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Maintenance and repair of concrete structures —

Part 2: Assessment of existing concrete structures

Entretien et réparation des structures en béton —

Partie 2: Évaluation des structures en béton existantes

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Contents

Page

Foreword iv
Introduction v
1 **Scope** 1
2 **Normative references** 1
3 **Terms and definitions** 2
4 **Framework of assessment** 4
4.1 General 4
4.2 Personnel 4
4.3 Objectives of assessment 6
4.4 Scenarios 6
4.5 Preliminary and detailed assessment 6
4.6 Reporting results of assessment 10
4.7 Judgement and decision 10
4.8 Intervention 10
5 **Site and laboratory investigation and data collection** 10
5.1 General 10
5.2 Planning and execution of inspection and data collection 10
5.3 Registration of condition 11
6 **Evaluation and verification** 13
6.1 Evaluation of action 13
6.2 Evaluation of materials and structural details 13
6.3 Verification of structural performance 15
6.4 Judgment 15
7 **Recommendation** 15
8 **Report** 16
Annex A (informative) **Assessment levels, investigative tests, and examples of assessments** 17
Annex B (informative) **Condition and Consequence Levels** 34
Annex C (informative) **Evaluation and Verification** 37
Annex D (informative) **Recommendations** 40
Annex E (informative) **Content of the Final Report** 42
Bibliography 44

Foreword

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

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

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

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

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

The committee responsible for this document is ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 7, *Maintenance and repair of concrete structures*.

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

Assessment of a concrete structure identifies and defines areas of distress, and verifies structural performance based on the evaluated condition of the structure. It includes the whole process from defining the work through the investigation, evaluation, verification, and registration to the final report. This is necessary as a basis for the design of the repair and the preparation of procedures to preserve or extend its remaining service life.

The report, concluding the assessment, includes a description of the structure, the investigation, the results of condition assessment, the verified structural performance, the expected future development, and a short presentation of possible repair principles and methods, including appropriate cost calculations. A detailed planning and design of the repair work (repair or rehabilitation project specification) is not part of the assessment, see ISO 16311-3.

This part of ISO 16311 gives the requirements for assessment of concrete structures, including a framework for the assessment, a format for documentation of the condition assessment with assessed condition level and consequence level, and a format for documentation of the performance assessment with verified specific structural performance.

This part of ISO 16311 is operable with standards for test methods. Some standards for test methods are under preparation by ISO but they will not all be available as International Standards at the date of publication of this part of ISO 16311. Until and after such International Standards are available, a national annex may list standards that have established suitability in the place of use of the methods. These may be national standards or standards of other regions or nations.

This part of ISO 16311 is primarily based on the principles given in ISO 13822, *Basis of design of structures — Assessment of existing structures*. Annex B in ISO 13822 has a detailed flowchart, included as Figure 1 in this part of ISO 16311.

Maintenance and repair of concrete structures —

Part 2: Assessment of existing concrete structures

1 Scope

This part of ISO 16311 describes general requirements and procedures for the assessment of concrete structures.

The assessment can be initiated under the following circumstances, but not limited to:

a) an anticipated change in use or extension of design service life;

b) structural deterioration due to time-dependent actions such as corrosion of reinforcement, fatigue, etc.;

c) safety and/or serviceability check (e.g. for earthquake and increased traffic actions) as required by authorities, insurance companies, owners, etc.;

d) structural damage by accidental actions. (See ISO 2394.)

This part of ISO 16311 does not cover

— qualification of personnel,

— contractual matters, and

— health and safety requirements for the protection of workers during the investigation and testing.

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.

In the case of reference to International draft standards, provisions given in the National Annex or project specification should be applied until the International Standard is available.

ISO 2394, *General principles on reliability for structures*

ISO 13822:2001, *Bases for design of structures – Assessment of existing structures*

ISO 16204, *Durability — Service life design of concrete structures*

ISO 16311-1, *Maintenance and repair of concrete structures — Part 1: General principles*

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

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

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

3 Terms and definitions

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

3.1
accidental action
action that is unlikely to occur with a significant value on a given structure over a given reference period

Note 1 to entry: Accidental actions are in most cases of short duration.

[SOURCE: ISO 2394:1998]

3.2
action, direct
assembly of concentrated or distributed mechanical forces acting on a structure

3.3
assessment
set of activities performed in order to verify the reliability of an existing structure for future use

[SOURCE: ISO 13822:2010]

3.4
condition
status of a structure or a structural member at a given time

3.5
condition description
statement of the condition status and level based on condition registration of a structure or a structural member

3.6
condition documentation
all information that explains the condition of a structure or a structural member

3.7
condition level
expression of the condition of a structure or a structural member, compared to a reference level

3.8
condition registration
survey and collection of information to define the condition of a structure or structural member

3.9
condition verification
comparison between condition and defined requirements

3.10
consequence level
expression of seriousness of consequences related to a defined reference level

3.11
damage
unfavourable change in the condition of a structure that can affect structural performance

[SOURCE: ISO 13822:2010]

3.12
defect
fault, or deviation from the intended level of performance of a structure or its parts

[SOURCE: ISO 15686-1:2000]

3.13
deterioration
process that adversely affects the structural performance, including reliability over time due to

— naturally occurring chemical, physical or biological actions,

— repeated actions such as those causing fatigue,

— normal or severe environmental influences,

— wear due to use, or

— improper operation and maintenance of the structure

[SOURCE: ISO 13822:2010]

3.14
environmental action
assembly of physical, chemical, or biological influence which may cause restraint effects or deterioration to the materials making up the structure, which in turn may adversely affect its serviceability, restorability, and safety

[SOURCE: ISO 13822:2001]

3.15
inspection
conformity evaluation by observation and judgement accompanied as appropriate by measurement, testing or gauging

Note 1 to entry: For structures, this evaluation consists of actions collecting information on the current state of a structure through observation and simplified non-destructive or destructive testing supplemented with materials and structural testing, as required.

[SOURCE: ISO 9000:2005, 3.8.2]

3.16
risk
combination of the probability or frequency of occurrence of an event and the magnitude of its consequences

[SOURCE: ISO 13824:2009]

3.17
symptom
indicator for the condition of a structure or structural member, based on one or more characteristics

3.18
visual inspection
inspection of a structure by visual observation in the preliminary investigation for its assessment

4 Framework of assessment

4.1 General

The overall assessment procedure shall comply with ISO 13822 and include the following main parts according to Figure 1, which is a general flowchart copied from ISO 13822:

— objectives of assessment;

— scenarios;

— preliminary assessment;

— detailed assessment;

— reporting results of assessment;

— judgement and decision;

— intervention.

A site visit is recommended prior to initiating the assessment.

4.2 Personnel

An assessment shall be performed by qualified personnel.

NOTE A National Annex can include requirements on qualification for personnel.

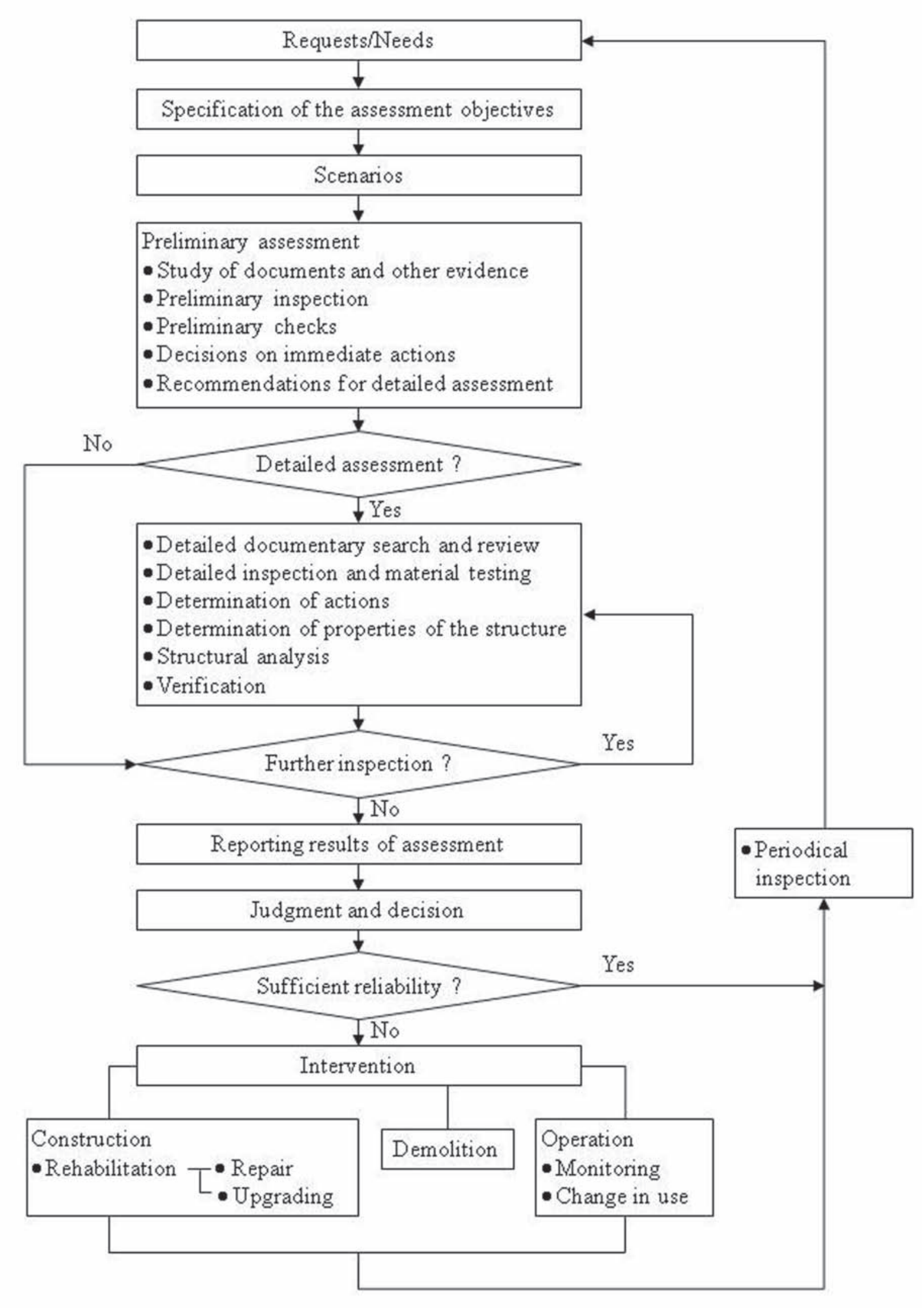


Figure 1 — General flowchart for assessment of existing structures (adapted from ISO 13822, Annex B)

4.3 Objectives of assessment

The objectives of the assessment of an existing concrete structure, in terms of its operable condition and its future structural performance, shall be specified in consultation with the client (the owner, the authority, insurance companies, etc.) based on the following performance levels:

a) safety performance level;

b) continued function performance level;

c) special performance requirements of the client.

