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Bases for design of structures — Assessment of existing structures

Bases du calcul des constructions — Évaluation des constructions existantes

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 13822 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 2, *Reliability of structures*.

Annexes A to H of this International Standard are for information only.

This corrected version of ISO 13822:2001 incorporates the following corrections. The flowchart in Annex B has been corrected and the year of publication of reference [8] in the Bibliography has been changed.

Introduction

The continued use of existing structures is of great importance because the built environment is a huge economic and political asset, growing larger every year. The assessment of existing structures is now a major engineering task. The structural engineer is increasingly called upon to devise ways for extending the life of structures whilst observing tight cost constraints. The establishment of principles for the assessment of existing structures is needed because it is based on an approach that is substantially different from the design of new structures, and requires knowledge beyond the scope of design codes. This document is intended not only as a standard of principles and procedures for the assessment of existing structures but also as a guide for use by structural engineers and clients. Engineers can apply specific methods for assessment in order to save structures and to reduce a client's expenditure. The ultimate goal is to limit construction intervention to a strict minimum, a goal that is clearly in agreement with the principles of sustainable development.

The basis for the reliability assessment is contained in the performance requirements for safety and serviceability of ISO 2394. Economic, social, and sustainability considerations, however, result in a greater differentiation in structural reliability for the assessment of existing structures than for the design of new structures

Bases for design of structures — Assessment of existing structures

1 Scope

1.1 This International Standard provides general requirements and procedures for the assessment of existing structures (buildings, bridges, industrial structures, etc.) based on the principles of structural reliability and consequences of failure. It is based on ISO 2394.

1.2 It is applicable to the assessment of any type of existing structure that was originally designed, analysed and specified based on accepted engineering principles and/or design rules, as well as structures constructed on the basis of good workmanship, historic experience and accepted professional practice. The assessment can be initiated under the following circumstances:

— an anticipated change in use or extension of design working life;

— a reliability check (e.g. for earthquakes, increased traffic actions) as required by authorities, insurance companies, owners, etc.;

— structural deterioration due to time-dependent actions (e.g. corrosion, fatigue);

— structural damage by accidental actions (see ISO 2394).

NOTE 1 This International Standard is applicable to historical structures, provided additional considerations are taken into account concerning the preservation of the historical appearance of the structure and the preservation of its historical materials.

1.3 This International Standard is applicable to existing structures of any material, although specific adaptation can be required depending on the type of material, such as concrete, steel, timber, masonry, etc.

1.4 This International Standard provides principles regarding actions and environmental influences. Further detailed consideration will be necessary for accidental actions such as fire and earthquake.

NOTE 2 Fire resistance requires properties different from those for structural safety and integrity. Also fire hazards can be created by change in use. Special requirements are necessary for seismic hazards, taking the dynamic action and structural response into account.

1.5 This International Standard is intended to serve as a basis for preparing national standards or codes of practice in accordance with current engineering practice and the economic conditions.

2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 2394:1998, *General principles on reliability for structures*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 2394 and the following apply. (See also annex A.)

3.1
assessment
set of activities performed in order to verify the reliability of an existing structure for future use

3.2
damage
unfavourable change in the condition of a structure that can affect structural performance

3.3
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

3.4
deterioration model
mathematical model that describes structural performance as a function of time, taking deterioration into account

3.5
inspection
on-site non-destructive examination to establish the present condition of the structure

3.6
investigation
collection and evaluation of information through inspection, document search, load testing and other testing

3.7
load testing
test of the structure or part thereof by loading to evaluate its behaviour or properties, or to predict its load-bearing capacity

3.8
maintenance
routine intervention to preserve appropriate structural performance

3.9
material properties
mechanical, physical or chemical properties of structural materials

3.10
monitoring
frequent or continuous, normally long-term, observation or measurement of structural conditions or actions

3.11
reference period
chosen period of time which is used as a basis for assessing values of variable actions, time-dependent material properties, etc.

NOTE The remaining working life or the minimum standard period for safety of an existing structure can be taken as reference period (see annex F).

3.12
rehabilitation
work required to repair, and possibly upgrade, an existing structure

3.13
remaining working life
period for which an existing structure is intended/expected to operate with planned maintenance

3.14
repair, verb
⟨of a structure⟩ improve the condition of a structure by restoring or replacing existing components that have been damaged

3.15
safety plan
plan specifying the performance objectives, the scenarios to be considered for the structure, and all present and future measures (design, construction, or operation, such as monitoring) to ensure the safety of the structure

3.16
structural performance
qualitative or quantitative representation of the behaviour of a structure (e.g. load-bearing capacity, stiffness) in terms of its safety and serviceability

3.17
target reliability level
level of reliability required to ensure acceptable safety and serviceability

3.18
upgrading
modifications to an existing structure to improve its structural performance

3.19
utilization plan
plan containing the intended use (or uses) of the structure, and listing the operational conditions of the structure including maintenance requirements, and the corresponding performance requirements

4 General framework of assessment

4.1 Objectives

The objective of the assessment of an existing structure in terms of its required 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, which provides appropriate safety for the users of the structure.

b) Continued function performance level, which provides continued function for special structures such as hospitals, communication buildings or key bridges, in the event of an earthquake, impact, or other foreseen hazard.

c) Special performance requirements of the client related to property protection (economic loss) or serviceability. The level of this performance is generally based on life cycle cost and special functional requirements.

4.2 Procedure

The assessment procedure is composed in general of the following steps so that the assessment is carried out taking into account the actual conditions of the structures (see the flowchart in annex B). The procedure depends on the assessment objectives (see 4.1), and on specific circumstances (e.g. the availability of the design documents, the observation of damage, the use of the structure). A site visit is recommended prior to initiating the procedure.

a) Specification of the assessment objectives.

b) Scenarios.

c) Preliminary assessment:

   1) study of documents and other evidence;

   2) preliminary inspection;

   3) preliminary checks;

   4) decisions on immediate actions;

   5) recommendation for detailed assessment.

d) Detailed assessment:

   1) detailed documentary search and review;

   2) detailed inspection and material testing;

   3) determination of actions;

   4) determination of properties of the structure;

   5) structural analysis;

   6) verification.

e) Results of assessment:

   1) report;

   2) conceptual design of construction interventions;

   3) control of risk.

f) Repeat the sequence if necessary.

The procedure outlined above may be applied to both the assessment of one specific structure and the assessment of a group of structures.

4.3 Specification of the assessment objectives

At the outset, the objective of the assessment of the structure shall be clearly specified in terms of its future performance in an agreement between the client, the authorities when relevant and the assessing engineer (see 4.1). The required future performance shall be specified in the utilization plan and safety plan.

4.4 Scenario

Scenarios related to a change in structural conditions or actions should be specified in the safety plan in order to identify possible critical situations for the structure. Each scenario is characterized by a predominant process or action and, where appropriate, by one or more accompanying processes or actions. The identification of scenarios represents the basis for the assessment and design of interventions to be taken to ensure structural safety and serviceability.

