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Some Basic Concepts in Building and their Relationship to Durability

Quelques concepts fondamentaux dans la construction en rapport avec la durabilité

Grundkonzepte der Baukonstruktion und ihre Beziehung zur Dauerhaftigkeit

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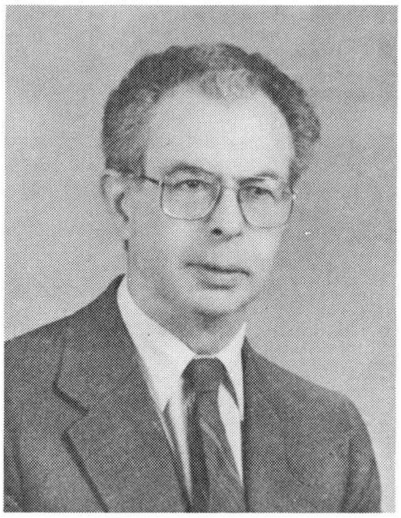

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SUMMARY

The basic concepts: essential requirements and performance criteria, quality assurance and human error, probabilistic reliability and safety differentiation, liability and technical insurance are briefly introduced and their relationship to durability is discussed.

RÉSUMÉ

Les concepts de base: exigences et critères de performance, assurance de qualité et erreur humaine, fiabilité probabiliste et différentiation de la sécurité, responsabilité et assurance technique sont brièvement introduits et on discute leur rapport avec la notion de durabilité.

ZUSAMMENFASSUNG

Die Grundkonzepte: Anforderungen, Beurteilungskriterien, Qualitätsgarantien, menschliches Versagen, Auftretenswahrscheinlichkeit, Sicherheitsdifferenzierung, Verantwortung und technische Versicherung werden eingeführt und ihre Beziehung zur Dauerhaftigkeit werden diskutiert.

1. Introduction

When dealing with basic concepts in building the introduction of the concept of durability corresponds to the introduction of the concept of time. Thus the usual way of dealing with durability consists in defining the essential requirements in general terms and in adding the conditions that these requirements should apply during the intended life of the structure.

However very seldom the intended life is quantifiable. The owner is unable to provide this information on firm hypotheses and both the designer and the builder do not know what durability they can offer. Durability depends not only on design and execution but also on the way inspections and maintenance are carried out.

On the other hand, as it shall be seen, the designer and the builder are liable for defects occurring or being detected during large periods of time. Pending on the juridic system in force in the country these periods are fixed in the civil law or in contracts or in both.

Standards play a very important rôle in the definition and implementation of basic concepts. The same occurs with legislation and contracts. The following discussion is centered in this type of documents, mainly in those in force in Western Europe.

2. Essential requirements and performance criteria

The International Standards ISO 2349 (1), General Principles on Reliability for Structures, states that the structural requirements of safety and serviceability should apply during the intended lifetime of the structures.

The Commentary on ISO 2349 (2) identifies the fulfilment of the structural requirements during the intended lifetime as the durability requirement. In this Commentary the adaptability requirement is defined as the facility to erect, to modify and to dismantle the structures.

When dealing with probabilistic reliability there is the need to define a lifetime or a reference period of time in order to compute probabilities of failure. However this does not mean that when lifetime is attained the structures are put out of service. Seldom at the design stage it is possible to define the durations of lifetime, both required or attainable.

Along time not only the mechanical properties of materials vary, deterioration occurs, but also environmental conditions and requirements may change. Thus durability and adaptability should be associated in order to keep the value of the structures.

The operations to be carried out after completion of the structure along time are: inspection, maintenance, repair, rehabilitation, adaptation and demolition. Within an economic approach generalized cost should be computed by adding to the initial cost the costs of these different operations taken at their different dates, multiplied by their probability of occurrence, and corrected by discounting. Furthermore in the generalized cost should also be included the cost of insurance against failure and other eventual construction defects.

By introducing discounting, expenses at a time t are transformed into actual expenses and thus may be added to the initial costs in order to compute the generalized cost referred to the initial date.