NOTE Reference is made to ISO 13822, 4.1

The objectives of the assessment shall be determined or confirmed before starting the assessment activities. Within the determined objectives of assessment, the assessment shall be carried out with the procedure given in Figure 1.

The objectives of an assessment, the extent and the application of methods and resources shall be defined in a project specification.

The extent of an assessment depends on the nature of the structure, if a rough cost estimate of recommended actions shall be included, etc.

The content of an assessment shall be re-evaluated continuously based on the observations.

NOTE A.1 gives more detailed description of purpose and scope of a condition assessment.

4.4 Scenarios

One or some scenarios to represent a possible change in structural performance shall be specified prior to the preparation of assessment to identify possible critical situations for the structure. These scenarios shall be developed with an understanding of the type of construction, the timeframe of construction, and the environment to which the structure or structural member were exposed. These scenarios include, but are not limited to (see also 16311-3)

— chloride exposure, and damage related to chloride-induced corrosion,

— carbonation-induced corrosion damage,

— mechanical (impact, overload, settlement, vibration, seismic, abrasion, fatigue, explosion, etc),

— chemical (alkali-aggregate reactions, aggressive agents, biological actions, etc), and

— physical (fire, frost damage, thermal effects, shrinkage, erosion, wear, etc).

Possible scenarios shall be reviewed thoroughly before carrying out the assessment activities. Scenarios shall be continuously checked during the assessment to identify possible

— critical situations for the structure, including structural safety and serviceability, and

— amendments of the layout of the assessment.

4.5 Preliminary and detailed assessment

4.5.1 Levels of assessment

The purpose and scope of the assessment is decisive for the level of assessment and the content of each level. The assessment shall not be taken any further than what is necessary to reach a firm decision on intervention to be taken.

Normally, the assessment is classified into two levels as follows.

a) Preliminary assessment (see 4.5.2): the aim is to provide information of the condition of the structure, clarify causes for and seriousness of the deterioration, giving basis for indicating an overall condition level, and a consequence level of the structure, including future safety and serviceability of the structure. Possible immediate actions have to be decided. If necessary, a detailed assessment shall be proposed.

b) Detailed assessment (see 4.5.3): the aim is in principle the same as for preliminary assessment, but a more detailed study of previous documents, a more detailed inspection and material testing, as well as structural analysis and verification, has to be carried out in order to make the correct judgement and decisions.

NOTE 1 A.1 provides additional information regarding levels of assessment.

NOTE 2 A.2 provides details on condition registration, including current information from construction and operation, observation on site, possible tests on site and in laboratory as well as a listing of symptoms and possible causes for defects.

4.5.2 Preliminary assessment

4.5.2.1 Study of documents and other data

Design and inspection documents, such as original design, drawings, project specification, structural calculations, as built documentation, previous assessments, and intervention, etc. provide important information. For many existing structures, it may be difficult to find such information and to be sure that the information is correct. Both structural requirements (e.g. service load, dead load, overload, wind, snow, etc.), and environmental conditions (e.g. chlorides, gasses, temperature, etc.) shall be documented, and if any changes have occurred. The use and possible misuse of the structure, compared to the original design assumptions, shall be documented, if possible.

4.5.2.2 Preliminary inspection

The preliminary inspection is primarily a visual observation, in some cases supported with simple types of testing at the structure (e.g. carbonation measurements). This inspection shall give information on the structural system and if any surface characteristics are visible (e.g. reinforcement corrosion, cracks, spalling, deformation etc.).

4.5.2.3 Preliminary checks

Based on the study of documents and other evidences, and the results of the preliminary inspection, preliminary checks shall be performed. This is to identify the critical deficiencies related to the future safety and serviceability of the structure or structural members. Such checks can be based on general knowledge and experience, or by simple calculations.

The results of the preliminary inspection and checks shall be described by condition levels and consequence levels.

The choice of an appropriate condition level shall be based on judgement of the observed symptoms and the preliminary checks, and related to a reference level for the structure or a structural member. Normally five condition levels are defined from “Good” to “Unsafe”.

NOTE 1 Annex B gives a more detailed description of the condition levels.

NOTE 2 Reference levels for different cause(s) for deterioration can be provided in a National Annex with a picture catalogue based on symptoms.

The consequences of the observed condition and the preliminary checks for a structure or a structural member, if nothing is done within a certain time, shall be described by consequence levels. The consequence levels refer to the consequence for the structure itself, and are independent of the reliability class of the structure, which shall also be recorded. Normally, five consequence levels are defined from “No consequences” to “Potentially hazardous or (structurally) unsafe consequences”.

NOTE 3 Annex B gives more detailed description of consequence levels.

4.5.2.4 Decisions on immediate actions

When the results of the preliminary inspection and/or the checks shows that the structure is in a dangerous condition, it has to be reported to the client that immediate interventions shall be taken in order to reduce the dangerous situation with respect to safety of the general public, workers or occupants, and adjacent structures. If the safety of a structure or structural member is not clearly understood after the preliminary assessment, a detailed assessment shall be performed immediately to assess the critical deficiencies, and if necessary, recommendations made to the client for intervention.

4.5.2.5 Recommendation for detailed assessment

When the preliminary inspection and checks clearly show that the consequences of any deficiencies are very low and that the structure or structural members are reliable for its intended use over the remaining design service life, a detailed assessment is not required.

In the case where a structure or structural members are reliable for a defined period of time, a plan for future assessment shall be described.

When the preliminary inspection and checks are not able to give answer to the question of reliability and serviceability of a structure or a structural member, or the information is insufficient for planning necessary intervention, a detailed assessment shall be recommended.

4.5.3 Detailed assessment

4.5.3.1 Detailed documentary search and review

The detailed assessment shall be done based on values of basic variables corresponding to the actual situation. For that purpose, investigation shall be intended to update the knowledge about the present state of the structure.

This includes a more comprehensive search and review of documents than described in 4.5.2.1, and is based on the preliminary assessment. Especially documents covering the following, if available, shall be reviewed:

a) drawings, specifications, structural calculations, construction records, inspection and maintenance records, details of modifications;

b) regulations, by-laws, codes and standards which were originally used for design, calculations and execution of the structure;

c) topography, subsoil and environmental conditions, groundwater level at the site.

4.5.3.2 Detailed inspection and material testing

The aim of the detailed inspection and material testing is to determine the cause(s) for the deterioration and the extent, as well as providing necessary information on dimensions of components and properties of materials assumed for structural analysis and necessary for planning possible interventions. Detailed inspection and material testing shall be carried out to collect more specific and useful data for evaluating the detailed information. Some necessary non-destructive and/or minor-destructive test methods shall be applied.

Detailed inspection and material testing shall result in supplementary information to the information found in the detailed documentary search and review.

4.5.3.3 Determination of actions

All kind of actions, both mechanical and environmental actions on the structure or structural members, shall be determined by analysis in accordance with ISO 2394, and evaluated on the basis of the current design codes, and taking into account provisions laid down in the safety and utilization plan. Changes of actions caused by the change in use or modification of the structure, shall be taken into consideration per 6.3.2.

4.5.3.4 Determination of properties of the structures

In some situations, the response of the structure or a structural member from action(s) has to be tested in order to predict the load-bearing capacity. This could be both static and dynamic testing. Load testing of a structure or structural member is very costly and time-consuming. However, this type of testing is normally not necessary, and used only when other approaches, such as detailed structural analysis or inspection alone do not provide clear indication or have failed to demonstrate adequate structural reliability. When this type of testing has to be performed, reference is made to ISO 13822, Annex D.

4.5.3.5 Structural analysis

Based on detailed documentary review, inspection and material testing, a structural analysis shall be carried out to determine the effects of the actions on the structure or structural members. When deterioration of an existing structure is observed, which is the normal situation for existing structures, the reliability assessment of the structure becomes a time-dependent deterioration challenge and this time-dependent development must be taken into account.

A structural analysis can be based on the principles given in ISO 2394. However, the limit state method developed in ISO 2394, has been adopted and used for preparing and harmonizing national and regional standards for structural design around the world, and in most situations, national codes and standards for safety philosophy and structural calculations, have to be employed.

When time-dependent structural analysis has to be performed, some examples of appropriate analysis methods are found in ISO 13822, Annex E. However, in most situations, national codes, standards, and guidelines for safety philosophy and time-dependent models, can be employed.

NOTE 1 For time-dependent deterioration, it is often more practical to use limit states like time to initiation of corrosion for reinforcement corrosion, based on data from the structure.

NOTE 2 ISO 16204 gives methods for evaluating time-dependent deterioration.

4.5.3.6 Verification

Based on the results from the evaluation and from the detailed assessment, the structural performance shall be verified with reference to defined requirements, i.e. requirements from government (e.g. standards, codes), owner, designer, user, etc. If necessary, structural analysis can be carried out to investigate structural behaviours with the consideration of the investigated properties. The results from the assessment shall be documented to clearly indicate and explain the investigated results.

Current codes and standards shall be used in the verification. Former codes and standards that were valid at the time of construction of an existing structure shall be used as informative documents. Alternatively, verification can be based on satisfactory past performance, taking into account time-dependant development of deterioration processes. If this approach is to be employed, reference is made to ISO 13822, Clause 8.

A more detailed presentation of evaluation and analysis of results of assessment for existing concrete structures are given in Clause 7.

4.6 Reporting results of assessment

As the final step, all the investigated and assessed results shall be documented in a report as presented in Clause 8.

4.7 Judgement and decision

Based on all information available from documentary review, inspection, and material testing, judgement and decisions shall be made.

The condition of a structure is classified in a condition level and a consequence level (see Annex B).

The probability that a given consequence may occur for a structure, or a structural member, at the present time or in the future, shall be evaluated. The conclusions drawn from this evaluation will provide an estimate of the risk represented by the defect.

The risk shall be evaluated and reported and be the basis for recommending whether any immediate action(s) are necessary or not. The consequence(s) leading to the risk shall be reported.

NOTE Annex C gives more detailed description of evaluation and verification.

If necessary, this shall end up with a project specification for maintenance and repair of a structure or a structural member. Reference is made to 16311-3, which gives information on planning and design of maintenance, repair, and prevention.

4.8 Intervention

When intervention of any kind is necessary, this is described in the project specification. Reference is made to 16311-4, which gives information on the execution of maintenance, repair, and prevention.

5 Site and laboratory investigation and data collection

5.1 General

The work on site and in the laboratory is a costly part of the assessment. It shall be planned carefully to perform the work in an effective way and on schedule.

To perform an assessment, the scope, the object to be assessed, the parties involved and their responsibilities shall be clearly defined by a qualified person. This shall be given in a project specification including at least

— a description of the work to be carried out, methods and the resources to be used,

— safety instructions and care to the surroundings,

— what the report shall include, and

— estimated cost and time schedule.

