Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 74 (1996)

Artikel: Basis of design: serviceability aspects

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DOI: https://doi.org/10.5169/seals-56053

Basis of Design
Serviceability Aspects

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Summary

A structure is expected to remain fit for the use during the intended working life and to sustain all actions and influences likely to occur with an appropriate reliability and in an economic way. The client focusses his attention on the requirements relating to serviceability. The serviceability aspects concern the funtionality and appearance of the structure as well as the comfort of user which are verified with criterias such as deformations, vibrations, stress or crack control. Considering the particular aspect of serviceability the criterias should be defined individually and recorded in the contract. Structural design codes may recommend indicative values.

1. Fundamental Requirements

Fundamental requirements have been identified and generally accepted which structures have to meet. According to these fundamental requirements a structure shall be designed and executed in such a way that it will remain fit for use for which it is required and sustain all actions and influences likely to occur during its intended working life with appropriate degrees of reliability and in an economic way (figure 1).

Several preventive measures in design and execution process are appropriate to meet the above requirements. Design procedures according to these two fundamental requirements implies that due regard is given to structural safety and serviceability, including durability, in both cases.

Adequate safety with respect to a hazard is ensured provided that the hazard is kept under control by appropriate measures or the risk is limited to an acceptable value. By the way, absolute safety is not achievable. Ultimate limit states are those associated with collapse, or with other forms of structural failure which may endanger the safety of people.

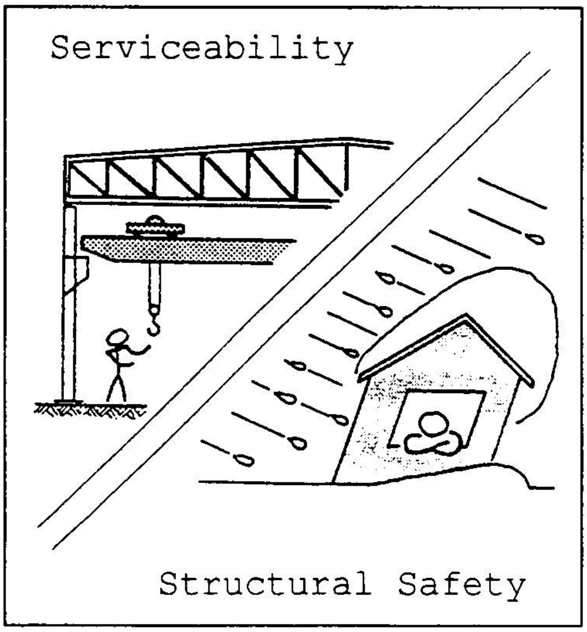

Fig. 1. Fundamental requirements: Serviceability and Structural Safety.

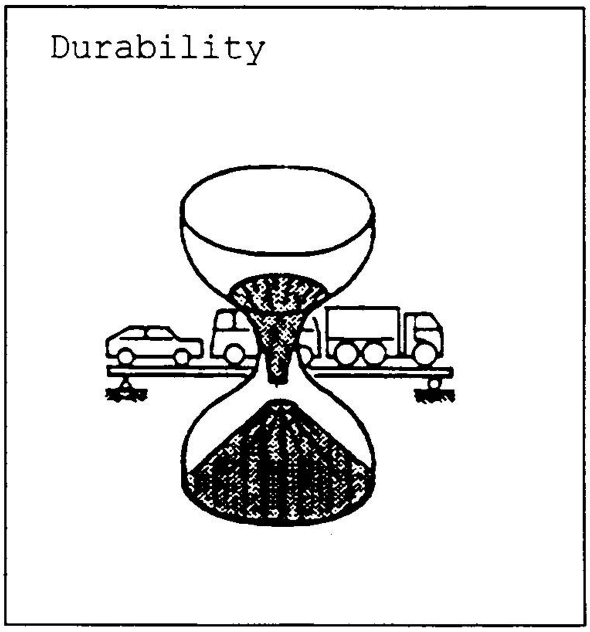

Fig. 3 Durability of Structures is related to its intended Working Life.

