Part I: General principles on quality assurance for structures

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Part I

General Principles on Quality Assurance for Structures

Principes généraux de l'assurance de qualité pour les structures porteuses

Allgemeine Prinzipien der Qualitätssicherung von Tragwerken

PREAMBLE

This document treats quality assurance with respect to safety, serviceability and durability of loadbearing structures. Other aspects of quality assurance may be important and may be treated in other documents. However, when applied to a building project, it may be important that all quality assurance procedures are coordinated and possibly integrated in one system.

The purpose and possible use of this document could be

- to serve as a basic document for international bodies concerned with loadbearing structures
- to be used by national code drafting committees as a basis for national codes on quality assurance.

The main content of this document is intended to be "general principles". However with regard to its possible use some "general methods" have also been included.

This document contains a number of terms, such as "hazard scenario", which are not in common engineering usage. Such terms indicate concepts which cannot readily be described in other ways and the use of these new terms is therefore considered desirable. Other terms, such as "management on the building site" are used to describe activities which may currently be organized in completely different ways in different countries but with the same objectives. A glossary of terms is given in Appendix 1.

PREAMBULE

Le présent document traite de l'assurance de qualité du point de vue de la sécurité, de l'aptitude au service et de la durabilité, pour les structures porteuses. D'autres aspects de l'assurance de qualité peuvent être importants et peuvent être traités dans d'autres documents. Cependant, il importe que les différentes procédures d'assurance de qualité utilisées pour une même construction soient coordonnées entre elles et éventuellement intégrées en un seul et même système.

Le but de ce document est de servir de base

- pour les organismes internationaux compétents en matière de structures porteuses
- pour les commissions nationales de codification pour l'assurance de qualité.

Le contenu principal de ce document est destiné à donner des "principes généraux". Cependant, considérant ses usages possibles, on y a inclu aussi certaines "méthodes générales".

Ce document contient un certain nombre de termes, tels que "hazard scenario" (schémas de danger) qui ne sont pas d'usage courant pour les ingénieurs. Ces termes expriment des concepts que ne peuvent être décrits directement d'autres manières, de sorte que leur usage apparaît souhaitable. D'autres termes, tels que "direction des travaux" sont utilisés pour décrire des activités qui peuvent être couramment organisées de manières complètement différentes dans différents pays, mais avec les mêmes objectifs. Un glossaire de certains termes est donné en Annexe 1.

VORBEMERKUNG

Das vorliegende Dokument befasst sich mit der Qualitätssicherung von Tragwerken im Hinblick auf Sicherheit, Gebrauchstüchtigkeit und Dauerhaftigkeit. Andere als wichtig erachtete Aspekte der Qualitätssicherung müssten an anderem Ort behandelt werden. Bei einer Anwendung von Qualitätssicherungs-Verfahren auf Bauvorhaben wäre jedoch anzustreben, dass alle in einem einzigen System integriert würden.

Das vorliegende Dokument kann

– internationalen Gremien, die sich mit Tragwerken befassen, als Arbeitsgrundlage dienen
– nationalen Normen-Kommissionen, die an Vorschriften für Qualitätssicherung von Tragwerken arbeiten, eine Grundlage geben.

Das Dokument enthält vorwiegend allgemein gültige Prinzipien. Im Hinblick auf seine Anwendung wurden jedoch auch einige allgemein anwendbare Methoden aufgenommen.

Das vorliegende Dokument enthält einige Begriffe, wie z.B. „Hazard Scenario", die der Sprachgebrauch des Ingenieurs nicht kennt. Solche Begriffe stehen für Konzepte, die in der gebotenen Kürze nicht anders beschrieben werden können. Der Gebrauch dieser neuen Begriffe ist wünschenswert. Andere Begriffe, wie z.B. „Management on the building site", stehen zur Umschreibung von Aktivitäten, die derzeit in verschiedenen Ländern in ganz verschiedenen Organisationsformen, jedoch mit den gleichen Zielen, ablaufen. Ein Begriffskatalog findet sich im Anhang I.

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1. INTRODUCTION

1.1 The concept of quality assurance

The following principles of quality assurance for structures aim at ensuring that the structural performance requirements are fulfilled in an economical manner. In this document the main requirements are related to safety, serviceability and durability.

The principles apply to the entire building process, viz. planning, design, construction, control and use of structures.

> Thus this document could also be regarded as a description of a way to rationalize the building process.

This document is in principle directed to every participant in the building process. However, it is intended mainly for international and national code writing committees and national authorities dealing with codes and recommendations concerning the quality assurance of structures.

The document is not intended to be operational but conceptual.

The function of quality assurance is to ensure that all activities influencing the final quality of a structural system

- are based on clearly defined fundamental requirements together with operational, environmental and boundary conditions.
- are correctly carried out by competent personnel and in accordance with previously elaborated plans.
- are executed by a systematic adherence to written instructions

and that this is verified by means of objective documentary evidence.

To a large extent, quality assurance consists of strategies against human errors. Experience shows that these are often the main cause of structural failure.

> In this document the concept of quality assurance is taken in a fairly broad sense but with the restriction that it is limited to safety, serviceability and durability. An outline of the components of the quality assurance concept is given in section 2. This is followed in sections

3 - 6 by a presentation of the aspects which are considered to be of most importance in structural engineering. These concern utilisation and hazard scenarios, tasks and responsibilities and quality control.

