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Serviceability Requirements

Exigences d'aptitude au service

Gebrauchstauglichkeitsanforderungen

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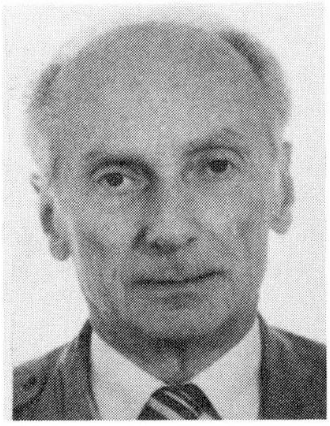

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SUMMARY

Serviceability requirements imposed on building structures are classified into three basic groups: human comfort, structural and equipment requirements. To specify limit values and to analyze structures two kinds of uncertainties are to be distinguished: vagueness in definition of limit states and randomness of basic variables. Methods of optimization may provide some guidance. Calculation, testing and professional judgement could be used for verification and assessment of structural serviceability.

RESUME

Les exigences d'aptitude au service imposées aux structures des bâtiments sont réparties en trois groupes: confort de l'utilisateur, exigences d'ordre structural et exigences relatives aux équipements. Il faut tenir compte de deux sortes d'incertitudes au cours de la détermination des valeurs limites et du calcul des systèmes porteurs, à savoir l'imprécision des états limites et le caractère aléatoire des variables de base. Les méthodes d'optimisation peuvent fournir à ce sujet une aide appréciable. Le calcul, l'expérimentation et l'appréciation du spécialiste sont d'excellents atouts pour évaluer et vérifier l'aptitude au service d'une structure donnée.

ZUSAMMENFASSUNG

Anforderungen an die Gebrauchstauglichkeit von Hochbautragwerken können in drei Klassen eingeteilt werden: Benützerkomfort, bauliche und einrichtungstechnische Anforderungen. Bei der Festlegung von Grenzwerten und der Berechnung sind zweierlei Unsicherheiten zu berücksichtigen, die Unschärfe der Grenzzustände und der stochastische Charakter der Basisvariablen. Optimierungsmethoden können hier Entscheidungshilfe geben. Berechnung, Experiment und Urteilsfähigkeit sind einsetzbar, um die Gebrauchstauglichkeit eines Tragwerks abzuschätzen und nachzuweisen.

1. INTRODUCTION

Serviceability of building structures and other civil engineering works is a broad concept, whose extent seems to be continuously expanding. This is caused by several trends in design and production of building structures as well as by increasing demands on their performance. Structural serviceability should cover an essential part of the overall structural performance, which, in accordance with the International Standards ISO 2394[1], ISO 6240[2], ISO 6241[3] and ISO 4356 [4], includes two basic groups of mechanical properties

-- safety or load bearing capacity, i.e. resistance to various actions without collapse or total disability of the structures or their elements,

-- serviceability, i.e. ability of structures and their elements to perform adequately in normal use.

Obviously, boundary between these two mechanical properties is not absolutely sharp and entirely unambiguous. Durability and fatigue of structures are examples of phenomena, that are frequently included in both these groups. Generally, it is understood, that violation of appropriate limit states of safety may cause risk of human life and malfunction costs many times exceeding the initial costs, whereas violation of serviceability limit states rarely lead to risk of human life and usually involve lower economic losses than in case of safety.

On the other hand overwhelming majority of structural defects observed nowadays, are classified as serviceability, rather than safety problems. That is why serviceability limits states are becoming more and more important technical as well as economical issue [5,6,7,8].

While safety problems usually involve strength, serviceability problems involve primarily deformations and displacements of different origin. It is to be noted here, that there are generally two independent sources of dimensional changes, that should be, in some cases, taken into account simultaneously when analyzing structural serviceability: deformations due to various actions including loads, and deviations due to various production procedures including setting out, manufacturing and erection. It follows from another contribution at that colloquium [9,10], that common procedures for dealing with structural serviceability are insufficient and need to be improved. However similar statement follows from other serious drawbacks of the current methods [5,7].

The underlying aim of this document is to unify basic classification of serviceability requirements, formulation of adequate criteria and general procedures for design and assessment of building structures with respect to the serviceability limit states. It is believed that some general guidance towards uniformity in specification and required probability of compliance with imposed requirements will be welcome, particularly, as the economy of modern buildings are increasingly controlled by their serviceability.

