
**Maintenance and repair of concrete
structures —**

**Part 3:
Design of repairs and prevention**

*Entretien et réparation des structures en béton —
Partie 3: Conception des réparations et prévention*





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Contents

	Page
Foreword	iv
Introduction	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Minimum considerations before repair and prevention design	2
4.1 General	2
4.2 Initial risk assessment	2
4.3 Assessment of defects and their causes	3
5 Strategies for maintenance, repair, and prevention	4
5.1 General	4
5.2 Options	4
5.3 Factors	4
5.4 Choice of appropriate strategy	5
6 Basis for the choice of specific repair and prevention design principles, strategies, remedies, and methods	6
6.1 General	6
6.2 Repair remedies and methods of maintenance, repair, and prevention	6
7 Properties of products and systems required for compliance with repair and prevention remedies	8
8 Design documentation requirements	9
9 Compliance with health, safety, and environmental requirements	9
10 Competence of personnel	9
Annex A (informative) Design of repairs and prevention	10
Bibliography	22

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).

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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*.

ISO 16311 consists of the following parts, under the general title *Maintenance and repair of concrete structures*:

- *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

The repair and prevention of defects and deterioration in concrete structures requires complex design work. This part of ISO 16311 defines the design principles, strategies, remedies, and methods for preventing accelerated deterioration and the repair of concrete structures that have suffered or may suffer damage or deterioration. It gives guidance on the choice of repair design principles, strategies, remedies, methods, and selection of products and systems which are appropriate for the intended use.

This part of ISO 16311 identifies key stages in the repair process:

- the need for assessment of the condition of the structure;
- the need for identification of the causes of deterioration;
- evaluating the options for repair and prevention, and decision-making;
- the selection of the appropriate remedies for repair and prevention;
- the selection of methods;
- the definition of properties of products and systems;
- the specification of maintenance requirements following repair and prevention.

This part of ISO 16311 does not deal with matters related to structural design and the verification of structural performance in both deteriorated and repaired condition. The information related to the deteriorated condition is presented in ISO 16311-2.

This part of ISO 16311 contains an [Annex A](#) which provides guidance and background information on the normative text.

Maintenance and repair of concrete structures —

Part 3: Design of repairs and prevention

1 Scope

This part of ISO 16311 defines basic considerations and decision-making for the specification of repair and prevention remedies, and management strategies for reinforced and unreinforced concrete structures using products and systems specified in other International Standards or Technical Specifications. This part of ISO 16311 covers only atmospherically exposed structures, and buried or submerged structures, if they can be accessed.

This part of ISO 16311 specifies repair and prevention design principles, and strategies for defects and on-going deterioration including, but not limited to:

- a) mechanical actions, e.g. impact, overloading, movement caused by settlement, blast, vibration, and seismic actions;
- b) chemical and biological actions from environments, e.g. sulfate attack, alkali-aggregate reaction;
- c) physical actions, e.g. freeze-thaw, thermal cracking, moisture movement, salt crystallization, fire, and erosion;
- d) reinforcement corrosion;
- e) original construction defects that remained unaddressed from the time of construction.

The execution of maintenance and repairs is covered in ISO 16311-4.

Further background information on the scope of this part of ISO 16311 is given in [Annex A](#).

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 14040, *Environmental management — Life cycle assessment — Principles and framework*

ISO 14044, *Environmental management — Life cycle assessment — Requirements and guidelines*

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16311-1 and the following apply.

3.1 defect

fault, or deviation from the intended level of performance of a structure or its parts

[SOURCE: ISO 15686-1:2000]

3.2 design service life

specified period of time for which a structure or its members is to be used for its intended purpose without major repair being necessary

[SOURCE: ISO 16311-1]

3.3 maintenance

set of activities undertaken to check, evaluate the performance of a structure and preserve/restore it so as to satisfy its performance requirements in service

[SOURCE: ISO 13823:2008]

3.4 passivity

state in which steel in concrete is protected by a thin film and the corrosion rate is minimized

Note 1 to entry: This film is destabilized or lost when concrete carbonates to the level of the reinforcing steel, when aggressive salts concentrate and attack the steel, or atypically, when all oxygen is depleted at the surface of the steel (i.e. submerged concrete members after many years).

3.5 prevention

remedial action to prevent or slow down further deterioration of a structure or structural member and reduce the possibility of damage to the user or any third party, inhibiting the progress of deterioration, and proactively preventing deterioration

3.6 protection

measure that is intended to prevent or reduce the development of defects in the structure

3.7 repair

restoration of a structure or its components to an acceptable condition by the renewal or replacement of worn, damaged, or deteriorated components

[SOURCE: ISO 13823:2008]

4 Minimum considerations before repair and prevention design

4.1 General

This clause outlines procedures that shall be undertaken to assess the current condition of a concrete structure prior to designing repair and prevention programs.

General guidance is given in [Annex A](#).

4.2 Initial risk assessment

The risks to health and safety from falling debris or localized structural failure due to removing deteriorated materials, and the effect of deterioration upon the mechanical stability of the concrete structure shall be assessed pre-repair work, as well as the anticipated loads and forces during repair work.

Where the concrete structure or a portion thereof is considered to be unsafe, appropriate actions and sequences shall be specified to make it safe before other prevention or repair work is undertaken and while underway, taking into account any additional risks that can arise from the repair work itself. Such action can include local prevention or repairs, the installation of support or other temporary stabilization measures, or partial or even complete demolition.

4.3 Assessment of defects and their causes

An assessment shall be made of the defects in the concrete structure, their causes, and of the ability of the concrete structure to perform its function per the detailed guidance provided in ISO 16311-2. This information is briefly summarized in the subsequent paragraphs.

The process of assessment of the structure shall include, but not be limited to, the following.

- a) Documentation of the materials and systems comprising the structure.
- b) The visible condition of the existing concrete structure.
- c) Testing to determine the condition of the concrete and reinforcing steel.
- d) The original design approach and potential design deficiencies.
- e) The environment, including exposure to deleterious species.
- f) The history of the concrete structure, including environmental exposure, and previous maintenance and repair programs.
- g) The conditions of use, (e.g. loading or other actions).
- h) Requirements for future use.

