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Maintenance and repair of concrete structures —

Part 4: Execution of repairs and prevention

Entretien et réparation des structures en béton —

Partie 4: Exécution des réparations et prévention

Reference number
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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 documents 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 7, *Maintenance and repair of concrete structures*, the secretariat of which is held by KATS. ISO 16311 consists of four parts:

— *Part 1: General principles*

— Part 2: Assessment of existing concrete structures

— *Part 3: Design of repairs and prevention*

— *Part 4: Execution of repairs and prevention*

Introduction

This part of ISO 16311 defines and specifies site application of products and systems and quality control of the work. To be operable, this part of ISO 16311 needs a National Annex or a reference to where national complementary provisions are given. This part of ISO 16311 can also be applied on specific projects where a project specification will supplement the standards in lieu of a National Annex applicable in the place of use.

The execution of maintenance and repair of concrete structures is an important and integral part of the complex process of protection and repair, and this part of ISO 16311 specifies how it shall be carried out. The specifications in this part of ISO 16311 are part of the definition of the intended use for the relevant products and systems. The execution shall be in accordance with this series of International Standards: ISO 22966, ISO 22965-1, ISO 22965-2, ISO 2394, and any other relevant ISO and National Standards valid in the place of use.

This part of ISO 16311 incorporates rules for the use of maintenance and repair materials and systems that are covered by International Standards. Until International Standards are developed, the standards cited in the National Annex (often regional or national standards) for materials and systems shall be followed.

Maintenance and repair methods applying traditional concrete construction work are listed in this part of ISO 16311, but reference is made to relevant standards.

Maintenance and repair methods applying electrochemical methods, e.g. cathodic protection, realkalisation of carbonated concrete, and chloride extraction, are listed in this part of ISO 16311, but reference is made to standards or guidelines valid in the place of use.

Maintenance and repair shall be executed according to a project specification including the necessary requirements on remedies, methods, and materials per ISO 16311-3.

This part of ISO 16311 contains an Annex A which provides guidance and background information to the normative text. The contents of Annex A are numbered in the same way as the normative text to facilitate reference, but prefixed with “A”.

Maintenance and repair of concrete structures —

Part 4: Execution of repairs and prevention

1 Scope

This part of ISO 16311 gives requirements for substrate condition before and during application, including structural stability, storage of materials, the preparation, and application of products and systems for the protection and repair of concrete structures, including quality control and qualifications of personnel, maintenance, health and safety, and the environment.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 1920-5:2004, *Testing of concrete — Part 5: Properties of hardened concrete other than strength*

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

ISO 1920-7:2004, *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, *Paints and varnishes — Determination of film thickness*

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

ISO 4288, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture*

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*

ISO 4628-5, *Paints and varnishes — Evaluation of degradation of coatings — Designation 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 degradation of coatings — Designation 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 4677-1, *Atmospheres for conditioning and testing — Determination of relative humidity — Part 1: Aspirated psychrometer method*

ISO 4677-2, *Atmospheres for conditioning and testing — Determination of relative humidity — Part 2: Whirling psychrometer method*

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 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 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, *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 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*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 16311-1, ISO 2394, ISO 13822, and ISO 19338 and the following apply.

3.1
bond
the 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 (i.e. a bond breaker is required) 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
hydraulic mortars and hydraulic concrete
mortars or concrete based on a hydraulic binder which is blended together with graded aggregates and can include admixtures and additions which, when mixed with mortar, set by hydrated reaction

3.6
mortars or concrete
hydraulic, polymer hydraulic, and polymer mortar and concrete

3.7
polymer hydraulic cement mortars and concrete
hydraulic mortars or concrete modified by the addition of a polymer

3.8
polymer mortars and polymer concretes
blended mixture of polymer binder and graded aggregate which set by polymerisation reaction

3.9
preformed hole
hole or slot formed or cut in concrete into which reinforcement or other fixing is to be anchored

3.10
quality plan
programme to ensure that the activities of a process are undertaken to comply with the intended design

3.11
overspray
airborne debris resulting from the application of sprayed concrete or mortar which can form an unwanted coating on the substrate

3.12
sprayed mortar or concrete
mortar or concrete applied under pressure through a nozzle delivered through pipes

3.13
wet on wet
application of a cementitious mortar or concrete onto the surface of a similar material which has set but not hardened

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 protection and repair, ambient conditions, and the characteristics of the materials contained in the structure and those of the protection and 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.

— The achievement of the compatibility of the original concrete and reinforcement with the protection or 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 protection and 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 prevention and repair

The remedies and methods of prevention and repair, given in Table 1 of ISO 16311-3, are described below, excluding those methods specified in other International Standards or 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 sub-clauses are given in Table 1 for each method together with any deviations, additions, necessary precautions, and limitations.

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 substrate and the structural status of the structure, so that the products and systems can be properly applied, and shall be carried out in such a way as to produce protection or repair which is in accordance with this and other parts of this part of ISO 16311. The requirements for preparation are given in the following sub-clauses and are related to the methods of repair and protection in Table 2.

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.

