# International Standard

# ISO 16311-3

Second edition
2024-03

# Maintenance and repair of concrete structures —

## Part 3:
## Design of repairs

*Entretien et réparation des structures en béton —*

*Partie 3: Conception des réparations*



Reference number
ISO 16311-3:2024(en)

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Published in Switzerland

# Contents

# Foreword

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

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

This second edition cancels and replaces the first edition (ISO 16311-3:2014) which has been technically revised.

The main changes are as follows:

— the definitions of “repair” has been updated.

A list of all parts in the ISO 16311 series can be found on the ISO website.

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

# Introduction

The repair of defects and deterioration in concrete structures requires complex design work. This document defines the design principles, strategies, remedies and methods for the repair of concrete structures that have suffered or can 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 document 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 decision-making;

— the selection of the appropriate remedies for repair;

— the selection of methods;

— the definition of properties of products and systems;

— the specification of maintenance requirements following repair.

This document 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 document contains Annex A which provides guidance and background information.

# Maintenance and repair of concrete structures —

# Part 3:
# Design of repairs

## 1 Scope

This document defines basic considerations and decision-making for the specification of repair remedies, and management strategies for reinforced and unreinforced concrete structures. This document covers only atmospherically exposed structures, and buried or submerged structures, if they can be accessed.

This document specifies repair 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.

## 2 Normative references

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

ISO 16311-1, *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*

## 3 Terms and definitions

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

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

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

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

**3.1**
**defect**
fault or deviation from the intended level of performance of a structure or its parts

[SOURCE: ISO 15686-1:2011]

**3.2**
**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, 3.15]

**3.3**
**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).

**3.4**
**protection**
measure that is intended to prevent or reduce the development of defects in the structure

**3.5**
**repair**
restoration of a structure or its components to an acceptable condition by the renewal or replacement of worn, damaged, or deteriorated components including prevention and protection

[SOURCE: ISO 13823:2008, 3.20, modified — "including prevention and protection" has been added.]



## 4 Minimum considerations before repair 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 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 as a pre-repair work, as well as the anticipated loads and forces during repair work.

Where the concrete structure or a portion thereof is considered unsafe, appropriate actions and sequences shall be specified to make it safe before other 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 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 concrete member or structure would no longer perform as intended, with no repair measures (other than maintenance of existing systems) applied.

The results of the completed assessment shall be valid at the time that the 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.