4.5 Preliminary assessment

4.5.1 Study of documents and other evidence

Design and inspection documents contain important information that is necessary for a thorough assessment of an existing structure. It shall be verified that the documents are correct, and that they are updated to include information of any previous intervention to the structure. Other evidence, such as the occurrence of significant environmental or seismic actions, large actions, changes in soil conditions, corrosion, and misuse of the structure, shall be recorded and documented.

4.5.2 Preliminary inspection

The aim of a preliminary inspection is to identify the structural system and possible damage to the structure by visual observation with simple tools. The information collected is related to aspects such as surface characteristics, visible deformations, cracks, spalling, corrosion. The results of the preliminary inspection are expressed in terms of a qualitative grading of structural conditions (e.g. none, minor, moderate, severe, destructive, unknown) for possible damage.

4.5.3 Preliminary checks

The purpose of the preliminary checks is to identify the critical deficiencies related to the future safety and serviceability of the structure with a view to focussing resources on these aspects in subsequent assessment. Based on these results, it is then judged whether a further investigation is necessary or not.

4.5.4 Decisions on immediate actions

When the preliminary inspections and/or checks clearly indicate that the structure is in a dangerous condition, it is necessary to report to the client that interventions should be taken immediately to reduce the danger with respect to public safety. If there is uncertainty, the critical deficiencies should be assessed immediately and actions taken, if necessary.

4.5.5 Recommendations for detailed assessment

The preliminary checks may clearly show the specific deficiencies of the structure, or that the structure is reliable for its intended use over the remaining working life, in which case a detailed assessment is not required. Where there is uncertainty in the actions, action effects or properties of the structure, a detailed assessment should be recommended in accordance with 4.6.

4.6 Detailed assessment

4.6.1 Detailed documentary search and review

The following documents, if available, should be reviewed:

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

— regulations and by-laws, codes of practice which were used for constructing the structure;

— topography, subsoil conditions, groundwater level at the site.

4.6.2 Detailed inspection and material testing

The details and dimensions of the structure as well as characteristic values of material properties can be obtained from design documents, provided that the documents exist and that there is no reason for doubt. In case of any doubts, the details and dimensions of components and properties of materials assumed for the analysis shall be determined from a detailed inspection and material testing. The planning of such an inspection is based on information that is already available. The detailed quantitative inspection will result in a set of updated values or distributions for certain relevant parameters that affect the properties of the structure (see annex C).

4.6.3 Determination of actions

Actions and, in particular, environmental actions on structures shall be determined by analysis in accordance with ISO 2394, taking into account provisions laid down in the safety and utilization plan.

4.6.4 Determination of properties of the structures

Testing of the structure is used to measure its properties and/or to predict the load-bearing capacity when other approaches such as detailed structural analysis or inspection alone do not provide clear indication or have failed to demonstrate adequate structural reliability (see annex D).

4.6.5 Structural analysis

Structural analysis in accordance with ISO 2394 shall be carried out to determine the effects of the actions on the structure. The capacity of structural components to resist action effects shall also be determined. The deterioration of an existing structure shall be taken into consideration. When deterioration of an existing structure is observed, the reliability assessment of the structure becomes a time-dependent deterioration problem as described in ISO 2394, and an appropriate analysis method shall be used. In the case of deteriorated structures, it is essential to understand the causes for the observed damage or misbehaviour.

Some examples of appropriate analysis methods to assess time-dependent reliability can be found in annex E.

NOTE For deterioration, it is often more practical to use service-life predictors (such as S-N curves for fatigue or time-to spalling models for corrosion of reinforcement) based on test data.

4.6.6 Verification

The verification of an existing structure should normally be carried out to ensure a target reliability level that represents the required level of structural performance (see 4.1 and annex F). Current codes or codes equivalent to ISO 2394 which have produced sufficient reliability over a long period of application may be used. Former codes that were valid at the time of construction of an existing structure should be used as informative documents. Alternatively, verification may be based on satisfactory past performance (see clause 8).

4.7 Results of assessment

4.7.1 Report

The results of assessment shall be documented in a report (see annex G for an example).

4.7.2 Conceptual design of construction interventions

If the structural safety or serviceability is shown to be inadequate, the results of the assessment should be used to recommend construction interventions for repair, rehabilitation, or upgrading of the structure to perform in accordance with the objective of the assessment for its remaining working life (see annex H).

4.7.3 Control of risk

An alternative approach to construction interventions, which may be appropriate in some circumstances, is to control or modify the risk. Various measures to control the risk environment include imposing load restrictions, altering aspects of the use of the structure, and implementing some form of in-service monitoring and control regime.

5 Data for assessment

5.1 General

Data for assessment should be related to the material properties, structural properties, dimensions, and other conditions as actually established for the existing structure and for previous and/or future actions on the structure.

NOTE Current codes are normally design codes and therefore cannot be used directly for assessment. First, the actual condition is considered, which is not normally foreseen in a design code. Secondly, if current codes have more severe requirements than the codes that were applied at the time of design, the existing structure may be judged to be unsafe. However, as discussed in clause 7 and annex F, reduced service life and target reliability level may be considered for an existing structure. Furthermore, refined analyses, testing and a consideration of the actual behaviour of a structure can help in this respect.

5.2 Actions and environmental influences

5.2.1 Actions

Actions shall be determined in accordance with current codes. Changes of actions caused by the change in use or modification of an existing structure shall be taken into consideration.

5.2.2 Environmental infuences

Environmental influences of a physical, chemical or biological nature that can have an effect on the material properties of an existing structure shall be taken into account. Changes in environmental influences as a result of change in use or modification of an existing structure shall be taken into consideration.

5.2.3 Original drawings and design specifications

The actions and environmental influences for which the structure was originally designed, may be determined from drawings and design specifications when there is no uncertainty about their validity.

5.2.4 Inspection

Environmental influences should be determined by inspection in cases of uncertainty. In such cases, some types of actions may also be determined by inspection, for example by measurement of dimensions of components.

5.2.5 Site-specific data

It can be advantageous to consider the specific characteristics of a structure or its surrounding or to observe actions when determining actions and environmental influences. It is important to adjust long-term and extreme effects that cannot be measured directly when collecting information on actions and environmental influences.

5.3 Material properties

5.3.1 Actual material properties

Material properties used in the assessment shall be the estimated actual material properties of the existing structure, not material properties specified in the original design of the structure or in a code or standard. The material properties shall be assessed by considering deterioration and possible influences of actions (e.g. fire) during the history of the structure.

5.3.2 Original drawings and design specifications

Material properties may be determined from drawings and design specifications when there is no uncertainty about their validity.

5.3.3 Material testing

In cases of uncertainty, material properties should be determined by testing, including non-destructive or destructive material testing. The testing should be planned to produce data which is of direct concern to the required safety and serviceability of the structure as shown by structural analysis. The use of the structure and the environmental influences on the structure shall be taken into account.