1.2 The building process

The building process is assumed to start with decisions concerning the desired performance requirements and with establishing boundary and environmental conditions. It is assumed to end when the use of the building ceases.

The building process is assumed to be made up of a sequence of events eg. planning, design, fabrication, etc., the details of which are dependent on the type of structure. The process can be subdivided into a number of stages between which either major decisions and/or interactions occur.

In order to make the content of this document somewhat more concrete it is assumed to be applied to some building process of a common type.

FIG 1 shows an example of a simplified flow chart of a building process. If another type had been chosen it might have affected the details and the examples in the following but not the principles.

The small cirkels on the chart are associated with interactions between individual persons or organizations and a need for one or more decisions. The chart is simplified to a great extent. In a building process there are normally several decision occasions every day; those given in the chart should only be regarded as examples of major decision occasions.

1.3 Feedback from experience

According to 1.1 the requirements for safety, serviceability and durability should be fulfilled in an economical manner. One of the measures that should be taken to reach this aim is to use experience obtained during execution of a project and subsequent maintenance of the structure.

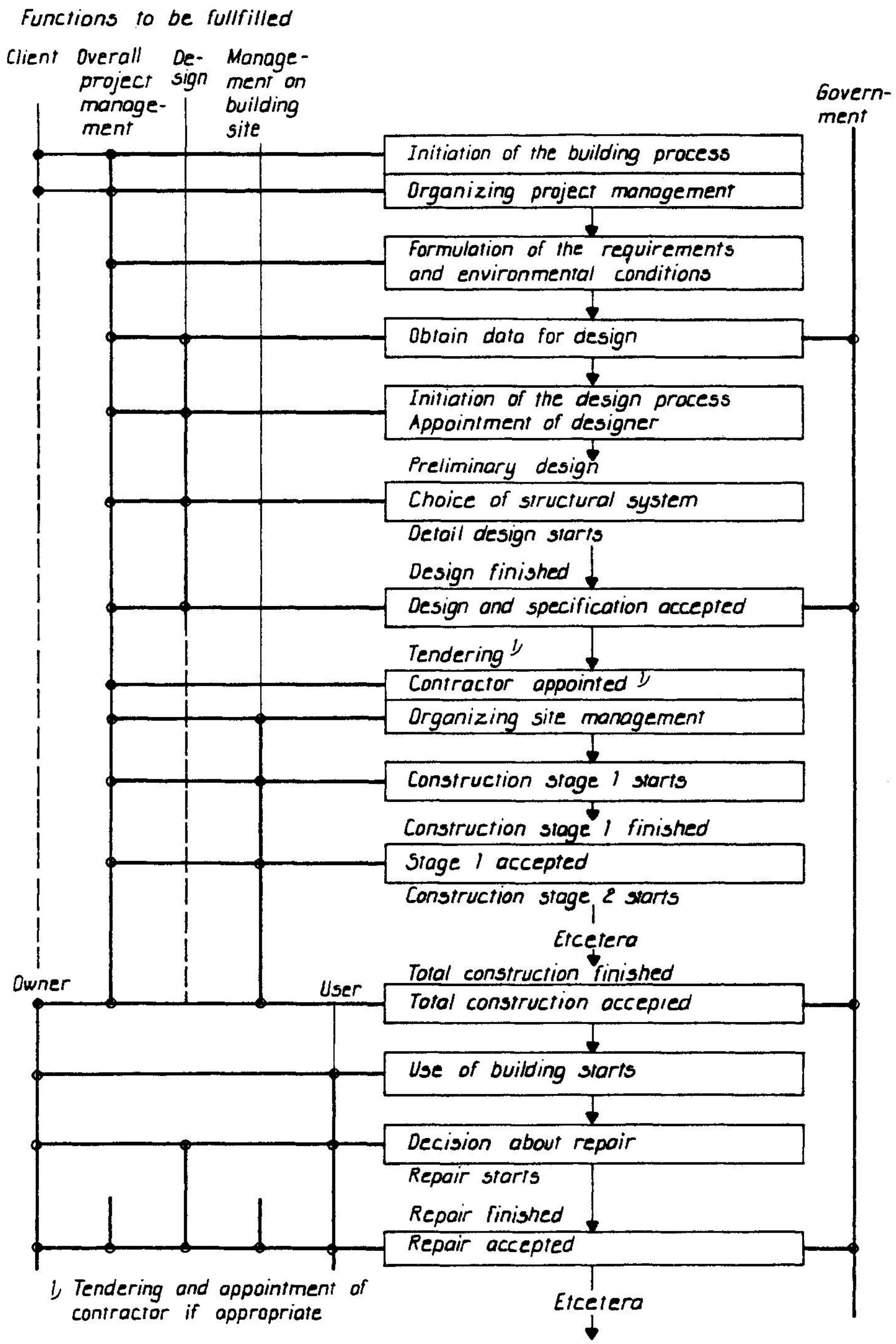

FIG 1 Stages of the building process showing interactions

In some cases experience obtained during one stage of the building process can be used for a later stage of the same project. For example, this is common for tunnel projects in rock where experience from the site is often a basis for the design.