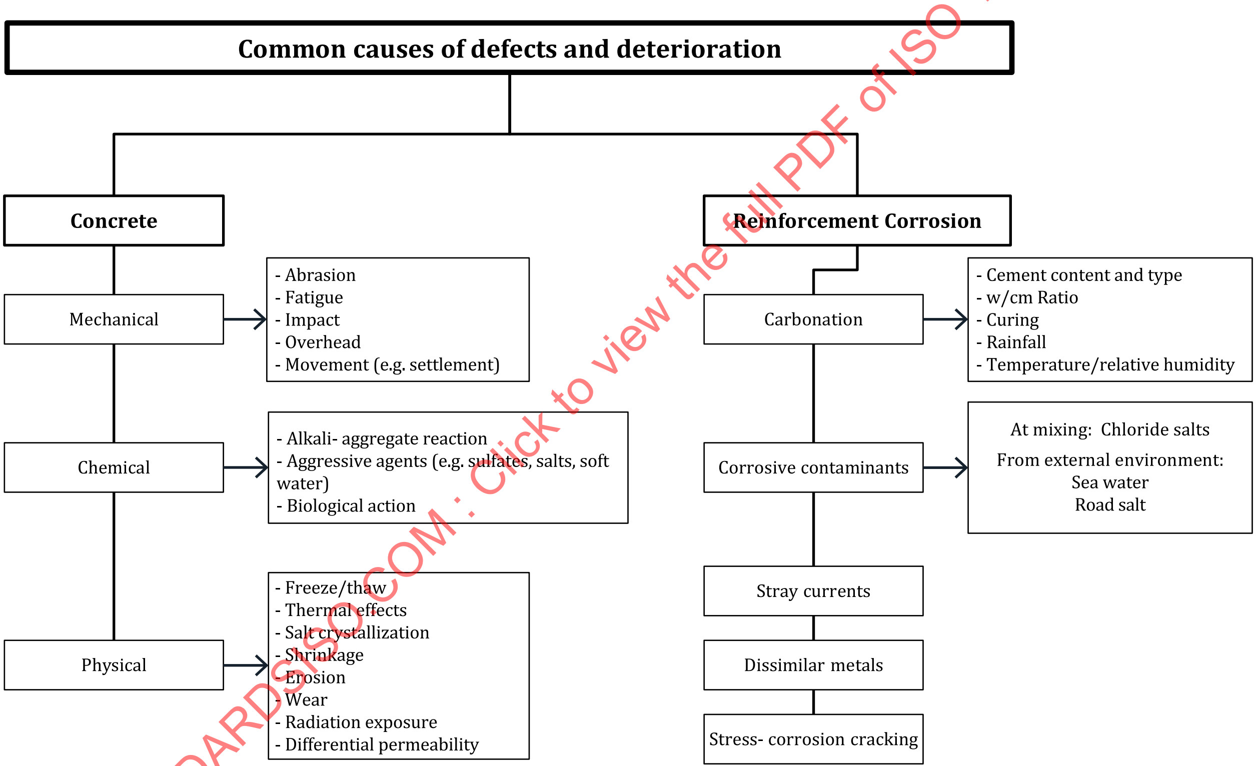



**Figure 1 — Common causes of defects and deterioration**



# 5 Strategies for maintenance and repair

## 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

In accordance with 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 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 work.

d) The required availability of the structure, permissible interruption to its use and opportunities for additional 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 repaired structure.

### 5.3.2 Structural

a) The actions including during and after implementation of the strategy.

b) The response mechanism against the actions, 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, member, part and whether it can be changed locally.

NOTE Exposure environment is classified for each member and part. Exposure classes are given in ISO 22965-1:2007, 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 assessment of the structure, client requirements and relevant provisions (e.g. safety requirements) valid in the place of execution. All repair work undertaken as part of a structure management strategy shall comply with this document.

A repair 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 design principles, strategies, remedies and methods

### 6.1 General

This clause specifies the basic repair 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 according to ISO 16311-2 and reconciling repair 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 repair and maintenance strategies with budgets and planning.

### 6.2 Repair remedies and methods of maintenance

#### 6.2.1 General

Maintenance and repair 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 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 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 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 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 Fibre Reinforced Plastic (FRP) strengthening |

[a] These methods can also be applied to other remedies.

**Table 1** *(continued)*

| Remedy | | Examples of repair strategies and methods |
|---|---|---|
| 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) |
| 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 can also be applied to other remedies. | | |

### 6.2.3 Repair of concrete and reinforcement by methods not mentioned in this document

The absence from this document 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 document, or the use of methods which do not have a substantial history of successful performance and are not specified in this document, can be satisfactory in appropriate circumstances.

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

Once the repair approach is determined according to 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, shall 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:

a) documentation of the repair design, including any test results pertinent to the design;

b) documentation of any quality control and assurance requirements for the execution of the repair design;

c) 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 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 document 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 document 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

## A.1 General

This annex provides guidance and background information for Clauses 4, 5, 6 and 7. Some aspects of the scope 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 document 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 have not always been adequate for normal exposure. In particular, “inadequate design, specification or construction or use of unsuitable construction materials” can lead to a poor-quality cover concrete, poor compaction and hence reduced durability of reinforced concrete. Other mechanisms can 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 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, for example solely or mainly to improve appearance, or to modify a concrete structure for a different use.

## A.2 Minimum considerations before repair

### A.2.1 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 document, 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<br>Documentation<br>Previous repair and maintenance | Defects and their classification and causes<br>Safety/structural appraisal before repair | Options<br>Remedies<br>Safety/structural appraisal during repair | Intended use of products<br>Requirements<br>- substrate<br>- products<br>- work<br>Specifications<br>Drawings<br>Safety/structural appraisal after repair | Choice and use of products and systems and methods and equipment to be used.<br>Quality control<br>Health and safety | Acceptance testing<br>Remedial works<br>Documentation |
| Relevant clauses of this document | | | | | |
| Clause 4 | Clause 4 | Clauses 5 and 6 | Clauses 6, 7 and 9 | Clauses 6, 7, 9 and 10 | Clause 8 |

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

Before any repair 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 Clause A.4.

### A.2.2 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 subclauses in this document.

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,

f) inadequate curing.

Other defects can 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,

g) dissimilar metals or environments causing corrosion of the reinforcing steel.