NOTE A project specification can, in some situations, be split into different documents. One part can be a definition and a description of the work as a basis for tender. One part can cover the planning of the work. One part can cover the survey and inspection itself. When a project specification is split into several parts, the subsequent parts depend on the results of the previous parts.

5.2 Planning and execution of inspection and data collection

The procedures and items of inspection shall be properly planned to achieve the aims of the assessment. Required detailed information for verification shall be obtained from the assessment. The engineer in charge shall clearly understand any primary concerns on structural performance and durability, and the importance of inspection items shall be considered before the inspection work starts.

The planning includes all preparatory work to be done by the inspector in order to carry out the assessment according to the purpose and scope of the assessment.

Conditions where the structure is located, that can be important for the execution of the work on site, shall be listed. It shall be decided if a visit to the structure is necessary before finalizing the planning.

Original information of the structure like drawings, calculations, and as built information shall be evaluated, if possible. Pre-stressed concrete structures require specialized expertise to complete their assessment.

Information from the service life of the structure, e.g. loads, environmental exposure, earlier condition assessments, and possible repair work, shall be evaluated, including strengthening by, e.g. composites.

A system for registration shall be worked out so that all observations and measurements are unambiguously located on the structure.

A detailed plan for what to do where on the structure, based on the purpose and aim of the inspection, shall be worked out.

A list of equipment shall be worked out, necessary for carrying out the planned work during the inspection on site.

Time and cost for the planned work, both on site, in laboratory as well as evaluating the registrations and the test results, and preparing the report, shall be a part of the planning.

The inspection and data collection shall be executed to obtain required data for verification of structural performance, durability, and remaining service life, based on the planning of the assessment.

NOTE A.1 gives more detailed description of the planning of an assessment.

5.3 Registration of condition

5.3.1 General

Registration of condition is a systematic collection of observations and test results on site and in laboratory. The extent of the registration shall be evaluated during the inspection to find out if the purpose and aim of the work will be achieved.

NOTE A.2 gives more detailed description of registration of condition, including properties that can be tested on site and in laboratory with current test methods indicated.

5.3.2 Registration and documentation of condition

The condition of a structure, or a structural member, shall be assigned by a condition level (see 4.5.2.3 and Annex B), based on one or more individual symptoms, or on a combination of more symptoms, or on test results. The condition level shall be defined based on a reference system given in the project specification for the assessment, condition levels may be defined in a National Annex to this part of ISO 16311.

NOTE The reference for evaluating the condition level is normally the original state of the structure or the structural member.

The condition shall be documented by description of visual inspection, sketches, drawings, photos, test results, and measurements.

If a defect is registered, with or without symptoms, it shall be given together with the reference system for evaluation of defects. Defects shall be documented by description of visual inspection, sketches, drawings, and photos.

5.3.3 Selection of inspection items

The detailed inspection shall include tests and measurements for concrete core strength, cover thickness, carbonation depth, chloride ion profile, and further document review and visual inspection, if necessary (see Annex A). The details and extent of data shall meet the requirements so that the engineer can verify structural performance, durability, and remaining service life.

5.3.3.1 Visual inspection

Visual inspection is the most important part of a preliminary assessment.

NOTE A listing of important defects/symptoms to look for in a visual inspection is given in Table A.1.

When the information from the visual inspection performed in the preliminary assessment is not enough for fulfilling the goal of the assessment, a further visual inspection shall be done to obtain additional data required. All possible resources related to deterioration, deformation, and any cause of problems to the structures, shall be examined in addition to the items of visual inspection in the preliminary assessment.

NOTE Examples of which are presented in A.3.

5.3.3.2 Tests and measurements

The basic tests and measurements during the detailed assessment may include items listed in Annex A. Annex A has a listing of current properties and test methods to be used on site and in laboratory. The location and number of data collecting points shall be determined in accordance with the relevant national codes, considering types of structure and homogeneity of materials. The equipment used for the test and measurements, shall be checked in terms of accuracy necessary for evaluation and verification.

When samples of concrete and reinforcement are required for estimation of their properties, they also shall be taken from the locations where the removal or cutting does not diminish the structural integrity and safety.

Actions on the structure shall be appropriately considered during the assessment. The information on the actions can be obtained from design documents when there is no doubt in their accuracy. However, the detailed evaluation of actions may be required when they are considered to be more severe than those specified in design documents or national codes.

5.3.3.3 Documentation of results after inspection

The results of test and measurements, as well as document review and visual inspection in the detailed inspection, shall be documented so that proper and efficient verification can be performed. The document shall include at least the following information:

a) list of reviewed documents;

b) necessary part of the documents;

c) summary of document review;

d) method of visual inspection;

e) data of visual inspection including photos and figures;

f) summary of visual inspection;

g) items and methods of tests and measurements;

h) data of tests and measurements;

i) summary of tests and measurements;

j) locations of test specimens in the structure.

NOTE Refer to Clause 8 for additional information.

6 Evaluation and verification

6.1 Evaluation of action

6.1.1 Principle

Actions used for the assessment shall be evaluated on the basis of the current design codes. Changes of actions caused by the change in use or modification of the structure shall be taken into consideration.

6.1.2 Evaluation based on documents

If deemed appropriate, actions may be determined from construction documents and the current design codes. For informative purposes, actions for which the structure was originally designed may be determined from drawings and design codes valid in the period when the original structure was designed.

6.1.3 Evaluation based on investigation

In cases when any uncertainty exists in actions, they shall be determined by investigation. Determination of long term and extreme actions may require statistical or probabilistic analysis.

NOTE It can be advantageous to consider the specific characteristics of the structure including its surrounding when determining actions.

6.2 Evaluation of materials and structural details

6.2.1 General

Collection of information from condition registration, including current information from construction and operation, observation on site, results from tests on site and in laboratory is addressed in Clause 5. This clause includes the evaluation and analysis of relevant observations and results.

6.2.2 Average value and variability

Not only the average value but also the variability of material properties and structural details, such as strength, modulus of elasticity and cover thickness, shall be taken into account for the detailed assessment. The variability is represented by the standard deviation (or the coefficient of variation) and the maximum allowable acceptable probability of failure shall not be exceeded.

6.2.3 Concrete

6.2.3.1 Compressive strength

The compressive strength of concrete shall be evaluated based on the result of the detailed assessment.

6.2.3.2 Modulus of elasticity

The modulus of elasticity of concrete shall be evaluated by the test of core samples when an empirical formula is not sufficient to derive it from the compressive strength.

6.2.3.3 Carbonation depth and rate

The vulnerability of reinforcement to carbonation-induced corrosion and future development shall be evaluated by the principle given in ISO 16204.

6.2.3.4 Chloride concentration and diffusion coefficient

The vulnerability of reinforcement to chloride-induced corrosion and future development shall be evaluated by the principles given in ISO 16204. The surface chloride ion concentration of concrete of the structure and an apparent diffusion coefficient are calculated at the same time by applying regression analysis using a solution to the diffusion equation based on Fick's second law to the total chloride ion concentration profile obtained from the concrete sample through chemical analysis.

6.2.3.5 Others

Frost damage, chemical deterioration, etc., shall be evaluated by acoustic, petrographic, and chemical analyses, crack observation by microscope, and other techniques for valuable information related to the concrete composition, present condition, and potential for future deterioration, if necessary.

6.2.4 Reinforcement

6.2.4.1 Yield strength

The yield strength of reinforcement shall be evaluated. Information on the yield strength of reinforcement from mill test reports furnished by the manufacturer of the reinforcement or that provided by a public institute of reinforcement for older structures can be used if the engineer and building officials are in agreement.

6.2.4.2 Reinforcement details

Numbers, locations, and dimensions of reinforcement shall be confirmed. Several reinforcement-related factors, such as development length, anchorage, and reduction in cross section or bond due to corrosion, shall be taken into account in addition to the yield strength of the reinforcement.

6.2.5 Structural details

6.2.5.1 Geometry of structure and structural members

Geometry of the member and structure, such as size and position, shall be checked with design documents. If any inappropriate differences are found, it shall be evaluated according to the result of investigation for precise structural assessment.

6.2.5.2 Cover thickness

Cover thickness of concrete to reinforcement shall be evaluated when durability or performance over time of the structure is assessed.

6.2.5.3 Identifying internal abnormalities by non-destructive tests

If internal abnormalities that can reduce structural capacity are suspected to exist, such as internal voids, cracks, and regions of inferior concrete quality, the locations and their severities shall be detected by some appropriate techniques, such as sounding, pulse velocity, impact-echo method, impulse-response method, ground-penetrating radar, infrared thermography, or radiography.

6.3 Verification of structural performance

6.3.1 General

The verification of structural performance shall be conducted by quantifying the structural performance with consideration of material conditions and structural details.

Structural performance encompasses structural safety, durability, and serviceability aspects.

The verification of structural performance shall be performed under the supervision of responsible engineers who have sufficient knowledge and experience in structural engineering, design, and assessment.

6.3.2 Basis of verification

Verification of structural performance may be based on codes and standards valid in the place of use at the time when the verification is carried out.

NOTE In most cases, current standards are related to the design of new structures, which may not be applicable to the assessment of existing ones. Therefore, verification of structural performance shall be based on codes and standards for existing structures. Verification against standards for design of new structures may result in unnecessarily conservative criteria.

6.4 Judgment

The performance of the structure shall be evaluated from the whole data and information of the present condition of the structure according to the applicable performance criteria specified in current design codes valid in the place of use. The following scenarios shall be possible.

a) The structure has sufficient performance. No further actions such as further detailed assessment or intervention shall be necessary.

b) The decision is postponed. Further detailed assessment needs to be done and/or some monitoring shall be continued.

c) The structure has insufficient performance. Some interventions shall be necessary.

7 Recommendation

Recommended action(s) shall be given based on the purpose and scope of the assessment and the results of the preliminary assessment and the detailed assessment. Recommended action(s) might be:

— extend the assessment and/or search for hidden defects;

— eliminate the cause(s) for defects or prevent the development of them;

— improve specific structural performance.

NOTE Principles and methods for the protection and repair are given in 16311–3.

Recommended action(s) shall be given with priority, and at what time each action is recommended to be carried out.

Cost shall be estimated on a very rough level for each recommended action.

NOTE 1 The cost estimate does not necessarily need to include provisions for design and oversight fees, escalation, project sequencing or phasing, and unforeseeable, hidden conditions. Such limitations in the cost estimate shall be identified to the fullest extent possible.

NOTE 2 Annex D gives more detailed description of recommendations.

8 Report

A report shall be produced for all assessments.

The report shall include at least the following chapters:

— Summary, basically an abstract of the report;

— Introduction, including scope of investigation;

— Original information;

— Registration of observations;

— Evaluation of condition assessment; including condition level and consequence level;

— Verification of structural performance;

— Conclusions;

— Recommendations;

— A rough cost estimate ("opinion of probable cost");

— Possible annexes giving details, if necessary.