The results of control activities can be regarded as experience that increases the knowledge (compare 5.1) about, for example, material and production processes.

The experience from building failures (severe or of minor importance) also form a valuable background for increasing the general level of knowledge. Thus code drafting and similar organizations should evaluate structural failures occurring during the execution of projects and the maintenance of structures.

2. COMPONENTS OF THE QUALITY ASSURANCE CONCEPT

2.1 Performance requirements

The performance requirements set out during the first phase of the building process concern the formulation of the specific requirements for the building and the requirements given in building regulations and codes.

See stage 2 in the flow chart shown in FIG 1.

These performance requirements have to be translated into technical terms for the loadbearing structure.

See stage 3 in the flow chart shown in FIG 1.

Thus, for example, stage 2 could be the specification of the intended use for the building and stage 3 the specification of the corresponding restrictions regarding deformations.

The performance requirements for a structure generally concern safety, serviceability and durability which, in this document, are defined in the following way

- Safety is the ability of a structure to sustain actions and other influences liable to occur during construction and use and to maintain sufficient structural integrity during and after accidents.
- Serviceability is the ability of a structure to perform adequately in normal use.

The requirements concerning safety and serviceability should apply throughout the anticipated time of use of each structure, which means that structures should be designed and maintained so that they have adequate durability.

Requirements for safety should be obligatory, while requirements for serviceability may be just recommendations.

The requirements for safety imply that there shall be an acceptably small likelihood of structural failure causing damage to property and loss of human life.

In every structure there are inherent hazards to life and property. The public at large, and those engaged in the construction industry in particular, expect that the danger caused by such hazards is restricted to an acceptable level. This is normally ensured by specifying safety requirements for structures.

In assessing the level of structural safety due consideration must be given to all circumstances that might lead to failure. These may be associated with

- an unfavourable combination of random variables such as actions, strengths, dimensions and others
- gross errors
- exceptional events
- lack of maintenance, etc.

The requirements for serviceability imply that there shall be an acceptably small likelihood of the structure becoming unfit for use. Thus the requirements concern restrictions against

- deformations which affect the efficient use of a structure or the appearance of structural or non-structural elements
- excessive vibrations producing discomfort or affecting non-structural elements or equipment (especially if resonance occurs)

- local damage (including cracking) which reduces the durability of a structure or affects the efficiency or appearance of structural or non-structural elements
- other special effects.

2.2 Consideration of utilisation scenarios and hazard scenarios

The measures to be taken to ensure safety, serviceability and durability of a structure are based on the relevant operational, environmental and boundary conditions. This involves the assessment of relevant utilisation scenarios and hazard scenarios.

Utilisation scenarios are descriptions of the foreseeable conditions associated with the normal use of structures. Each utilisation scenario defines a possible situation during which a particular set of operational and environmental conditions exist.

> A utilisation scenario can, for example, consist of a load combination, related to normal use, combined with the other conditions which are valid at the same time. Thus a large number of utilisation scenarios can be found. However, only a limited number of them are of interest in the context of quality assurance.

Hazard scenarios are descriptions of foreseeable conditions, dominated (in most cases) by <u>one</u> hazardous occurence, which alone or in combination with other normal conditions could cause the loadbearing function of a structure to be lost.

> The hazard could be related to occurrences outside the structure such as wind, impact, fire, but also to faults inside the structure, for example a very low strength in some component.

Section 3 of this document contains proposals for the description of utilisation scenarios and hazard scenarios and the corresponding measures to be taken.

2.3 Initial choice of structural system and material

With regard to safety, the choice of the structural system should be made so that important parts of it have the ability to maintain sufficient structural integrity during and after accidents. Specific hazard scenarios may involve actions or other influences, which the structure is not supposed to sustain without damage. However the structure should not be damaged to an extent disproportionate to the extent of the original accident.

Thus the existence of a particular hazard scenario may influence the choice of structural system, since if the structural system is changed some of the relevant hazard scenarios may also be changed. There is clearly an interaction between the choice of structural system and the assessment of the relevant hazard scenarios.

The activity between the stages 4 - 5 in the flow-chart in FIG 1 consists of preliminary design made in order to obtain a basis for the choice of structural system and general arrangement. Often a number of alternative designs have to be studied at this stage.

2.4 Analysis and design

A structure shall be designed so that it fulfills the specified requirements for safety, serviceability and durability.

Principles for analysis and design are given in the JCSS-document "General principles on reliability for structural design".

The design should, where possible, be such that it facilitates quality assurance activities and other activities within the building process.

Thus during the design, due regard should be paid to the feasibility of carrying out the control as well as to the feasibility of maintenance and repair.

2.5 Measures against human errors

The frequency of occurrence of human errors can be reduced considerably by taking suitable measures. These include

- improving professional education
- selection of qualified staff
- improving working procedures
- precautionary measures against unintentional or deliberate human errors and negligence
- additional precautions in the case of new design or construction methods for which there is little prior experience.

> Working procedures may be improved, for example, by improving communications between persons and between organizations and by protecting persons from disturbing influences. These could be physical in nature (e.g. noise, bad weather) or of a psychological character (e.g. stress, shortage of time).