According to this way of thinking the definition of lifetime for judging the economic duration of the structure is obtained by assumptions concerning the evolution of expenses along time. As these expenses have to be corrected and reduced, only occurrences in a near future are significant. Expenses in the far future are erased by discounting (3). The adoption of a discount factor of the order of magnitude of 6% practically allows to disregard expenses occuring after 50 years. These expenses are transformed into present values smaller than 5% of the actual ones. Consequently it is difficult and it becomes unnecessary to define lifetime. Structures should be conceived in order to facilitate both dismantling and prolongation of their lives, being easy and economic to maintain and to adapt.

In architectural design further to the requirement of adaptability the concept of flexibility is also introduced. Flexibility meaning the facility of using the construction according to different lay-outs (4).

In structural design the performance criteria corresponding to the essential requirements are expressed by ultimate and serviceability limit states. This usual approach may be improved by taking into account recent scientific and technical studies.

The concept of safety, as protection of life and property, may be generalized to include protection, or even promotion, of physical and mental health, as shown in the international CIB conference held in Stockholm in September 1988 (5).

The concept of serviceability, taken as fitness for use, may be much upgraded by the concept of intelligent building (6). By including capacities of information supply, resources management and operations control the level of service that buildings may render is much higher than the level implicit in the traditional concept of passive serviceability.

Furthermore by adding to the concepts of durability and adaptability the qualities of being pleasant and secure leads to an essential requirement which may be designated by "friendly". Under the concept of security are included the conditions of avoiding personal accidents, caring disabled and avoiding intrusions.

About twenty years ago, when the structural requirements of safety, serviceability and durability were adopted at an international level, it was expected that they would stay unchanged for a long time. However the rapid progress of cognitive sciences, the recognition of the need to enlarge the humanistic components of the essential requirements and the possibilities offered by the generalized use of computers jointly contributed to a complete change of the situation.

Particularly concerning durability of buildings and bridges horizons between 50 and 100 years were referred to. It is now clearly understood that the very valuable patrimony, both in buildings and public works, cannot be put out of service and rebuilt at short intervals of the order of magnitude of 50 years. Hence the need to adopt design criteria and execution techniques allowing to increase durability significantly. In a pure economic context this corresponds to adopt discounting factors considerably smaller than 6%.

3. Quality assurance and human error

The International Standards ISO series 9000, (7), define quality assurance as a set of planned activities which allow to guarantee that a product or a service satisfies established requirements.

According to this definition quality assurance is a management tool guiding how to take correct decisions and how to avoid errors.

In planning quality assurance, four levels are usualy identified:

- Level 1 - Activity limited to the quality of the final product.
- Level 2 - Includes the control of the production process.
- Level 3 - Extends the control to the production management, including production programming, definition of responsibilities, documentation and auditories.
- Level 4 - Concerns the whole management, including flow of information, motivation, professional upgrading, etc.

The choice of the quality assurance level should depend on the importance of the risks to be avoided.

The fulfilment of the requirements of durability is difficult to verify by control during construction. The correct detailing of the structure, the choice of adequate materials and their protection, the care taken during execution and appropriate inspections and maintenance are important activities in order to achieve durability.

The promotion of quality in building may be viewed from two angles. One angle corresponds to the implementation of standardized quality assurance. The other one consists in the implementation of results from cognitive and human sciences. Lessons from experience are a fundamental source of information to accomplish quality and particularly to achieve durability. Defects, incidents and accidents are in most cases due to human errors. The early detection of these errors and the prompt diffusion of information concerning them should avoid their repetition and thus prevent large potential expenses (8).

In France the "Agence pour la Prévention des Désordres et l'Amélioration de la Qualité des Constructions" within its system of collection of information concerning accidents in buildings has installed an alert system which allows the rapid diffusion of information on accidents thus avoiding their repetition. Other agencies such as the National Housing and Building Council in the United Kingdom, the Bostadsgaranti in Sweden and the Building Defect Fund in Denmark have installed analogous procedures.

The sociological and psychological study of human error is deserving more and more attention. According to Reason (9) human errors are classified in two classes: slips and mistakes. Slips are errors committed at the execution phase and mistakes are errors in the planning phase. Basic error tendencies are: false sensations, attentional failures, memory lapses, unintended words and actions, recognition failures, inaccurate and blocked recall, errors of judgement and reasoning errors.