The nature and causes of defects and deficiencies, including combinations of causes, shall be identified and recorded (see [Figure 1](#)).

The approximate extent and likely rate of increase of defects shall then be assessed. An estimate shall be made of when the member or concrete structure would no longer perform as intended, with no prevention or repair measures (other than maintenance of existing systems) applied.

The results of the completed assessment shall be valid at the time that the prevention and repairs are designed and carried out. If, as a result of passage of time or for any other reason, there are doubts about the validity of the assessment, a new assessment shall be made.

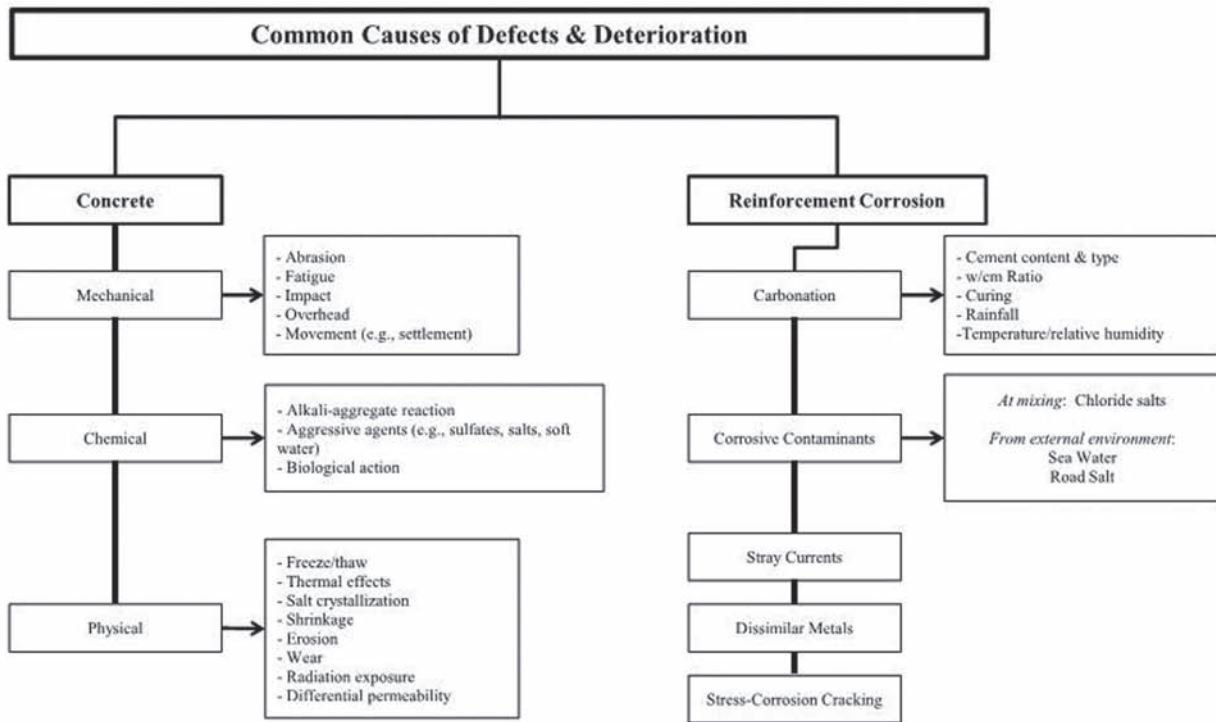


Figure 1 — Common causes of defects and deterioration

5 Strategies for maintenance, repair, and prevention

5.1 General

This clause identifies options and factors to be considered when choosing a strategy for the management of the structure.

5.2 Options

Per ISO 16311-1, the following options shall be taken into account in deciding the appropriate action to meet the future requirements for the life of the structure.

- a) Do nothing for a certain time while monitoring the structure.
- b) Re-analyse the structural capacity, possibly leading to a downgrade in function.
- c) Prevent or reduce further deterioration.
- d) Strengthen or repair and protect all or part of the concrete structure.
- e) Reconstruct all or part of the concrete structure.
- f) Demolish all or part of the concrete structure.

5.3 Factors

The factors that shall be considered when choosing a management strategy include, but are not limited to the following categories.

5.3.1 General

- a) The intended use and remaining service life of the structure.
- b) The required performance of the structure.
NOTE This can include, for example, fire resistance and watertightness.
- c) The likely service life of the repair and prevention work.
- d) The required availability of the structure, permissible interruption to its use and opportunities for additional prevention, repair, and monitoring work.
- e) The acceptable number and cost of repair cycles during the design life of the concrete structure.
- f) The comparative whole life cost of the alternative management strategies, including future inspection and maintenance or further repair cycles.
- g) Properties and possible methods of preparation of the existing substrate.
- h) The appearance of the protected and repaired structure.

5.3.2 Structural

The actions and how they will be resisted, including during and after implementation of the strategy.

5.3.3 Risk assessment

- a) The consequences of structural failure.
- b) Health and safety requirements.
- c) The effect on occupiers or users of the structure and on adjacent structures and the general public.

5.3.4 Environmental

- a) The exposure environment of the structure and whether it can be changed locally.

NOTE Exposure classes are given in ISO 22965-1, Annex A.2.

- b) The need or opportunity to protect part or all of the concrete structure, from weather, pollution, salt spray, etc., including protection of the substrate during the repair work.

5.4 Choice of appropriate strategy

The choice of strategy for the structure shall be based on the above assessment of the structure, client requirements, and relevant provisions (e.g. safety requirements) valid in the place of execution. All repair and prevention work undertaken as part of a structure management strategy shall comply with this part of ISO 16311.

A repair and prevention remedy or remedies shall be chosen according to [Clause 6](#), that is:

- a) appropriate to the type, cause or combination of causes and to the extent of the defects;
- b) appropriate to the future service conditions.