Even if good working conditions can be achieved and the work proceeds smoothly it will be found impossible to avoid errors completely. Suitable control measures should be instituted to check each stage of the planning and execution for the presence of errors.

> Thus the construction work should be planned so that important parts will be accessible for inspection during the work.

Recommendations for suitable preventive measures against human errors should be provided wherever appropriate.

2.6 Responsibilities

It is of the utmost importance that the responsibilities of persons involved in the planning, design, construction, control and use of structures are clearly defined.

> Many cases of structural failures and poor serviceability can be traced back to human errors (in its broadest sense) arising in those situations where responsibilities are not clear.

Section 4 of this document contains proposals for the allocation of responsibilities to those involved in the building process. These proposals may be elaborated with due regard to national legislation.

2.7 Control

All steps in planning, design, construction and use of a structure should be controlled to an extent related to the consequences of possible deviations from the intentions (including the result of human errors), the cost of control, etc. Ideally an optimal amount of control should be aimed at.

> Many cases of structural failures and poor serviceability of structures are caused by errors which remain undetected by those engaged in the building process.

Control should also include the introduction, execution and supervision of measures required in the event of disagreement between the results aimed at and the results obtained.

Sections 5 and 6 of this document contain suggestions towards the principles and methods of the required control. The detail and manner in which these suggestions are presented in a code depend on national legislation.

2.8 Project documentation

Important project documents should be stored throughout the entire life of the building, updated and made available to authorised specialists when required.

> This is already done in some countries. However, in most countries storage of documents is not generally required.
>
> The important documents may for example be:
>
> - drawings and other descriptions
> - the utilisation plan (see section 3)
> - the safety plan (see section 3)
> - working documents produced by the specialists which are relevant to structural safety (e.g. structural calculations, technical reports, control reports).
> - use and maintenance instructions.

- list of names of responsible persons connected with the work and of firms involved with the construction.

3. UTILISATION SCENARIOS AND HAZARD SCENARIOS

3.1 Utilisation scenarios

In order to ensure the serviceability and durability of a structure all relevant utilisation scenarios should be considered which may result, for example, in the following

- agreed actions during service phases, including a description of static and dynamic components
- actions during erection phases, in so far as it may influence the serviceability of the completed structure
- temperature effects arising out of use.

In addition, the accompanying influences under which the serviceability of the structure has to be ensured should be selected, as for example

- from climatic environment which may exist at the site of the structure, such as wind, water, snow, ice, temperature and combinations of them.
- tectonic and geotechnical influences, including the influence of the construction on the surroundings and viceversa.
- effects of ground water, water-bearing ground strata, running water and surface water.

For the purposes of analysis and design, utilisation scenarios have to be modelled and quantified.

It is often convenient to give the utilisation scenario models and the corresponding measures taken to ensure serviceability and durability in the form of a utilisation plan.

3.2 Utilisation plan

The utilisation plan should specify the agreed utilisation scenarios which should be catered for and lay down the requirements concerning the behaviour of the structure during service (compare 2.1). All quantitative data supplied in this connection are to be regarded as agreed values.

The utilisation scenarios and the requirements relating to the service behaviour of the structure should be used for defining design situations for the structure. All other data relating to utilisation scenarios and structural behaviour not explicitly contained in the utilisation plan should be assumed by the structural engineer in accordance with good engineering practice.

Where risks of damage to property are dealt with in the utilisation plan, it should also be clearly stated where financial liability for such damage rests. If required, such risks may need to be monitored in order to reduce the extent of consequential damage.

If the owner or the user of a structure requires that the likelihood of poor serviceability shall differ from what is accepted in the building codes this should be stated explicitly in the utilisation plan.

Building codes should as far as possible be written so that they facilitate simple and clear agreements on utilisation scenarios and the corresponding requirements regarding structural behaviour. These may be included directly as elements of the utilisation plan in the case of straightforward projects.

3.3 Hazard scenarios

In order to ensure the safety of a structure, the safety of users, persons involved in its construction and all third parties, all possible hazards should initially be considered. The hazards may occur for example as a result of

- specified values of actions being exceeded considerably
- values of strength of materials or resistance of components being considerably below the specified values
- values of geometrical parameters deviating considerably from the specified values
- deleterious effects on the resistance of the structure due to exceptionally unfavourable environmental conditions

- planning, design, construction or use getting out of control as a consequence of a gross error or an exceptional event.

The gross errors include the effect of gaps in information, omissions, misunderstandings, etc. They also include negligence regarding maintenance and repair of the structures.

> Exceptional events could for example cause actions of a type which were never specified at the design (for example explosions). They could also cause a considerable decrease in the resistance of a structure (for example fire).

In its broadest sense hazard scenarios form the basis for the specification of adequate safety measures.

> It is often convenient to describe the relevant hazard scenarios and the respective safety measures in a safety plan.

For the purposes of analysis and design, hazard scenarios have to be modelled and quantified.

Basically the measures to be adopted in response to each hazard scenario would consist of one or more of the following

- eliminating the hazards through measures directed at the source of such hazards
- bypassing the hazards through changing structural concepts, location of structure etc.
- overcoming hazards through control and/or installation of warning systems
- dimensioning for hazards
- accepting the possibility of failure due to the hazards and trying to reduce the consequences.