5.3.4 Sampling and testing procedure

Sampling and testing methods should be in accordance with the relevant International Standards. Sampling locations and methods which may jeopardize structural reliability shall be avoided. Repair and/or reinforcement shall be carried out immediately after sampling.

5.3.5 Analysis of test results

When samples are tested, the material properties of the structure shall be determined, statistically if possible, from the test results.

5.4 Properties of the structure

5.4.1 Testing for static and dynamic properties of structure

If the properties of the structure are not sufficiently understood or if it is not feasible to establish the required dimensions and material properties by measurement, testing of the structure may be required to define structural properties. Dynamic testing shall be carried out if the dynamic properties of an existing structure are required and are not available from other sources (see annex D).

5.4.2 Geotechnical investigation

Geotechnical and subsoil influences on structural behaviour shall be investigated.

5.5 Dimensions

5.5.1 Actual dimensions

In determining dimensions of components in an existing structure, the actual dimension should be used.

5.5.2 Determination of dimensions

Dimensions may be determined from drawings and design specifications when there is no uncertainty about their validity. In cases of uncertainty, dimensions should be determined by inspection and measurement.

6 Structural analysis

6.1 Models

Structural performance shall be analysed using models that reliably represent the actions on the structure, the behaviour of the structure, and the resistance of its components. The analytical model should reflect the actual condition of the existing structure.

6.2 Limit states

The structure shall be analysed for the ultimate limit states and serviceability limit states, using the basic variables and taking account of relevant deterioration processes.

6.3 Basic variables

The following basic variables for use in structural analysis shall be determined by updating information about the actual condition of the structure:

a) actions;

b) material properties and geotechnical conditions;

c) dimensions of the structural components and subsoil geometry;

d) model uncertainties.

6.4 Model uncertainties

The uncertainty associated with the validity and accuracy of the models should be considered during assessment, either by adopting appropriate partial factors in deterministic verifications or by introducing probabilistic model factors in reliability analyses.

6.5 Conversion factors

Conversion factors reflecting the influence of shape and size effect of specimens, temperature, moisture, duration-of-load effects, etc., shall be taken into account.

6.6 Uncertainty about the condition of components

When an existing structure is analysed, the level of knowledge about the condition of components shall be taken into account. This may be achieved by adjusting the assumed variability in either the load-carrying capacity of the components or the dimensions of their cross sections, depending on the type of structure.

6.7 Deterioration models

When deterioration of an existing structure is observed, the deterioration mechanisms shall be identified and a deterioration model predicting the future performance of the structure shall be determined on the basis of theoretical or experimental investigation, inspection and experience.

7 Verification

7.1 Bases

The assessment of an existing structure shall be based on the verification of structural safety and serviceability.

7.2 Reliability assessment

The reliability assessment shall be made taking into account the remaining working life of an existing structure, the reference period, and changes in the environment of a structure associated with an anticipated change in use.

Economic, social and sustainability considerations result in a greater differentiation in structural reliability for assessment of existing structures than for the design of new structures.

7.3 Limit states

Verifications shall be based on the limit state concept. Attention should be paid to both the ultimate and serviceability limit states. Verification may be carried out using partial safety factor or structural reliability methods with consideration of structural system and ductility of components.

Partial safety factors given in current codes may be modified to take into account the inspection and test results (concerning, for example, quality of workmanship, conditions of maintenance and strength variation of materials).

7.4 Plausibility check

The conclusion from the assessment shall withstand a plausibility check. In particular, discrepancies between the results of structural analysis (e.g. insufficient safety) and the real structural condition (e.g. no sign of distress or failure, satisfactory structural performance) shall be explained.

NOTE Many engineering models are conservative and cannot always be used directly to explain an actual situation. See also clause 8.

7.5 Target reliability level

The target reliability level used for verification can be taken as the level of reliability implied by acceptance criteria defined in proven and accepted design codes. The acceptance criteria shall be stated together with clearly defined limit state functions and specific models of the basic variables.

The target reliability level can also be established taking into account the required performance level for the structure (see 4.1), the reference period, and possible failure consequences. Lower target reliability levels for existing structures may be used if they can be justified on the basis of socio-economic criteria (see annex F).

8 Assessment based on satisfactory past performance

8.1 Assessment of safety

Structures designed and constructed based on earlier codes, or designed and constructed in accordance with good construction practice when no codes applied, may be considered safe to resist actions other than accidental actions (including earthquakes) provided that

— careful inspection does not reveal any evidence of significant damage, distress or deterioration,

— the structural system is reviewed, including investigation of critical details and checking them for stress transfer,

— the structure has demonstrated satisfactory performance for a sufficiently long period of time for extreme actions due to use and environmental effects to have occurred,

— predicted deterioration taking into account the present condition and planned maintenance ensures sufficient durability, and

— there have been no changes for a sufficiently long period of time that could significantly increase the actions on the structure or affect its durability, and no such changes are anticipated.

8.2 Assessment of serviceability

Structures designed and constructed based on earlier codes, or designed and constructed in accordance with good construction practice when no codes applied, may be considered serviceable for future use provided that

— careful inspection does not reveal any evidence of significant damage, distress, deterioration or displacement,

— the structure has demonstrated satisfactory performance for a sufficiently long period of time for damage, distress, deterioration, displacement or vibration to occur,

— there will be no changes to the structure or in its use that could significantly alter the actions including environmental actions on the structure or part thereof, and

— predicted deterioration taking into account the present condition and planned maintenance ensures sufficient durability.

9 Interventions

Responding to the requirements defined in the utilization plan, assessment of existing structures may result in several possible interventions including repair, rehabilitation, performance monitoring and maintenance of critical components, upgrading (see annex H), and demolition. The cost and risk associated with each of the interventions should be estimated.

10 Report

10.1 General

Assessment of an existing structure is typically carried out in a manner involving a number of phases of work. Some form of report is usually required at the end of each phase of the work. The following clauses are related primarily to the form of the final report which should be issued upon the completion of the assessment.

10.2 Conclusions

Clear conclusions with regard to the objective of the assessment in terms of performance requirement (see 4.3) and the scenarios (see 4.4) should be stated after careful assessment of the structural reliability and cost of interventions as well as public safety, structure preservation and life cycle cost.

10.3 Sufficient reliability

If the existing structure is verified to have sufficient reliability, no further action is required.

10.4 Insufficient reliability

If an assessment concludes that the reliability of a structure is insufficient, appropriate interventions should be proposed.

10.5 Recommendations for interventions

Recommendations for possible construction and/or operational interventions that are available to the client as a logical follow-up to the conclusions should be presented. While the engineer should indicate a preferred solution, it should be noted that the client makes the final decision on interventions. Temporary intervention for unsafe condition may also be required immediately.

10.6 Inspection and maintenance plan

In all cases, an inspection and maintenance plan during the remaining working life should be specified depending on the results of assessment and the utilization plan, and submitted to the client. The date or conditions for the next assessment should be recommended.