6 Basis for the choice of specific repair and prevention design principles, strategies, remedies, and methods

6.1 General

This clause specifies the basic repair and prevention strategies and remedies which shall be used, separately or in combination, to protect, maintain, or repair concrete structures. Determining the suitability of these remedies and methods for a particular condition can only be assessed after a thorough evaluation of the component or structure per ISO 16311-2 and reconciling repair and prevention design principles that include, but are not limited to:

- a) do no harm to the structure or member;
- b) adopt proven techniques and products with a documented record of success in similar projects;
- c) harmonize prevention, repair, and maintenance strategies with budgets and planning.

6.2 Repair remedies and methods of maintenance, repair, and prevention

6.2.1 General

Maintenance, repair, and prevention remedies are based on chemical, electrochemical, or physical remedies that can be used to prevent or stabilize the deterioration of concrete, or corrosion of the steel or other embedded metals, or to strengthen the concrete structure.

[Table 1](#) contains examples of repair and prevention methods which apply the remedies. Only methods which comply with the remedies shall be selected, taking into account any possible undesirable consequences of applying a particular method or combination of methods under the specific conditions of the individual repair.

Execution of the repairs and prevention is addressed in ISO 16311-4.

6.2.2 Remedies and methods addressing defects in concrete and reinforcement corrosion

Remedies 1 to 6 in [Table 1](#) address defects in the concrete or concrete structures that can be caused by the following actions, separately or in combination:

- a) mechanical: e.g. impact, overloading, movement caused by settlement, vibration, seismic actions, and blast;
- b) chemical and biological: e.g. sulfate attack, alkali-aggregate reaction;
- c) physical: e.g. freeze-thaw action, fire, thermal cracking, moisture movement, salt crystallization, and erosion.

Remedies 7 to 11 in [Table 1](#) address reinforcement corrosion caused by:

- a) physical loss of the protective concrete cover;
- b) chemical loss of alkaline pH in the protective concrete cover as a result of reaction with atmospheric carbon dioxide (carbonation);
- c) contamination of the protective concrete cover with corrosive agents (usually chloride ions) which were incorporated in the concrete when it was mixed or which have penetrated into the concrete from the environment;
- d) stray electrical currents conducted or induced in the reinforcement from neighbouring electrical installations;
- e) stress corrosion cracking of prestressed members;

f) galvanic corrosion (e.g. dissimilar metals, differential environments).

Where there is existing corrosion of reinforcement or a danger that corrosion will occur in the future, one or more of remedies of corrosion repair and prevention shall be selected.

In addition, the concrete itself shall be repaired, where necessary, according to Remedies 1 to 6.

Table 1 — Remedies and Methods for repair and prevention of concrete structures

Remedy		Examples of Repair Strategies and Methods
1.	Protection against ingress	1.1 Hydrophobic impregnation
		1.2 Impregnation
		1.3 Coating
		1.4 Surface bandaging of cracks
		1.5 Filling of cracks
		1.6 Transferring cracks into joints
		1.7 Erecting external panels ^a
		1.8 Applying membranes ^a
2.	Moisture control	2.1 Hydrophobic impregnation
		2.2 Impregnation
		2.3 Coating
		2.4 Erecting external panels
		2.5 Electrochemical treatments
3.	Concrete restoration	3.1 Hand-applied, localized patches
		3.2 Recasting members with concrete or mortar
		3.3 Spraying concrete or mortar
		3.4 Replacing members
4.	Structural strengthening	4.1 Adding or replacing embedded or external reinforcing bars
		4.2 Adding reinforcement anchored in pre-formed or drilled holes
		4.3 Bonding plate reinforcement
		4.4 Adding mortar or concrete
		4.5 Injecting cracks, voids, or interstices
		4.6 Filling cracks, voids, or interstices
		4.7 Prestressing - (post tensioning) or FRP strengthening
5.	Increasing physical resistance	5.1 Coating or membranes
		5.2 Impregnation
		5.3 Adding mortar or concrete
		5.4 Applying a membrane
6.	Resistance to chemicals	6.1 Coating
		6.2 Impregnation
		6.3 Adding mortar or concrete
7.	Preserving or restoring passivity	7.1 Increasing cover to reinforcement with additional mortar or concrete (preservation only) or applying a coating
		7.2 Replacing contaminated or carbonated concrete
		7.3 Electrochemical realkalisation of carbonated concrete
		7.4 Realkalisation of carbonated concrete by diffusion
		7.5 Electrochemical chloride extraction
		7.6 Applying a membrane (preserving passivity only)

Table 1 (continued)

Remedy		Examples of Repair Strategies and Methods
8.	Increasing resistivity	8.1 Hydrophobic impregnation
		8.2 Impregnation
		8.3 Coating
9.	Cathodic control	9.1 Limiting oxygen content (at the cathode) by saturation or surface coating
10.	Cathodic protection	10.1 Applying an electrical current to achieve a protective electrochemical potential
11.	Control of anodic areas	11.1 Active coating of the reinforcement
		11.2 Barrier coating of the reinforcement
		11.3 Applying corrosion inhibitors in or to the concrete
		11.4 Installation of discrete galvanic anodes
^a These methods may also be applied to other remedies.		

6.2.3 Protection and repair of concrete and reinforcement by methods not mentioned in this International Standard

The absence from this part of ISO 16311 of a specific method, or the application of a method to a new situation, shall not be taken to mean that such a method or application is necessarily unsatisfactory. The application of methods to situations unforeseen in this part of ISO 16311, or the use of methods which do not have a substantial history of successful performance and are not specified in this part of ISO 16311, may be satisfactory in appropriate circumstances.

7 Properties of products and systems required for compliance with repair and prevention remedies

Once the repair approach is determined per [Clause 6](#), the products and systems to be used shall be selected in accordance with requirements given in one or more of the following:

- a) International standards;
- b) Regional standards;
- c) National standards;
- d) National technical approvals;
- e) Approvals according to project specification.

Descriptions and acceptance values of properties, in relation to specific products and systems, have to be documented by test methods valid in the place of use and specified in the project specification.