3.4 Safety plan

The safety plan should specify the measures to be adopted in response to the relevant hazard scenarios.

In planning and specifying measures to be adopted in response to the hazard scenarios it should be noted that the possibilities mentioned in 3.3 are often used in combination. In such cases, all measures together shall totally account for the hazard scenario under consideration.

In the safety plan the hazard scenarios should be used to define the design situations for which the structure should be designed in order to maintain sufficient structural integrity.

A data control plan containing the necessary checks, supervisory measures and procedures is also a complement to the safety plan. See 5.4.

As soon as the structure is handed over to the owner, the latter takes over the responsibility for its subsequent use and maintenance. The safety plan should provide him with all necessary information for the use and maintenance of the structure.

Where specific hazards are mentioned in the safety plan as accepted risks, the measures required to exclude danger to persons should be clearly outlined, and the bearer of financial liability defined. If required, such risk may need to be supervised according to a supervisory plan which then should also form part of the safety plan (see 5.5).

The detail and format of the safety plan i.e. whether written or oral etc, should depend on the complexity of the project and the degree of danger to human life.

4. TASKS AND RESPONSIBILITIES

4.1 General

Individual persons or organizations entrusted with the tasks of planning, design, construction, control and use of a structure have specific responsibilities connected with the safety and serviceability of the structure. It is important that the meaning and scope of their responsibility is clarified to all concerned.

The responsibilities can be delegated so that different persons are responsible for different tasks. However for each foreseeable activity during the building process and for each interface between activities there should be somebody that bears the responsibility.

> In almost all countries building codes deal with structural matters. However in many countries the organizational matters are entirely or partly dealt with in the general law and not in the building code.

The following description of responsibilities and duties relates to the functions to be fulfilled and not to any specific category of persons. Thus a number of tasks and activities are listed and for each of them someone has to be responsible. They are grouped in different categories of functions but this is to some extent arbitrary and could also be combined in another way. The description is divided into two parts. The first part concerns the planning, design and construction of a structure. The second part concerns the use of the structure.

> Thus one function could be divided between several persons and several different functions could be fulfilled by one person.

4.2 The responsibilities related to planning, design and construction

4.2.1 The organization of activities

In this document it is assumed that the nature of the structure and the organization of the activities are such that one can distinguish between the functions of

- the client
- the overall project management
- the designer
- the management for production of materials and products
- the management on the construction site.

4.2.2 The client and the overall project management

The overall project management is appointed by the client who could be an individual person or an organization.

The overall project management bears the complete and overall responsibility for the whole project. Parts of the responsibility can be delegated to persons or organizations with special functions.

The overall project management has the responsibility for selecting persons and organizations who have other functions within the project and of checking that they have the necessary qualifications. Such other persons or organizations may, for example be

- designers
- specialists
- contractors
- material suppliers
- independent consultants.

The overall project management has the responsibility to formulate the primary requirements and constraints and bears implicitly the liability for risks related to this.

The overall project management has the obligation to organize and coordinate the activities of the specialists and contractors participating in the project so that

- the responsibilities of all parties are clearly specified with particular attention being paid to interfaces and communication
- restraints on the smooth running - with respect to building programme, organizational and technical matters - of the project are kept to a minimum

- the quality assurance concept is consistently and responsibly applied in the planning, design and erection stages.

The overall project management should arrange for the preparation, maintenance and updating of the important project documents (see 2.8) until the building is finished.

The overall project management is responsible for preparing the instructions for the user.

4.2.3 The function of the designer

The function includes detailed planning, design and other similar activities such as work as a technical specialist.

The function includes the responsibility to ensure that the construction fulfils its function throughout its life and that the owner receives an optimum economic performance in all phases of erection, use and maintenance of the construction. While endeavouring to reach this optimum, the designer or the specialists should heed the safety demands of the public and site personnel and observe other relevant constraints which may exist.

The function includes an obligation to formulate and present to the overall project management the basis for decisions so that the risks taken can be compared with the benefits accruing.

Although the final decisions may be taken by the overall project management based on the advice of the designer and other specialists, the responsibility for the correctness of such advice still rests with the designer and the specialists.

The building codes should give the designer and the specialists a right to decline responsibility for the decisions of the overall project management if their advice is disregarded and more particularly on matters connected with foreseeable risks regarding safety or severe damage to property. If, in such a case, safety is affected the designer and the specialists may also have a responsibility to take some preventative measures.

4.2.4 Management of the production of materials and products

If no other special agreement has been made, the management of production of materials and products has the responsibility that the materials or products delivered complies with the specifications given in building codes or in connection with the order.

The management of production of materials and products is responsible for the internal quality control (compare 5.2.3).

4.2.5 Management on the construction site

The management of the activities on the construction site can be undertaken

- by personnel directly appointed by the overall project management as a delegated task
- by personnel appointed by a contractor
- by a combination of these two. In this case, the division of responsibility must be clearly defined.

The management on the construction site includes the responsibility to organize and coordinate the activities of the personnel working on the construction site in connection with the erection of the structure.