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

Repair remedies and methods		Preparation See clauses	Application See clauses	Quality control See clauses
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.5.	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.5.	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

Table 1 — *(continued)*

Remedies and methods		Preparation See clauses	Application See clauses	Quality control See clauses
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 electo-osmotic pulse to reduce water content of the concrete. Refer to A.5.	System dependent	System dependent	System dependent
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, 8.2.4, 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, 8.2.3, 8.2.5, and ISO 22966	9.1, 9.2
3.4	**Replacing structural members**	ISO 2394	ISO 22966	9.1, 9.2

Table 1 — *(continued)*

Remedies and methods		Preparation See clauses	Application See clauses	Quality control See clauses
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 b	9.1, 9.2
4.7	**Prestressing (post-tensioning) or FRP strengthening**	ISO 2394	ISO 22966	9.1, 9.2

Table 1 — *(continued)*

Remedies and methods		Preparation See clauses	Application See clauses	Quality control See clauses
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
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

Table 1 — *(continued)*

Remedies and methods		Preparation See clauses	Application See clauses	Quality control See clauses
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	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
	— Coatings	7.1, 7.2.1, 7.2.2	8.1, 8.2.1, 8.2.7	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.

Table 1 — *(continued)*

Remedies and methods		Preparation See clauses	Application See clauses	Quality control See clauses
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
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

Table 1 — *(continued)*

Remedies and methods		Preparation See clauses	Application See clauses	Quality control See clauses
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.5 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. 8.2.2 and 8.2.5 apply only to cementitious grouts.

[b] 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 needs to 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.

Table 2 — Preparation of substrate

Preparation process	Sub-clause numbers (background information in Annex A)	References	Method numbers							
			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, 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

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 might 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 protection and 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 might 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;

   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 protection and 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 protection and repair are to be used (see A.6.3).

f) For method 11.2 the degree of cleaning shall be to Sa 21/2 (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 protection and repair which is in accordance with other parts of ISO 16311 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 part of ISO 16311.

Protection shall be provided so that preparation, application and subsequent curing shall be carried out in accordance with this part of ISO 16311.

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 part of ISO 16311 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 sub-clauses and are related to the methods of repair and protection in Table 3.

8.2 Structural strengthening to restore member capacity —methods

8.2.1 Bonding

Bonding requirements shall be specified and for applied mortar and concrete, shall comply with a standard 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.

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 the standard for sprayed concrete or guidelines valid in the place of use.

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.

Table 3 — Application of products and systems

Application process	Sub-clause numbers (background information in Annex A)	References	Method numbers							
			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.

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.

Formwork shall be fixed in place as soon as possible after the substrate has been prepared as specified in Clause 7 of this part of ISO 16311. 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.

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 standards 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 of this part of ISO 16311. 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 of this part of ISO 16311.

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 standards 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.7.3.2);

b) Remaining reinforcement shall not be damaged.

8.3.3 Replacement

Added or replaced embedded reinforcement shall comply with 8.2.8 of this part of ISO 16311, ISO 22966, ISO 6935-2, and standards or guidelines valid in the place of use.

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 protection and 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 standards or guidelines valid in the place of use.

The storage conditions and periods for use of products and systems shall comply with Clause 5 of this part of ISO 16311 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 International Standards. Where no International Standard exists, reference can be given to national or regional standards or test methods valid in the place of use.

Tests given in National Standards are informative.

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.8.2.

When methods not included in this part of ISO 16311 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 the protection and 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 and prevention design.

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

11 Health, safety, and the environment

The execution of the repairs and the products and systems used, shall comply with the requirements of the relevant health and safety, environment protection and fire regulations in the place of use.

Table 4 — Summary of tests and observations for quality control

Test or observation number See A.8.2	Characteristic	Test method (or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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
Substrate conditions before and/or after preparation													
1	Delamination	Hammer sounding	T		Once before application	■	■		■			■	
2	Cleanliness	Visual	O			■	■	◆	■		■ 1	■ 3	■
		wipe test	T		After preparation and immediately before application								
3	Surface Unevenness	Visual	O		Before application		■					■	
4	Roughness	Visual,	O				◆		◆		■ 2	■	
		sand test	T	ISO 3274 and ISO 4288									
		or profile meter	T										

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method |or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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	Hydrophobic impregnation and impregnation
						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
5	Surface tensile strength of substrate	Pull-off test	T			◆	◆		◆			■	
6	Crack width and depth	Mechanical or electrical gauge,	O					◆					
		Core and visual,	O										
		or Ultrasonic	T	ISO 1920-7:2004									
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	◆	◆	◆ 4			◆	■	
		Site sampling and laboratory analysis,	T										
		Resistivity test,	T										
		Relative humidity probes	T										

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method |or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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	Hydrophobic impregnation and impregnation
						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
10	Temperature of substrate	Thermometer	O		Throughout application	■	■	◆	■			■	■
11	Carbonation	Phenolphthalein test	T			◆			□			◆	
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							■	■		

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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	Hydrophobic impregnation and impregnation
						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
18	Corrosion of existing reinforcement	Half cell tests	T							◆	◆	◆	
		or visual	O										
19	Cleanliness of reinforcing plates	Visual	O	ISO 8502-2 through –4	Once before application						■		
36	Compressive strength	Core and crushing test	T	ISO 1920-3, –4, and –6					◆			◆	
		Rebound hammer test	T	ISO 1920-7									
Acceptance of products and systems													
20	Identity of all applied products	Written certification	O		Before use	■	■	■	■ 5	■	■	■	■
Condition and requirements before and/or during application													
21	Ambient temperature	Thermometer	O		Throughout application	■	■	■	■		■	■	■