Serviceability for the intended use is obtained if the structure behaves within fixed limits. The requirements concerning serviceability aspects (figure 2) are related to:

- the funtion of the structure or parts of it with regard to, for example, watertightness, building physics, boundary conditions of non-loadbearing elements, building services or equipment,
- the comfort of user,
- the appearance of the structure, where, for example, the presence of water, cracking or deflection may be deemed unsatisfactory.

Service states which constitute a hazard for the structure, for example resonance or loss of resistance due to corrosion or fatigue, shall be included in the safety considerations.

Durability relates to the prevention of detoriation of material under the condition of planned inspections and adequate maintenance.The durability of a structure in its environment shall be such that it fullfills its funtion during the design working life (figure 3).

Construction is not an end in itself. A new project for a construction work starts always on the initial impulse of the client. It lies in his responsibility to give a clear vision and a definition of the project and to identify the purpose and the intended use of a structure. The service requirements may be influenced by economic considerations relating to the costs of construction, inspection, and maintenance. In consideration of the particular characteristics of the service requirements the serviceability aspects are clearly situated in the centre of interest of the client.

In consequence of these considerations the service requirements have to be determined in the contract as well as the design working life, during which the proper function of the structure is expected to be ensured. The service requirements are based on the consensus of the client with

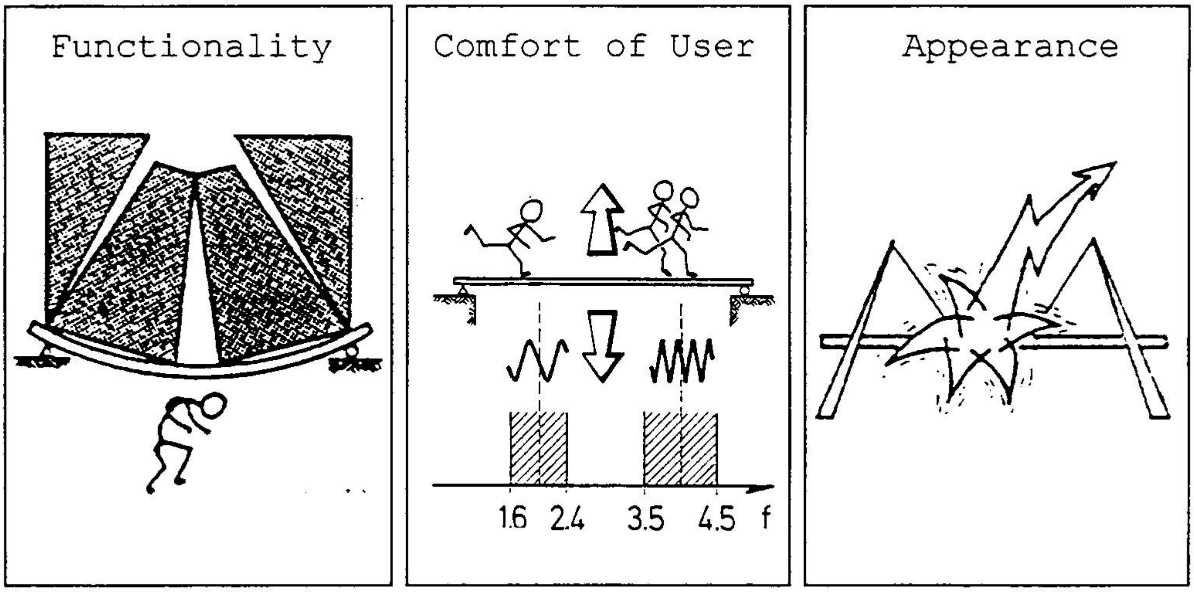

Fig. 2. Serviceability Aspects: Funtionality, Comfort of User, and Appearance.

the designer. The design codes of practice may only give indicative instructions and recommendations.

In contrast to the serviceability the structural safety is related to risk of life. The level of reliability in relation of structural safety concerns the public interest and is normally detremined by acceptance at national level.