The management on the construction site has the responsibility for the quality control of materials and components produced at the construction site and for the control in connection with the erection of the structure.

As regards material and components produced at other factories and workshops, the management on the construction site may be given the responsibility to check that the internal control is satisfactory and that relevant control documents have been delivered. In some cases this can be reduced to a responsibility for identification of the material or the components.

4.3 The responsibilities related to the use of the structure

4.3.1 Owner and user

Regarding the use of a structure there are in most cases only two parties involved

- the owner
- the user.

An owner is a person or an organization that owns the building in a legal sense.

A user is a person or an organization that uses the building either because the building is generally available (for example a bridge) or according to an agreement with the owner.

4.3.2 The responsibility of the owner

The owner has the responsibility concerning the need for appropriate maintenance of the structure and has an obligation to have the safety of the structure re-examined if there is an intention of change of use or alterations to the structure.

The owner has the responsibility to make inspections to ascertain the need for maintenance and repair (compare 5.2.6).

In some cases the responsibility of the owner may be delagated, for example, to a user according to a special agreement.

4.3.3 The responsibility of the user

The building code and the utilisation plan should give the basis for a specification of the responsibilities of the user.

The user is responsible for the observance of all rules and conditions of use made known to him in instructions for the user or in other documents, for example, road traffic acts for bridges.

5. PRINCIPLES OF CONTROL

5.1 Introduction

Effective control during planning, design and dimensioning, erection and use of structures has to be implemented and performed by all parties involved.

The notion control includes all checks, verification measures and inspections regarding:

- design
- production of material and components
- erection on the construction site
- use of the building or structures.

Every control consists of

- the collection of information
- a judgement based on this information
- a decision based on this judgement.

Control serves the following purposes:

- to ensure an acceptable quality of design, materials, products and work on the construction site
- timely detection of hazards involving the safety of people and/or damage to property during construction and use of the building or structures
- to obtain experience (compare 1.3).

5.2 The control process

5.2.1 General

Control can be considered as a special process going on parallel to the building process.

In many cases the persons or organizations who are responsible for the building process are also responsible for the control activities. Thus there is a close connection between the building process and the control process and it is important that the control is executed in such a way that it does not interact unfavourably with the building process.

One can distinguish between the following different types of control depending on the person or organization undertaking it (compare 4.2)

- individual self-control
- internal control
- control handled by the overall project management
- control executed by the public authority.

5.2.2 Individual self-control

In this document it is assumed that participants in the building process aim at carrying out their respective tasks with care and skill. This can only occur through continuous individual self-control measures. These include the checking of documents and information communicated to other persons.

5.2.3 Internal control

Internal control is assumed to be organized and performed wherever work is performed by more than one person or more than one group of persons. Codes should state the obligation to such internal control.

Internal control may concern, for example, design work in an office, material production at a factory, production of components in a workshop and erection of a building at the construction site. Those who have the responsibility for the site management should check especially all quality control documents required by codes.

Sometimes the internal control system is subjected to verification by some outside agency.

5.2.4 control handled by the overall project management

Those who have the responsibility for the overall project management may also be made responsible by building regulations for ensuring that all control measures throughout the whole building process are implemented effectively. They may delegate some of their control functions to qualified specialists.

Specialists entrusted with the responsibility for control have to report on their control activity. Building codes should state such duties and the formal requirements to be observed.

An independent consultant with additional control tasks may also be employed. Codes may require such independent control in all cases where

- very complicated problems have to be solved
- a structural failure would endanger a very large number of persons or have very large economic consequences.

Codes should state the special circumstances which require additional control by an independent consultant.

The task of the independent consultant should be stated in the control plan (see section 5.4). The field of activity of the consultant may extend over the whole building process or be restricted to certain sections only.

5.2.5 Control executed by the public authority

The control executed by public authorities is based on building laws and/or codes. The aim is generally connected with the society having requirements for safety and a quality that is acceptable on the whole. Therefore this kind of control should not be considered as a substitute for the kind mentioned in 5.2.2 - 5.2.4.

5.2.6 The owner's inspection of the building

To ensure that the safety and serviceability of a structure is maintained throughout its anticipated time of use it is necessary to make inspections to find out about the need for maintenance and repair.

The intervals between inspections should be chosen with due regard to

- the environmental conditions
- the properties of the material
- the reliability of protective measures
- the sensitivity of the structure to local damage
- the consequences of failure.

5.3 The degree of control

A rigorous control process includes all types mentioned under 5.2 and is recommended for important structures or structural parts if the consequences of failure are severe. For structures or structural parts of minor importance it may often be sufficient to limit the control to individual self-control and internal control. Then, the control executed by the public authorities might consist of merely a check that the internal control has been executed in an acceptable way.

If a control process consists of several steps it is important that the activities involved in these steps are as far as possible mutually indenpendent in a statistical sense. Othervise the efficiency of the control will be reduced.

5.4 Planning of control

5.4.1 Control stops

The whole building process from planning to use of the structure should be sub--divided by control stops. Such control stops should be introduced, mainly at points where responsibility is transferred from one party to another or where one phase of the building process gives way to another.

Each control stop contains control measures which should be exercised before the next stage of the building process can commence. The production and the control should be planned so that any delays to the building process will be as short as possible.