Experimental data and psychological studies or the occurrence of errors in structural engineering and on ways to avoid or to correct them should be pursued (10).

The use of quality assurance techniques in the planning, design and construction of a pre-stressed concrete bridge is exemplified in (11). Further to general concepts on quality management, an example of quality manual for a contractor and a set of check-lists are presented. These check-lists concern: qualification of participants, quality requirements and conditions, identification of drawings, costs, archive (documents store) conditions, quality manual, utilization manual, and reliable performance of a task.

Thus to achieve quality, and the implicit durability, two lines are open: i) to follow the quality assurance procedures indicated above and ii) to resort to the different branches of human sciences which deal with error and to derive rules or procedures which would allow to minimize these errors and their consequences.
As the two lines converge to the same aim they may be duly combined.

4. Probabilistic reliability and safety differentiation

A general rule for designing structures consists in verifying that the probability of failure computed according to the probabilistic reliability theory, referred to a given interval of time, does not exceed given limits. It is considered that failure is attained when a limit state is reached. Theoretical probability of failure should be distinguished from the effective probability of failure which includes human error.

The lessons from experience concerning the past behaviour of structures of different types show that although they are designed in such a way that their probability of failure during the reference lifetime is sufficiently small, in fact the percentage of structures which fail is higher than the one that would correspond to the adopted theoretical probability of failure. This is due to human errors not being considered in the theory of probabilistic reliability.

Thus, conceptually, two probabilities of failure should be distinguished: theoretical probability of failure and effective probability of failure.

In failure human error is prevalent in determining the effective probability of failure. However to discuss the problem of safety differentiation the two following cases should be considered:

1 - The effective probability of failure is considerably larger than the theoretical probability of failure.

2 - The effective probability of failure is of the same order of magnitude of the theoretical probability of failure.

In the first case, to increase safety, decisions to be taken should consist in varying the quality assurance plan. If it is wished to reduce the effective probability of failure, a higher level of quality assurance should be adopted e.g. by moving from level 1 to levels 3 or 4. This change will affect the probability distributions of the main basic variables, in particular the probability distributions of the mechanical properties of materials. The adoption of more stringent production and conformity control reduces the lower tails of the probability distributions of the mechanical properties of the materials. Although the real probability of failure is reduced, and the same being deemed to occur to the theoretical probability of failure, it is to be expected that the reevaluation of this probability will allow to keep unchanged or even to reduce the γ_m values, instead of increasing them.

In the second case, it is not possible to reduce significantly the effective probability of failure without reevaluating the theoretical probability of failure. Thus a simple strategy will consist in increasing the partial factor γ_f or/and γ_m, without any further change in the quality assurance plan.

The Nordic "Guidelines for Loading and Safety Regulations for Structural Design" (12) include safety differentiation by considering safety classes accordingly to the following table.

Consequences of failure	Safety class
Slight personal injury and insignificant public loss.	Low safety class
Some personal injury and significant public loss.	Normal safety class
Extensive personal injury and very significant public loss.	High safety class

This classification is influential in two aspects. In the choice of the partial safety factors which product gives the factor $\gamma_m = \gamma_{m_1} \times \gamma_{m_2} \times \gamma_{m_3} \times \gamma_{m_4} \times \gamma_n$ and in varying inspection classes to be applied to design, materials and execution. Three inspection classes are considered: moderate, normal and stringent. It is specified that for "structures and elements of structures assigned to the high or normal safety classes inspection shall correspond to the classes stringent or normal".

The partial factor γ_n, equal to 1 in the normal safety class, is reduced by 10% in the low safety class and increased by 10% in the high safety class. However these variations may be compensated by the change of the partial factors γ_{m_1} which depend on the coefficient of variation of the material strength, and of the partial factor γ_{m_4} which directly depends on the scope of inspection. γ_{m_2} related to the accuracy of the analytical model and γ_{m_3} related to the type of failure (brittle or ductile) may be left unchanged. So, as indicated above, in the first case (effective probability of failure considerably larger than the theoretical probability of failure), to improve safety it is sufficient to increase the quality assurance level leaving the partial factor γ_m unchanged, or even decreasing it.