2. Preventive Measures

The conditions of use are a matter of convention. The fundamental requirements related to the functionality, the comfort, or appearance are to be specified in advance. The required reliability relating to serviceability may be achieved by one or a suitable combination of different measures. The choice of suitable materials, the appropriate design and detailing are as important as the clearly specified conditions of use.

An example of a concrete structure shall clarify the choice of different measures to meet the requirements with regard to functionality. The clarification basins of a sewage plant with a length of approximately 100 m which are situated in a field where the ground water is used for the water supply of a town are expected to be watertight for understandable reasons. The following measures have been taken to fullfill the required good function of the structure:

- The conditions of use and in consequence the actions to be considered, e.g. the relevant level of ground water, have been verified and specified in the beginning of the design process.
- The basins are designed without any dilatation joint along the whole length. A special sliding layer beyond the foundation minimizes the ground friction.
- The concrete mix is designed with special respect to low shrinkage deformations of the structure.

- The reinforcement and prestressing are designed and detailed in such a way, that the crack pattern due to imposed deformations, for example due to temperature variation, does not reduce the function of the basins.
- The basins are executed in especially arranged stages in order to minimize the differential shrinkage between the different structural components.

The combination of all measures ensured the projected behaviour under the predicted conditions of use. In addition the durability of the structure was improved by means of the above measures.

The specifications of the technical requirements represent the first step of quality assurance. Clearly written and unambiguous specifications indicate the level of quality requirements to all participants involved in the design and execution process. In the second step procedures for design, production, execution which are under control and adjusted to the particular aspects of every project, guarantee that the requirements are successfully met.

Analysis of many damages observed in practice clearly demonstrate the fact ,that inadequate behaviour of structures under service conditions and a considerable number of damages to so called secondary structural elements are caused by insufficient transfer of informations and poor operational arrangements. These damages could have been avoided easily if the requirements and conditions would have been known to everybody. The continuity of the flow of information is asked. Hence, the measures related to organistaion and management are at least as important as the measures to be respected on the technical level, especially in consideration of the servicability limit states.

3. Design Concept

Apropriate design and detailing are two important of different possible measures to assure the fundamental requirements. The limit states design concept is generally appreciated and used in structural engineering practice. Limit states are states beyond which the structure no longer satisfies the design performance requirements. In the limit state design concept the design procedure follows a red line on a path with several steps. The various steps are indicated in table 1.

Both kinds of verification, the verification of ultimate limit states as well as the verification of serviceability limit states, are based on the same design concept and follows comparable design steps

4. Design Situations and Effects of Actions

In accordance with 'Basis of Design' the various design situations shall be considered and critical load cases identified. Seviceability aspects are mostly related to persistant design situations which refer by definition to the conditions of normal use. However, under certain circumstances serviceability requirements may also to be met under accidental situations. For example, it is highest interest that a hospital is not so heavily damaged under well defined seismic actions to get lost of its funtion as a part of a life line.

The serviceability requirements are related to conditions of use which may represent, in consideration of the nature of the specified requirement, a quasi-permanent, frequent, or rare situation. The relevant types of design situations and load cases have to be defined individually for each structure under consideration of the specified conditions of use.

The experiance shows, that most requirements concerning the funtionality of the structure such as with regard to boundary conditions of non-loadbearing elements, finishes, building services, equipment, or building phisics are related to quasi-permanent design situations and load cases.

	Structural safety:	Serviceability:
1.	*Identification of design situations*	
	Hazards	**Conditions of use**
	• persistant situations • transient situations • accidental situations • seismic situations	• persistant situations
2.	*Specification of requirements*	
	• Resistance • Stability • Rotation Capacity	**• Function of structure • Comfort of user • Appearance of structure**
3.	*Choice of measures*	
	• Definition of the structural concept • Choice of suitable materials • Appropriate design and detailing • Professionel execution in accordance with project • Specified quality management	
4.	*Specification of performance criterias*	
	• Strength • Strain Rates, etc.	**• Deformations, • Vibrations • Stress Limitations, etc.**
5.	*Identification of design situations, load cases and load arrangements*	
	Ultimate Limit States	**Serciceability Limit States**
6.	*Determination action effects*	
	E_d	$E_{d,ser}$
7.	*Verifications of performance criterias under a given action effect*	
	$S_d (E_d) \leq R_d$	$C_d (E_{d,ser}) \leq C_{lim}$