Care shall be taken that products and systems do not undergo adverse physical or chemical reactions with each other and with the concrete structures.

Repair products that are part of a system for repair shall not normally be tested individually unless one or more of the repair products are intended to meet particular performance requirements in its own right.

ISO 16311-4 gives details of site application requirements. If on-site application conditions cannot reasonably be made to fulfil the application conditions specified for the product or system, alternative products (if any) or alternative repair remedies or methods shall be specified to avoid such a conflict.

8 Design documentation requirements

Unless otherwise agreed, the following shall be provided to the owner of the structure at the conclusion of the design effort:

- 1) documentation of the repair and prevention design, including any test results pertinent to the design;
- 2) documentation of any quality control and assurance requirements for the execution of the repair and prevention design;
- 3) instructions for inspection and maintenance to be undertaken during the remaining design service life of the repaired part of the concrete structure.

9 Compliance with health, safety, and environmental requirements

The repair and prevention design shall comply with the requirements of relevant health and safety, environmental protection, and fire regulations valid in the place of use.

Where there is a conflict between the properties of specific products or systems and environmental protection or fire regulations, use shall be made of alternative repair remedies or methods which avoid such a conflict.

10 Competence of personnel

This part of ISO 16311 presupposes that personnel have the necessary skill and adequate equipment and resources to design, specify, and execute the work in accordance with the relevant parts of this International Standard and the requirements of the project specification.

NOTE In some countries, there are special requirements regarding the level of knowledge, training, and experience of personnel involved in the different tasks.

Annex A (informative)

Design of repairs and prevention

A.1 General

This Annex provides guidance and background information on the normative text.

A.2 Scope

Some aspects of the scope will require specialized knowledge and structural design. Examples include structural requirements of fire-damaged concrete, assessment and repair of pre-stressed concrete, damage due to seismic actions and increasing structural capacity by replacement or addition of embedded or external reinforcement, electrochemical and materials concerns.

The scope does not include non-structural construction materials used in conjunction with concrete, such as floor screeds or render and plaster finishes.

- a) The scope of this part of ISO 16311 does not include detailed guidance on inspection, testing, and assessment before and after repair. This is covered by ISO 16311-2.
- b) In well designed and constructed concrete structures built according to standards for design, execution and materials valid in the place of use, the concrete cover should normally protect reinforcement from corrosion under conditions of normal exposure in natural environments, including marine environments and where de-icing salts are used. With older structures, previous standards may not have been adequate for normal exposure. In particular, “inadequate design, specification or construction or use of unsuitable construction materials” may lead to a poor quality cover concrete, poor compaction and hence reduced durability of reinforced concrete. Other mechanisms may cause premature deterioration, including fire, mechanical actions, or chemical attack.
- c) For waterproofing of vertical surfaces, vapour-permeable materials are normally used; for waterproofing horizontal surfaces, materials that are impervious to water and water vapour are normally used, but this depends on the intended use of the structure and vapour transmission requirements.
- d) Site application and details of methods of repair and prevention are provided in ISO 16311-4, including the preparation of the concrete and reinforcement before application of products and systems.

Products and systems may be applied for purposes other than repair and prevention, for example solely or mainly to improve appearance, or to modify a concrete structure for a different use.

A.3 Minimum considerations before repair and prevention

A.3.1 General

This clause is not a detailed guide to undertaking a structural appraisal or a condition assessment of the concrete structure. This information is presented in ISO 16311-2. To help users of this part of ISO 16311, Figure A.1 gives an example of the phases of a repair project.

PROJECT PHASES					
INFORMATION ABOUT THE STRUCTURE	PROCESS OF ASSESSMENT	MANAGEMENT STRATEGY	DESIGN OF REPAIRS and PREVENTATIVE MEASURES	EXECUTION OF REPAIRS and PREVENTATIVE MEASURES	ACCEPTANCE OF REPAIRS
Basic considerations and actions					
Condition and history of structure Documentation Previous repair and maintenance	Defects and their classification and causes Safety/structural appraisal before repair and prevention	Options Remedies Methods Safety/structural appraisal during repair and prevention	Intended use of products Requirements - substrate - products - work Specifications Drawings Safety/structural appraisal after repair and prevention	Choice and use of products and systems and methods and equipment to be used. Quality control. Health and safety	Acceptance testing Remedial works Documentation
Relevant clauses of this part of ISO 16311					
Clause 4 of this part of ISO 16311	ISO 16311-2 and clause 4 of this part of ISO 16311	Clauses 5 and 6 of this part of ISO 16311	Clauses 6, 7, and 9 of this part of ISO 16311	Clauses 6, 7, 9, and 10 of this part of ISO 16311, and ISO 16311-4	Clause 8 of this part of ISO 16311, and ISO 16311-4

Figure A.1 — The phases of a typical repair and prevention project

Before any repair and prevention work can start, a data collection exercise needs to be completed to establish the current condition of the structure, the maintenance history and the likely future performance. Ideally, this should be undertaken in the context of a structure management strategy, which is discussed in more detail in [A.4](#).

A.3.2 Assessment of defects and their causes

This subclause provides background information on the assessment of defects and their causes and does not provide detailed comment on the individual sub-clauses in the normative text.

Defects and causes

Defects in concrete structures can result from inadequate design, specification, supervision, execution, and materials, including

- a) inadequate structural design,
- b) inadequate mix design, insufficient compaction, insufficient mixing,
- c) insufficient cover,
- d) insufficient or defective waterproofing,
- e) contamination, poor or reactive aggregates, and
- f) inadequate curing.

Other defects may become apparent during service, including the effects of

- a) reinforcement corrosion,
- b) severe climate, atmospheric pollution, chloride, carbon dioxide, aggressive chemicals,

- c) foundation movement, impacted movement joints, overloading,
- d) impact damage, expansion forces from fires,
- e) erosion, aggressive groundwater, seismic action,
- f) stray electric currents, and
- g) dissimilar metals or environments causing corrosion of the reinforcing steel.