The general method of structural reliability of considering random basic variables and multiplying or dividing their characteristic values by partial factors, γ, may also be applied to analytical models expressing deterioration phenomena (13). However up to now these models have not yet been established for the most important deterioration mechanisms.

Also according to the consequences of failure it would be possible to apply durability differentiation rules leading to the variation of partial factors affecting basic variables (dimensions, mechanical properties, chemical contents, etc.). However, as it was indicated in relation to structural safety, these variations may be less influential than those which result from the variation of quality assurance procedures.

A problem related to safety and durability that deserves particular attention results from the tendency of building with the same design and execution technique a huge number of identical components or structures. The possibility of covering wide markets allows to obtain reduction of costs by producing large series. There is however a dangerous counterpart resulting from the possibility of a single error affecting a very large number of cases.

5. Liability and technical insurance

The problems of post-construction liability and technical insurance are being studied by the CIB Working Commission W 87, created in 1985. This commission collected information on the legislation and practice in several countries. A state-of-the-art report is being prepared.

The Commission of the European Communities, has published a set of monographs, one for each member state, concerning "Control, Contracts, Liability, and Insurance in Building" (14). These monographs show the diversity of legal systems in Western Europe. In the Latin countries civil law results from the evolution of the Justinian Code of old Rome, and from Napoleonic Code published in 1804. The Anglo-Saxonic countries apply the common law system. Most of the rules of law are based in the custom, practice and usage of the people as defined by decisions of appeal courts.

Legal liability may be considered in two situations: contract and tort. Tort covers all wrongs other than breach of contract. In building it is important to make clear which of the participants in the building process are liable due to duty of care or duty of result. Conditions of contract may impose or not duty of result. Tort being out of contract leads to duty of care only.
The legal framework of liability influences the quality of building and consequently durability. However during the last years, in some countries, the very rapid increase of the number of claims and lawsuits instead of contributing to better building simply resulted in an increase of final prices and in the creation of a litigation climate which reduces productivity.

The protection against these claims may be found in professional liability insurance. However its cost is much increasing (15).

In building, and in the post-construction period, further to the usual types of insurance, two types of technical policy insurance apply: liability insurance and property insurance.

In some countries further to contract fire, earthquake and other natural risks insurance it is possible to cover post-construction defects which may arise during a period, usually of ten years, after the completion of the construction. This insurance applies particularly to housing and may be obtained through special schemes such as those offered by the National Housing and Building Council in U.K., Bostadsgaranti in Sweden, Defects Fund in Denmark, and GIW, Garantie Institute Woningbau in the Nederlands. In France post-construction insurance is obligatory due to the Spinetta law of 1987, and applies to all types of buildings (8).

6. Conclusions

The relationship of four groups of basic concepts to durability was discussed. The first group concerns essential requirements and performance criteria. It is concluded that when applied to building the essential requirements: safe, serviceable and durable may be enlarged becoming: healthy, intelligent and friendly. Friendly concept includes the performance criteria: pleasant, secure, durable and adaptable.

This enlargement of semantic domain results from the explicit inclusion in the essential requirements of the humanistic component. In the same way an enlarged concept of durability is obtained by associating to it the concepts of inspection, maintenance, adaptation, repair and demolition.

The second group concerns quality assurance and human error.

It is concluded that to achieve quality, and implicitly durability, standard quality assurance procedures should be followed. The level of these procedures should be commensurate to the risks involved. Furthermore by resorting to cognitive sciences human errors and their consequences should be minimized.

The third group concerns probabilistic reliability and safety differentiation.

It is concluded that the theory of probabilistic reliability may be extended to cover deterioration models also, the same occurring to safety differentiation.

Practical consequences are derived from the distinction between theoretical and effective probabilities of failure, leading to explicit differentiation rules.

The fourth group concerns liability and technical insurance.

It is concluded that the present tendency to resort more and more frequently to liability claims based on negligence should be denounced. The generalization of professional liability and post-construction defects insurances would be beneficial not only to protect the different participants in the building process but also to improve the quality, and concomitantly the durability, of the built patrimony.

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