Hazardous phases during erection and use should be separated by control stops and supervised according to a carefully prepared supervision plan. This especially holds for those hazard scenarios which are to be overcome by measures of control and supervision.

Control stops and all necessary details of control measures to be performed should be specified by the overall project management in collaboration with the specialists involved.

For ordinary structures, building codes may specify appropriate control stops and regulate all necessary details.

5.4.2 Control plan

A special control plan should be established by the overall project management in collaboration with the specialists involved, especially in cases where

- control tasks are vested in different persons
- the execution of the construction and/or the use of the structure creates a potential danger to a very large number of persons.

The control plan should contain all details of control.

For the design control, the plan should include

- checking that the requirements and conditions used in the design are in accordance with those specified
- checking that the relevant calculation models are used and that the numerical calculations are correct
- checking that drawings and other design documents are in accordance with the design calculations and with given specifications.

For the control of material and products and for the control of the erection on the construction site the plan should include

- responsibilities regarding control
- subject of control
- time schedule including control intervals
- control procedures
- control criteria and acceptance rules
- requirements of reports and documentation
- procedure in the case of deviations from control criteria.

5.5 Supervision of special risks

In order to minimize danger to human life (and to reduce the risk of damage to property) a supervision and warning system should be introduced where special circumstances requires certain hazards to be countered by measures of supervision.

The special circumstances may be derived from the utilisation plan or the safety plan. The introduction of protective measures when special risks arise should not be left to improvisation. According to the risks envisaged, protective measures should be pre-planned to some extent.

All supervision measures found necessary to overcome risks could be stated in a supervision plan. This plan contains the supervision measures together with all details.

The basis for the elaboration of a supervision plan is a careful analysis of the situation to be supervised with respect to hazard indicators. Hazard indicators in this respect are all changes in a situation which can easily be observed or monitored and which may indicate the presence of increased risk.

A continuous supervision of special risks should be ensured by making a person responsible for it and naming his representative.

The persons charged with supervision activities should be carefully instructed by the project management with respect to the hazards envisaged and the hazard indicators. They should also be required to report on events and phenomenon which, though not specified in the supervision plan, may, according to their experience, have a relationship to the risk supervised.

The supervision activities should periodically be checked with respect to proper functioning. The same holds for automatic warning systems.

6. METHODS OF CONTROL

6.1 Introduction

Regarding the type of activity that is controlled one can distinguish between

- design control
- control of materials and components
- control of fabrication and/or construction at the construction site
- control during the use of the structure.

According to the simplified flow chart shown in FIG 1 these types of activity are differentiated in time. However in many cases the first three types of activity go on simultaneously.

The principles of control (according to section 5) are to a great extent the same but the methods of control differ for the different types of activity.

6.2 Design control

6.2.1 General

The design work consists mainly of design calculations and of preparing drawings, material specifications and similar documents.

The calculations are based on the specified requirements and conditions. The drawings, material specifications, etc. are based on the design calculations but also directly on the specified requirements and conditions.

The drawings are the main link between the design work and the construction work and are therefore in principle the primary object of design control. However, as the drawings are based on calculations, it is in many cases convenient or necessary to control the design calculations in order to verify that the whole design process is in accordance with the requirements of section 1.1.

6.2.2 Control of the calculations

Control of the calculations can be executed with different techniques and to different extent. However in any case the following checks should always be made

- checking that the calculations are based on the relevant fundamental requirements and operational, environmental and boundary conditions
- checking that calculations are made for all structural parts for which the design problem is of such a character that calculations are necessary
- checking that the relevant calculation models are used
- checking that there are no discrepancies between different parts of the calculation
- checking that all forces acting on the structure are correctly transmitted through the structure to the foundations.

Three different techniques for the checking of the calculations can be used

- total direct checking which means that the calculations are followed step by step.

  The advantage of this method is that discrepancies are immediately discovered. The disadvantage is that the person who makes the checking can be directed too much by the calculations. Therefore, in this case it is necessary too make special checks, for example, to discover any omissions.

- total parallel checking which means that special checking calculations are made completely separately from the design calculations. The results of the two different calculations are compared at certain points, determined beforehand.

  An advantage of this method is that the person who does the checking is not influenced significantly by the original design calculation. Another advantage is that the checks can be made with simplified methods in many cases. The disadvantage is that if discrepancies occur it is sometimes difficult to find their source.

- partial checking which means that certain representative parts of the calculation are chosen and checked with direct checking or parallel checking. For the rest of the calculation the results are checked by means of comparison.

  This method has the advantage of being the most rapid method. However it requires an experienced person to do the work.

Often a combination of the methods can be used. This is especially the case if the calculations are made by computer. Then direct checking is not convenient and in many cases not possible.

6.2.3 Control of the drawings

Control of the drawings should generally consist of checking

- that the results obtained from the calculations are correctly transferred to the drawings
- that the drawings are in accordance with given requirements

- that the drawings are mutually consistent
- that the drawings are in accordance with given environmental and boundary conditions
- that the drawings are made in such a way that they are unambiguous and that the risk of misunderstanding them is small.

