Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 69 (1993)

Artikel: Serviceability and tolerances

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DOI: https://doi.org/10.5169/seals-52542

Serviceability and Tolerances

Aptitude au service et tolérances

Gebrauchstauglichkeit und Toleranzen

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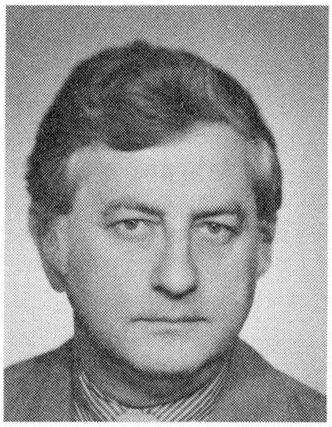

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SUMMARY

Two independent sources of dimensional changes should be taken into account when analyzing structural serviceability: deformations due to various actions including loads as well as deviations due to production procedures. General principles for simultaneous consideration of both kinds of dimensional changes are simplified for most frequently applied serviceability requirements.

RESUME

Deux sources de déviations dimensionnelles doivent être considérées dans l'analyse de l'aptitude au service des constructions: déformations dues aux actions sur les structures et déviations causées par des processus de construction. Les principes généraux de calcul tenant compte des deux types de déviations dimensionnelles sont simplifiés pour les cas les plus fréquents du calcul de l'aptitude au service.

ZUSAMMENFASSUNG

Bei der Untersuchung der Gebrauchstauglichkeit von Bauwerken sollten zwei Ursachen für geometrische Abweichungen unterschieden werden, nämlich Verformungen unter verschiedenen Einwirkungen und Herstellungstoleranzen. Für die häufigsten Gebrauchstauglichkeitsanforderungen werden allgemeine Prinzipien der gekoppelten Betrachtung beider Einflüsse sowie ein vereinfachtes Verfahren vorgestellt.

1. INTRODUCTION

Serviceability of building structures is a broad concept, which is affected by all kinds of possible dimensional changes of structural components and elements from their nominal or target configurations. Generally, there are two different sources of dimensional changes:

- structural deformations due to actions, including physical and chemical causes and all kinds of loads - called shortly deformations,
- induced deviations due to production procedures including setting out, manufacturing and erection - called shortly deviations.

Deformations can be affected by some deviations (for example by cross section height and supporting conditions). As a rule, however, this dependence is insignificant and consequently deformations and deviations may be considered as mutually independent sources of dimensional changes.

Compliance with serviceability requirements is generally dependent on both kinds of dimensional changes, on deformations as well as on deviations. Consequently, both kinds of dimensional changes should be considered simultaneously to verify appropriate design criteria whenever mutual interaction of deformations and deviations occurs. The following explanatory examples of serviceability requirements represent typical cases, where such an interaction may arise:

- visual requirements on sag of horizontal components,
- operational requirements on flatness of floors,
- tightness of bed and ceiling joints of partition walls,
- watertightness of cladding joints.

This short list may help to identify other important cases of structural serviceability, where combination of deformations and deviations play a significance role, but obviously is far from being exhaustive.

Current methods of serviceability analyses of building structures neglect entirely the effect of deviations and, therefore, need to be improved. The aim of this contribution is to state relevant fundamental principles and to propose simplified rules for simultaneous consideration of both sources of dimensional changes. It is perhaps the first attempt to include effect of deviations in serviceability analyses and, consequently, developed methods may need further improvement.

2. BASIC CONCEPTS

To verify specified requirements, appropriate serviceability parameters (for example displacement of the midspan point of a horizontal component, width of a joint) are to be identify first. In most cases only one parameter $z(t)$, t being time, could be considered independently of the other serviceability parameters. The basic value of the parameter $z(t)$ is the reference or nominal value z_R, which is specified in the design and to which all kinds of dimensional changes are to be related. It is the time independent value determined for modular and structural requirements without taking into account all kinds of deformations and deviations. In some cases the reference value is zero (sag of horizontal components), in other cases is equal to a certain non zero intended (design) size (width of joints).