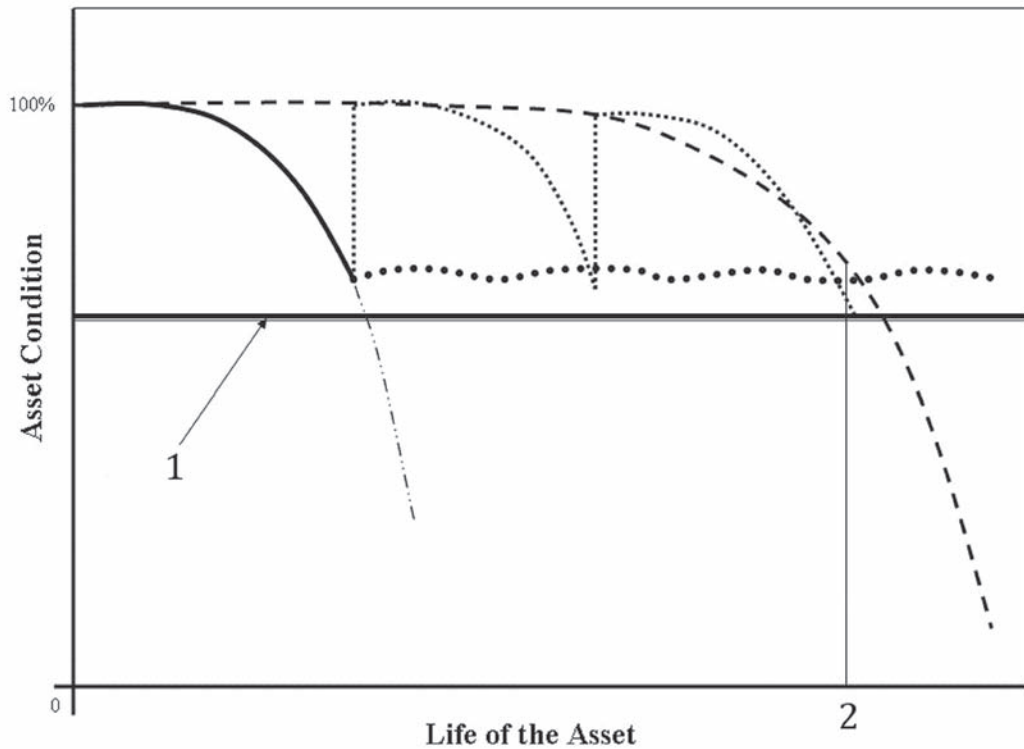
Common causes of defects in concrete and reinforcement are summarized in [Figure 1](#).

A.4 Strategies for maintenance, repair, and prevention

A.4.1 General

A structure management strategy is not chosen on technical grounds alone, but also on economic, functional, environmental, and other factors, and most importantly the owner's requirements for the structure.

The design life of the repaired concrete structure is a key consideration in the design of the repair and prevention system. Options range from those that can restore the design life of the concrete structure in a comprehensive single operation, to simpler options that may require repeated maintenance or where components of the repair may need to be reapplied (e.g. surface protection systems), as illustrated in [Figure A.2](#) below.



Key

- 1 critical condition
 - 2 design service life
 - — — — ideal life curve
 - actual deterioration curve
 - . . . — Projected deterioration
- Repair based on:
- restoring to initial state
 - maintaining current state

Figure A.2 — Typical repair and prevention cycles over the life of a deteriorating asset

A.4.2 Options

Maintaining or restoring safety is an essential requirement of a structure management strategy. A range of options may be available to meet this prerequisite. These options should normally be assessed for their efficacy over the remaining life of the structure, termed life cycle costing, per ISO 14040 and ISO 14044.

Consideration of the options and their consequences will generally include examination of different aspects, for example initial cost, maintenance costs, and the possible need to introduce restrictions on the use of the structure. Each option is likely to have a different level of future deterioration risk.

When choosing options for repair and prevention systems, an important consideration is the life to first maintenance of the individual products, as they may not last the design life of the concrete structure. Factors such as access, renewal, and reparability of repair and prevention systems are important considerations.

A.4.3 Factors

This subclause lists the factors that need to be considered when making an informed judgement on the relative costs and benefits of the possible technical options for repair.

A.4.3.1 General

- a) Correct monitoring and maintenance of the repair and prevention work will result in a longer service life for both the repairs and the structure.
- b) The nature and use of the structure may have a significant influence on the choice of the management strategy, the repair remedies, and the equipment and systems to be used, particularly noise and dust generation from preparing the substrate (e.g. office buildings, hospitals, etc).
- c) In the case of premature deterioration, service life can be extended by repair and prevention. However, deterioration is an on-going process and an informed choice may have to be made between
 - i) carrying out repair and prevention which will extend the service life to attain the original design life, and
 - ii) carrying out repair and prevention which will extend the life for a lesser period in the knowledge that there will be additional repair and prevention costs in the future.
- d) Properties and possible methods of preparation of the existing substrate can have an effect on the final appearance of the protected and repaired structure.

A.4.3.2 Structural

The structural appraisal prior to repair can be extended to predict the effects of the repairs on the structural capacity, both during repair and after the work has been completed.

Particular attention needs to be paid to the volume of concrete and reinforcement that is cut away from loadbearing structural members and the effect this will have on the structural capacity. An example is the removal of concrete from compression members, altering load paths such that the repairs are effectively not loadbearing. Should this be of structural significance, repair remedies should be considered that minimize the breakout and repair and/or shoring to relieve dead load during repair.

A.4.3.3 Risk Assessment

- a) An important stage in the structure management strategy is to assess the structural consequences from any deterioration and the repair process itself before work begins.
- b) Health and safety requirements are given in national regulations and guidelines.
- c) The materials and methods used in the selected repair remedies will potentially affect operatives as well as occupiers, users or third parties. Examples include: products that contain harmful or malodorous components; creation of noise, dust and vibration; water or airborne debris from preparation processes; or plant movements.