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method |or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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
22	Ambient humidity	Hygrometer	O	ISO 4677-1&2	Throughout application	■	◆	◆			■	■	■
23	Precipitation	Visual	O		Daily	■	■	◆	■	◆	◆	■	◆
24	Wind strength	Anemometer	O		Before use	■	■						
25	Dew Point	Hygrometer and thermometer	O	ISO 4677-1&2	Throughout application If product requires it	◆	◆					■	◆
26	Wet thickness of coating	Comb or wheel gauge	T	ISO 2808	After application		◆						
27	Consistency of concrete	Slump test	T	ISO 1920-2	Daily or for each batch				■		■ 6		
		Vebe test	T	ISO 1920-2									
		Flow table test	T	ISO 1920-2									
		Flow trough test	T										
	Consistency of mortar and cement grout	Flow trough test	T										
		Flow table test	T										
		Overhead test	T										

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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
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, –4 and –6	Once after repair				■				
		Rebound hammer test	T	ISO 1920-7									
40	Position of reinforcement	Visual or	O		Once before application					■	■		
		Cover meter	T										

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method |or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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
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		■					◆ 7	◆
30	Covering of coating	Visual	O	ISO 4628-1-6:2003, 04	Once to judge the efficiency		■						■
31	Penetration of impregnation	Core and visual,	O			◆							
		Quantity measurement	T	ISO 2808									
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 1920-5:2004									

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method |or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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
33	Degree of filling of cracks	Core and visual or	O					◆					
		ultrasonic test	T	ISO 1920-7:2004									
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, –4 and –6	Once per member type				■				
		Rebound hammer	T	ISO 1920-7									
37	Density of hardened concrete	Oven dry method	T	ISO 1920-5	Once after repair				■				

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method |or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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
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 1920-7:2004					◆				
		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					◆	◆		

Table 4 — *(continued)*

Test or observation number See A.8.2	Characteristic	Test method |or observation (including equipment used where relevant)	Test (T) or Observation (O)	ISO Standard reference	Frequency of test or observation	Method numbers							
						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
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 1920-7:2004									
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						◆				

1 Cleanliness of concrete substrate or hole

2 Roughness of concrete substrate or hole

3 Cleanliness of plates and concrete substrate

4 Moisture content of crack and surrounding concrete

5 Water for mixing should be chemically tested if written confirmation of potable water is not available

6 Consistency of grouting cementitious or polymer grout

7 Dry thickness of protective coating on plates

Annex A
(informative)

Commentary on the Execution of Repairs and Prevention

A.1 Additional references

The information and references in Clause A.1 apply to the references given in informative Annex A.

ISO 565, Test sieves — Metal wire cloth, perforated metal plate and electroformed sheet — Nominal sizes of openings

A.2 Definitions

The definitions in Clause 3 apply to the annex.

A.3.1

blasting

removal of matter from the concrete substrate to a maximum depth of 2 mm

A.3.2

grit blasting

blasting using abrasive as an additive in air

A.3.3

mechanical removal

removal of substrate by percussive or abrasive means

A.3.4

non-selective hydrodemolition

removal of concrete to a selected depth by using high pressure water techniques

A.3.5

selective hydrodemolition

removal of damaged concrete leaving sound concrete of a selected strength using high pressure water techniques

A.3.6

soaking

filling cracks in a horizontal surface by means of gravity using a pond of filling material above the crack

A.3.7

water blasting

blasting using high pressure water with or without abrasives as an additive

A.3 Structural stability during preparation, protection 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 might not 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.4 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.6.3.2 and A.7.1.

A.5 Methods of protection and repair

Some of the methods listed in this International Standard are or will be standardized in national or regional standards. The methods 1.4, 1.6, and 11.3 are described below.

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.

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 number or Test or observation number in Clause A.9
SUBSTRATE CONDITIONS BEFORE AND/OR AFTER PREPARATION				
■	Cleanliness	Visual	After preparation and immediately before application	2
◆	Surface tensile strength of substrate	Pull-off		5
◆	Vibration	Accelerometer		8

Table A.1 *(continued)*

Status of test or Observation	Characteristic	Test method or observation (including equipment used where relevant)	Frequency of test or observation	Test Ref. ISO number or Test or observation number in Clause A.9
■	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	ISO 4677-1&2
◆	Precipitation	Visual	Daily	23
◆	Dew point	Hygrometer and	Throughout	25
		thermometer	application if product requires it	ISO 4677-1&2
■	Adhesion	Pull-off	On completion	35

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 standards 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.

Method 2.5 Electrochemical treatment

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

Method 4.1 Adding or replacing embedded or external steel

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

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.

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.

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.