10.7 Documented information

All the information obtained in the assessment should be documented in a report for the client, including the objective of the assessment, name of engineer (or firm), description of the structure, methods and results of the assessment, as well as recommendations for relevant further steps, if necessary (see annex G).

10.8 Reporting style

The report shall be concise and clear. A recommended report format is indicated in annex G.

11 Judgement and decision

11.1 Decision

The final decision on interventions, based on engineering judgement and the recommendations in the report and considering all the information available, is made by the client in collaboration or in consultation with the relevant authority.

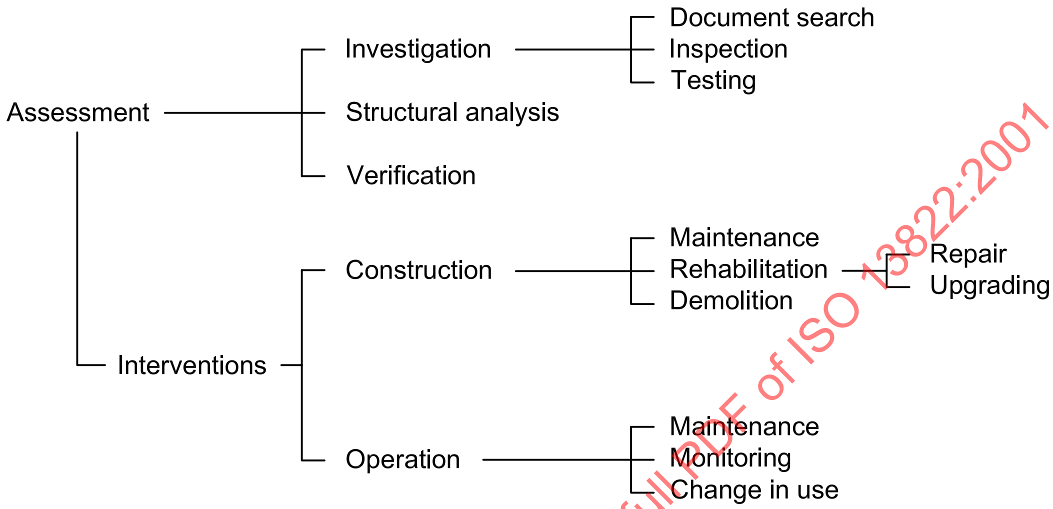
NOTE If the client does not respond in a reasonable time in matters of public safety, the engineer might have the legal duty to inform the relevant authority.

11.2 Change in use

An important change in use of the structure made after the assessment invalidates the recommendations proposed in the report.

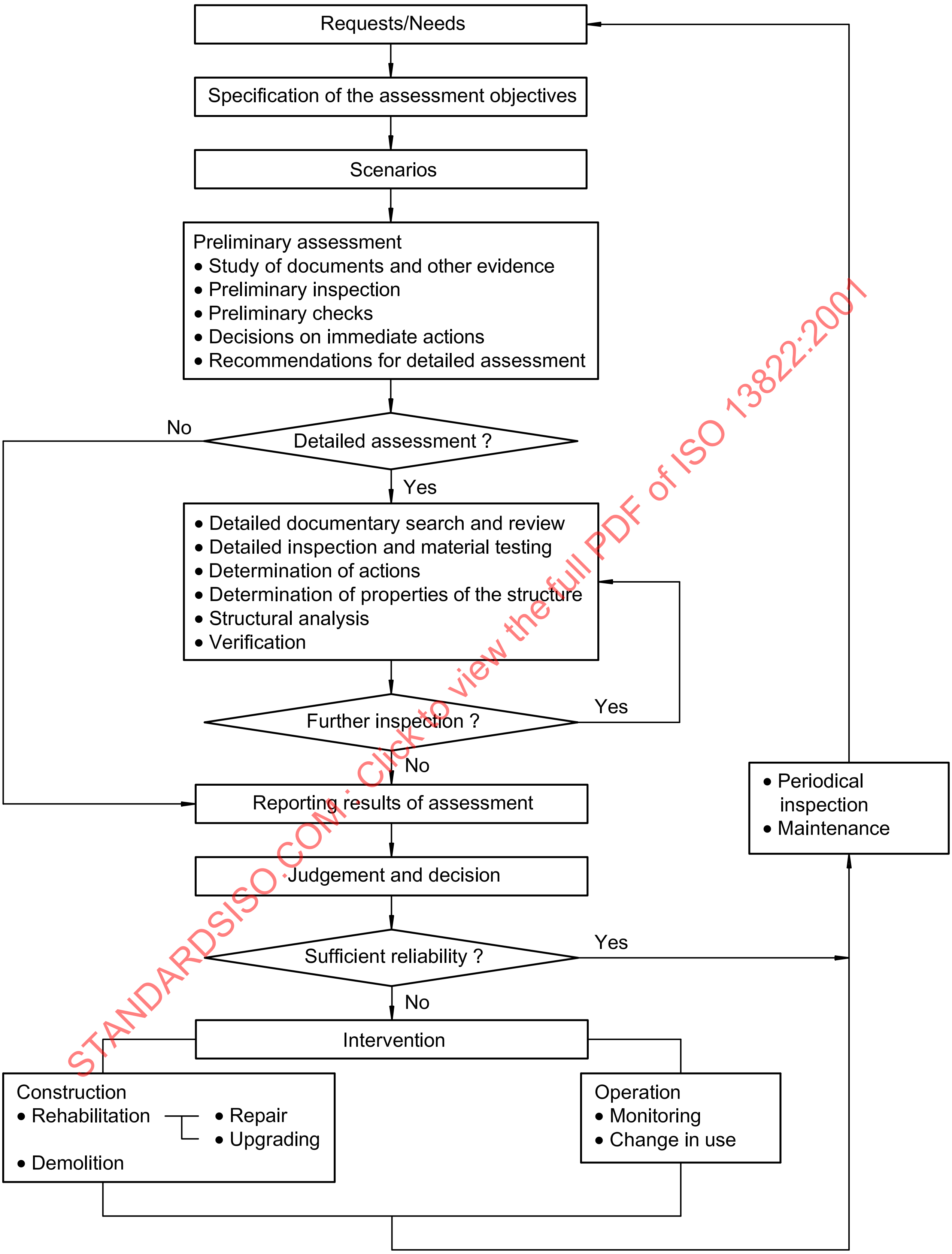
Annex A
(informative)

Hierarchy of terms



Annex B
(informative)

General flowchart for assessment of existing structures


Requests/Needs
Specification of the assessment objectives
Scenarios
Preliminary assessment
• Study of documents and other evidence
• Preliminary inspection
• Preliminary checks
• Decisions on immediate actions
• Recommendations for detailed assessment
No
Detailed assessment ?
Yes
• Detailed documentary search and review
• Detailed inspection and material testing
• Determination of actions
• Determination of properties of the structure
• Structural analysis
• Verification
Yes
Further inspection ?
No
Reporting results of assessment
Judgement and decision
Yes
Sufficient reliability ?
No
Intervention
Construction
• Rehabilitation
• Repair
• Upgrading
• Demolition
Operation
• Monitoring
• Change in use
• Periodical inspection
• Maintenance

Annex C
(informative)

Updating of measured quantities

C.1 Types of inspection

C.1.1 An investigation of an existing structure is intended to update the knowledge about the condition (state) of the structure with respect to a number of aspects. Often, the first impression of the condition of a structure is based on a qualitative inspection. The description of possible damage of the structure is in verbal terms such as "none, minor, moderate, severe, destructive, unknown". Decisions based on such observation are made in a purely intuitive way by experts. A better judgement on the structure can be made on the basis of quantitative inspections, which characterize the current properties of the structural components. For all inspection techniques one should have information on the probability to detect damage, if present, and on the accuracy of the results.