A.4.4 Choice of appropriate strategy

The management strategy should reflect the Owner's requirements for the design and service life of the structure, and maintenance and repair options, which reflect the management strategy, should be developed.

The initial causes of the defects need to be identified. Generally, repair and prevention will deal successfully with the causes and consequences of defects. In some cases, other issues may be contributing to the deterioration (e.g. blocked drains on bridge decks that lead to chloride contamination of the substructure) and it may be necessary to deal separately with these issues before a successful repair

can be carried out. If correction of the cause is not possible (e.g. in a marine environment), the repair and prevention must be designed to resist the cause as far as possible.

A.5 Basis for the choice of specific repair and prevention remedies and methods

A.5.1 General

Selection of appropriate repair options is the most important part of design of the repair project. Several approaches may be possible, with the final selection based on a variety of factors (see [A.4.1](#)).

Suitable repair methods should be specified for all chosen remedies. Where possible, the specification should include the appropriate performance requirements for products and systems for the intended use. Producers may need to be consulted to verify that their products fulfil the intended requirements.

Products and systems for the intended use should be selected taking into account the condition of the substrate and the assessment of defects and their causes as detailed in [4.3](#) of this part of ISO 16311 and in ISO 16311-2.

A.5.2 Remedies and methods of maintenance, repair, and prevention

A.5.2.1 General

Several repair and prevention methods may be chosen in combination. Care needs to be taken to consider the possible adverse effects of the chosen methods and the consequences of interactions between them.

Examples of possible adverse effects include:

- a) hydrophobic impregnation system used to reduce the moisture content of concrete, which can increase the rate of carbonation;
- b) surface coating, which can entrap moisture, leading to breakdown in adhesion or reduced frost resistance;
- c) post-tensioning, which can cause deleterious tensile stresses in the structural members;
- d) electrochemical methods, which can cause embrittlement of susceptible prestressing steel, alkali aggregate reaction with susceptible aggregates, a decrease in frost resistance due to increased moisture contents, or, if under water, corrosion in adjacent structures or vessels.

Products and systems should be compatible with each other and with the original concrete structure.

Where there is a history or risk of reinforcement corrosion, Remedies 7 to 11 in [Table 1](#) should be considered in addition to Remedies 1 to 6, because the expansive effects of on-going reinforcement corrosion may damage concrete in the future if left unchecked.

A.5.2.2 Remedies and methods addressing defects in concrete

This subclause provides background information on repair remedies 1 to 6 in [Table 1](#) and does not provide detailed comment on the individual subclauses in the normative text.

Remedy 1 — Protection against ingress

Protection against ingress includes measures to reduce the porosity or permeability of the concrete surface. This is achieved by treating the concrete surface (e.g. using a surface protection system) or sealing cracks (e.g. injection of cracks, or by bandaging or filling the surface).

Normal structural cracks have widths that are within the limits given in design standards valid at the place of use and open and close under the control of the reinforcement in concrete. Overload or under-design of a structure may result in structural cracks that exceed the limits defined in actual standards.

Non-structural cracks may form in the concrete for a number of reasons, e.g. plastic shrinkage or settlement, heat of hydration, thermal contraction, and these may be much wider than structural cracks and may open and close in response to both structural loads and environmental effects such as temperature changes.

Cracks of any width may cause deterioration and the consequences should be considered. Where there is a danger that corrosive contaminants will penetrate the concrete at cracks, consideration should be given to protecting cracks that are currently free from contamination by filling them in accordance with Method 1.4.

Once the causes, ranges of movements, and effects have been established, including whether the crack is live (e.g. opening and closing in response to loads or thermal effects) or inactive, then options for repair can be selected from Methods 1.1 to 1.8. Some surface protection systems are suitable for application over live normal structural cracks but few will bridge wide, non-structural cracks, which may need to be sealed by other methods.

Some cracks in hardened concrete form as a result of reinforcement corrosion. These cracks are often the first visual sign that there is a corrosion problem. Cracks caused by corrosion must not be repaired simply by filling or sealing. These defects should be repaired by methods that apply Remedies 7 to 11.

The possibility of further movement of the cracks adversely affecting the repair should be considered.

It should be noted that Method 1.8 (applying membranes) may be equally applicable to Remedies 2, 6, and 8.

Remedy 2 — Moisture control

Moisture control is used in the repair of concrete to control adverse reactions by allowing concrete to dry, as well as preventing moisture build-up. Adverse reactions can include alkali-silica reaction and sulfate attack. Saturated concrete can also be susceptible to freeze-thaw damage.

Surface protection systems applied to vertical and soffit surfaces should be permeable to water vapour to allow moisture to escape from the concrete.

Upper surfaces of horizontal concrete members (e.g. a suspended floor slab in a car park) can have an impermeable surface protection system applied.

Surface protection systems should not normally be applied to concrete containing excess moisture and product manufacturers should advise on appropriate application conditions.

Remedy 3 — Concrete restoration

Concrete restoration is normally carried out using hand-applied patch repairs, or recasting with flowing concrete or mortar, or applying concrete or mortar by spraying. Replacement of members can include materials other than reinforced concrete. Further advice on sprayed concrete can be given in standards valid in the place of use.

Remedy 4 — Structural strengthening

It is essential when using Remedy 4 that all stresses associated with a repair and the original or deteriorated structure are considered. Certain systems may impose additional stresses on the repaired structure, resulting in changes in the original structural function.

While injecting or sealing cracks will not structurally strengthen a structure, injection may be used to restore the structural condition prior to cracking (e.g. when temporary overloading has occurred).

Remedy 5 — Increasing physical resistance

Removal of the concrete surface by physical actions, such as impact or abrasion, may affect the structural or durability performance of the structure. The causes need to be identified and physical protective measures might need to be taken to reduce their effects, as well as applying the repair methods.

Remedy 6 — Increasing resistance to chemicals

Where concrete has been attacked, the chemicals have to be identified, and suitable preventive measures might need to be taken, as well as the applying repair methods.

The resistance of concrete to different classes of environmental attack is defined in ISO 22965-1.

