleaned to Sa 21/2, or the standard deemed appropriate in the place of use (see ISO 8501-1).

The surface of fibre-reinforced or other plates to be bonded, shall be prepared in accordance with the specification.

Adhesives shall be applied to comply with the specified ambient conditions.

The exposed surface of plates or fibre-reinforcement shall be protected as specified.

8.3 Defects caused by reinforcement corrosion

8.3.1 Coating reinforcement

Bonding requirements for coatings on reinforcement shall be specified and shall comply with standards or guidelines valid in the place of use. The whole exposed circumference of the exposed reinforcement surface shall be uniformly coated.

Coatings shall not be allowed to contaminate existing concrete if it is detrimental to the bond between the existing concrete and the repair products and systems. The treatment of reinforcement to prevent corrosion shall comply with ISO 14654 and ISO 14657 or guidelines valid in the place of use.

8.3.2 Removal

If reinforcement is removed, the following requirements shall be met:

a) the concrete substrate shall not be damaged (see A.5.3.2);

b) remaining reinforcement shall not be damaged.

8.3.3 Replacement

Added or replaced embedded reinforcement shall comply with 8.2.8, ISO 22966 and ISO 6935-2, and standards or guidelines valid in the place of use.

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To avoid the risk of creating conditions which can cause corrosion, reinforcement shall not make electrochemical contact with a dissimilar metal.

Where electrochemical methods of repair are to be applied, added reinforcement shall be in sufficient electrical contact with existing reinforcement to comply with the repair remedy and method chosen.

9 Quality control

9.1 General

The execution of the work shall be carried out in accordance with a quality plan prepared for the project. The personnel performing the work shall have the required skill and experience, and have the required equipment available to ensure a satisfactory performance of the work in accordance with the work specification.

Products and systems for the execution of work shall satisfy the quality control requirements in ISO 22966 or guidelines valid in the place of use.

The storage conditions and periods for use of products and systems shall comply with Clause 5 and the product manufacturer's specification.

9.2 Quality control tests and observations

The properties of the substrate, acceptance for suitability of products and systems, the conditions for their application, and final properties of the hardened products and systems, shall be subject to quality control which shall be undertaken using tests and observations given in Table 4.

References for test methods are given for tests in ISO 1920-2, ISO 1920-3, ISO 1920-4, ISO 1920-5, ISO 1920-6 and ISO 1920-7. Where no International Standard exists, reference can be given to national or regional standards or test methods valid in the place of use.

Maximum and minimum parameters and frequency of observation or testing shall be in accordance with the project specification. If no frequency is specified, those given in Table 4 shall apply. If no maximum and minimum parameters are specified, guidance is given in A.6.2.

When methods not included in this document are used, similar requirements for quality control are necessary.

The status of the characteristics to be tested is as follows:

- ■ For all intended uses
- ⧫ For certain intended uses where required by the specific or operating conditions
- □ For special applications only

10 Maintenance following completion of remedial action

Unless otherwise agreed, the following shall be provided to the owner or owner's representative.

a) Documentation of repairs that have been carried out, including information on all used materials and any test results.

b) Documentation of any quality control and assurance requirements completed during the execution of the repair design.

c) Instructions on inspection and maintenance to be undertaken during the remaining design service life of the repaired part of the concrete structure.

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11 Health, safety and the environment

It is the responsibility of the user of this document to ensure that the requirements of the relevant health and safety, environment protection and fire regulations in the place of use are taken into consideration for the execution of the repairs and the products and systems used.