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.6 Preparation of substrate

A.6.1 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 — Mechanical percussion and abrasion
Grit and sand blasting
Water with low pressure

b) Roughening — Mechanical percussion and abrasion
Grit and sand blasting
Water with high pressure

c) Removal — Mechanical percussion
Water with high to very high pressure

A.6.2 Preparation of concrete

A.6.2.1 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 might 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.6.2.2 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.6.2.3 Concrete removal

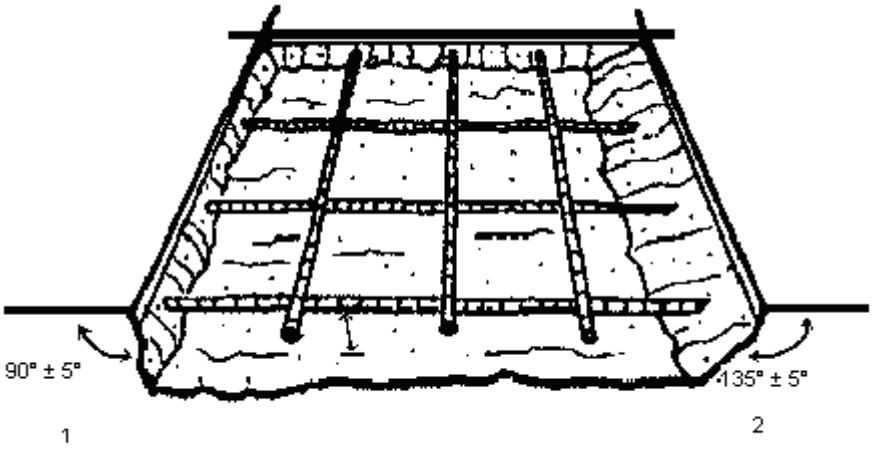
The extent of the removal should take into account the relevant factors and any need to provide uncontaminated cover on all sides of the reinforcement.

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.



Key

1 minimum angle

2 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 might 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 must 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:

— 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 are 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.6.3 Preparation of reinforcement

A.6.3.1 General

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

A.6.3.2 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 Sa21/2, “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 might be necessary.

A.7 Application of products and systems

A.7.1 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.7.2 Defects in concrete and structural strengthening

A.7.2.1 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.

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

A.7.2.2 Hand applied mortar or concrete

Provision must 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.7.2.3 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 might 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, e.g. if finished with rule or hand tools.

A.7.2.4 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.7.2.5 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 (for example hessian) covered with transparent plastic sheeting is economical and very effective even under the most severe drying conditions.

During the hydration and hardening process of the concrete, it is important that the temperature gradient throughout the structure is as flat as possible to avoid thermal cracking.

Products and systems containing polymer modifiers (pcc) have special curing requirements because a balance must be struck between the need to retain moisture to cure the cement and the need to reduce moisture to allow film forming of the polymer component to gain strength.

A.7.2.6 Cracks and joints

Filling cracks can be by injection, soaking, or vacuum techniques. Before filling any cracks contamination such as oil or other contaminants must be removed. The tolerable amount of moisture or water in the cracks depends on the properties of the filling material. Cracks can be cleaned and dried by methods including the use of water and solvents and clean air under pressure. If cracks are injected, sealing of the cracks is usually necessary to ensure that injection can be completed without interruption. Parts of nozzles remaining in the structure should be of material which will not cause electrochemical reaction. Care must be taken that the pressure of injection does not produce further cracks or other detrimental effects to the substrate, other components or the environment. The use of thixotropic grouts can give rise to unacceptably high pressures.

Surplus filling and sealing material is usually removed.

The equipment for soaking must ensure an adequate, uninterrupted flow of the crack-filling material until absorption has ceased.

Other methods of filling cracks are based on vacuum techniques.

If there are significant changes in crack-width during filling and hardening, then the time of injection must be selected where possible to allow re-injection at the moment of maximum crack width and within the workability time of the product.

Crack filling is not appropriate if expansive reaction in the structure is likely.

Cracks should be completely filled if possible. The degree of filling can be established by taking and examining cores or ultrasonic testing. See test no. 33, A.8.2.

Complete filling of fine cracks is difficult to attain. Epoxy resins with a low viscosity and special fine cement/grout, can give good results. This should be proven in pre-tests.

Sealing of cracks with bandages might be preferable if cracks are contaminated, too small for filling or if longitudinal and/or shear movements are more than 25 % of the crack width. If no other information is available, pre-tests might be necessary to determine the adhesion and tightness of bandages.

Cracks might require to be converted into joints if considerable changes in crack-width are expected, e.g. due to thermal effects or structural movement. New joints should be compatible with the existing joints. If reinforcement is to be cut, any harmful effects shall be taken into account, in particular with regard to the load bearing capacity and the corrosion risk. The design of the joint and use of material shall be in accordance with relevant standards or guidelines valid in the place of use.

A.7.2.7 Surface coatings and other treatments

There is a danger of the occurrence of efflorescence when electrochemical processes are used. Unless it is removed, it interferes with the bond between the coating and the concrete.

Surface applied inhibitors can leave a surface deposit which can hinder bond of a subsequent coating.

Impregnation and hydrophobic impregnation can be applied by hand, spray, vacuum method or via a gel.

For Hydrophobic impregnation using a silane or siloxane, the penetration can be improved by applying the material in two stages, wet on wet.