This part of ISO 16311 covers products and systems which may protect the concrete against environmental attack by chemicals listed in ISO 22965-1 and to severe chemical attack by chemicals listed in standards valid in the place of use.

Under certain conditions, soils, water treatment works, and sewage can generate acids or sulphates that can promote attack on the concrete and reinforcement.

Reinforcement corrosion, General

Reinforcement may be at risk of corrosion for a wide variety of reasons, including poor quality or missing concrete cover, contamination e.g. by chlorides, advancing carbonation, or other physical, chemical or electrochemical effects.

Carbonation

Where the reinforcement is protected by some remaining uncarbonated cover (as indicated by a carbonation test, refer to standards valid in the place of use), Methods 1.2, 1.3, and 1.8 are examples that can be used to reduce access of carbon dioxide to the concrete.

Where the reinforcement is in contact with carbonated concrete, the passivity will have been lost and corrosion can begin. A variety of methods can be used to arrest corrosion in this situation, using one or more Remedies and Methods.

As well as carbon dioxide, other air-borne acidic pollutants, such as sulfur dioxide, can attack both concrete and reinforcement in areas where pollution is high, for example in chimneys.

Chlorides or other corrosive contaminants

Corrosion caused by the ingress of chloride ions is more difficult to treat than corrosion caused by carbonation.

The presence of chloride ions at the depth of the reinforcement breaks down the passive layer in uncarbonated concrete and allows corrosion to begin. Where elevated chloride ion contents have been detected (as indicated by the chloride ion content test, see standards valid in the place of use), then there is a risk that reinforcement corrosion can occur. The concentration that triggers corrosion varies in each individual case and depends on many factors including the cement type, w/c-ratio, the source of chloride, the alkalinity of the concrete and the exposure environment.

The source of the chlorides is also important, in particular whether the chlorides were cast into the concrete at the time of construction, or has entered the concrete subsequent to hardening. For a given chloride content, chloride which has entered the concrete from an external source is more aggressive in terms of corrosion risk. Corrosion risk can also be increased by carbonation of concrete containing relatively low concentrations of chloride ion.

Traditionally, a value of 0,4 % by mass of cement was used as the threshold above which reinforcement corrosion would occur. More recent research shows the value can be much lower than this, sometimes below 0,2 %, although in certain environmental conditions much higher values can be tolerated. Therefore, it is important to calibrate the risk of corrosion against the actual prevailing conditions of each structure and no "safe" limit should be assumed.

Reinforcement corrosion can also be caused by halides other than chlorides, or other water-soluble chemicals.

Treatment of local areas of concrete that are contaminated by chloride ion can be successfully carried out by patch repair that removes all the contaminated concrete. However, where contamination is

extensive, treatment of areas of damage alone will not provide a lasting repair solution. Areas repaired with new mortar or concrete can initiate corrosion in adjacent areas of contaminated concrete (often termed incipient anode or ring anode effect). In these situations, additional repair remedies will need to be considered if corrosion is to be arrested, such as those given in Remedies 7 to 11.

Remedy 7 — Preserving or restoring passivity

General

The Methods relate to treating or replacing the concrete surrounding the reinforcement to reduce the risk of corrosion. Some of the methods include electrochemical treatment of the reinforcement.

Method 7.1 Increasing cover with additional mortar or concrete (preservation only) or applying coating

Where the reinforcement remains passive, an additional layer of mortar or concrete may be added over carbonated concrete or applying a coating to provide additional protection.

Method 7.2 Replacing contaminated or carbonated concrete

Where reinforcement has lost protection as a result of carbonation or chloride ingress, the structure may be repaired by replacing the contaminated or carbonated concrete with new concrete or mortar in accordance with Method 7.2. Additional protection may be required in the form of a surface protection system in accordance with Remedy 1. In the case where chloride ions remain in the concrete, there will be a risk of recontamination of the repair by diffusion and incipient anodes forming on reinforcement in the surrounding concrete. In these situations, additional repair remedies might need to be considered.

Method 7.3 Electrochemical realkalisation of carbonated concrete

Where the reinforcement is active or passive, additional corrosion protection can be provided by electrochemical re-alkalisation, which raises the alkalinity of carbonated concrete and provides passivity to the reinforcement.

The application of suitable coatings may extend the life of the treatment.

Method 7.4 Re-alkalisation of carbonated concrete by diffusion

There is limited experience with this method, but two approaches have been used in some situations.

One approach involves application of a highly alkaline cementitious concrete or mortar to the surface of carbonated concrete, allowing the concrete to be re-alkalised through diffusion from the surface. The approach relies upon maintaining the concrete in a moist condition that permits effective diffusion to the depth of the reinforcing bars over the duration of the treatment, which takes many months.

The other approach involves application of an impermeable coating (e.g. polyurethane) to the concrete surface where the concrete behind is kept saturated. Alkalis in the uncarbonated concrete will diffuse towards the coating over approximately one year to re-alkalise the concrete at the depth of the reinforcing bars. The concrete has to be saturated by ground water, condensation water, etc., and cannot be exposed to frost.

Method 7.5 Electrochemical chloride extraction

Where the reinforcement is active or passive due to chloride ion ingress, additional corrosion protection can be provided by electrochemical chloride extraction, which reduces the chloride ion content in the concrete surrounding the reinforcement and provides passivity.

Remedy 8 — Increasing electrochemical resistivity

Internally in dry buildings, corrosion is seldom a problem even if the concrete is carbonated at the depth of the reinforcement. This is because the low moisture content in enclosed buildings tends to raise the electrical resistivity of the concrete to a level where the corrosion rate is insignificant.

In some situations, the resistivity of external concrete can be increased through the application of ventilated external cladding, water-repellent surface treatments, pore-filling impregnation, or surface coatings (Remedies 1 and 2). The technique for reducing the corrosion rate by limiting the moisture content, for example by over-cladding, is limited to situations where concrete can be prevented from taking up water from other sources. Also, the escape of moisture from the concrete should not be impeded.