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Table 4 — Summary of tests and observations for quality control

Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
						Hydrophobic impregnation and impregnation	Surface coating	Filling cracks, voids, or interstices	Application of mortar and concrete	Adding reinforcing steel bars	Installing bonded rebars in preformed holes	Plate bonding	Coating reinforcement
						1.1, 1.2, 2.1, 2.2, 5.2, 6.2 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4
Substrate conditions before and/or after preparation													
1	Delamination	Hammer sounding	T		Once before application	■	■		■			■	
2	Cleanliness	Visual	O			■	■	♦	■		■ [a]	■ [c]	■
		Wipe test	T		After preparation and immediately before application								
3	Surface Unevenness	Visual	O		Before application		■					■	
4	Roughness	Visual	O				♦		♦		■ [b]	■	
		sand test	T	ISO 3274 and ISO 21920-3									
		or profile meter	T										
5	Surface tensile strength of substrate	Pull-off test	T			♦	♦		♦			■	

[a] Cleanliness of concrete substrate or hole.

[b] Roughness of concrete substrate or hole.

[c] Cleanliness of plates and concrete substrate.

[d] Moisture content of crack and surrounding concrete.

[e] Water for mixing should be chemically tested if written confirmation of potable water is not available.

[f] Consistency of grouting cementitious or polymer grout.

[g] Dry thickness of protective coating on plates.

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Table 4 *(continued)*

Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
						Hydrophobic impregnation and impregnation	Surface coating	Filling cracks, voids, or interstices	Application of mortar and concrete	Adding reinforcing steel bars	Installing bonded rebars in preformed holes	Plate bonding	Coating reinforcement
						1.1, 1.2, 2.1, 2.2, 5.2, 6.2 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4
6	Crack width and depth	Mechanical or electrical gauge,	O					♦					
		Core and visual,	O										
		or Ultrasonic	T	ISO 1920-7									
7	Crack movement	Mechanical or electrical gauges	O				□	♦	□			♦	
8	Vibration	Accelerometer	O						□			♦	
9	Moisture content of substrate and cracks	Visual	O		Before and during application								
		Site sampling and laboratory analysis,	T			♦	♦	♦ [d]			♦	■	
		Resistivity test,	T										
		Relative humidity probes	T										
10	Temperature of substrate	Thermometer	O		Throughout application	■	■		■			■	■
11	Carbonation	Phenolphthalein test	T			♦			□			♦	

[a] Cleanliness of concrete substrate or hole.

[b] Roughness of concrete substrate or hole.

[c] Cleanliness of plates and concrete substrate.

[d] Moisture content of crack and surrounding concrete.

[e] Water for mixing should be chemically tested if written confirmation of potable water is not available.

[f] Consistency of grouting cementitious or polymer grout.

[g] Dry thickness of protective coating on plates.

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Table 4 *(continued)*

Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
						Hydrophobic impregnation and impregnation	Surface coating	Filling cracks, voids, or interstices	Application of mortar and concrete	Adding reinforcing steel bars	Installing bonded rebars in preformed holes	Plate bonding	Coating reinforcement
						1.1, 1.2, 2.1, 2.2, 5.2, 6.2 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4
12	Chloride Content	Site sampling and chemical analysis	T			♦			□			♦	
13	Penetration of other contaminants	Site sampling and chemical analysis	T				♦		□				
14	Crack contamination	Core and chemical analysis	T					♦					
15	Electrical resistivity	Wenner test	T						□				
16	Cleanliness of existing reinforcement	Visual	O	ISO 8501-1	Once before application					■			
17	Size of existing reinforcement	Visual	O							■	■		
18	Corrosion of existing reinforcement	Half-cell tests	T							♦	♦	♦	
		or visual	O										
19	Cleanliness of reinforcing plates	Visual	O	ISO 8502-2, ISO 8502-3, ISO 8502-4	Once before application						■		

[a] Cleanliness of concrete substrate or hole.

[b] Roughness of concrete substrate or hole.

[c] Cleanliness of plates and concrete substrate.

[d] Moisture content of crack and surrounding concrete.

[e] Water for mixing should be chemically tested if written confirmation of potable water is not available.

[f] Consistency of grouting cementitious or polymer grout.

[g] Dry thickness of protective coating on plates.