C.1.2 Proof loading or load testing is a special kind of quantitative inspection. The purpose may be to prove that a particular structural component is fit for use. One might also want to get indications of a larger group of components. For further information, see annex D.

C.1.3 Also investigations of actions may help on the assessment. The investigation will depend on the type of action. For permanent actions such as the weight of the structure itself, dimensions and/or densities should be measured. For offshore structures, one may check the local wave climate. For wind actions on structures of special shape, the shape coefficients can be measured in a wind tunnel. For industrial loads, measurements may indicate differences from the original design assumptions. Care must be taken: actions in codes are intended to represent the maximum in 50 year values which cannot be measured directly. In general it is of course not possible to measure this directly.

C.2 Evaluation of inspection results

C.2.1 Given the result of an investigation, there is a need to update the properties and reliability estimates of the structure. Two different methods can be distinguished:

a) a direct updating of the structural failure probability;

b) updating of the (multivariate) probability distribution of the random variables.

The second method can be used to derive updated design values to be used in the partial factor format and for comparing directly with limit values (cracks, displacements).

When evaluating the inspection results of a certain structural member, it should be kept in mind that these results can also affect the reliability of other members or even members of other structures. For instance, the detection of cracking or corrosion in one member will make the presence of cracks and corrosion in other similar members more likely

C.2.2 Direct updating of the structural failure probability [method a) in C.2.1] can formally be carried out using the following basic equality from probability theory:

$$P\{F \mid I\} = \frac{P\{F \cap I\}}{P\{I\}} \tag{C.1}$$

where

$\cap$ means the intersection of two events;

| means conditional upon;

F designates local or global structural failure;

I stands for the inspection information, for instance “the fatigue crack at joint B is smaller than the detection limit”.

The denominator $P\{ I \}$ in equation (C.1) is a normalizing constant, which follows from

$$P\{F \mid I\} + P\{S \mid I \} = 1,0$$

where S stands for “non-failure” or “survival”.

C.2.3 The updating procedure of the multivariate or individual probability distributions [method b) in C.2.1] is given formally by:

$$f_X(x \mid I) = C\, P\{ I \mid x\}\, f_X(x) \tag{C.2}$$

where

X is a basic variable or statistical parameter;

I is an inspection result [as in equation (C.1)];

$f_X(x)$ is the probability density of X before updating;

C is a normalizing constant;

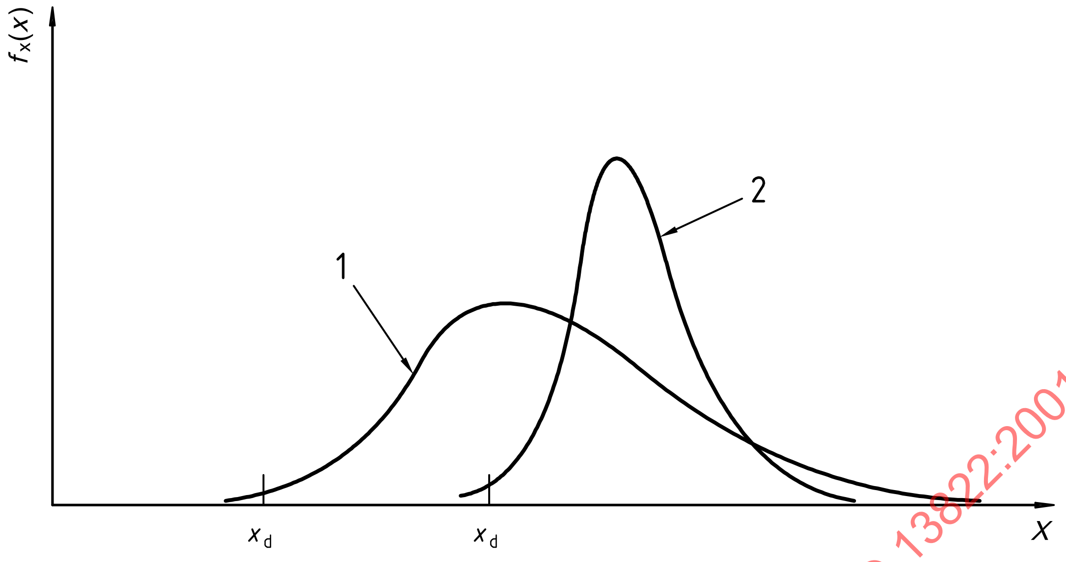
$f_X(x \mid I)$ is the probability density of X after updating with information I;

$P\{ I \mid x\}$ is the likelihood of finding information I for given value x of X.

An illustration of equation (C.2) is presented in Figure C.1. Note that in general the design value of the updated distribution might also be lower than the design value of the initial distribution.

NOTE 1 Further information can be found in ISO 2394, ISO 2854 and ISO 12491.

NOTE 2 When the updating procedure is performed for each random variable separately, a possible error is that correlations between basic variables after updating are neglected. Whether or not this is acceptable depends on the typical aspects of each individual problem.



Key

1 Initial distribution

2 Updated distribution

Figure C.1 — Original and updated probability density function for an inspected variable X

C.2.4 Once updated distributions for the basic variables in the structure have been found, one may calculate the updated failure probability $P\{F \mid I\}$ by performing a probabilistic analysis. A more practical procedure is to determine updated design values for each random variable. For a resistance parameter X, the design value can be obtained from (see ISO 2394):

$$x_d = \mu (1 - \alpha\beta V) \quad \text{(normal random variable)} \tag{C.3}$$

$$x_d = \mu \exp(-\alpha\beta\,\sigma - 0{,}5\sigma^2) \quad \text{(log normal random variable)} \tag{C.4}$$

where

x_d is the updated design value for X;

μ is the updated mean value;

α is the probabilistic influence coefficient;

β is the target reliability index;

V is the updated coefficient of variation;

$\sigma^2 = \ln\left(1 + V^2\right)$

The value of the target reliability index β is discussed in annex F; the values of α can be taken equal to those commonly used for new structures (0,7 for the dominating load parameter, 0,8 for the dominating resistance parameter and 0,3 for non-dominating variables according to ISO 2394).