A.7.2.8 Plate bonding or FRP strengthening

Bonded external plate reinforcement can consist of mild steel or fibre reinforced composite or other material of appropriate standard capacity and durability. The use of stainless or high yield steel is not recommended.

Surface preparation of the concrete substrate is recommended as follows:

The surface tensile strength should be established. Weak, damaged and deteriorated concrete should be removed and replaced. When wide enough for repair products to access, cracks should be filled with compatible structural repair material.

A.7.3 Defects caused by reinforcement corrosion

A.7.3.1 Coating reinforcement

Coatings for reinforcement are included in many repair systems. Coating on reinforcement can act as a barrier or can be used to prevent coated areas acting as an anode and so prevent corrosion of untreated reinforcement. Inhibition can also be achieved by surrounding the reinforcement with alkaline cement paste with or without a polymer modifier. If cement paste is used, it should not be allowed to set before cementitious mortar or concrete is applied or placed or the bond between repair material and reinforcement can be adversely affected.

A.7.3.2 Removal and replacement

Additional or replacement reinforcement can be fixed using mechanical connection, by welding, by lapping to existing reinforcement or by anchoring into the concrete substrate.

Reinforcement fixings or other attachments made from dissimilar metals embedded in reinforced concrete, can cause rapid local corrosion of reinforcement if there is direct or indirect electrical contact between them. A similar problem can arise through electrical contact between items made from the same type of steel if they are in different environments, e.g. different concentrations of oxygen.

Care must be taken when removing or replacing reinforcement when using techniques involving the application of heat not to damage either the reinforcement or the concrete substrate.

A.8 Quality control

A.8.1 General

The personnel undertaking the execution of the protection and repair work should be suitably experienced and should possess written evidence of their competence where this is available to them.

As indicated in Clause 9 (Normative), site testing is a method of measuring the characteristics and quality required for products and systems on their arrival on site and for their performance during and after application. Site testing is also a method of measuring the condition of the structure and the substrate on which the products and systems are to be applied and the condition of the environment in which the products and systems are to be applied.

Some test methods are described in International Standards, but where no such standard exists, tests should be carried out in accordance with National standards, guidelines valid in the place of use or in the tests or observations described in A.8.2.

A.8.2 Quality control tests and observations

Table A.2 — Guidance on acceptable maximum and minimum parameters for tests of characteristics is as follows

Test No	Characteristics	Method	Maximum and Minimum Parameter
10	Temperature of substrate	All	Repair material dependent.
23	Precipitation	All	Usually none but some materials can be applied to damp or wet surfaces
24	Wind strength	1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 5.1, 5.2, 5.4, 6.1, 6.2, 7.1, 7.6, 8.1, 8.2, 8.3, 9.1	Wind strength maximum of 8 m/s.
25	Dew point	1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 4.3, 5.1, 5.2, 5.4, 6.1, 6.2, 7.1, 7.6, 8.1, 8.2, 8.3, 9.1, 11.1, 11.2	Depends on material but usually no application at temperatures less than 3 °C above dew point to minimize risk of excess moisture compromising repair material or coating installations
33	Degree of filling of cracks	1.4, 1.5, 4.5, 4.6	Min. 80 % of crack filled.
35	Adhesion	3.1, 3.2,	It depends but can never be greater than the surface
	mortars and concrete	3.3, 4.4, 5.1, 5.4, 6.1, 7.1, 7.2, 7.4, 7.6	tensile strength of the substrate.
35	Adhesion	1.2, 2.3	It depends on and can never be greater than the surface
	surface coatings	5.1, 6.1, 7.1, 8.1, 9.1	tensile strength of the substrate.
36	Compressive strength	3.1, 3.2, 3.3, 4.4, 5.1, 5.4, 6.1, 7.1, 7.2, 7.3, 7.6	Compatibility with the parent concrete is an important factor.
44	Adhesion of crack filling material to substrate	1.5, 4.5, 4.6	It depends, but can never be greater than the surface tensile strength of the substrate.

Description of quality control tests and observations

Test or observation no. 1. Delamination

Tapping or sounding on a concrete surface can be carried out with a light hammer or other impact echo equipment. The purpose is to detect delaminated areas of the concrete structure or loose single aggregates in the surface of the substrate.

Test or observation no. 2. Cleanliness

The surface should be checked visually for the presence of:

— hardened cement and overspray;

— flaws, such as gravel pockets;

— efflorescence;

— powdering and sanding;

— loose particles such as dust or concrete spalling (e.g. above reinforcement);

— organic growths;

— contaminants such as oil, grease or paraffin;

— debonding agents, curing agents or residues of old coatings;

— debonding of mortar.

The presence of dust or contaminates on the surface of the substrate can be detected by visually wiping or scratching the concrete surface. An adhesive strip applied to the surface will indicate the presence of dust when removed

Test or observation no. 3. Surface unevenness

Visual inspection will reveal the presence of cavities pores and pits on the surface of the substrate which would cause an interruption of an even thickness of a bonding or coating film.

Unevenness of substrate can be established using a steel straight edge.

Irregularities can be remedied as specified in 8.2.2, 8.2.6, and 8.2.7.

Test or observation no. 4. Roughness

The roughness can be determined with the use of a profile meter or using the sand area method. The surface texture profile method is described in ISO 3274 and ISO 4288.