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Table 4 *(continued)*

Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
						Hydrophobic impregnation and impregnation	Surface coating	Filling cracks, voids, or interstices	Application of mortar and concrete	Adding reinforcing steel bars	Installing bonded rebars in preformed holes	Plate bonding	Coating reinforcement
						1.1, 1.2, 2.1, 2.2, 5.2, 6.2 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4
36	Compressive strength	Core and crushing test	T	ISO 1920-3, ISO 1920-4, ISO 1920-6					♦			♦	
		Rebound hammer test	T	ISO 1920-7									
Acceptance of products and systems													
20	Identity of all applied products	Written certification	O		Before use	■	■	■	■	■	■	■	■
Condition and requirements before and/or during application													
21	Ambient temperature	Thermometer	O		Throughout application	■	■	■	■		■	■	■
22	Ambient humidity	Hygrometer	O		Throughout application	■	♦	♦			■	■	■
23	Precipitation	Visual	O		Daily	■	■	♦	■	♦	♦	■	♦
24	Wind strength	Anemometer	O		Before use	■	■						
25	Dew Point	Hygrometer and thermometer	O		Throughout application If product requires it	♦	♦					■	♦
26	Wet thickness of coating	Comb or wheel gauge	T	ISO 2808	After application		♦						

[a] Cleanliness of concrete substrate or hole.

[b] Roughness of concrete substrate or hole.

[c] Cleanliness of plates and concrete substrate.

[d] Moisture content of crack and surrounding concrete.

[e] Water for mixing should be chemically tested if written confirmation of potable water is not available.

[f] Consistency of grouting cementitious or polymer grout.

[g] Dry thickness of protective coating on plates.

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Table 4 *(continued)*

Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
						Hydrophobic impregnation and impregnation	Surface coating	Filling cracks, voids, or interstices	Application of mortar and concrete	Adding reinforcing steel bars	Installing bonded rebars in preformed holes	Plate bonding	Coating reinforcement
						1.1, 1.2, 2.1, 2.2, 5.2, 6.2 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4
27	Consistency of concrete	Slump test	T	ISO 1920-2	Daily or for each batch								
		Vebe test	T	ISO 1920-2									
		Flow table test	T	ISO 1920-2									
		Flow trough test	T						■		■ [f]		
	Consistency of mortar and cement grout	Flow trough test	T										
		Flow table test	T										
		Overhead test	T										
28	Air content of fresh concrete	Pressure method	T	ISO 1920-2					♦				
34	Thickness or cover of repair material	Core and visual	O		Once after repair				■				
		Cover meter test	T										
36	Compressive strength	Cube and crushing test	T	ISO 1920-3, ISO 1920-4 and ISO 1920-6	Once after repair								
		Rebound hammer test	T	ISO 1920-7									
40	Position of reinforcement	Visual or	O		Once before application								
		Cover meter	T										

[a] Cleanliness of concrete substrate or hole.

[b] Roughness of concrete substrate or hole.

[c] Cleanliness of plates and concrete substrate.

[d] Moisture content of crack and surrounding concrete.

[e] Water for mixing should be chemically tested if written confirmation of potable water is not available.

[f] Consistency of grouting cementitious or polymer grout.

[g] Dry thickness of protective coating on plates.

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Table 4 *(continued)*

Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
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						1.1, 1.2, 2.1, 2.2, 5.2, 6.2 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4
Final hardened condition													
1	Delamination	Hammer sounding	T		Once per member type to judge efficiency of repair				■				
15	Electrical resistivity	Wenner test	T						□				
29	Dry thickness of coating	Wedge cut or quantity measurement	T	ISO 2808	Once to judge the efficiency		■					♦ [g]	♦
30	Covering of coating	Visual	O	ISO 4628-1, ISO 4628-2, ISO 4628-3, ISO 4628-4, ISO 4628-5, ISO 4628-6	Once to judge the efficiency		■						■
31	Penetration of impregnation	Core and visual,	O			♦							
		Quantity measurement	T	ISO 2808									

[a] Cleanliness of concrete substrate or hole.

[b] Roughness of concrete substrate or hole.

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[d] Moisture content of crack and surrounding concrete.