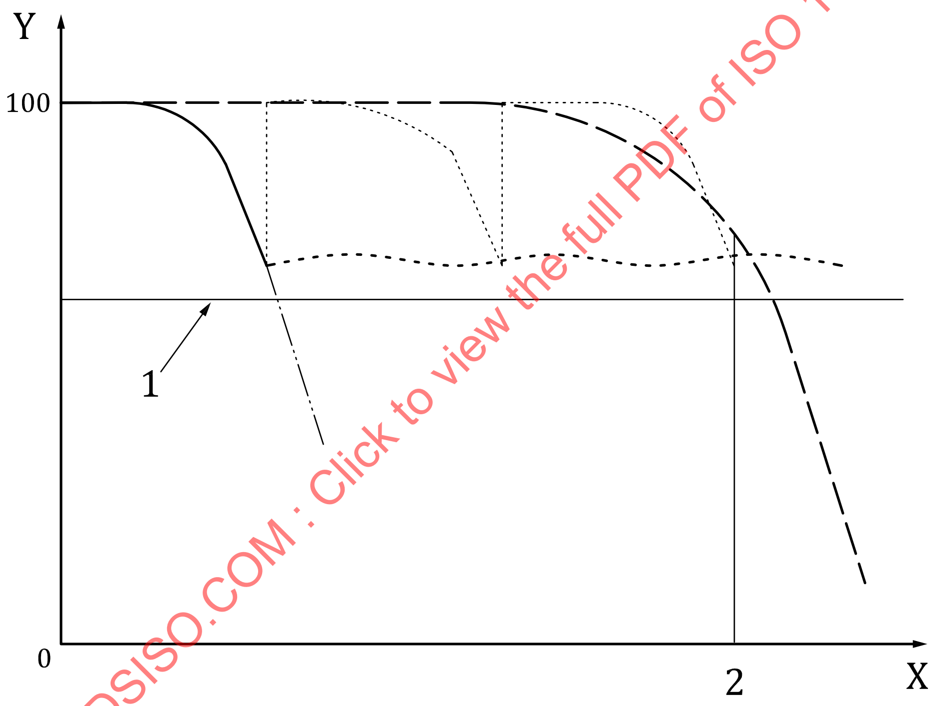
Common causes of defects in concrete and reinforcement are summarized in Figure 1.

## A.3 Strategies for maintenance and repair

### A.3.1 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 system. Options range from those that can restore the design life of the concrete structure in a comprehensive single operation, to simpler options that can require repeated maintenance or where components of the repair will need to be reapplied (e.g. surface protection systems), as illustrated in Figure A.2 below.




**Key**

X life of the asset

Y asset condition

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 cycles over the life of a deteriorating asset**

### A.3.2 Options

Maintaining or restoring safety is an essential requirement of a structure management strategy. A range of options can 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, according to ISO 14040 and ISO 14044.

Consideration of the options and their consequences generally includes 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 systems, an important consideration is the life to first maintenance of the individual products, as they will possibly not last the design life of the concrete structure. Factors such as access, renewal and reparability of repair systems are important considerations.

### A.3.3 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.3.3.1 General

a) Correct monitoring and maintenance of the repair work will result in a longer service life for both the repairs and the structure.

b) The nature and use of the structure can 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. However, deterioration is an on-going process and an informed choice will have to be made between:

   1) carrying out repair which will extend the service life to attain the original design life,

   2) carrying out repair which will extend the life for a lesser period in the knowledge that there will be additional repair 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.3.3.2 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.3.3.3 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.3.4 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 will deal successfully with the causes and consequences of defects. In some cases, other issues can be contributing to the deterioration (e.g. blocked drains on bridge decks that lead to chloride contamination of the substructure) and it can 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 shall be designed to resist the cause as far as possible.



## A.4 Basis for the choice of specific repair remedies and methods

### A.4.1 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 will possibly 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 and in ISO 16311-2.

### A.4.2 Remedies and methods of maintenance, repair

#### A.4.2.1 General

Several repair 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 can damage concrete in the future if left unchecked.

#### A.4.2.2 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 this document.

#### A.4.2.2.1 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 standard which is validated in the place of use at the place of use and open and close under the control of the reinforcement in concrete. Overload or under-design of a structure can result in structural cracks that exceed the limits defined in actual standards.

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

Cracks of any width can 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 in Table 1.

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 will possibly 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 shall 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.

Method 1.8 (applying membranes) can be equally applicable to remedies 2, 6, and 8.

#### A.4.2.2.2 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.

#### A.4.2.2.3 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 design standard which is validated in the place of use in the place of use.

#### A.4.2.2.4 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 can 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).

#### A.4.2.2.5 Remedy 5 — Increasing physical resistance

Removal of the concrete surface by physical actions, such as impact or abrasion, can 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.

#### A.4.2.2.6 Remedy 6 — Increasing resistance to chemicals

Where concrete has been attacked, the chemicals shall be identified, and suitable preventive measures will possibly 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 document covers products and systems which can protect the concrete against environmental attack by chemicals listed in ISO 22965-1 and to severe chemical attack by chemicals listed in design standard which is validated in the place of use 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.

##### A.4.2.2.6.1 Reinforcement corrosion, general

Reinforcement can 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.

##### A.4.2.2.6.2 Carbonation

Where the reinforcement is protected by some remaining uncarbonated cover (as indicated by a carbonation test, refer to design standard which is validated in the place of use 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.

##### A.4.2.2.6.3 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 design standard which is validated in the place of use 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.

#### A.4.2.2.7 Remedy 7 — Preserving or restoring passivity

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. The methods are classified by mechanism into 4 types.

— 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 can be repaired by replacing the contaminated or carbonated concrete with new concrete or mortar in accordance with method 7.2. Additional protection can 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 will possibly 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 can extend the life of the treatment.

— Method 7.4 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.

#### A.4.2.2.8 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.