NOTE Annex E gives more detailed description of the content of the report.

Annex A
(informative)

Assessment levels, investigative tests, and examples of assessments

A.1 Assessment levels

A.1.1 General

The purpose and scope of an assessment is decisive for the choice of assessment level. An assessment may be carried out on the following levels:

— preliminary assessment;

— detailed assessment.

Both from a technical and an economical point of view, it is recommended to start with a preliminary assessment, provided that the circumstances prompting the assessment do not immediately dictate a detailed assessment is executed. This will make it easier to decide what parts of the structure need a more detailed assessment. In some situations, the preliminary assessment reveals defects and symptoms that have to be further inspected as part of a detailed assessment.

Condition of concrete structures is assessed by using the information categorized into the following three groups as shown in Figure A.1.

a) As-built construction records and documentation.

NOTE The information in this category is about materials strength, member dimension, etc. at the completion of the construction. In other words, the information is related to original performance of the structure before starting service. Records indicate maintenance activities such as repair or strengthening.

b) Deterioration and deformation.

NOTE The information in this category is about phenomena occurring on the structure after completion, such as cracking, spalling, and deflection.

c) Actions.

NOTE The information in this category is about external actions to structures. Loads and environmental conditions are such actions.

Investigation in the assessment is to obtain the above mentioned information depending on the level of assessment and the type of condition to be assessed.

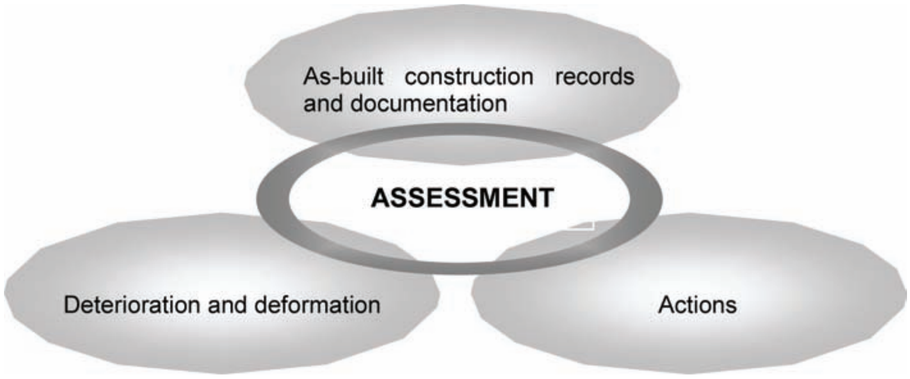


Figure A.1 — Three categories of information obtained by assessment

A.1.2 Preliminary assessment

A preliminary assessment is primarily a visual inspection of the structure, possibly supplemented by some measurements in field and laboratory testing (e.g. carbonation depth of concrete cover, chloride content, etc.)

The goals of a preliminary assessment can be the following.

— Give a general evaluation of the condition for a structural part, a structure or a number of structures.

— Develop plans for a detailed assessment, if necessary.

— Establish whether previously recorded areas of visual deterioration have increased in severity.

— Document the initial development of deterioration.

— Identify consequences for the presence of defects.

— Evaluate the necessity of preventive action(s).

Since this primarily is a visual inspection, there is normally a limited need for scaffolding, lift, etc. The visual inspection is carried out from the ground, boat, or accessible places on the structure like roofs, balconies, etc. supported by the use of binocular. Ladder, lift, etc. may be used in situations where it is necessary for fulfilling the scope. This has to be evaluated in each situation. A preliminary assessment does not include any inaccessible areas (e.g. subgrade members like foundations) or underwater inspection.

The visual inspection includes a general registration of visual defects and symptoms like cracks, fissures, spalling, displacements, deformations, rust spots, etc. Actual defects/symptoms to look for during the visual inspection can be, but not limited to

— spalling,

— cracks, fissures, and crazing,

— honeycombs,

— reinforcement corrosion,

— deformation and displacement,

— elution,

— efflorescence of lime, salt, etc.,

— delaminating, loose concrete,

— disintegration,
— overgrowing,
— discolouring,
— wearing and abrasion,
— erosion, and
— scaling

Table A.1 has a listing of symptoms and possible causes for defects, although this list cannot be considered all-inclusive.

This effort is supplemented by a review of all available documentation, including but not limited to

— drawings of structural system,
— reinforcement drawings,
— specifications,
— structural design,
— materials,
— concrete mix design,
— pouring protocols,
— minutes from meetings,
— storing and transportation of materials and products,
— executed testing, and
— executed control.

Actual information to evaluate from the operation period, but not limited to, can be

— former assessments,
— former repair and maintenance,
— conditions during operation,
— load history (overload),
— change of use of the structure,
— physical loads,
— accidents (mechanical, water, fire, gas etc.),
— use of chemicals (salts etc.),
— reconstruction, and
— environmental information (humidity, temperature, chemical and biological loads).

Information from the construction and operation period is very useful for giving knowledge of the design and mode of operation, revealing critical or special exposed structural parts, being a base for registration and testing, and reducing the extent of the registration. Documentation from the

Table A.1 — Symptoms and possible causes for defects

Causes ⇒ **Symptom ⇓**	Drying shrinkage	Reinforcement corrosion	Frost cracking	Alkali reactions	Elution	Sulfate attack	Acid attack	Salt attack	Temperature attack	Plastic shrinkage	Plastic settlement	High curing temperature	Freezing in fresh concrete	Casting defects	Overload
Spalling		•		•				•	•						•
Spalling along reinforcement		•													
Delamination	•	•	•					•	•						
Disintegration/weathering			•			•	•	•	•				•		
Cracks along reinforcement		•								•	•				
Diagonal/inclined cracks															•
Arbitrary located cracks	•		•						•	•		•	•		•
Transverse cracks												•			•
Dark and moist cracks				•	•										
Crazing	•		•	•		•		•	•	•					
Cracks with efflorescence		•		•	•										
Lime/salt efflorescence					•										
Rust efflorescence		•													
Gel efflorescence				•											
Honeycomb														•	
Deflection/deformation														•	•
Displacement / settlement														•	•
Edge curl/Curling	•														•
Crushing															•

construction and operation period is normally very imperfect. However, it should be aimed at collecting as many relevant data as possible. Experience shows that even limited information may be very useful.

A list of items or questions obtained during the records review concerning as-built status, alterations, or possible changes in structure use since its original construction, should be developed and checked in the field. Alterations to existing structures in service are common and must be carefully noted and evaluated, because they represent potentially sensitive areas in the structural system.

If structural problems are suspected, special attention should be given to connections, support regions, areas of abrupt geometry change, and areas in the structure where load concentrations occur. Where cracks of structural significance are found, consideration should be given to monitoring the movements of the cracks. This information will be of value for future investigations.

Additional measurements may be necessary where alterations to a structure have been made without proper documentation. It is common to encounter alterations in a structural system that has been made without an awareness of the significance that such alterations can have on the structural system. If there is reason to believe that alterations can be affecting a structural system's response or capacity, recommendations for remedial action can be appropriate. The owner should be notified immediately if the nature and extent of problems discovered require urgent action.

When the preliminary assessment reveals situations that have to be examined more in detail, such as conditions relating to safety or potential hazards, the assessment report should include recommendation for the detailed assessment.

A standard relation between the items of inspection and expected information in the preliminary assessment is presented in Table A.2. It is normally difficult to separate the relation for safety from that for serviceability. Therefore, these relations are given in the same boxes in Table A.2.

Table A.2 — Items of inspection for preliminary assessment

Performance	Items of assessment	
	Document review	Visual inspection
Safety and serviceability	Characters at completion and records — dimensions, shapes — reinforcement — materials strength (concrete, steel) — quality control records Actions — design loads — working loads	Deterioration and deformation — cracking — deflection, settlement, inclination — spalling
Durability	Characters at completion and records — cover thickness — concrete strength (design strength, specified strength) — materials and mix proportion of concrete — years after completion Actions — temperature, humidity, distance from coastline and the like — wetting condition such as rainfall	Deterioration and deformation — cracking — spalling — rust stain — colour change — substance extruded

A.1.3 Detailed assessment

A detailed assessment comprises a more thorough visual inspection and comprehensive measurements are made on the structure and in laboratory on samples from the structure.

The goals of a detailed assessment might

— undertake a survey of the extent of the damage,

— determine the cause(s) for the observed defect(s),

— evaluate whether the damage will increase in severity if left unaddressed,

— evaluate possible repair and maintenance principles and methods,

— provide necessary information for designing the repair work, including the development of recommended repairs, and

— provide necessary information for planning maintenance.

The detailed investigation is a thorough visual inspection including registration of visual defects, symptoms, and extent of damage along with some structural calculations. The inspector has to be close to the concrete surfaces, and there may be a need for scaffolding, lift, ladder, boat, raft, etc. Detailed assessment includes inspection in water or hidden (formerly inaccessible) members, if necessary.

In addition to the visual inspection, a detailed assessment normally includes measurements of the following:

— carbonation depths;

— thickness(es) of concrete cover;

— chloride content and chloride profiles;

— crack widths and extents;

— areas of delamination;

— electrochemical potentials;

— bond;

— displacements;

— local removing of concrete for control;

— identification of previous repaired areas, if applicable.

Other test methods may be necessary, depending on cause(s) for deterioration, etc. Not all the tests mentioned need to be carried out in all detailed assessments. The types of tests have to be evaluated in each situation, depending on hypotheses.

Normally, a detailed assessment will provide enough information for the choice of repair principles and methods, and for producing a specification for the repair work. However, in some situations, the detailed assessment reveals defects and symptoms that have to be further inspected.

A relation between the items of investigation and expected information in detailed assessment is listed in Table A.3. Information for safety and serviceability is in the same box as in the case of preliminary assessment. Test and measurement is particular inspection for the detailed assessment. Expected information listed in Table A.3 is an example. The assessment engineers will select the items depending on the method of evaluation and verification.

Table A.3 — Items of investigation for detailed assessment

Performance	Items of assessment		
	Document review	Visual inspection	Test and measurement
Safety and serviceability	Characters at completion and records — structural calculation methods — correctness of structural calculation — other information unchecked in preliminary inspection Actions — records on topography — subsoil conditions — ground water level — other information unchecked in preliminary inspection	Deterioration and deformation — cracking (pattern, width, depth) — spalling (area, depth)	Characters at present — dimensions, shapes — reinforcement — concrete strength and modulus of elasticity — stiffness of structures (loading test) Deterioration, degradation, and deformation — deflection, settlement and inclination Actions — working loads
Durability	Characters at completion and records — quality control records — inspection records — maintenance records — other information unchecked in preliminary inspection Actions — records on topography — subsoil conditions — ground water level — winds — sea water splash — other information unchecked in preliminary inspection	Deterioration, degradation, and deformation — cracking (pattern, width, depth) — spalling (area, depth) — rust stain (area) — colour change (area) — substance extruded (thickness, hardness)	Characters at present — cover thickness — concrete strength — materials and mix proportion of concrete Deterioration, degradation and deformation — carbonation depth — Cl^- content Actions — temperature, humidity — CO_2 concentration — transported Cl^- — precipitation

A.2 Investigative tests

A.2.1 General

Table A.4 shows the most common properties to be documented on site, a short description of aim of the documentation and examples of corresponding test methods. Some of the methods are used in most assessments and some are used in very special situations only. The choice of test methods depends on purpose, hypothesis, and aim of the assessment.