With chloride-contaminated concrete, the risk of corrosion is more significant. Methods that increase the resistivity of the concrete cannot be adequate in themselves to reduce corrosion of the reinforcement. In this situation, additional repair Remedies might be needed.

Remedy 9 — Cathodic control

Remedy 9 relies upon restricting access of oxygen to all potentially cathodic areas, to the point when corrosion cells are stifled and corrosion is prevented by the inactivity of the cathodes.

Saturation of the whole of a self-contained reinforced concrete unit is an example of the application of this remedy. Limiting oxygen content (at the cathode) by saturating the concrete, should be used only where the whole of the member is under water and where reinforcement of the submerged member is electrically isolated from all reinforcement in members which are not submerged, or where there is no effective return path for ionic currents through the concrete.

Even in this immersed situation, the risk of corrosion can be increased by the presence of contaminants such as chlorides and additional remedies can be required.

While surface coatings can be applied to concrete structures that have a low oxygen diffusion rate, in practice it might be difficult to control corrosion by this method, particularly where chlorides are present. The quality of surface preparation and application needs to be to a very high standard to provide a defect-free barrier.

Note that application of a coating that is a partial barrier to oxygen can restrict selection of other repair Remedies (e.g. an impressed current cathodic protection system is unlikely to work if applied over an oxygen resisting coating).

Remedy 10 — Cathodic protection

Cathodic protection is especially appropriate where chloride contamination is significant, or carbonation to the depth of the reinforcement is extensive, resulting in a high risk of corrosion of reinforcement.

Impressed current cathodic protection, can control corrosion regardless of the level of chloride contamination in the concrete and limits the amount of concrete removal to that damaged by corrosion. Its long term effectiveness depends on adequate monitoring and maintenance. Its main components are the anodes, which can have a very long service life in excess of 20 years.

Cathodic protection is effective for achieving long-term corrosion control and counteracts the incipient anode problem and the effect of concrete contamination.

There are many different types of external anode systems used in cathodic protection, some of which use an impressed current from an external power source, while others use galvanic (sacrificial anode) action.

Remedy 11 — Control of anodic areas

Where contamination of the concrete is extensive, but it is not possible to remove all contaminated concrete, incipient anode formation can be controlled by treating the surface of the reinforcement in the patch repair to prevent corrosion. Coatings can be applied directly to the reinforcement where it is exposed as part of concrete restoration. These coatings can contain active pigments, which may function as anodic inhibitors or by sacrificial galvanic action. Discrete galvanic anodes can also be installed at the perimeter of the patch to control the incipient anode.

Other types of coating can form barriers on the surface of the reinforcement. This method can only be effective if the reinforcement is prepared to be free of corrosion and the coating is complete (i.e. the bar

must be completely encapsulated and the coating is defect-free). The method should not be considered unless the whole of the circumference of the reinforcing bar can be coated. The effect of the coating on bond between the reinforcement and concrete should also be considered.

Alternatively, corrosion inhibitors can be used that chemically change the surface of the steel or form a passive film over it. Corrosion inhibitors can be introduced either by addition to the concrete repair product or system, or by application to the concrete surface followed by migration to the depth of the reinforcement. Inhibitors that are applied to the surface of the concrete must penetrate the concrete down to the level of the reinforcement to take effect. There is currently no standard for inhibitors, so evidence of the effectiveness of any such product should be obtained before specifying its use. Note that some corrosion inhibitors work by control of both anodic and cathodic areas (see Remedy 9).

In severe conditions, additional repair remedies may be required.

A.6 Properties of products and systems required for compliance with the remedies of repair and prevention

To avoid any possible confusion, it is intended that the properties of a system for concrete repair should be tested and compared with the relevant performance requirements in project specification or standards valid in the place of use. It is not intended that each component product of a system is tested and evaluated individually against the performance requirements unless the products can be used by themselves to meet the performance requirement.

For example, the properties of a surface protection system for a car park deck can contain multiple products such as a primer, elastic layer, sealing layer, and wearing layer, each layer being of the thicknesses specified by the manufacturer. Compliance with the performance requirements is measured on the system applied in accordance with the manufacturer's recommended values and this would be stated in the certificate for the products that comprise the system.

Particular attention is required to the temperature and humidity conditions at application, because most repair products have been formulated to perform within a given range of ambient application conditions. Application guidance is given in ISO 16311-4.

A.7 Design documentation requirements

Contemporaneously with the development of a concrete repair design, a maintenance management system should be developed and reported to the Owner as guidance for achieving the design service life of the proposed repair work and the structure.

Parts of the protected or repaired concrete may have a remaining design service life that is short in comparison with the rest of the concrete structure. Examples include surface protection systems, sealants, and weatherproofing materials. Should the integrity of the structure depend on the performance of such products and systems, it is essential that they are regularly inspected, tested, and renewed if necessary.

The following listing gives information for future maintenance which should be included:

- a) the design service life of the concrete structure;
- b) identification of each product and system where the design service life is expected to be less than the remaining design service life of the concrete structure;
- c) the date at which each product and system is next to be inspected or tested;
- d) the method of inspection to be used, including how results are to be recorded and how future inspection dates are to be decided;
- e) a specification for systems with continuous treatment and monitoring, for example as used in an impressed current cathodic protection system;

- f) a statement of precautions to be taken or restrictions to be applied, for example maintenance of surface water drainage, maximum pressure for washing or prohibition of the use of de-icing salt.

A.8 Health, safety, and the environment

A.9 Competence of personnel

Personnel should be appointed who are familiar with repair and prevention of concrete works and recognized as competent. This requirement requires to all persons involved in the repair process, including repair scheme designers, repair contractors, and repair works inspectors.

A quality system should be employed to ensure that the specified quality requirements are met and that the right repair methods are used.

Appropriate arrangements should be made for acceptance inspection.

All documents relating to the repair work should be stored in a suitable project management system.

Bibliography

- [1] ISO 15686-1:2000, *Buildings and constructed assets — Service life planning — Part 1: General principles*
- [2] ISO 13823:2008, *General principles on the design of structures for durability*