Tab. 1. Steps in Limit States Design Procedure

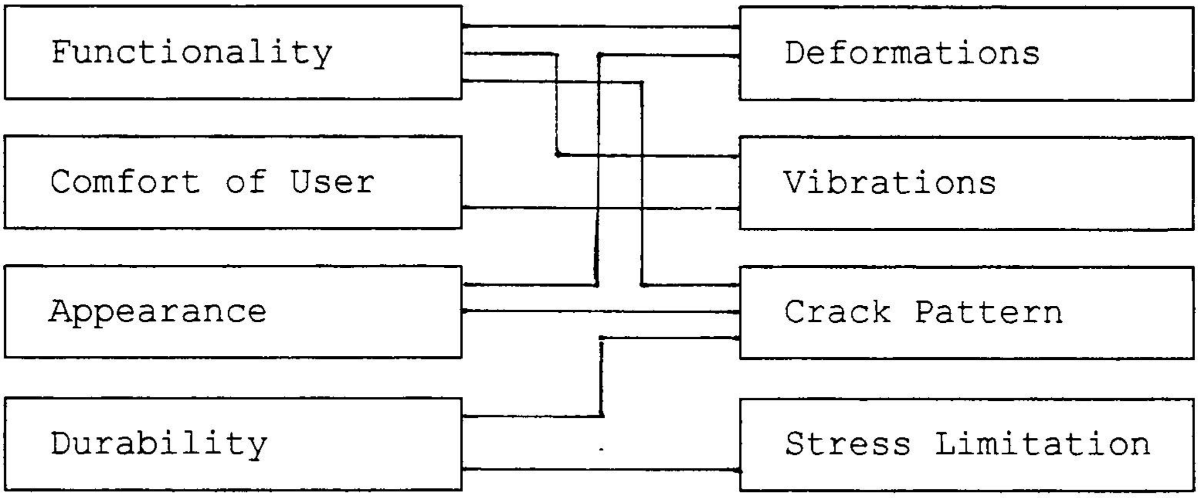

Fig. 4. Relation of Structural Requirements and Performance Criterias.

Again the serviceability requirements with respect to the appearance of the structure are usually to be considered under quasi-permanent design situations and load cases.

The comfort of user, however, is mainly touched under frequent actions during normal use.

A local damage to the structure itself or to a non loadbearing element may reduce the durability or influence the appearance in a unsatisfactory manner. In such a case the distinction between reversible and irreversible serviceability limit states has to be made. Irreversible serviceability limit states might be linked to rare load cases.

In each critical load case identified for the verification of a specific serviceability limit state only compatible load arrangements, sets of deformations, and imperfections which may occur simultaneously have to be considered. In addition only those portions of actions have to be taken into account which are relevant for the verification under consideration. However long-term structural behaviour effects have to be taken into account, such as creep, relaxation, and shrinkage effects.

5. Performance Criterias

Usually, the fundamental requirements, such as funtionality of the structure, comfort of user or appearance, can not be verified directly. Rather, performance criterias are identified as representative for the structural behaviour by means of which the requirements are controlled. Serviceability limit states which may require consideration include:

- Deformations and displacements,
- Vibrations,
- Crack pattern,.
- Stress limitations.

Whereas the deformations, displacements, and vibrations may be determined in the design process, the crack pattern is measured in crack width and crack spacing. To avoid damage including permanent or accumulative deformations, which may influence the effective function of the structure adversely, the maximum stresses or stress ranges are limited.

The performance criterias have to be well assigned to the various requirements (figure 4). Deformations and displacements may affect the appearance of the structure as well as the effective function including the functioning of equipment and services and including damage to non-loadbearing elements or finishes.

In special cases excessive deformations may increase the loads acting on a structure. For example, if water is retained on a roof due to its deformations, the load effect of water increases. Such bumping effects have to be considered under the aspect of structural safety.