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Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
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						1.1, 1.2, 2.1, 2.2, 5.2, 6.2 8.1, 8.2	1.3, 2.3, 5.1, 5.4, 6.1, 7.1, 7.6, 8.3, 9.1	1.5, 4.5, 4.6	3.1, 3.2, 3.3, 4.4, 5.3, 6.3, 7.1, 7.2, 7.4	4.1	4.2	4.3	5.4
32	Permeability of coating or repair material or filled cracks to water	Karsten test	T		Once to judge the efficiency	■	♦	♦	♦				
		Core and penetration test	T	ISO 1920-5									
33	Degree of filling of cracks	Core and visual or	O					♦					
		ultrasonic test	T	ISO 1920-7									
34	Thickness of cover	Core, visual or		ISO 1920-6	Once per member type				■				
		covermeter test											
35	Adhesion of coating, adhesion of repair material	Cross-cut test	T	ISO 2409	Once for each type of surface or member		■		■				
		Pull-off test	T	ISO 4624									
36	Compressive strength	Core and crushing or	T	ISO 1920-3, ISO 1920-4 and ISO 1920-6	Once per member type				■				
		Rebound hammer	T	ISO 1920-7									

[a] Cleanliness of concrete substrate or hole.

[b] Roughness of concrete substrate or hole.

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Table 4 *(continued)*

Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
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37	Density of hardened concrete	Oven dry method	T	ISO 1920-5	Once after repair				■				
38	Shrinkage cracking in repair mortar and concrete	Mechanical gauge and visual	O		Once to judge the efficiency				■				
39	Presence of voids in and behind hardened repair material	Ultrasonic test or	T	ISO 1920-7					♦				
		radiography or	T										
		core and visual	O										
40	Position of reinforcement	Visual	O							■	■		
		Cover meter test	T										
41	Bond of reinforcement	Pull out test	T		As required					♦	♦		
42	Presence of voids between bonded plates and substrate	Impact echo test	T		Once to judge the efficiency								
		Hammer sounding	T									■	
		Ultrasonic test	T	ISO 1920-7									

[a] Cleanliness of concrete substrate or hole.

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[c] Cleanliness of plates and concrete substrate.

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Table 4 *(continued)*

Test or observation no. See A.6.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method no. in Table 1							
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43	Structural performance	Load test	T		As required							♦	
44	Adhesion of crack filling material to substrate	Core and visual	O					□					
		Core and compaction test	T	ISO 1920-6									
45	Colour and texture of finished surfaces	Visual	O						♦				

[a] Cleanliness of concrete substrate or hole.

[b] Roughness of concrete substrate or hole.

[c] Cleanliness of plates and concrete substrate.

[d] Moisture content of crack and surrounding concrete.

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Annex A
(informative)

Commentary on the execution of repairs

A.1 Structural stability during preparation and repair

Deterioration damage and the process of repair can cause reduction in the load bearing capacity of the structure. This should be taken into account in the design of the repair method and subsequent application, any requirement for the permanent or temporary removal of dead and live loads, the provision of temporary or permanent additional support and the design of the order of the repair to accommodate the load.

Although many repairs do not affect structural performance, it should be recognized that successive repairs carried out to the same concrete structure over a period of time can create a danger of progressive weakening caused by repeatedly cutting away structural concrete and replacing it with new material.

The replacement material cannot carry its share of the load if it has different properties to those of the materials removed, because of shrinkage or initial thermal contraction, or because of stresses in the structure at the time of the repair.

A.2 General requirements

If vibration (for example, due to construction operations or traffic) is expected during the setting of repair concrete or mortar, the selected product or system should be capable of withstanding the vibration without adverse effects or the vibration should be reduced or eliminated by restricting its causes to the necessary extent. See also A.4.3.2 and A.5.1.

A.3 Methods of repair

The methods 1.4, 1.6 and 11.3 are described below.

a) Method 1.4 Surface bandaging of cracks

The method is to seal cracks in the concrete to prevent the passage of deleterious agents. Additional quality control testing information is presented in Table A.1.