As an alternative procedure, one might also determine first a characteristic value x_k and calculate the design value by applying the appropriate partial factor γ_m:

$$x_d = x_k / \gamma_m \tag{C.5}$$

$$x_k = \mu (1 - kV) \quad \text{(normal random variable)} \tag{C.6}$$

$$x_k = \mu \exp(-k\sigma - 0{,}5\sigma^2) \quad \text{(log normal random variable)} \tag{C.7}$$

The value k = 1,64 is usually used. It may be helpful to consider both methods and to use the most conservative result.

For loads and geomechanical properties, a similar procedure may be applied, but usually another distribution type will be more appropriate.

After the evaluation of the updated design values, one may check the structural reliability using the standard procedure for new structures: it should be verified that, based on the design material and geometrical properties, all relevant limit states are not reached when the design actions are applied to the structure.

C.3 Example

The idea behind this example is based on the testing procedure of timber for new structures. The example is presented only as an illustration of the theory. Formulae and numbers have been highly simplified. It should be noted that, in particular for deteriorated structures, data may have to be chosen with much care.

Consider a simply supported timber beam loaded by a point load Q in its mid span. The safety margin for such a beam is given by:

$$M_S = Wf - QL/4 \tag{C.8}$$

The designation of all variables and the numerical values used in this example are presented in Table C1. All random variables are assumed to be normally distributed.

Table C.1 — Data used in example

X	**Designation**	**Unit**	**Mean**	**CV**	**Value of x_k**
L	Span	m	4	—	4
W	Plastic section modulus	m^3	0,010 4	—	0,010 4
I	Moment of inertia	m^4	0,000 2	—	0,000 2
Q	Load	kN	100	0,2	100
f	Material strength	MPa	20	0,15	15
E	Modulus of elasticity	GPa	30	0,15	30

Failure of the beam corresponds to the event $M_S < 0$. Using standard reliability techniques (see ISO 2394), one may evaluate a failure probability $P\{M_S < 0\}$ = 0,002 8. The corresponding reliability index is β = 2,77. This may be considered as being too low (see annex F). For a semi-probabilistic judgement of the reliability, one might use the characteristic values in the last column of Table C1. The standard requirement is:

$$\frac{Wf_k}{\gamma_m} > \frac{\gamma_F Q_k L}{4} \tag{C.9}$$

where

γ_m is the partial resistance factor;

γ_F is the partial load factor.

Taking γ_m = 1,2 and γ_F =1,5 one finds:

$$\frac{Wf_k}{\gamma_m} = \frac{(0{,}010\ 4)\ (15)}{1{,}2} = 0{,}130 \text{ MNm} = 130 \text{ kNm} \qquad \text{(C.10)}$$

$$\frac{\gamma_F\ Q_k\ L}{4} = \frac{(1{,}5)\ (100)\ (4)}{4} = 150 \text{ kNm} \qquad \text{(C.11)}$$

Therefore, the timber beam considered in this example does not satisfy the requirement expressed by equation (C.9).

Assume next that the beam is proof loaded by a deterministic load Q_t = 50 kN. Let a deflection of 9 mm be measured. According to the theory of elasticity, the deflection is given by

$$u = Q_t\ L^3/48EI$$

which means that equivalently E may be estimated as:

$$E = Q_t\ L^3 / 48\ I\ u = (50)(4^3)/(48)(0{,}000\ 2)(0{,}009) = 37 \text{ GPa} \qquad \text{(C.12)}$$

This indicates that the beam is stiffer than average. Since for timber, stiffness and strength show a positive correlation, this test result also indicates a more reliable resistance. Let the correlation between E and f be quantified as $\rho_{E,f}$ = 0,5. Using standard formulae from the theory of the multi-dimensional normal distribution, one may derive as “updated” mean and standard deviation for the strength f:

$$\mu_{f|E=37\text{ GPa}} = \mu_f + \rho_{E,f}\sigma_f \left[\frac{37-\mu_E}{\sigma_E}\right] \qquad \text{(C.13)}$$

$$= 20 + (0{,}5)(3{,}0)\left[\frac{37-30}{4{,}5}\right] = 22 \text{ MPa}$$

$$\sigma_{f|E=37\text{ GPa}} = \sigma_f\sqrt{1-\rho_{E,f}^{\ 2}} = 2{,}6 \text{ MPa} \qquad \text{(C.14)}$$

Given these updated distributions for f, one may calculate the failure probability, $P\{M_S$ < 0|test result}, as being 0,000 08 corresponding to β = 3,76, which may be considered as sufficient. In a partial factor verification, one may update the characteristic value for f as,

$$f_k = \mu_{f|\text{test result}} - 1{,}64\sigma_{f|\text{test result}} \qquad \text{(C.15)}$$

$$= 22 - (1{,}64)(2{,}6) = 18 \text{ MPa}$$

This raises Wf_k/γ_m from 130 kNm to 153 kNm which is also sufficient. It should be noted that the updating given by equations (C.13) and (C.14) is valid for the considered beam only.

Annex D
(informative)

Testing for static and dynamic properties of structures

D.1 Objectives

D.1.1 Many kinds of field testing are useful for the assessment of static and dynamic properties of existing structures (e.g. a horizontal loading test or a forced vibration test of a complete structure, a vertical loading test or a forced vibration test of components of a structure, a horizontal or vertical microtremor measurement of a structure). Load testing of a complete structure is costly and time-consuming. However, there may be some structures that are not amenable to calculation. In such cases, the only way to assess the properties of the structure is to carry out field tests.

D.1.2 Testing for the static and dynamic properties of structures may be selected as a part of an assessment provided there is a satisfactory reason, such as the following.

a) The testing is useful in providing additional evidence including cases when deterioration of structural components has occurred, when there is a change of use, or when construction has not been carried out in accordance with the design drawings and specifications.

b) When calculations cannot be completed with confidence, load testing and vibration testing can provide an improved understanding of the actual behaviour of the structure, which cannot be obtained in any other ways.

c) Structural components forming part of an existing structure behave differently from the behaviour assumed during the design.

D.1.3 Testing for static and dynamic properties of structures should have clear objectives. Examples of the objectives are

a) to predict directly the ultimate resistance or to establish serviceability properties of structural parts,

b) to obtain specific material properties,

c) to examine the behaviour of existing structures or structural components,

d) to identify system parameters used for verification of analysis, such as fundamental period, damping factor, and

e) to evaluate the load-bearing capacity of structure by a specific load test, i.e. proof loading.

D.1.4 Testing for the static and dynamic properties of the structures may be selected if the following conditions are met.

a) The testing is conducted in such a manner as to prevent sudden and uncontrollable collapse during the test.

b) Load sharing among structural components should be taken into consideration. Load sharing can occur such that adjacent components also act in resisting the applied load when a single component is loaded. Load sharing also influences the dynamic properties of the structure.

c) It is important in the load testing and vibration testing that the structure be exposed and accessible for visual inspection before, during and after the test.

d) The influence of temperature changes on the instrumentation should be considered.