Test or observation no. 5. Surface tensile strength of substrate

Surface tensile strength can be measured on site using a pull-off test. It can be used directly on the surface to be tested or at a position on the surface which has been partially cored if strength at a specified depth beneath the surface is required. Care should be taken with the preparation of the surface and the number and position of tests so that they are properly representative.

Test or observation no. 6. Crack width and depth

Crack width can be measured by electrical or mechanical gauge on exposed structures. The most important crack characteristics (crack width and changes in crack width) are subject to weather related changes. When these characteristics are determined, the following additional data should therefore be recorded:

a) date, time;

b) weather conditions i.e. air temperature, cloud cover/rain (including values on preceding days);

c) surface temperature of the component in the crack-relevant zones and in special cases also in the interior of the component.

Drilled cores can be used to determine the type and size of crack, the state of the crack and crack edges and any remedial previous measures. Drilling cores invariably represents a disturbance, and should therefore be restricted to necessary cases. Ultrasonic tests yield also good information on crack characteristics. They can be used only by properly trained and experienced personnel.

Test or observation no. 7. Crack movement

Crack widths can be measured with mechanical or electrical gauges and measurements should be given to an accuracy of at least 0,1 mm. It will usually be sufficient to compare the crack width visually with a calibrated line on a line-width rule. More experience is needed to use a crack magnifier.

Methods with differing sensitivity can be used to measure the changes in distance associated with changes in crack width as follows:

a) line width rule;

b) glass plates or strain gauges can be fixed over a crack;

c) crack magnifier;

d) thin plaster markers can be applied by brush to the concrete surface. When the cracks in the concrete widen, cracks also appear in the plaster. Their width can readily be determined with the crack magnifier. Repeated readings can be used to follow slow changes in crack width, including long-term alterations. If necessary, a number of plaster markers can be applied at intervals to the same crack. The required accuracy and precision of the measurements will need to be determined on a case-by-case basis.

Where changes in crack width during the course of the day are observed, the relevant data must be recorded several times a day. Where changes in crack width are traffic-related, characterization of the traffic might be necessary in order to allow more effective analyses of the results. The selected measuring periods should be such that adequate conclusions on short-term and daily changes in crack width at the planned filling time can be drawn from the results.

On superstructures of monolithic bridges and similar structures exposed to direct weathering, there are daily changes in crack width, in some cases dependent on insulation. The maximum changes are to be expected in cloudless days in the summer months, but not on days with high cloud cover and high air temperatures. At the crack width maximum, traffic influences also usually lead to extreme values of short-term crack width changes.

Test or observation no. 8. Vibration

When applying products or systems, it is important to observe vibration due to causes such as traffic, equipment or windy weather. To register the vibration one can use vibration measurement equipment e.g. an accelerometer. No restrictions on causes of vibration should be made if the vibration values are within the values for dynamic loads accepted by the product or systems during the application.

Test or observation no. 9. Moisture contents of substrate and cracks

The moisture content of the substrate can be evaluated by the following tests and observations:

a) Visual

The surface moisture can be observed using the following approximate guide:

— ‘dry’ - A freshly produced fracture surface with a depth of approximately 20 mm must not become visibly lighter in colour as a result of drying out;

— ‘moist’ - The surface has a matt, moist appearance with no shiny water film; the pore system of the substrate must not be water-saturated i.e. drops of water applied to the concrete substrate must be soaked up, leaving the surface matt again after a short time;

— ‘wet’ - The pore system can be water-saturated; there can be a surface shine on the concrete, but no free surface water.

A further visual indication can be obtained by covering the surface with a polythene film for 24 h. If no moisture is evident the surface and subsurface can be considered dry;

b) with use of relative humidity probes;

c) by measuring the electrical resistivity, using the Wenner probe test, and relating the measurements to absolute moisture content, as measured in the laboratory. There is also a two pin conductivity test which can be related to absolute moisture content;

d) by taking site samples and testing in the laboratory.

The moisture content in cracks can be observed by taking samples or cores and visual observation.

Test or observation no. 10. Temperature of substrate

Measuring the temperature of a concrete or steel surface should be carried out with a thermometer made for measuring surface temperatures. If there is a need for exact measurement of the temperature of a substrate, after a suitable material for ensuring thermal contact with substrate has been applied, the measurement can be carried out as follows. The thermometer should be placed in the position for measurement under the centre of an insulating material such as an expanded polystyrene plate with the size of 0,5 m^2 and 70 mm thick. The measurement should be carried out when the temperature is stable i.e. when the change of the temperature with the passage of time is less than 1 °C/5 min.

Test or observation no. 11. Carbonation testing

The depth of carbonation can be measured using microscopy techniques or the application of a chemical indicator to freshly cut or fractured surfaces. Refer to regional or national methods, and project specification requirements.

Test or observation no. 12. Chloride content

The chloride content of concrete substrate can be obtained by obtaining dust samples and by subsequently testing in the laboratory. Alternatively there are site test systems which can be used that are based on electrochemical technology.