6.3 Control of materials and components and of construction at the construction site

6.3.1 The control procedure

General

Concerning the control procedure one can distinguish between

- production control, which is a control of a production process. The purpose of this control could be the steering of a production process and the guarantee of an acceptable result.
- compliance control, which is a control of the output from a production process. The purpose of this control is to ensure that the product complies with given specifications.

In these two control procedures the properties of materials, components or structures that are the object of the control are not necessarily the same.

Production control

Production control is mainly directed to the production process.

The control may, for example, concern material, components, production equipment and the time used for different parts of the production process.

Production control also includes

- identification of materials and components
- preliminary tests (made before production starts)
- considering (before production starts) the fitness of materials or components to be used in the production
- tests (during the production) for steering the production.

Compliance control

Compliance control should be concerned with the control of the products resulting from a production process and their compliance with the given specifications.

However, it may often be convenient to include some prescriptions about the production process in the specifications. In this case the specifications concerning the process and the specifications concerning its results shall be compatible.

The controller should also try to recognize if anything abnormal, not envisaged in the specifications, has occurred. It is necessary to specify the properties that should be controlled. These properties are always more or less conventional and generally relate to the design calculations. They may be

- qualitative, and may be checked by a visual control, comparison to drawings or specimens etc.
- quantitative, i.e. they can be measured.

A visual examination could be made in order to find faults or to compare with agreed samples.

6.3.2 Control criteria and acceptance rules

General

Regarding the control criteria and the acceptance rules one distinguish between

- total control
- statistical control.

Total control

If the control is total every produced unit should be controlled. The acceptance rules imply that a unit is judged as good (accepted) or bad (not accepted). Normally the criteria, if they are quantitative, refer to given tolerances.

If a certain number of the produced units can be considered a priori as identical one could be admitted not to control every unit.

In certain cases the units may be classified as belonging to different quality classes instead of being accepted or not accepted.

Statistical control

A statistical control procedure generally consists of the following parts

- batching the products
- sampling within each batch
- testing the samples
- statistical judgement of the results.

A batch must be such that it can be regarded as homogeneous with regard to the properties which are the subject of the control. This means that all units within a batch are produced under essentially the same conditions. If the properties of the products vary with time after production this has to be considered in the batching procedure. The batching should in principle be made by the person responsible for the control.

Within each batch a number of units are taken as a sample which is then submitted to testing. The methods of sampling should be given in the codes.

The assessment of a batch is made by comparing the test results with the given criteria. These are normally of the following types.

a) The criteria refer to the results obtained for the sample as a whole.

If a property of the product is quantitative the results may be given as some parameters (mean, standard deviation, fractile etc) of the statistical distribution for some value describing the property.

If a property is qualitative the result may be given as the proportion of the specimens of the sample that fulfil given requirements.

b) The criteria refer to the extreme results.

If a property of the product is quantitative an extreme result may for example be the most unfavourable value or the range between a minimum and a maximum value.

The assessment of the results should be made with regard to a given level of confidence or a given interval of confidence. The level of confidence is the probability that a criteria will be satisfied if the corresponding hypothesis is true (for example the hypothesis that the true value of a certain fractile of the population lies within a chosen interval). The level of confidence is not the probability that the hypothesis is true if the criteria is satisfied.

In principle the criteria should be obtained by a general statistical approach, which may include the use of statistical parameters which characterize the population, OC-curves, etc. However, the conditions on which this approach is based are in most cases not explicitly expressed in the final criteria. The conditions should generally be considered only as a rough description of the required goal. In practical cases, the goal is to avoid - as well as possible - the acceptance of products with a quality that is definitely unsatisfactory, even if it is assumed in the calculations that a small proportion of such products exists.

It should be noted that the justification for a decision based on statistical control may be considered to be unfounded for one or more of the following reasons

- unsatisfactory batching
- unsatisfactory sampling
- wrong assumptions for the statistical deductions
- the level of confidence is different from 1.

The total probability for an incorrect decision (in any sense) is often considerably greater than the value of the probability assumed at the design stage. Therefore it may be necessary

- to add to the main criteria certain absolute requirements for the test results and to require a certain global control (for example testing of a completed structure).
- to increase the number of test specimens if the criteria implies that the results obtained are on the bound of what is allowable. In such a case it may be unavoidable that the supplementary tests have to be made in another way.

GLOSSARY Appendix 1

Operational conditions

Conditions relating to the use of a building, for example, loads on floors, indoor temperature, etc.

Environmental conditions

Conditions determined by the environment of the building and external natural phenomena for example wind load, outdoor temperature, properties of soil.

Boundary conditions

Conditions determined by legal restrictions, by activities going on in the neighbourhood of the building etc. for example restriction regarding the height of a building, the necessary clearance under a bridge.

Safety, Serviceability and Durability, see 2.1

Utilisation scenarios and Hazard scenarios, see 2.2

Building code

In this document the term "building code" is used to cover all structural codes not just those used for building structures.

Client

A person or an organization which has found that there is a need for a building of some specific kind and therefore initiates the building process.

Overall project management

A person or an organization to which the client has given the right to take the final decisions about the building project.

Management on the construction site

A person or an organization to which the overall project management (or in certain cases the law) has given the right to take the decisions about a specified group of questions on the construction site.

Owner

A person or an organization which owns the building in a legal sense.

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