2 SERVICEABILITY REQUIREMENTS

Serviceability requirements should guarantee adequate performance of the building in normal use [1]. In general, serviceability requirements commonly imposed on buildings and civil engineering works, could be classified into the following three basic groups, which correspond to the functional requirements specified in the International Standard ACE 6241/3/, in several national standards as well as in working documents of developing international codes:

(1) human comfort, which may be further divided in two subgroups:

-- appearance requirements (to limit annoying visual effects due to deformations and cracks of structural components),
-- physiological requirements (to limit discomfort due to vibration, penetration of air, dust and sound);

(2) structural requirements (to limit local damage including stress, strain, excessive cracks and to guarantee, smooth assembly, watertightness, drainage and proper functioning of attached elements, coverings, doors and windows);

(3) equipment requirements (to guarantee proper functioning of all kinds of equipment, including machinery, pipes, cables, ducts and their supports).

These basic groups comprise typical serviceability requirements, which are most frequently imposed on newly designed structures. Explanatory examples in brackets may help, but obviously are far from being exhaustive. They may serve as an aide-memoir to identify all appropriate functions of structures and to specify adequate serviceability requirements.

Indicated basic groups of serviceability requirements are obviously overlapping and/or criteria derived from them may be mutually dependent or interactive. This may result in complex general criteria dependent on span of the components or other relevant characteristic. In particular cases, however, often only one type of serviceability requirement is decisive in design and assessment of structural serviceability.

3. SERVICEABILITY CONDITIONS

It is a common rule that serviceability requirements lead to criteria for adequate deformations, displacement or other mechanical indicators, which are called serviceability parameters. To identify relevant serviceability requirements and their quantitative specification in terms of suitable serviceability parameters is the most important and difficult task of design and assessment of structural serviceability.

The serviceability parameters u_i are suitable mechanical variables (as for example deflection at midspan, slope at a given point, acceleration, crack width), which should characterize ability of a structure to be used for the purpose for which it is intended. Usually only one serviceability parameter u, or two parameters u_i are considered for a structure at a time [10].

Serviceability requirements should be then expressed in terms of the chosen parameters u_i as serviceability conditions, usually in the form of simple inequalities between the actual (calculated) structural values $z_i(t)$ of the parameters u_i and their limit values (constrains) l_i, t being time. Most often, the serviceability conditions state, that the actual structural value $z_i(t)$ of the serviceability parameter u_i should not exceed, or may exceed only within a limited time period, specified limit values l_i.

The most frequently applied serviceability criterion, concerning just one parameter u, has the following simple form

$$z_i(t) \le l_i \,. \qquad (1)$$

In some cases, however, more complicated criteria, including both upper and lower limit values [10], or concerning a set of parameters u_i and corresponding actual values $z_i(t)$ and the limit values l_i, may be applied. The limit values l_i are dependent on the building occupancy, considered time period and on the reversibility of the caused unserviceability. Generally, however, they are not dependent on the material used for the load bearing structure, and may be usually considered as time independent quantities.

4. UNCERTAINTIES

There are two kinds of uncertainties to be considered when analyzing serviceability limit states:

-- vagueness in the definition of serviceability limit states, as in most cases unserviceability develop gradually with increasing value of appropriate parameters,

-- randomness of loads, mechanical and geometric characteristics, sensitivity of occupants and attached structural components and equipment.

While randomness of basic and resulting variables can be handled mathematically through the well established theory of probability, less familiar imprecision and vagueness in definition of limit values l_i may be handled by methods of newly developing theory of fuzzy sets [11,12,13,14].

Thus to analyze serviceability limit states a probabilistic approach should be used similarly as in the case of ultimate limit states. In the latter case the annual probability of failure is of the order 10^{-3} to 10^{-6}, in the former case the annual probability of exceeding serviceability conditions (unserviceability) is of the order 10^{-3} to 10^{-2} or even greater. However, if the consequences of unserviceability are serious (hospitals, power plants, etc.), then unserviceability should be allowed only with approximately the same probability as in the case of ultimate limit states.

Unless methods of probabilistic analysis and structural optimization [16,17] will provide more accurate data, it is recommended to determine design values of the actual structural values of serviceability parameter under the following assumptions

-- actions are considered by their characteristic value (for irreversible consequences as damage of attached nonstructural components), or by frequent value (for reversible consequences as visual disturbance); upper values are taken for unfavourable actions, lower values for favourable actions;

-- dimensions are considered by their nominal values, given in design documentation;

-- materials characteristics are considered by their unfavourable characteristic values (*5%* fractiles);

-- prestressing force is considered similarly as mechanical properties by *5%* fractile.