Free movement shall be maintained. Adhesive shall not be applied to free tape width.

If no other information is available, pre-tests shall be carried out to determine the adhesion and tightness of bandages against penetrants.

The relevant characteristics to be tested are shown in Table A.1.

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Table A.1 — Quality control method 1.4

Status of test or Observation	Characteristic	Test method or observation (including equipment used where relevant)	Frequency of test or observation	Test ref. ISO no. or Test or observation no. in Clause A.6
Substrate conditions before and/or after preparations				
■	Cleanliness	Visual	After preparation and immediately before application	2
♦	Surface tensile strength of substrate	Pull-off		5
♦	Vibration	Accelerometer		8
■	Crack width and depth	Mechanical gauge, Core and Visual or Ultrasonic	Once before application	6
■	Crack movement	Strain gauge, crack magnifier or glass plates	Throughout application	7
■	Temperature of substrate	Thermometer	Throughout application	10
■	Moisture content of surrounding concrete	Site sampling and Laboratory test Visual or resistivity test, relative humidity probes	Before and during application	9
Acceptance				
■	Identity once before use	Written certification	Before application	20
Conditions and requirements before and/or during application				
■	Ambient temperature	Thermometer	Throughout application	21
♦	Ambient humidity	Hygrometer	Throughout	22
			application	
♦	Precipitation	Visual	Daily	23
♦	Dew point	Hygrometer and	Throughout	25
		thermometer	application if product requires it	
■	Adhesion	Pull-off	On completion	35

b) Method 1.6 Transferring cracks into joints

This method makes use of existing cracks as an integral part of the structure. The design of the joint and use of materials shall be in accordance with ISO 22966 or guidelines valid in the place of use.

Joints shall be formed in accordance with the relevant standards or guidelines valid in the place of use.

c) Method 2.5 Electrochemical treatment

This method shall be designed and executed in accordance with ISO 12696 or guidelines valid in the place of use.

d) Method 4.1 Adding or replacing embedded or external steel

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There is a risk of promoting electrochemical action if new reinforcement is added to structures infected with chlorides

e) Method 7.1 Increasing cover to reinforcement with additional mortar or concrete or coating

The application of surface coatings can assist in the preservation of passivity.

f) Method 9.1 Limiting oxygen content (at the cathode) by saturation or surface coating

The effectiveness of saturation to prevent oxygen transmission to the reinforcement depends upon the gaseous oxygen impermeability achieved when saturated with water. The effectiveness when surface coatings are used depends upon the characteristics of the surface coating.

g) Method 11.2 Barrier coating of the reinforcement

The effectiveness of the method depends upon the ability of the coating to isolate the reinforcement from the local environment, and so it is important that there are no gaps in the coating.

h) Method 11.3 Applying corrosion inhibitors in or to concrete

Inhibitors are applied as a surface treatment or are added to repair products and systems.

Inhibitors act as chemical agents which discourage the formation of anodic regions on the reinforcement. Their effectiveness depends on the ability of the product and system to penetrate and affect the surface of the reinforcement. The effectiveness of such products is not well documented.

A.4 Preparation of substrate

A.4.1 General

Dust and loose fine material left on the substrate after concrete has been removed, can contain enough unhydrated cement to set in the presence of moisture. Although the material is weak, once set it can be very difficult to remove from the rough surface of the prepared substrate and it is important to remove it before setting can occur.

Pull-off tests can only be used to measure the surface tensile strength of the surfaces which are reasonably flat.

The methods of cleaning, roughening and removal include the following.

a) Cleaning

   1) Mechanical percussion and abrasion

   2) Grit and sand blasting

   3) Water with low pressure

b) Roughening Mechanical percussion and abrasion

   1) Grit and sand blasting

   2) Water with high pressure

c) Removal Mechanical percussion

   Water with high to very high pressure

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A.4.2 Preparation of concrete

A.4.2.1 Cleaning

The purpose of cleaning is to remove dust, loose material and contaminants so as to improve the bond between the cleaned surface of the concrete substrate and the material being applied. Water blasting, clean compressed air, and vacuum cleaning are effective methods.