Some of the methods are standardized in ISO, regional, or national standards. When this International Standard is used in a country, the test methods to be used have to be listed in a national annex or in the project specification for an assessment.

Drilling of cores for testing in laboratory is commented in A.2.3.1.

A.2.2 Properties to be documented and tests to be performed on site

A National Annex of tests should be considered.

Table A.4 — Properties to be documented on site and short description of possible test methods

No	Property to be tested	Short description	Test method(s) - examples, if available
1S	Bond strength	The aim is to document the bond between the concrete substrate and a surface layer or a concrete layer. The test method is direct dolly pull-off using a dolly bond to the surface with a test area defined by coring through the layer to be tested.	
2S	Carbonation depth	The aim is to document the depth of the carbonation, normally measured at the same places as concrete cover. The pH-indicator, phenolphthalein, can be applied *in situ* or on extracted concrete samples. For *in situ*, a hole is drilled or chiselled, cleaned for dust and sprayed with phenolphthalein, and the carbonation depth is measured. For extracted samples, the cut surface must be fresh, free of concrete dust, and the phenolphthalein is sprayed in a similar manner as the drilled hole.	
3S	Chloride content	The aim is to document the chloride content in the concrete at different depths. The analyses needs concrete dust drilled into a position of interest in the concrete. Dust may be taken from different depths to find a chloride profile.	
4S	Compressive strength	Concrete compressive strength can be documented on site, normally by using the rebound test: A piston is shot against the concrete surface and the recoil is measured. The recoil gives an indication of the compressive strength, but it is influenced also by many other factors.	ISO 1920-7:2004. Testing of concrete – Part 7: Non-destructive tests on hardened concrete.
5S	Concrete cover	Concrete cover is normally measured by the use of a "covermeter" with the aim of evaluating the reinforcement corrosion durability when compared with the carbonation depth and the chloride profile. Covermeters are based on electromagnetic principles and the measured response depends on depth and diameter of the steel.	
6S	Corrosion rate	Corrosion rate can be measured on site by the use of one of two principles: i) Linear polarization resistance or ii) Impedance. An average corrosion rate is measured over a defined steel surface. The experience with these methods is limited.	
7S	Crack width	Crack width is measured on the concrete surface by the use of a crack comparator or a crack microscope. The measured crack width can be used for evaluating the risk of reinforcement corrosion and the tightness of the concrete. Possible changes of crack widths have to be documented by measurements over time.	
8S	Delaminations	Delaminations are normally documented by knocking on the concrete surface with a hammer. The sound is quite different when knocking on delaminated or cracked concrete than sound, intact concrete.	
9S	Electrical resistivity	Electrical resistivity is normally measured in combination with electrochemical potentials with the aim of making it easier to interpret the electrochemical potential measurements. The most used methods are i) the AC (alternating current) method measuring between two electrodes in or on the concrete surface, or ii) Wenners 4-electrode method using 4 electrodes.	

Table A.4 *(continued)*

No	Property to be tested	Short description	Test method(s) - examples, if available
10S	Electrochemical potentials	Electrochemical potentials are measured with the aim of localizing areas where the reinforcement is corroding. The measurements are based on the principle that corroding reinforcement has another electrochemical potential than passive steel.	
11S	Humidity - relative	Relative humidity in the concrete is important for most deterioration mechanisms. It is normally documented by drilling a hole in the concrete to the depth where the humidity should be measured and put a humidity sensor into the hole. The measuring principle may be based on electrical capacity in a thin plastic film or on the dew point.	
12S	Levelling	Levelling is used with the aim of documenting deformation, displacement and settlement at a certain time or over time. All measurements have to be related to known reference points.	
13S	Permeability - air	Air permeability gives information of the tightness against gas ingress into the concrete. In the most used method, developed by Figg, an overpressure is established in a chamber mounted on the concrete surface. The reduction of the pressure over time can be used for calculating a permeability factor.	
14S	Permeability – water	Water permeability gives information of the tightness against water ingress into the concrete. Several methods are used, all measuring the ingress of water into the concrete when exposed to water pressure at the surface. A permeability factor can be calculated.	
15S	Temperature	Temperature is normally measured in combination with other properties like relative humidity and corrosion rate. Thermo couples placed in holes, drilled into the concrete, is the most used test principle.	
16S	Tensile strength	The aim of the test is to document the tensile strength of the concrete. The test method is direct dolly pull-off using a dolly bond to the surface with a test area defined by coring through the layer to be tested. Indirect tensile strength may be tested by pull-out force	ISO 1920-7:2004, *Testing of concrete — Part 7: Non-destructive tests on hardened concrete*
17S	Ultrasonic pulse velocity	Ultrasonic pulse velocity is used to point out invisible defects. It is based on the principle that the ultrasonic pulse velocity depends on the soundness of the material. Both sender and receiver can be placed on the same side, but placing on opposite sides is better.	ISO 1920-7:2004, *Testing of concrete — Part 7: Non-destructive tests on hardened concrete*

A.2.3 Laboratory tests

A.2.3.1 General

Table A.5 shows the most common properties to be documented in laboratory and a short description of the corresponding test methods. Some of the methods are used in most assessments and some are used in very special situations only. The choice of test methods is depending on purpose, hypothesis, and aim of the assessment.

Some of the methods are standardized in ISO, regional or national standards. When this ISO-standard is used in a country, the test methods to be used have to be listed in a national annex or in the project specification for an assessment.

Most tests in laboratory are carried out on samples drilled from the structure. The size of the core depends on what it should be used for. For most tests, a diameter of 75 mm and a length of 200 mm are sufficient. The core should normally be drilled perpendicular to the concrete surface, and should, as far as possible, not contain any reinforcement. The samples must be marked clearly and unambiguously. After drilling or chiselling, the holes should be filled with mortar or concrete with approximately the same quality as the base concrete. Refer to Method: ISO 1920-6:2004 Testing of concrete – Part 6: Sampling, preparing and testing of concrete cores for further guidance.

A.2.3.2 Properties and test methods to be used in laboratory

Table A.5 — Properties to be documented in laboratory and short description of possible test methods

No	Property to be tested	Short description	Representative Test method(s), if available.
1L	Alkali reactivity	Possible rest alkali reactivity in the concrete can be documented by petrographic analysis or by rest expansion in drilled cores. In petrographic analysis, possible reactive rocks are identified by microscopic analysis. Rest expansion is measured as expansion on drilled cores exposed to extreme alkali reactive environment.	
2L	Bond strength	The aim is to document the bond between the concrete substrate and a surface layer or a concrete layer. Drilled samples are mounted in a tensile testing machine and exposed to tension.	
3L	Carbonation depth	Carbonation depth may be documented in different ways. i) The most commonly used method is to spray phenolphthalein on a freshly split cylinder and measure the depth from the surface. ii) Thin section microscopy may be used when samples are prepared for other purposes. The thin section has to be taken perpendicular from the concrete surface. In fluorescent impregnated samples, there is a marked difference in the colour in carbonated and not carbonated concrete. Differential thermal analysis may be used.	
4L	Cement content	Cement content may be determined by analysing the content of acid soluble silicates. If the cement type is known, the cement content may be determined relatively correct. If the cement type is unknown, or the concrete contain an unknown amount of silica fume, or other additions containing silicates, the content of calcium is analysed and compared with the acid soluble silicates. This method will not work when the aggregate contain lime.	

Table A.5 *(continued)*

No	Property to be tested	Short description	Representative Test method(s), if available.
5L	Chloride content	Concrete powder is ground from the sample, normally at different distances from the surface, in order to find a chloride profile. Several test methods are available in the laboratory. Most commonly used test methods are i) spectrophotometer (absorption of light in a solution), ii) Mohrs method (titration with silver nitrate), and iii) Volhardts method (titration with ammonium thiocyanate). The most accurate results are achieved when both the cement content and chloride contents are measured for every sample.	
6L	Chloride diffusion coefficient, surface chloride content	Based on chloride content at different depths, a chloride profile can be calculated by the least square method and the use of Fick's second law of diffusion. The results are achieved chloride diffusion coefficient, surface chloride content and background chloride content.	
7L	Chloride resistance	Resistance of concrete against chloride ingress can be documented by different test methods. The most commonly used methods in laboratory are all more or less accelerated. In Bulk Diffusion methods, the concrete is exposed to water with high chloride concentration. In Salt Spray Tests, the concrete is exposed to alternating between spraying with water containing high concentration of chlorides and drying periods. In the AASHTO or modified AASHTO methods, a direct current (DC) is applied, forcing the chlorides into the sample.	
8L	Compressive strength	Compressive strength is documented by pressing cylinders drilled from the structure. The size of the sample and the diameter-length ratio influence the results. Before testing, the ends of the samples have to be made plane and perpendicular to the axis by grinding or preparing with mortar of cement or sulfur.	ISO 1920-4:2004, *Testing of concrete — Part 4: Strength of hardened concrete*
9L	Density	The density of the concrete is of general interest and gives an indication if anything is wrong with the sample. Density is normally routinely measured as the ratio between mass and volume.	ISO 1920-5:2004, *Testing of concrete — Part 5: Properties of hardened concrete other than strength*
10L	Diffusivity of water vapour	Diffusion of water vapour is of most interest, sometimes diffusion of other gases like oxygen, may be of interest. Diffusion of water vapour is measured by the "cup-method". The material to be tested is placed as a tight cover over a glass container with water. It is placed in a chamber with low relative humidity and the diffusion of water out of the glass container is found by measuring the mass over time.	**Method 1:** ISO 7783-1, *Paints and varnishes — Determination of water-vapour transmission rate — Part 1: Disk method for free films* **Method 2:** ISO 7783-2. *Paints and varnishes — Coating materials and coating systems for exterior masonry and concrete — Part 2: Determination and classification of water-vapour transmission rate (permeability).*
11L	E-modulus	The E-modulus is normally tested when compressive or tensile strength is tested. Under increasing stress, the stress and corresponding strain are measured and the E-modulus is calculated.	