Test or observation no. 13 and No.14. Penetration of other contaminants and crack contamination

The concrete substrate and cracks can be contaminated by agents that cause deterioration of the substrate and repair products and systems and encourage corrosion of reinforcement. Such contaminants include carbon dioxide, chlorides, sulphates and other organic and inorganic substances. The history of the structure and its environment is likely to indicate possible contamination. If contamination is suspected samples can be taken by drilling or coring and tested in the laboratory to establish content and profiles.

Test or observation no. 15. Electrical resistivity

Resistivity of substrate and repair material can be measured by a method based on the Wenner 4 probe method of soil resistivity testing. Resistivity of repair material should be measured on the site applied material or on prepared specimens and is normally specified to be between 50 % and 200 % of that of the substrate for electrochemical methods 7.3, 7.5, and 10.1.

Test or observation no. 16. Cleanliness of existing reinforcement

The required degree of cleanliness of steel reinforcement depends upon the method of repair selected. It is best judged by comparing the appearance of the cleaned steel with that defined in ISO 8501-1 e.g. Sa21/2.

Test or observation no. 17. Size of existing reinforcement

The size of reinforcement should be measured mechanically to establish the cross-section dimensions at positions where corrosion products have been removed to obtain the minimum cross-sectional area so that structural calculations can be made and comparisons made with the specification.

Test or observation no. 18. Degree of corrosion of existing reinforcement

Loss of steel-area on reinforcement due to corrosion can be estimated by measuring mechanically. Special attention should be given to the detection of corrosion pits in the steel.

Epoxy or other impermeable coatings on reinforcement should be inspected closely as cracks or defects in the coating in combination with high chloride levels can give rise to increased corrosion at the damaged position and a reduction in bond of the coating. The reason for the corrosion is that the reinforcing steel is insulated by the coating from the protecting alkaline environment.

Corrosion can also be detected by potential mapping using half cell tests.

Test or observation no. 19. Cleanliness of reinforcing plates

Steel plates should be free of mill scale, rust, grease and other contaminants. The degree of cleanliness should be to Sa 21/2 as defined in ISO 8501-1. Composite plates should be cleaned as specified.

Test or observation no. 20. Identity

Identity can be established by means of marking and labelling samples or by written certificate.

Test or observation no. 21. Ambient temperatures

Ambient temperature can be measured using thermometers. The accuracy of the reading should be at least plus or minus 1° C.

Measurements should be made in the immediate vicinity of the works. The temperature sensor should not be exposed to direct solar radiation. Measurements should be taken sufficiently often to record changes of 2° C and to record reducing or increasing temperature movement.

Test or observation no. 22. Ambient humidity

Ambient humidity can be measured by the methods given is ISO 4677-1&2

Test or observation no. 23. Precipitation

Precipitation can be observed visually or if relevant recorded with the use of a gauge. It can include rain, snow, dew and spray.

Test or observation no. 24. Wind strength

Wind velocity should be measured by means of anemometer so that maximum values during application can be measured and work suspended if so specified.

Test or observation no. 25. Dew point

For the application of many polymers and other products, the substrate must be dry and dew must be avoided unless otherwise specified. The dew point depends directly on the ambient relative atmospheric humidity and on the ambient temperature. It occurs only when the substrate temperature is lower than or equal to the dew point temperature.

The following table (extract of table given in ISO 4677-1&2) gives the temperatures of dew points, knowing the ambient temperature and the ambient relative atmospheric humidity.

Ambient temperature (°C)	Dew point temperatures (°C) for ambient relative humidity between 40 and 100 % RH						
	40 %	50 %	60 %	70 %	80 %	90 %	100 %
35	19,4	23,0	26,1	28,7	31,0	33,1	35
30	15,0	18,5	21,4	23,9	26,2	28,2	30
25	10,5	13,9	16,7	19,6	20,1	23,2	25
20	6,0	9,3	12,0	14,4	16,5	18,3	20
15	1,5	4,2	7,3	9,6	11,6	13,4	15
10	−3,0	0,1	2,6	4,8	6,7	8,5	10
5	−7,0	−4,7	−2,0	0	1,9	3,5	5

The repair or protection product cannot usually be applied when the ambient temperature is less than 3 °C above dew point but this depends on the material (see Table A.2).

The air temperature is measured using a mercury or digital thermometer. The required accuracy is ±0,5 °C.

For the surface temperature measurement, digital electronic thermometers can be used.

Required accuracy: ±0,5 °C.

For the air humidity assessment, see test no. 22.

Test or observation no. 26. Wet thickness of coating

The method no. 1 of ISO 2808 gives two methods for measuring a wet thickness: comb gauge and wheel gauge.

The first seems easier to adapt from its use for measuring paints and varnishes to use for measuring coatings of repair products. The gauge consists of a stainless steel comb, the outer teeth of which form a baseline. The inner teeth are progressively shorter so as to present a range of gaps between the teeth and the baseline, and the size of each gap can be read from a scale on the gauge. Immediately after the application of the product, the comb gauge is placed firmly onto the substrate in such a way that the teeth are normal to the plane of the surface and the gauge does not slip. The gauge is removed and the teeth are examined to determine which is the shortest one to touch the wet coating. Minimum three readings are taken in different places in a similar manner to obtain representative results over the repaired area.

A wheel gauge can also be used.