Vibrations may cause discomfort of the user or may cause damage to the structure or the materials which it supports. Excessive dynamic effects in structures succeptible to vibrations have to be related to ultimate limit states.

Large crack widths and an unsatisfactory crack pattern may disturb the appearance of the the structure and, hence, irritate the user. In addition the effective funtion are no longer ensured with unacceptable crack width.

6. Verifications

The distinction of the various fundamental reqirements with respect to serviceability limit states asks for a comprehensive analysis of the relevant design situations including the identification of the load cases in due relation to and consistant with the specified requirements such as funtionality, comfort of user, and appearance.

The serviceability is verified in comparing the calculated actual performance criterias under consideration with limiting values (table 1). As an example, when considering a limit state of serviceability the requirement of which is controlled by deformations it shall be verified that:

$$w_{d}(E_{d,ser}) \leq w_{lim}$$

where:

$w_{d}(E_{d,ser})$ is the deflection due to the design value of the action effects under the considered conditions of use and the relevant load cases.

w_{lim} is the limiting value of the deflection for the specified requirement.

All the different parts of the deflection are to be taken into account if necessary in accordance with the specified requirement. A deflection may be expressed as the sum of the following parts (figure 5):

$$w = w_1 + w_2 + w_3 + w_4$$

where:

w_1 is the camber,e.g. the form of structural steelwork as fabricated or the camber of concrete structures obtained by falsework and formwork

w_2 is the deflection under the permanent actions including the long-term deflection.

w_3 is the deflection due to the quasi-permanent value of a variable action including the corresponding long-term deflection.

w_4 is the deflection due to the short-term (frequent or characteristic) value of one variable action.

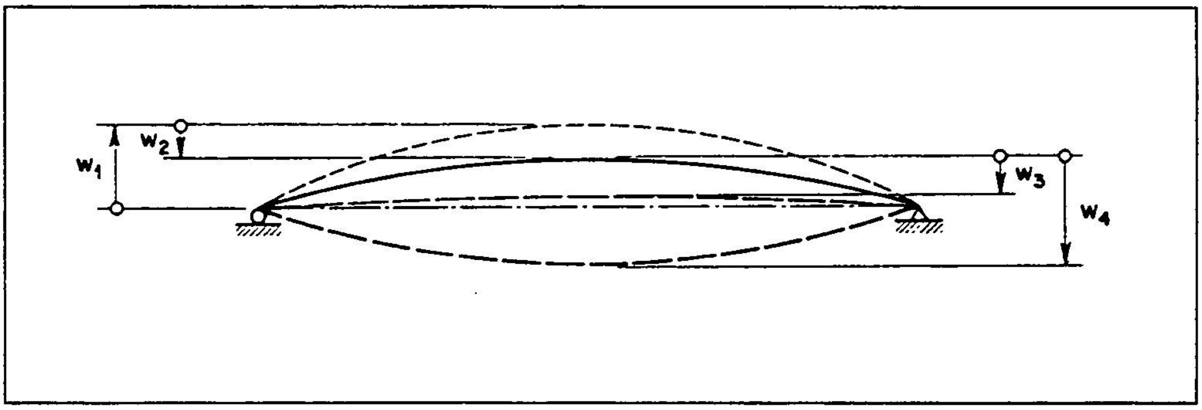

Fig. 5. The different parts of the deflection of a beam.

The verification of the other performance criterias such as vibrations or stresses are applied by analogy.

Regarding the strict correspondance between the conditions of use on one side and the requirements on the other side the action effects, the load cases, and the limiting values of the performance criterias are to be obtained in an similar consistancy. For example, the limitation of the deflection of a floor slab may end up on a different level, if the requirement takes into consideration the function of finishes with brittle behaviour or if the requirement concerns the comfort of user.

Since the requirements and conditions of use are determined in agreement between the client and the designer, the analysis of the design situations and load cases as well as the determination of the limits of the relevant performance criterias have to be considered individually in each design process. The structural design codes can only give indicative values and recommandations of general interest, unless otherwise specified.