The limit values of serviceability parameters should be considered by their fractiles or expected total unserviceabilities [9,14] corresponding uttermost to *20%*, in accordance with the significance of possible consequences. In some cases methods of optimization may provide more accurate specification [17,18].

5. STATE OF STRUCTURE

The state of a structure exposed to various physical and chemical causes, including load, is described by time dependent random variables (functions) $z_i(t)$ representing actual induced deviations and structural response to various actions expressed in terms of serviceability parameters u_i. As mentioned above the state of a structure is affected by both, deformations and deviations. Generally the random function $z_i(t)$ should consequently include effects of time dependent deformations of structural components due to physical and chemical causes including load, as well as effects of deviations induced by setting out, manufacturing and erection [10].

An actual structural value $z(t)$ of the serviceability parameter u (deflection, amplitude), may be a monotonic (irreversible) or fluctuating (partially reversible) function of time. At any time t, the variable $z(t)$ is a random quantity, which might have a considerable scatter [15,16]. Behaviour of the random function or $z(t)$ is described by a probability density function $\varphi_z(u|t)$ characterized by the mean $\mu_z(t)$, standard deviation $\sigma_z(t)$, skewness $a_z(t)$ and possibly by other statistical characteristics. Positive skewness $a_z(t)$ is likely to be expected for such parameters as deflection and amplitude [3].

To determine reliable statistical characteristics of the variable $z(t)$, appropriate physical and chemical causes including loads, must be considered. Load combinations should correspond to the nature of relevant requirements and specified serviceability parameters. In many cases only approximate values of other various physical and chemical causes are available.

6. LIMIT VALUES

As already mentioned, relevant requirements are usually stated very vaguely, imprecisely, often only verbally and, consequently may be very subjective [9,14,18]. To specify limit values l for serviceability parameters u, the following attributes should be therefore stated:

- considered serviceability requirement,
- structure or structural element to be verified,
- serviceability parameter and its limit value,
- corresponding probabilistic measures (probability or unserviceability),
- design situations to be considered,
- the load combinations to be taken into account,
- recommended simplified rules (e.g. limiting span/depth ratio),
- possible structural solutions including detailing to reduce risk of unserviceability.

This list of attributes seems to be useful to prepare standard specifications and recommendations for verification of structural serviceability and could be included in operational standard documentations, in order to enable alternative specifications. In view of economic aspects, client, contractor or architect may have their own demands different from code recommendations. In such cases mutually agreed serviceability requirements should be specified in a special contract.

7. ASSESSMENT AND VERIFICATION

Assessment and verification of each serviceability requirements may be generally done by means of calculation, test or judgment. The choice depends on the stage of building activity (designed, constructed, completed or old structure) and also on the particular serviceability requirement.

A calculation indicates the extent of satisfaction with serviceability requirements by means of theoretical model of behaviour, which should take into account all sources affecting actual value of the serviceability parameter, as for example creep, shrinkage, development of cracks, plastic deformations, local instability, induced deviations if they occur at appropriate design situation. It is however generally preferable to design the structure in such a way as to limit if not exclude all the possible unfavourable phenomena violating adequate performance and derived serviceability requirements.

A test provides a basis for assessing the satisfaction of serviceability requirements of a structure or structural elements. Direct measurements or other means of determination of the actual value of considered serviceability parameter under either real conditions of use, or conditions appropriately correlated to use, are then employed. A professional judgment or appraisal can permit the extend of satisfaction of serviceability requirements to be assessed on the basis of comparison with well established solutions.

In all cases appropriate reliability over specified time period need to be considered. Accepted level of probability or unserviceability should be related to expected consequences. In some cases structural optimization methods, based on minimum life cycle cost, may provide some guidance [14,16,17].

8. CONCLUSIONS

(1) Serviceability requirements could be classified into the following groups:
- -- human comfort,
- -- structural requirements,
- -- equipment requirements.

(2) There are two kinds of uncertainties to be considered when analyzing serviceability limit states:
- -- vagueness in the definition of serviceability limit states,
- -- randomness of loads, mechanical and geometric characteristics, sensitivity of occupants and attached structural components and equipment.

(3) Standard recommendations for limit values should include relevant attributes in order to enable an alternative specification,

(4) Verifications of structural serviceability may be done by calculation, testing or professional judgment.

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