Test or observation no. 27. Consistency of concrete or mortar

In addition to the Slump, Vebe, and Flow Test table test given in ISO 1920-2, a test using a trough can be used to test the consistency of flowing concrete.

Test or observation no. 28. Air content of fresh concrete

Use the test given in ISO 1920-2.

Test or observation no. 29. Dry thickness of coating

The dry thickness of the surface coating can be measured by knowing the quantity of product applied by using ISO 2808, Method Number 2.

The thickness can also be measured by destructive means such as:

— profilemeter method given in ISO 2808;

— wedge cut method (a special apparatus is available which includes a microscope with illumination devices and cutting tool) given in ISO 2808 method 6B;

— drilling of core samples and measuring the film thickness (is more destructive and there is no standard).

Test or observation no. 30. Covering of coating

Gaps, holes and defects in the coating can be detected visually and as given in ISO 4628-1:2003 to ISO 4628-6:2007.

Test or observation no. 31. Penetration of impregnation

The penetration of impregnation depends on the substrate porosity and on the product penetration ability. It is possible to get an estimation of it by knowing the quantity of product used. For that, ISO 2808 can be used (method No.2 : determination of dry-film thickness by calculation from film mass per unit area).

It is also possible to determine penetration by examination of cores.

Test or observation no. 32. Permeability of coating or repair material or filled cracks to water

The principle of the German Karsten Test is to measure the volume or the weight of water penetrating per unit time into concrete by means of a glass calibrated tube previously sealed watertight to the tested surface. The diameter of the tube, depending on the standard used, can be 20 mm, 50 mm, 100 mm. The height of the water column, depending on the standard used, can be 100 mm, 150 mm, 200 mm.

The results obtained depend on:

— quantity of penetrating water during the time of the test (linear or not, limited or not);

— temperature conditions;

— moisture content of the test area.

Cracks which are filled and with a firm bond between concrete and sealing material can be visually taken as impermeable to water. In doubtful cases cores can be taken and penetration tests carried out as indicated by ISO 1920-5:2004.

Test or observation no. 33. Degree of filling of cracks

Drilled cores are to be taken to assess the degree of filling. Usually small-diameter cores (50 mm or less) are taken from representative sections of the filled cracks.

Ultrasonic test methods as given in ISO 1920-7:2004 can also give information about the state of filling. Present methods available demand expert skill and sophisticated test equipment to produce reliable results on site.

Test or observation no. 34. Thickness or cover of repair materials

Cover of concrete over reinforcement can be established by means of a cover meter which is an electromagnetic device. Concrete cover can also be established by taking cores and by removing repair material.

Test or observation no. 35. Adhesion of coatings, adhesive, and repair material

Adhesion of coatings can be tested using the cross cut test as specified in ISO 2409 and for adhesion of repair materials, a pull off test as specified in ISO 4624. The cross-cut test can be used for layers less than 0,5 mm in thickness and the pull off test for thicker layers.

Test or observation no. 36. Compressive strength

Compressive strength of original precast concrete and hardened repair concrete or mortar, can be measured by means of taking cores and crushing them in accordance with ISO 1920-3, 4 and 6 or with the use of a rebound hammer in accordance with ISO 1920-7. When using the latter method, care should be taken to ensure that the instrument is properly calibrated. The nature of the latter method and the possible variation in the surface of the concrete or mortar make it useful for indication of comparative strength rather than absolute values.

Test or observation no. 37. Density of hardened mortar or cement

The density of hardened repair mortar or cement should be established using tests given in ISO 1920-5. If the density of the original concrete is required it can be established by taking cores and measuring the weight and volume.

Test or observation no. 38. Shrinkage, cracking in repair material

This can be observed visually and measured with a gauge. Very fine cracking can be detected by wetting the surface and allowing to dry. As it dries, the cracks can be seen as they retain water for a longer period then the uncracked surface.

Test or observation no. 39. Presence of cracks and voids in hardened repairs material

Voids including those caused by inadequate compaction, injection, or filling of cracks, can be detected by means of radiography reference, radar, or ultrasonic pulse velocity measurement reference per ISO 1920-7:2004. Alternatively, cores can be taken and visually examined.

Test or observation no. 40. Position of reinforcement

The position of reinforcement with respect to the outer surface of the concrete and to other reinforcement, can be measured mechanically when concrete has been removed or by means of a cover meter when reinforcement is not visible.

Test or observation no. 41. Bond of reinforcement

Refer to national or regional methods provided in the project specifications.

Test or observation no. 42. Presence of voids between bonded plates and substrate

The presence of voids can be detected by tapping or similar impact echo methods and by using ultrasonic testing.

Test or observation no. 43. Load tests

Site load tests might be required if the load bearing capacity of an member or structure has to be established after repair or strengthening.

Test or observation no. 44. Adhesion of crack filling material to substrate

There is no site test for measuring adhesion strength of crack filling material. However, an indication of the adhesion can be established by taking cores and inspecting and by testing the cores to failure using the test.

Test or observation no. 45. Colour and texture of finished surface

The colour and texture of the finished surface of repairs should match as far as possible the original.

A.9 Health, safety, and the environment

Particular care is advisable when dealing with dangerous and radioactive substances.

NOTE 1 Legislations and standards valid in the place of use must be followed.

ICS 91.100.30

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