Where contaminants are on or have penetrated beneath the surface, it can be necessary to remove them using methods for example involving the use of solvents or steam cleaning.

Chlorides and other contaminants can be detected by site sampling and chemical analysis.

Contaminants embedded in the surface can include tie wire, nails and timber.

Cleaning of concrete surfaces without removal of concrete is normally performed with water pressures up to 18 MPa.

Water blasting, using high water pressure techniques, is used for cleaning or superficial removal of concrete. Membranes, asphalt residues, colour markings and laitance are other examples of materials which can be removed.

Cracks and joints can be cleaned with water jetting, flushing with water or compressed air.

When using compressed air, care shall be taken that the air is clean and does not contaminate the substrate with oil.

A.4.2.2 Roughening

Roughening is used for removal of concrete and gives a textured surface with good bonding for a new layer of concrete or mortar cast, applied or sprayed onto original concrete.

A.4.2.3 Concrete removal

The extent of the removal should take into account the relevant factors and any need to provide uncontaminated cover on all sides of the reinforcement.

Structural considerations can limit the extent of the removal.

Where methods 7.3, 7.5 and 10.1 are to be used, honeycombed or delaminated concrete, surface coatings, and previous repairs with unacceptably high electrical resistivity should be removed. For these methods, it is not necessary to remove original sound concrete from around reinforcement.

Tying wire fragments, nails and other metal debris embedded in the concrete should be removed where possible.

The edges where concrete is removed should be cut at a minimum angle of 90° to avoid undercutting and a maximum angle of 135° to reduce the possibility of debonding with the top surface of the adjacent sound concrete and should be roughened sufficiently to provide a mechanical key between the original material and the repair product.

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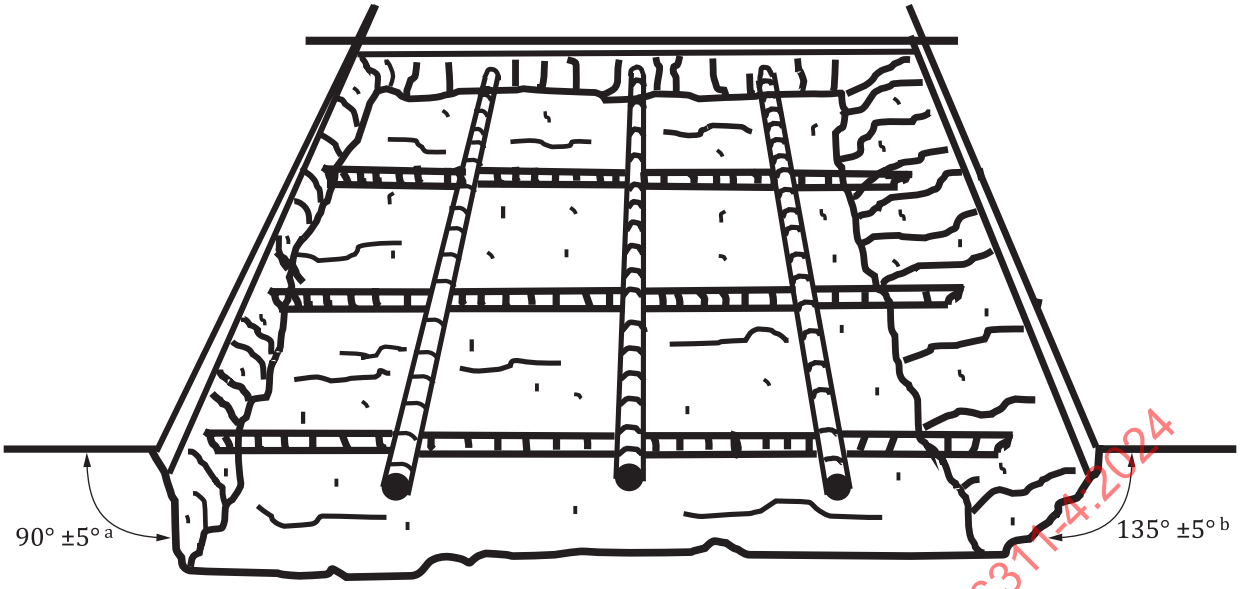

a Minimum angle.

b Maximum angle.