Table A.5 *(continued)*

No	Property to be tested	Short description	Representative Test method(s), if available.
12L	Freeze–thaw resistance	Both direct and indirect test principles are used. The most used indirect test principle is the microscope pore structure analyses, giving spacing factors and specific surface of the pores. The most used direct test principles are: Freezing in air and thawing in water, measuring the change in dynamic E-modulus, and freezing of saline water at the top of the concrete, measuring the mass loss.	
13L	Porosity	Porosity measurements can be used for calculating density of the solid material, suction porosity, macro porosity, total porosity, resistance number, capillary number and w/c-ratio. Disks of the concrete are dried and then placed a few mm in water. Mass increase and corresponding time are registered. At the end of the test, water is pressed into the sample, giving the total porosity.	
14L	Microstructure analysis	Two microscopic methods are mostly used. i) Plane section microscopy, normally impregnated with fluorescent epoxy and studied in reflected polarized light. ii) Thin section microscopy also normally impregnated with fluorescent epoxy and studied in transmitted polarized light.	
15L	Tensile strength	Two different test methods are used. i) Drilled cylinders or sawn prisms are subjected to tension in a tensile testing machine by gluing steel plates on the ends of the sample. This gives the direct tensile strength. ii) Splitting tensile strength by using a drilled cylinder subjected to compression loads along two diametrically opposite axial lines. This method overestimates the tensile strength by 10–15 %, but is quick and practical to use.	ISO 1920-4:2004, *Testing of concrete — Part 4: Strength of hardened concrete*
16L	Watertightness	Two different principles of test methods are used: i) Concrete disks are subjected to water pressure from one side and the amount of water pressed through is measured. A permeability coefficient can be calculated using Darcy's law. ii) A concrete cylinder is subjected to water pressure for some days, the cylinder is split and the intrusion depth is measured.	ISO 1920-5:2004, *Testing of concrete — Part 5: Properties of hardened concrete other than strength*

A.3 Examples of Investigative Programs

A.3.1 Concrete cracks, cavity, and peeling

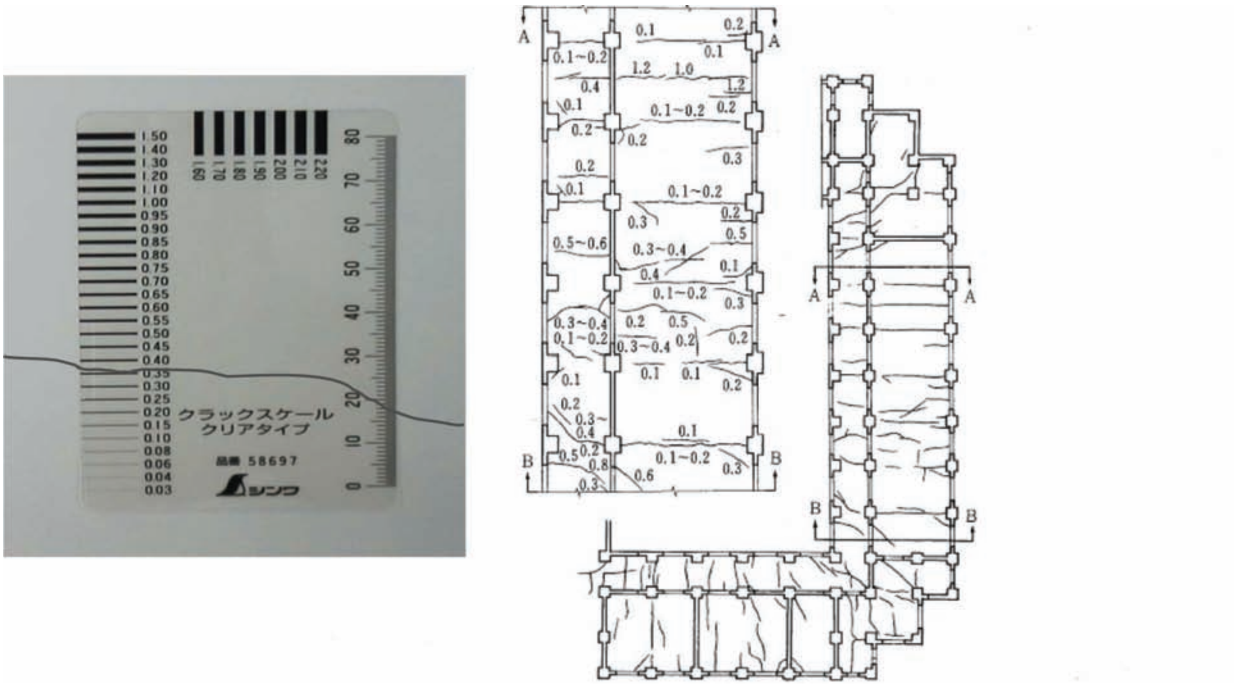
A.3.1.1 Preliminary inspection

In the preliminary assessment, the following subjects are inspected for cracks, cavity, and peeling of concrete.

a) Inspection of the condition of the cracks, such as crack pattern, crack width, and crack length.

NOTE Inspection of crack patterns, crack widths, crack lengths are carried out on targeted cracks. It is recommended to record the data on a general construction plan, ground plan, stereoscopic plan (Figure A.2), etc. The locations of the tips of cracks are essential to estimate the state of stress of the concrete. Therefore, it is necessary to perform visual inspection until the tips of cracks can no longer be observed and record the observed data accordingly. Making lattice marks on the surface of the structure and writing on the engineering drawing in correspondence to these marks is useful for improving the accuracy. Recently, technology has been developed to automatically trace crack patterns on the concrete surface based on digital photographs of the surface of the structure.

a) Elevations



b) Plan views

Figure A.2 — Typical record sketch of observed cracks using crack scale indicating location, orientation, and size of cracks

b) Investigation of the engineering drawings, design reports, and specifications.

c) Investigation of construction records, such as materials used, mixture proportions, casting and curing methods, work schedule, geological condition of the foundation, and environmental condition.

d) Investigation of the service loads and environmental conditions such as variations in temperature and humidity, etc.

e) Investigation of cause of cracks using typical pictures (see Figure A.3).

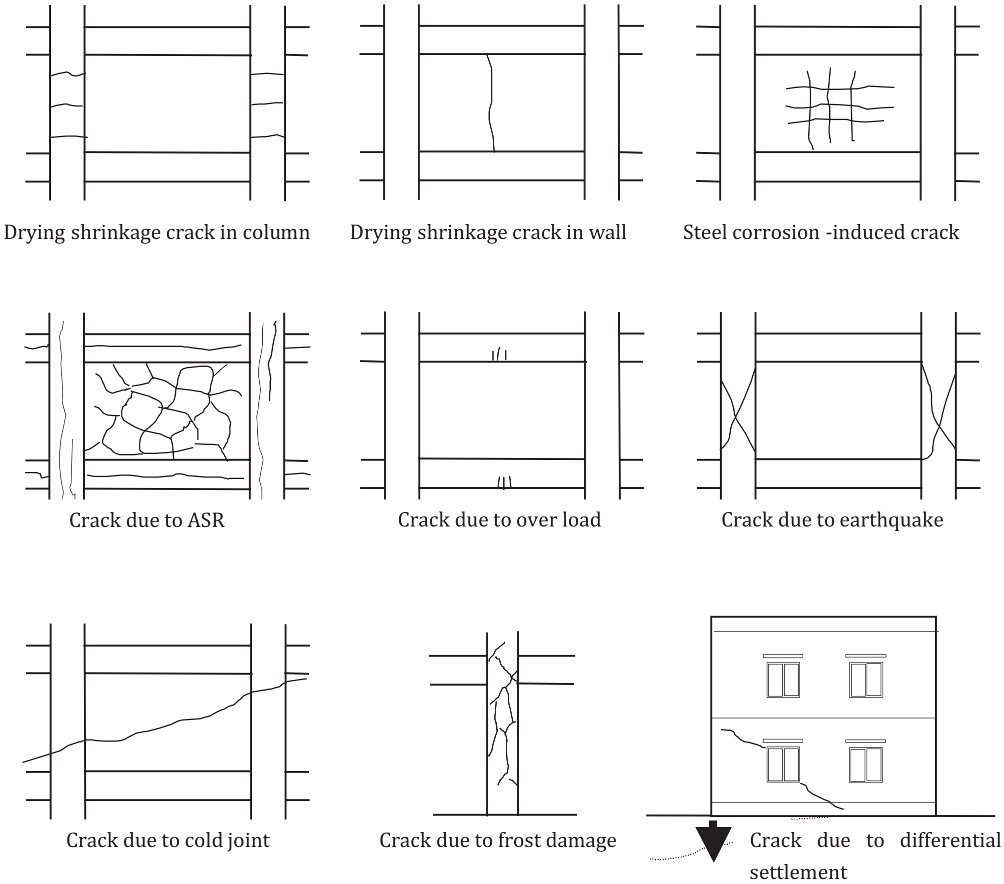


Figure A.3 — Typical crack patterns

A.3.1.2 Detailed Inspection

In the detailed assessment, the following subjects are inspected for cracks, cavity, and peeling of concrete.

a) Depth of crack with destructive method and/or ultra-sonic method is specified in ISO 1920-7:2004.

b) Flaking and peeling with impact-echo method by microphone measurement. Standard test method for measuring the P-wave speed and the thickness of concrete plates using the impact-echo method.

NOTE A stress pulse is introduced into a test object by mechanical impact on the surface. The stress pulse propagates into the object along spherical wave fronts as P-stress waves and S-stress waves. In addition, a surface wave (R-wave) travels along the surface away from the impact point. The P-stress waves and S-stress waves are reflected by internal interfaces (flaws, defects, voids, etc.) or external boundaries. The arrival of their reflected waves, or echoes, at the surface where the impact was generated produces displacements that are measured by a receiving transducer and recorded by a data acquisition system. The success of the method depends, in part, on using an impact of the correct duration.

c) Delamination with infrared thermography is specified in ASTM D 4788.

NOTE The vehicle-mounted infrared scanner and video recorder is driven over the centre of each lane of a bridge deck. The data from the scanner is recorded on video tape. Delaminations appear as white or "hot" areas on a gray or "cooler" background in the video image on a monochrome scanner system during daytime testing. During night-time testing, the delamination will appear as dark or "cooler" areas on a white or "warmer" background. Delaminations will appear as the warmer colours on colour scanner systems during daytime testing. Calibration of thermal anomalies using sounding techniques are used to determine the colours associated with delaminations. The conventional video image is used to edit the infrared image and separate those patches or surface defects that can be present and can appear as hot areas. The video recording is used to map the delaminated areas at a suitable scale.

A.3.2 Strength properties

A.3.2.1 Preliminary inspection

In the preliminary assessment, the following subjects are inspected for strength properties of concrete:

a) engineering drawings, design reports, and specifications;

b) investigation of construction records, such as materials used, mixture proportions of concrete and placing/curing.

A.3.2.2 Detailed inspection

In the detailed assessment, the following subjects are inspected for strength properties of concrete.

a) Strength test using core specimen specified in ISO 1920-6:2004.