As demonstrated above, the actual structural value of the serviceability parameter $z(t)$ may be affected by two separate sources of dimensional changes, deformations and deviations. While displacement of a given point due to structural deformations could be described by time dependent random function $x(t)$, deviations are represented by time independent variable y. Both these quantities are assumed to have normal distribution. The resulting serviceability parameter $z(t)$, is then described by normal random function, which is the sum

$$z(t) = z_R + x(t) + y\ , \tag{1}$$

Generally two limiting values, lower and upper limits l_L and l_U are specified for the parameter $z(t)$ to guarantee compliance with serviceability requirements. Thus, the following serviceability condition is to be satisfied

$$l_L \leq z(t) \leq l_U\ . \tag{2}$$

For the sake of simplicity both limit values l_L and l_U are assumed to be deterministic values, even though, as follows from other contributions at this Colloquium, that there is considerable vagueness in their definition.

As follows from Equation (1), the serviceability parameter $z(t)$ is a random quantity which may be handled by methods of classical theory of probability. Consequently, in order to verify the above condition (2), two probabilities p_L and p_U, which are permitted for overstepping the lower and upper limit l_L and l_U respectively, are to be specified. Equal probabilities for both limits, $p_L = p_U = p$, of the order of 10^{-2} to 10^{-1} are usually proposed for serviceability limit states.

3. DEFORMATIONS AND DEVIATIONS

Deformations are always caused by various time dependent actions, which lead to random structural responses. Using appropriate mechanical models of structural analyses, random function $x(t)$, representing a deformation, could be described by the mean function $\mu_x(t)$ and standard deviation $\sigma_x(t)$. For the purpose of serviceability analyses, the standard deviation may be often approximated by time independent value σ_x. However, actual distribution of structural deformations may have considerable asymmetry (mostly with positive skewness). Then normal distribution is only an approximation and other more suitable probabilistic models (lognormal distribution) are to be applied.

In accordance with principles of accuracy analyses [1], statistical characteristics of deviations are specified by the mean μ_y (systematic deviation from the reference value) and limit deviation δy, which is equal to one half of the tolerance width Δy. The standard deviation σ_y is related to the limit deviation δy or to the tolerance simply as

$$\sigma_y = \frac{\delta y}{k} = \frac{\Delta y}{2k}\ , \tag{3}$$

where the coefficient k depends on the probability p accepted for overstepping the limit deviations; for $p = 0.05$, $k = 1.65$. This concept of tolerance specification is illustrated in Fig.1.