Figure A.1 — Concrete removal

If corrosion is present on the circumference of the reinforcing bar which is exposed after removal of damaged concrete, the depth of removal will possibly need to be increased to expose the whole bar depending on the repair specification. The clearance around reinforcement and the minimum distance between the reinforcement bar and the remaining substrate should be at least 15 mm or the maximum aggregate size of the repair material plus 5 mm whichever is the greater to allow proper compaction. Chloride contaminate concrete should be removed on all sides of the reinforcement for a minimum of 20 mm.

If there is no corrosion on the reinforcement, carbonated, and/or chloride contaminated concrete can remain if electrochemical methods are used or the concrete is sufficiently dry.

In thermal and mechanical removal of concrete, micro-cracks can occur in the concrete left in place. The layer containing micro-cracks should be removed using water blasting with or without abrasive or should be treated to restore its integrity if the surface tensile strength is not sufficient for the products and systems to be applied. Cracking can be detected by wetting the surface and allowing it to dry. Cracks retain water and can be seen as dark lines. If thermal processes are used to remove concrete, the introduction of heat shall be carefully controlled to prevent damage and if damage occurs, further removal carried out by other means to remove any contaminated concrete.

Hydrodemolition is a fast and effective way of removing concrete, keeping the removal of sound concrete to a minimum. No micro-cracks develop and unsound concrete is removed selectively leaving sound concrete intact. Selection is carried out around a mean removal depth. This procedure can be employed if it is carried out with equipment of known performance. The requirements to be met are to achieve the selection between sound and unsound concrete, to remove concrete without leaving shadows and only a small amount of low ridges underneath the reinforcement and to do the work without creating pits. Removal to a generally predetermined minimum depth is possible, but where concrete is locally weak, the depth of removal will be deeper.

The equipment normally used for selective hydrodemolition operates with a pressure of 60 MPa to 110 MPa. In selective hydrodemolition, it is necessary to specify equipment prequalified for the method. Surface roughness can vary considerably and is affected by the distance between the nozzle and the substrate, water pressure, water flow, feed rate, equipment and concrete quality.

Water pressure, which is usually metered at the pump, can be categorised as follows:

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— Low Pressure Up to 18 MPa - Used for cleaning concrete and steel substrate.

— High Pressure 18 MPa - 60 MPa - Used for cleaning steel substrate and for removal of concrete.

— Very High Pressure 60 MPa - 110 MPa - Used for concrete removal when low water volume is necessary.

Cutting with high pressure water is defined as cutting with a water jet so that a narrow slit or small hole is formed. The method is used, for example, to cut away parts or make holes in reinforced concrete. By adding abrasives to water, it is also possible to cut steel.

A.4.3 Preparation of reinforcement

A.4.3.1 General

Structural performance can be changed by loss of section or pitting of the reinforcement.

A.4.3.2 Cleaning

For practical reasons, cleaning will normally be to the whole periphery of the bar. It will normally extend 50 mm or more beyond the extent of the corrosion along the length of the bar. Structural considerations can limit the amount of concrete which can be removed and the cleaning which can be carried out. Potential mapping can assist in detecting corrosion.

The standard of cleaning for method 11.1, using coatings with active pigment, is normally to Sa2, “thorough blast-cleaning”. For method 11.2, using barrier coatings to Sa2½, “very thorough blast-cleaning”, is normally specified. Cleaning can be difficult to achieve under site conditions.

Where access for cleaning is prevented or difficult due to bar congestion, contact between bars, proximity to the concrete substrate, or other bars or other factors, the method and standard of cleaning should be specified. If corrosion products and contaminants cannot be removed or, if the coating cannot be applied to all areas intended to be treated, the performance of the coating can be changed. Sa standards for blast-cleaning are given in ISO 8501-1. Any method of cleaning, including grit blasting, can be used.