NOTE The examination and compression test of cores cut from hardened concrete is a well-established method, enabling visual inspection of the interior regions of a member to be coupled with strength estimation. Other physical properties which can be measured include density, water absorption, indirect tensile strength, expansion due to alkali-aggregate reaction, carbonation depth, chloride penetration depth, and so on. Cores are also frequently used as samples for chemical analysis following strength test.

b) Non-destructive test with the following test methods:

NOTE All tests need calibration to evaluate the strength of concrete.

— rebound hammer test specified in ISO 1920-7:2004;

NOTE The methods included are: a) determination of rebound number, b) determination of ultrasonic pulse velocity, and c) determination of pull-out force.

— ultrasonic pulse test specified in ISO 1920-7:2004;

NOTE 1 This test cannot be regarded as a proper substitute for standard compression test but rather as a method for determining the uniformity of concrete in structures, and comparing one concrete against another.

NOTE 2 The strength can be estimated from the pulse velocity by a pre-established graphical correlation between the strength and velocity. The relationship between them is not unique, and is affected by many factors, e.g. aggregate size, type, and content; cement type and content; water/cement ratio; and moisture content.

— pull-out test specified in ISO 1920-7:2004;

— penetration resistance test.

NOTE A driver delivers a known amount of energy to either a steel probe or pin. The penetration resistance of the concrete is determined by measuring either the exposed lengths of probes that have been driven into the concrete or by measuring the depth of the holes created by the penetration of the pins into the concrete.

A.3.3 Permeability

A.3.3.1 Detailed inspection

Permeability of concrete is tested for the following subjects in the detailed assessment:

a) air permeability;

b) water permeability.

A.3.4 Moisture content

Moisture content of concrete is tested in the detailed assessment with core specimen specified in ISO 12570:2000.

A.3.5 Carbonation

Carbonation of concrete is tested by the following methods in the detailed assessment:

a) drill method as minor destruction, TG-DTA, X-ray diffraction analysis, electron probe microanalysis (EPMA);

b) test with core specimen.

A.3.6 Frost damage

Frost damage of concrete is tested by the following methods in the detailed assessment:

a) estimation of surface strength and the depth of deterioration with Ultrasonic test specified in ISO 1920-7:2004 (see 1.2);

b) test with core specimen (see 1.2);

c) pore distribution, air void system and number of micro cracks.

A.3.7 Chemical corrosion

Damage due to chemical corrosion of concrete is tested by the following methods in the detailed assessment:

a) electron probe microanalysis (EPMA);

b) test with drilled powder or specimen.

A.3.8 Alkali silica reaction

Damage due to the presence of expansive gel is observed as part of a petrographic analysis in a detailed assessment.

A.3.9 Chloride ingress

A.3.9.1 Detailed investigation

Chloride ingress in concrete is investigated using acid digestion or rapid chloride ion permeability.

A.3.10 Reinforcement

A.3.10.1 Position of reinforcement

A.3.10.1.1 Preliminary investigation

In the preliminary assessment, the following subjects are inspected for position of reinforcement:

a) inspection of engineering drawings, design reports, and specifications;

b) inspection of construction records, such as surveying of rebar positions.

A.3.10.1.2 Detailed inspection

In the detailed assessment, the following subjects are inspected for position of reinforcement:

a) electromagnetic testing;

NOTE The most reliable application of this method to in situ reinforcement location and cover measurement will be for lightly reinforced members. As the complexity and quantity of reinforcement increases, the value of the test decreases considerably, and special care should also be taken in areas where the aggregates may have magnetic properties.

b) radar test;

c) chipping of concrete cover.

A.3.11 Corrosion

Corrosion of reinforcement is inspected by the following methods in the detailed assessment:

a) half-cell potential method and polarization resistance method;

NOTE When there is active corrosion, current flow (in the form of ion migration) through the concrete between anodic and cathodic sites is accomplished by an electric potential field surrounding the corroding bar. The equipotential lines intersect the surface of concrete and the potential at any point can be measured using the half-cell potential method. By mapping equipotential contours on the surface, those portions of the structure where there is a high likelihood of corrosion activity are identified by their high negative potentials. The potential value is measured relative to a reference half-cell placed on the concrete surface. The reference half-cell is usually a copper/copper sulfate or silver/silver chloride cell but other combinations can be used.

b) chipping of concrete cover.

Annex B
(informative)

Condition and Consequence Levels

B.1 Condition levels

B.1.1 General

To classify the condition of structures or structural parts in a uniform way, the concept of condition levels is introduced. It is defined as the expression of the condition of an object compared to a reference level, normally the original state of the object. The condition level is normally determined based on combined evaluation of different visual observations. It may in some situations be based on a single symptom.

A National Annex may include a picture catalogue with examples of condition levels for different causes of deterioration, based on symptoms. This will improve the objectiveness of the condition level decision. However, the reference condition should be defined in each situation.

When describing the condition of a structure or a structural part in a general way, the oral classification should be used. The classification by numbers is more useful when handling larger numbers of data in a statistical way.

B.1.2 Levels

The assessment of visible damage can be difficult with subjective criteria and the experience level of the inspector. Moreover, deterioration that is acceptable in one area may not be acceptable in other circumstances. Nonetheless, before commencing field studies, guidelines should be established so that a consistent representation and understanding of the significance of the damage is possible. Six condition levels are defined.

Condition level 0 — Good condition. No symptoms of deterioration.

No symptoms of deterioration are visible. However, a greater part of the initiation period, e.g. due to carbonation or chloride ingress, may already have passed.

Condition level 1 — Minor symptoms of deterioration

Minor symptoms of deterioration are visible. It gives the situation at the time when the inspection was carried out and says nothing on the rate of development of the deterioration.

Condition level 2 — Moderate symptoms of deterioration

Moderate symptoms of deterioration are visible. It gives the situation at the time when the inspection was carried out and says nothing on the rate of development of the deterioration.

Condition level 3 — Severe deterioration

Severe symptoms of deterioration are visible. Falling concrete parts may be dangerous, but the loss of serviceability and safety of the structure are minimal.

Condition level 4 — Potentially hazardous

Strong symptoms of deterioration are discovered, and the consequence may be decrease site or public safety. Immediate action must be taken.

Condition level 5 — Unsafe

Strong symptoms of deterioration are discovered, and the consequence decrease site or public safety. Immediate action must be taken.

A principle illustration of the condition levels, depending on time, is shown in Figure B.1.

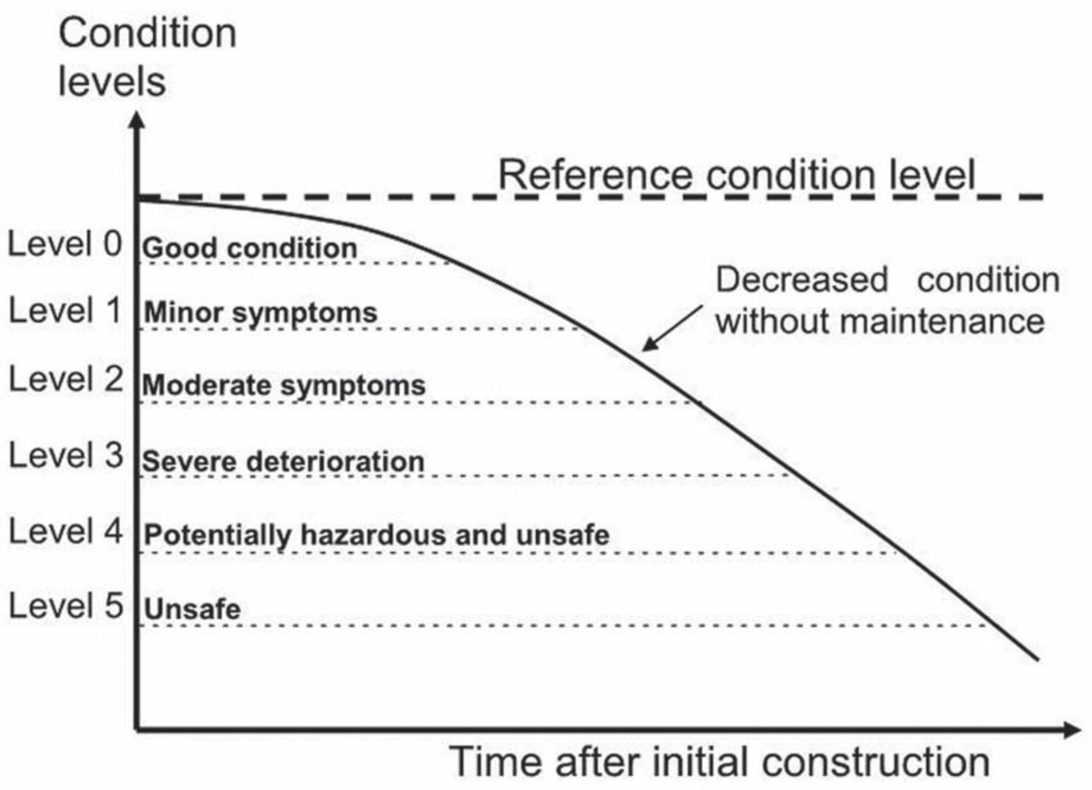


Figure B.1 — Principle illustration of the condition levels, depending on time

B.2 Consequence Levels

B.2.1 General

To classify the consequences of the observed condition for a structure, or a structural part, in a uniform way, the concept of consequence levels is introduced. It is defined as the expression of the seriousness of the consequences of an object related to a defined reference level. The evaluation of the consequences of a condition level is important for the evaluation of repair actions. The decision of a consequence level is normally based on the assumption that no repair or maintenance is done within a certain time.

The following types of consequences might be evaluated:

— safety (e.g. fire, traffic, load bearing capacity, person, falling concrete parts, etc.);

— cost (e.g. investment, works cost during closure, closure of roads/bridges, maintenance cost, etc.);

— aesthetics (e.g. colour, surface structure, etc.);

— health and environment (e.g. noise, vibration, dust, pollution, etc.).

The types of consequences used in the consequence evaluation and decision of consequence level, have to be defined in each situation.

The consequence level might be based on a combined evaluation of different visual observations, symptoms and structural calculations. It might in some situations be based on a single symptom, but that is not normal. The reference level for evaluation of the consequence level may be based on a single, some, or all types of consequences. When the consequence level is given separately for each type of consequences, the actual type of consequences should clearly be given, e.g. by a capital letter before the number (e.g. S2 for a safety consequence level 2).

Depending on the importance of a structure, equal structures with equal condition level, may have different consequence levels.

When describing the consequence of a condition for a structure or a structural part in a general way, the oral classification should be used. The classification by numbers is more useful when handling larger numbers of data in a statistical way.