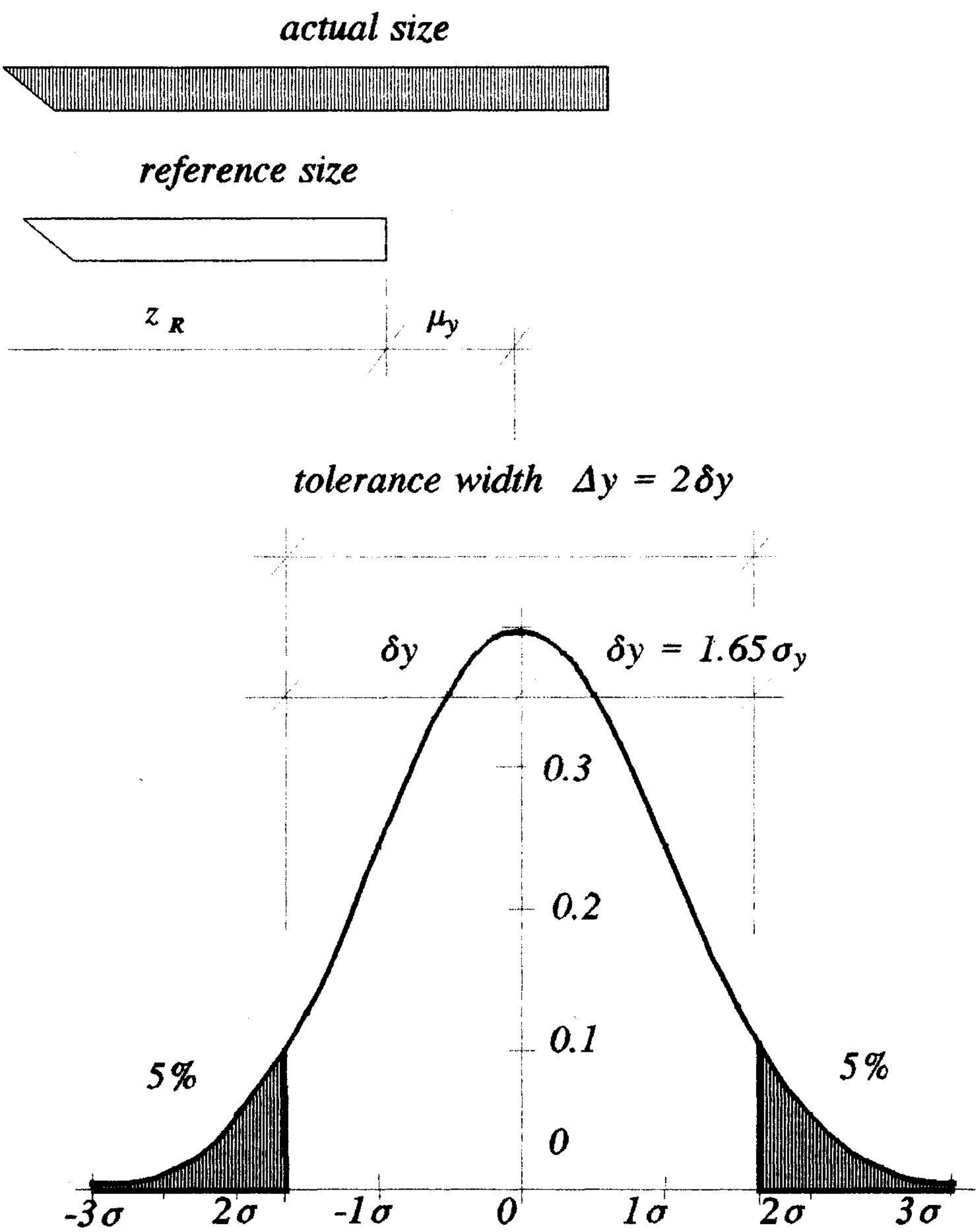

Figure 1 Characteristics of deviations y.

4. SERVICEABILITY CONDITIONS

Statistical characteristics of the serviceability parameter $z(t)$ follow from Equation (1)

$$\mu_z(t) = z_R + \mu_x(t) + \mu_y , \qquad \sigma_z^2(t) = \sigma_x^2(t) + \sigma_y^2 \approx \sigma_z^2 . \tag{4}$$

As indicated by the second relationship of Equation (4), the standard deviation $\sigma_z(t)$ may be usually approximated by time independent value σ_z. General form of the serviceability condition (2) can be then rewritten in terms of the statistical characteristics of the parameter $z(t)$ as

$$z_R + \mu_z(t) - k_L \sigma_z \geq l_L , \qquad z_R + \mu_z(t) + k_U \sigma_z \leq l_U . \tag{5}$$

where the coefficients k_L and k_U are dependent on the probabilities p_L and p_U; if $p_L = p_U = p = 0.05$, then $k_L = k_U = k = 1.65$.