D.2 Test planning

D.2.1 Agreement to test plan

Prior to the execution of the testing, a test plan should be agreed with the client and testing organization. In the test plan, the objective of the test and all specifications necessary for the selection of the test specimens, and the execution of the tests and the test evaluation should be clearly stated. In particular, the plan of the test should include descriptions of the items described in D.2.2 to D.2.8.

D.2.2 Scope of test plan

Information required from the test should be clearly stated, for example the required properties, the influence of certain parameters varied during the test and the range of validity.

D.2.3 Expected behaviour

It is essential to present a description of all properties and circumstances which can influence the behaviour at the limit state under consideration (e.g. geometrical parameters and their tolerances, material properties, scale effects and environmental influences). Modes of failure and/or calculation models with the corresponding variables should be described. When the prediction of the critical failure modes expected in the test is extremely doubtful, the test plan should be developed on the basis of accompanying pilot tests.

D.2.4 Specification of test specimen

The properties of the test specimen should be specified, in particular, the dimensions, sampling procedures and restraints. Normally a representative sample in the statistical sense should be aimed for.

D.2.5 Static and dynamic loading and vibration specifications

Loading procedure and environmental influences in the test should be specified, in particular, loading points, loading paths in time and space, excitation locations, excitation forces, temperatures, loading by deformation or force control, etc. Loading paths and excitation forces should be selected such that they are representative for the anticipated scope of application of the structural component. Account should be taken of possible unfavourable effects of those actions, which are considered in calculations in comparable cases. Interaction of actions with structural response should be considered where relevant.

D.2.6 Measurements plan

Prior to the execution of the test, a list should be made of all relevant properties of each individual test specimen (e.g. time histories of displacements, velocities, accelerations, strains, forces and pressures, required frequency and accuracy of measurements and measuring devices). Similarly, a plan of observation points and methods for observation and recording should be made. Depending on the type of test, it is recommended that some measurements be made available during the test.

D.2.7 Testing arrangement

Special attention should be given to measures to ensure sufficient strength and stiffness of the loading and supporting rigs, and clearance for deflections, etc.

D.2.8 Consent

In all cases, consent should always be obtained from the client (owner, authority, insurance companies, etc.), and full consideration should be given to any possible adverse effects on the structure or occupants. The consent of local authorities may also be required.

D.3 Evaluation of test results

D.3.1 The measurement of the static, dynamic or both properties obtained in the test should be compared with those predicted by analytical models. When a large deviation from the prediction occurs, the reason should be investigated and explained, involving additional tests if necessary.

D.3.2 Where relevant, the evaluation of test results should be on the basis of statistical methods. In principle, the test should lead to a statistical distribution for the preselected unknown variables, including the statistical uncertainties. Based on this distribution, design values, characteristic values and partial safety factors to be used in partial coefficient design can be derived. Only the characteristic value can be derived while the partial factor is taken from normal design procedure.

D.3.3 If the test results depend on the load duration or history, amplitude of vibrational response, volume or scale, environmental influences or other non-structural effects, the analytical model should take these items into account by use of appropriate factors, non-linearity and scaling rules.

D.3.4 When the test results are evaluated to be valid, the extrapolation can be available to cover other loading paths or excitation forces while it requires additional information (e.g. from experiences of previous tests or analytical studies).

D.4 Report

It is recommended to report the test results using the content outlined in annex G. It may be appropriate to report the test results separately or to put them in an annex to the main report.

Annex E
(informative)

Assessment of time-dependent reliability

E.1 Introduction

When assessing the reliability and remaining working life of existing structures, the effect of time variations both in the strength, due to, for example, deterioration, and the load characteristics should be taken into account. When only the load varies with time, the method described in ISO 2394 and bibliographic reference [3] may be used for the assessment. For time-variant reliability problems where the resistance is deteriorating and the loading is time- invariant, the reliability assessment may be performed by considering the strength characteristics corresponding to the end of the working life of the structure. When both the strength characteristics and the load characteristics vary with time, the assessment requires special consideration as described in this annex.

E.2 Terms and definitions

For the purposes of this annex, the following terms and definitions apply.

E.2.1
load characteristics
qualitative and quantitative description of load intensity, which may vary in time, such as the duration, interval and occurrence rate of the load events and the mean value and standard deviation of the intensity at any point in time

E.2.2
non-homogeneous random vector process
$\boldsymbol{X}(t)$
random function of time such that for any point in time the values of the elements X_i of the vector are random variables

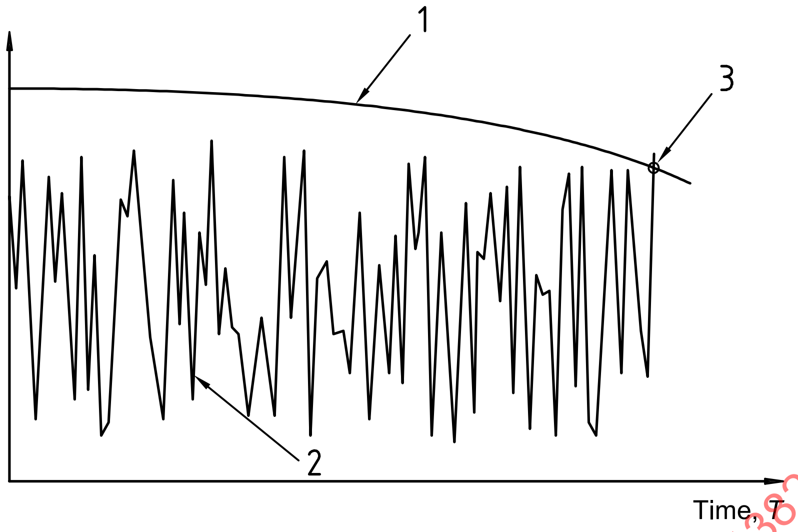
NOTE The statistical characteristics of X_i in a non-homogeneous random vector process vary with time.

E.2.3
strength characteristics
qualitative and quantitative description of the strength of a structure or a structural component, which may vary in time, such as the mean value and standard deviation of the strength.

E.2.4
threshold
limit value, which may be a function of time, beyond which a structure or a structural component is in an unfavourable state

E.3 Strength characteristics varying slowly in time

E.3.1 When the strength is slowly deteriorating and the load characteristics vary with time, the reliability assessment in principle could be addressed as a first passage problem of a non-homogeneous random vector process (see ref. [3]. Figure E.1 illustrates the process schematically. In spite of the simplicity of concept, considerable simplifications are needed for in most practical applications.



Key

1 Threshold (e.g. resistance) $b(t)$

2 Action effect $X(t)$

3 Failure

Figure E.1 — Illustration of the time-dependent problem with strength characteristics varying slowly with time

E.3.2 When the threshold $b(t)$ is high enough, it may be assumed that the threshold crossing process is a Poisson process with intensity v_X. The probability distribution function of the time to the first crossing of the threshold, $F_T(t)$, may thus be estimated by

$$F_T(t) = 1 - \exp\left[-\int_0^t v_X\{t, b(\tau)\}\,\mathrm{d}\tau\right] \tag{E.1}$$

where $v_X[t, b(t)]$ is the local out-crossing rate of the load process, $X(t)$, above the time varying threshold, $b(t)$, at time t.