The discovery of unsafe or potentially hazardous conditions mandates that the owner be notified immediately of the consequences of the condition. Temporary evaluation, shoring measures, or other emergency safety measures, if applicable, should be recommended to the owner. If public safety is involved, a follow-up of the conditions should continue with the owner until satisfactory safety measures are implemented.

B.2.2 Levels

Normally, five consequence levels are defined. Based on the observed condition(s) and the purpose/function of a structure, the seriousness of the consequences is evaluated.

Consequence level 0 — No consequences

The evaluation of the situation results that no consequences are found.

Consequence level 1 — Small consequences

The evaluation of the situation results that small consequences are found.

Consequence level 2 — Medium consequences

The evaluation of the situation results that medium consequences are found.

Consequence level 3 — Large consequences

The evaluation of the situation results that large consequences are found.

Consequence level 4 — Hazardous consequences

The evaluation of the situation results that structurally unsafe or potentially hazardous consequences are found.

Annex C
(informative)

Evaluation and Verification

C.1 Evaluation and Verification

C.1.1 General

Evaluation is a process of determining the adequacy of a structure or component for its intended use by analysing systematically the information and data assembled from reviews of existing documentation, field inspection, condition survey, and material testing. This investigative process of evaluation cannot be completely standardized into a series of well-defined steps because the number and type of steps vary depending on the specific purpose of the investigation, the type and physical condition of the structure, the completeness of the available design and construction documents, and the strength and quality of the existing construction materials. Only general guidelines are presented in this Annex.

Structural evaluations should be performed to determine the load-bearing capacity of all critical members of the structure, and the structure as a whole. The ability of the structure to support all present and anticipated loads, according to applicable code requirements or standards, should be considered. Where these code requirements are not met with the structure in its current condition, appropriate strengthening methods and techniques should be determined. The need to meet architectural requirements should also be evaluated. Both changes in architectural layout and modifications to the façades of the structure should be evaluated. Final schemes should be selected by the client from various design alternatives. The cost of various alternatives should be estimated and the implications evaluated.

C.1.2 Evaluation of the Concrete Structure

C.1.2.1 Dimensions and Geometry

The actual dimensions of the structure and architectural layout should be evaluated for use, access, and needed space. The field-measured cross-sections of the critical structural components should be reviewed. Discrepancies between the field-measured dimensions and those indicated on available drawings should be evaluated.

C.1.2.2 Materials Evaluation

Field and laboratory test results should be studied so that components of the structure that require repair can be identified. The structural components which require total replacement should be identified and new materials selected. All existing materials should be evaluated for strength, quality, and satisfactory performance in terms of life expectancy, future loads, and intended usage. Where maintenance and repair is required, the appropriate materials should be studied and recommendations made. The materials should be selected based on the environment, type of use, life expectations, and compatibility with existing materials. After evaluation of the existing conditions, it may be determined that protection from further deterioration is required. Methods such as coating, shielding, or specialized systems (e.g. cathodic protection) can be considered.

C.1.2.3 Structural Evaluation and Verification

Using the information obtained from the field inspection, dimension and geometry evaluation, and material evaluations, the load-bearing capacity of the structure or portion of the structure undergoing evaluation should be determined, and verification that the structure meets or exceeds the established criteria should be confirmed.

The choice of the evaluation method depends on such factors as the nature of the structure and the amount of information known about its existing condition. The typical choices are 1) evaluation by analysis, 2) evaluation by analysis and full-scale load testing, or 3) evaluation by analysis and structural modelling.

Evaluation by analysis, the most common method, is recommended when sufficient information is available about the physical characteristics, material properties, structural configuration, and loadings to which the structure has been and will be subjected. Evaluation by analysis and full-scale load testing or structural modelling, or both, is recommended when the complexity of the design concept and lack of experience with the structural system make evaluation solely by analytical methods unreliable, or when the nature of existing distress introduces significant uncertainties into the magnitude of the parameters necessary to perform an analytical evaluation, or when the geometry and the material characteristics of the structural members being evaluated cannot be readily determined

Critical structural components, including members and connections, should be identified for evaluation based on the document review, dimension and geometry check, and material evaluation. The capacities of the critical structural components should be determined. Sophisticated methods such as finite element analyses may be used. All existing and expected dead loads and live loads, equipment and piping loads, and applicable code-mandated wind and earthquake requirements, must be considered. Where applicable, the non-structural components should also be evaluated to ensure that they are capable of resisting the prescribed loads and deformations. The effect of non-structural components on the overall performance of the structure should also be considered.

C.1.2.4 Evaluation of Maintenance and Repair Options

Even if the existing structure appears to meet all the strength and durability requirements, cosmetic or other types of repairs may still be required to restore the structure to an appropriate condition. Alternate repair methods, as well as the possibility of using the “do nothing approach,” should be evaluated based on comparative cost estimates, schedules, and relative levels of interference with the operations.

When the existing structure (or components) does not meet the strength requirements, alternate methods of strengthening should be evaluated, comparative cost estimates should be prepared for the various alternates and a recommendation for the selected method or methods should be made for the owner’s approval. Where the structure to be restored is occupied, the effect of repair or strengthening procedures on the normal operations of the structure must be considered. This includes effects such as noise, dust, and physical interruption of operations. The possibility of work during off hours, (nights, weekends, holidays) should be evaluated because it often proves to be desirable and cost effective.

C.1.2.5 Evaluation of Maintenance and Repair Costs

A cost evaluation should be conducted for all feasible repair alternatives. The cost of maintenance and repair is subject to many factors; however, the cost for certain types of structural repair or strengthening work can often be reasonably estimated based on previous experience. Such an estimate can form the basis for an initial decision regarding the appropriate alternative to be selected and the overall economic feasibility of the project. A more detailed cost of rehabilitation should be documented, taking into account the location of the project and the existing and available labour and skilled contractors. These costs should be computed for the approximate time of the actual construction schedule. It must be recognized that unanticipated conditions requiring extra cost are common in many maintenance and repair projects and adequate contingencies should be provided. In the event the estimated costs exceed the available budget, another cycle of possible reductions should be studied. The final maintenance and repair program then can be modified and approved by the owner, who should be advised that actual costs can be determined only after preparation of detailed contract documents (drawings and specifications) and after obtaining firm bids from contractors. If the cost of upgrading is determined to be prohibitive, possible alternate uses of the structure should be studied, or a recommendation made for continuing its present use or for phasing out its use.

C.1.3 Verification of Condition

Verification that the structure or member is performing to its target level is most easily established by comparing its present condition to its original design criteria. In the absence of this information or guidance, satisfactory previous performance with respect to safety and serviceability can be evaluated.

NOTE ISO 13822:2001 provides a detailed procedure for verification analysis.

Annex D
(informative)

Recommendations

D.1 General

The recommendations must address the following topics: action plan, cost estimates, scheduling, and determining constraints and feasibility.

D.2 Action plan

The recommendation should clearly point out an appropriate course of action, such as

1) accept the structure as-is,

2) strengthen the structure to correct deficiencies identified,

3) change the use of the structure, or

4) phase the structure out of service.

The course of action that will best satisfy the owner's objectives should be considered and an appropriate and cost-effective solution for the repair should be developed. Effective plans should address what action should be taken and how it should best be accomplished. Where budget constraints are severe, it may be necessary to assign priorities to repairs and to stage the program accordingly over several years. Feasible alternatives to the recommended plan of action should be identified including estimated costs and payback periods.

D.3 Cost estimates

Project costs often influence every aspect of a recommended repair plan and, while not necessarily controlling the final recommendations, can have a major influence on them. Cost estimates should address the owner's requirements and consider the effects of interruptions of normal operations. Additionally, it is helpful to study possible phasing (or staging) of the project and to identify the influence that deferring of a particular phase would have on future repair costs. Inflation rates and interest rates should both be taken into account when evaluating the impact of a deferment on a repair program. Finally, the life expectancy of various systems and alternate repair schemes, and the life expectancy of the entire structure, should be considered. The total cost estimate should also include cost of the required engineering services, testing services, and contingencies.

D.4 Scheduling

Project schedule may be determined by the urgency of the repair needs, the availability of funds, the effects on ongoing operations, and the optimal construction conditions. If repair work is required outdoors, work may be delayed until the weather is suitable, or temporary protection measures may have to be considered. The schedule must consider the lead time for engineering and for preparation of construction documents. Sufficient time should be allowed for contractor selection and mobilization. Where unknown conditions exist, sufficient time should be allowed for possible modifications and additional engineering services if newly discovered deficiencies are found during repair. Adequate delivery time for special materials, new or replacement equipment, or prefabricated components should be considered.

D.5 Constraints and feasibility determination

Repair often involves the constraints associated with working around existing operations. Special considerations are warranted for construction operations that produce dust, noise, odor, vibrations, or involve hazardous materials. Site access and materials handling problems should also be considered. Special project planning meetings are often helpful in determining the most appropriate way of handling these constraints. It is of critical importance to ensure that any constraints mandated by the owner be considered and incorporated into the repair plan.

Annex E
(informative)

Content of the Final Report

E.1 Introduction

The results of the entire inspection should be summarized in a final report. This report generally includes a brief description of the following basic areas addressed during the evaluation process:

a) purpose and scope of investigation;

b) existing construction and documentation;

c) field observations and condition survey;

d) sampling and material testing;

e) evaluation;

f) findings and recommendations.

E.2 Purpose and scope of investigation

This section of the report should describe the purpose and scope of the investigation as agreed with the owner, including any modifications made during the course of the evaluation.

E.3 Existing construction and documentation

A brief summary of information on the existing structure including location, size, history, architectural, and structural details, etc., should be included in this section. The results of the documentation review should be summarized and supplemented by photographs, copies of drawings, and any other pertinent information as applicable. A list of all the documents collected and their sources should be included.

E.4 Field observations and condition survey

The results of the condition survey for all portions of the structure, including its envelope and foundations, should be included. The report should briefly describe methods and equipment used, results of as-built verification efforts, including all deviations, major deficiencies that require remedial work, and all portions of the structure that are to be altered for change of use or appearance. The report should also include photographs, sketches, drawings, and other pertinent information prepared during the inspection and field survey operations.

E.5 Sampling and material testing

The locations, methods, and results of the non-destructive and destructive testing performed during the detailed inspection should be summarized. The results may be supplemented with photographs and copies of laboratory test reports as appropriate. The results should indicate adequacy in terms of physical condition, strength, and future performance of all structural and architectural materials tested.

E.6 Evaluation

The report should summarize the results of the strength evaluation of the structure. All assumptions made and methods used in the evaluation process should be clearly documented. A brief description of each repair alternate or strengthening method studied, along with sketches showing typical details, cost estimates, and the impact of the repair method, should be included.

E.7 Findings and recommendations

The findings from each preceding task discussed should be summarized in this section of the report. The findings should include a discussion of the condition of the structure and the feasibility of the repair. Annex D details report elements for recommendations.

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