It follows from Equation (4), that the serviceability conditions given by Equation (5) may be expressed in terms of statistical characteristics of deformations and deviations as

$$\mu_x(t) + \mu_y - k_L \sqrt{\sigma_x^2(t) + \sigma_y^2} \geq l_L - z_R , \qquad \mu_x(t) + \mu_y + k_U \sqrt{\sigma_x^2(t) + \sigma_y^2} \leq l_U - z_R . \tag{6}$$

The above inequalities represent general form of serviceability conditions for one parameter, when both deformations and deviations are taken into account.

In many practical cases, however, the mean μ_y of deviations y (systematic deviation) is zero. Further, using the second row of Equation (4), the standard deviation $\sigma_z(t)$, may be often approximated by a time independent quantity σ_z. Then the mean deformation $\mu_x(t)$ should satisfy the following simplified conditions, which are derived from the previous Equation (6)

$$\mu_x(t) \geq l_L - z_R + k_L \sigma_z , \qquad \mu_x(t) \leq l_U - z_R - k_U \sigma_z . \tag{7}$$

Note, that if both limits l_L and l_U are specified (for example when width of joints is verified), then the maximum standard deviation σ_z (the optimum case), which could be permitted, can be used if the reference value z_R is related to the mean deformation $\mu_x(t)$ as follows

$$z_R = \frac{l_L + l_U}{2} - \mu_x(t) , \tag{8}$$

This relationship is effectively applied in accuracy analyses of assembled structures [1], which are closely linked, if not directly belong, to serviceability limit states (for example case of tightness requirements imposed on internal and external joints). Practical examples, including detail numerical calculations may be found in the book [1], or in other references indicated in [1].

When structural serviceability is analyzed, usually the upper limit $l_U = l$ is considered only. If the reference value z_R is zero (for example in case sag of horizontal components), then the mean deformation should satisfy the following condition

$$\mu_x(t) \leq l_U - k_U \sigma_z . \tag{9}$$

which follows from Equation (7). The above Equation (9), might be the most frequently applied criterium for verification of serviceability limit states when effects of deviations are considered.

5. EXAMPLE

The functional requirement on flatness of a floor is specified in as of the permissible deviation z from a straight edge, say $z = 4\ m$ per $2\ m$. Expected accuracy of a specified production technique is $\delta y = 3\ m$ per $2\ m$. In view of Equation (3), its standard deviation is

$$\sigma_y = \frac{3}{1.65} = 1.82\ mm . \tag{10}$$

If the span of the bearing horizontal component is $L = 3.6\ m$, then its midspan deflection could be $L/250 = 14.4\ m$ with the standard deviation $2.9\ m$ (assuming coefficient of variation about 20%). The maximum deflection of the span $2\ m$ is about $(2/3.6)^4 \times 12 \approx 1.5\ m$ with the standard deviation $\approx 0.3\ m$. The resulting standard deviation of the parameter z, follows then from Equation (4) as

$$\sigma_z = \sqrt{1.82^2 + 0.3^2} = 1.84\ mm . \tag{11}$$

and the maximum permissible mean deflection of a span of $2\ m$ follows from Equation (9) as

$$\mu_x = 4 - 1.65 \times 1.84 = 0.96\ mm . \tag{12}$$

Thus the deflection of the span $3.6\ m$ should not exceed $(3.6/2)^4 \times 0.96 = 10.1\ m$, which is about $L/360$.

Mutual interaction of deformations and deviations is obviously dependent on considered serviceability requirement and assumed input data. Nevertheless, the above example clearly indicates, that proposed principles and simplified rules could be virtually applied, and may be, therefore, considered for possible improvement of existing methods commonly applied for serviceability analyses.

6. CONCLUSIONS

(1) In some serviceability limit states both deformations, due to various actions, and deviations, induced by production procedures, must be considered simultaneously.
(2) Existing methods of serviceability analyses neglect entirely the effect of deviations and need to be improved.
(3) Proposed principles and simplified rules provide efficient procedures to include effect of deviations and should be considered when revising present methods of serviceability analyses.

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