E.3.3 The threshold function $b(t)$ is often a function of the resistance R**,** for example, in fatigue crack growth problems where the residual strength is a function of the time in-variant crack growth material properties. In this case $b(t)$ is written as $b(t,R)$. Furthermore the statistical characteristics of the load process $X(t)$ may depend on other usually slower varying processes or stationary sequences Q. This is for example the case when considering wave-induced loading where the wave force spectrum depends on the stationary sequence describing the sea state characteristics. Introducing both R and Q and applying the approximation given in reference [5], equation (E.1) is rearranged and approximated by

$$F_T(t) = 1 - E_R\left\{\exp\left[-\int_0^t E_Q\left[v_X\{\tau, b(\tau, R), Q\}\right]\mathrm{d}\tau\right]\right\} \tag{E.2}$$

in which $E_R[\,\bullet\,]$ and $E_Q[\,\bullet\,]$ are the expectation of $\bullet$ in terms of R and Q, respectively. Commercial software is readily available for the evaluation of equation (E.2). For codification purposes, the solution to equation (E.2) in the case of stationary renewal processes and monotonously decreasing thresholds should be considered (see reference [6]).

E.3.4 When the hazard function, $h(t)$, defined as the conditional probability of failure that failure occurs in the interval $(t, t + \mathrm{d}t]$, given that the structure has survived up to t is available, the probability distribution function of the time to failure can be expressed (see ref.[4]) as

$$F_T(t) = 1 - \exp\left[-\int_0^t h(\tau)\,\mathrm{d}\tau\right] \qquad \text{(E.3)}$$

E.3.5 When the resistance is modelled as a function of time as $R(t) = R \cdot g(t)$, where $g(t)$ is the degradation function defining the fraction of the initial strength R remaining at time t, and the load occurrence is modelled by Poisson process with mean occurrence rate λ. Then the probability of failure within time interval [0, t] is expressed (see references [4] and [7]) as

$$F(t) = 1 - E_R\left[\exp\left\{-\lambda t \cdot \left[1 - \frac{1}{t} \cdot \int_0^t F_S\left[R \cdot g(\tau)\right]\mathrm{d}\tau\right]\right\}\right] \qquad \text{(E.4)}$$

in which $F_S(s)$ is the probability distribution function of load intensity, S.

Figure E.2 illustrates schematically the load process and degradation of resistance. In Figure E.2, $f_R(r)$ and $f_S(s)$ are the probability densities of R and S, respectively, and $\mu_R(t)$ and μ_S are the mean values of $R(t)$ and S, respectively. This approach can address the deterioration due to corrosion, sulfate attack to concrete structures, and similar environmental effects. The effect on inspection and repair can be considered by modelling $g(t)$ accordingly. Examples of application of this approach to a real structure can be found in reference [8].

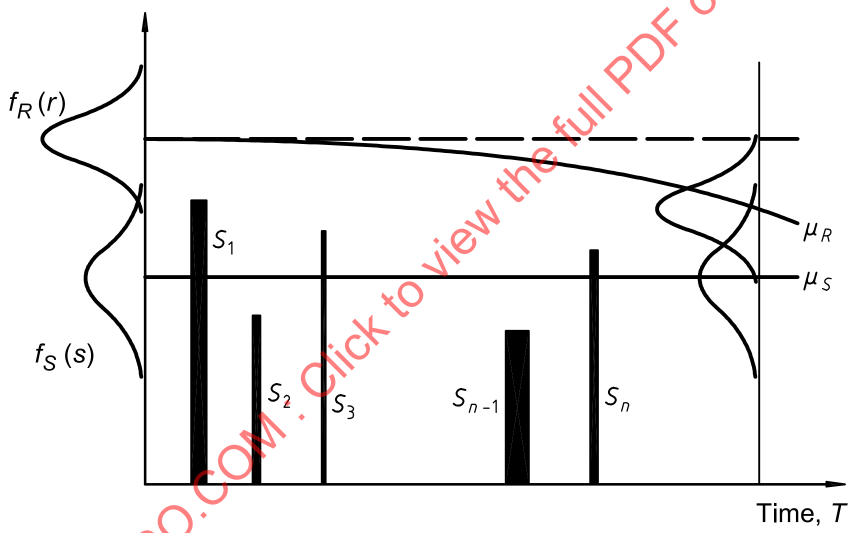
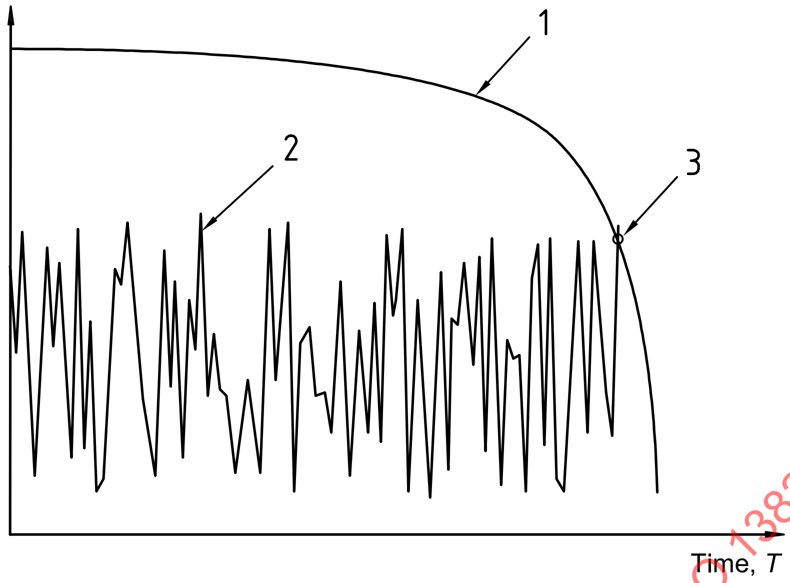


Figure E.2 — Schematic representation of load process and degradation of resistance

E.4 Strength characteristics varying rapidly with time

When the strength characteristics deteriorate rapidly, it may be sufficiently accurate to approximate the time-dependent problem by a time-independent problem in which the load intensity is represented by its maximum value and the strength characteristics is represented by its lowest value during the reference period. For example, the probability of failure due to fatigue crack growth for the interval [0, t] is assessed sufficiently accurately by using the strength characteristics corresponding to time t, i.e. the lowest value during the reference period, and the maximum value distribution of the load during the reference period. The situation is schematically illustrated in Figure E.3.



Key

1 Threshold (e.g. resistance) $b(t)$

2 Action effect $X(t)$

3 Failure

Figure E.3 — Illustration of the time-dependent problem with strength characteristics varying rapidly with time