Removal of chlorides on the surface of the steel or in pits in the steel, can only be achieved by water under pressure, normally at low pressure below 18 MPa but if low volumes of water are required, pressures up to 60 MPa can be necessary.

A.5 Application of products and systems

A.5.1 General

The temperature of the substrate and repair mortar or concrete should not differ materially to avoid the risk of loss of bond and loss of hydration.

Surface working of concrete or mortar can cause the formation of shrinkage cracks as the treatment can give rise to a cement rich surface layer.

A.5.2 Defects in concrete and structural strengthening

A.5.2.1 Bonding

A rough surface profile is beneficial for the bond between old and new concrete and repair products and systems. This can be achieved by hydrodemolition or mechanical means. The roughness produced by hydrodemolition is considerably greater than that produced by mechanical hammers, which is in turn greater than that produced by grit blasting. If hydrodemolition is used, there is normally a good bond between the concrete substrate and the repair material and mechanical connection is not necessary for the transfer of shear and tensile stress if below that provided by the bond capacity.

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A textured surface can be given to the surface of repair mortar or concrete before it has set to assist in the mechanical key for a subsequent layer.

Where cementitious or polymer repair products and systems are used, it should be decided whether it is appropriate to apply a bonding primer. The use of bonding coats can reduce bond if the bond coat sets before the application of subsequent products.

Where cementitious repair products and systems are used without a bonding primer and the surface is to be pre-wetted as specified in 8.2.2, 8.2.3 or 8.2.4 for a minimum period, the surface should not be allowed to dry before application of the products and systems. However, surface pores and pits should not contain water when the material is placed, or bond can be diminished. An indication of this is the appearance of the surface which should be dark matt without glistening. The purpose of wetting the surface is to prevent the transfer of water from the repair product to the substrate detrimentally affecting the hydration of the repair product.

Polymer hydraulic mortars can set with a smooth polymer rich layer on the surface, which is harmful to the bond of subsequent layers or surface treatment.

A.5.2.2 Hand applied mortar or concrete

Provision shall be made to allow for the difference in properties between polymer mortar and concrete and cementitious products and systems. General polymer mortar and concrete have higher coefficients of thermal expansion and higher resistance to water vapour and lower resistance to fire or high temperatures than cementitious alternatives.

Polymer mortar and concrete can be used underwater or where high abrasion resistance is necessary, fast gain of strength or thin layers are required, or where it is impossible to provide curing for cementitious materials.

A.5.2.3 Sprayed concrete and repair mortar

Sprayed concrete and mortar can be applied by the wet or dry process

Sprayed concrete or mortar should be applied at an angle as close as possible to 90 degrees to the substrate, and at a distance of between 0,5 m and 1,0 m between the nozzle and the substrate.

If sprayed concrete is applied to a thickness greater than 70 mm, it can be necessary to incorporate reinforcement within it to prevent the development of shrinkage cracking and to assist in mechanical bond

Care is required to avoid the formation of voids behind the reinforcement.

For sprayed concrete which has set between layers, that is not wet on wet, the surface should be cleaned by low pressure water or compressed air. Sprayed concrete does not normally require a bonding coat.

An additional non-structural layer can be applied if there are special requirements for the surface of the repair material, for example, if finished with rule or hand tools.

A.5.2.4 Cast repair mortar or concrete

Drainage layers on formwork surfaces prevent the formation of surface voids and decrease the water cement ratio of the surface layer.

A.5.2.5 Curing

Where it is important to avoid cracks caused by plastic or drying shrinkage, curing of hydraulic mortar and concrete (cc) is most effectively carried out by supplying an excess of water over the surface. If it is usually impractical to apply water manually throughout the required curing period but the use of perforated hoses to feed water to absorbent material (e.g. hessian) covered with transparent plastic sheeting is economical and very effective even under the most severe drying conditions.

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