International Standard ISO 3443/4

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Tolerances for building — Part 4 : Method for predicting deviations of assemblies and for allocation of tolerances

Tolérances pour le bâtiment — Partie 4 : Méthode pour la prévision des écarts d'assemblage et pour la disposition des tolérances

First edition — 1986-12-15

UDC 69.02 : 621.753.1 **Ref. No. ISO 3443/4-1986 (E)**

Descriptors : buildings, components, assembling, dimensional coordination, dimensional deviations, dimensional tolerances.

Price based on 11 pages

ISO 3443/4-1986 (E)

Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 3443/4 was prepared by Technical Committee ISO/TC 59, *Building construction.*

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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Tolerances for building — Part 4 : Method for predicting deviations of assemblies and for allocation of tolerances

0 Introduction

This part of ISO 3443 forms one of a series concerning tolerances for building and building components.

It should be read in conjunction with ISO 3443/1, ISO 3443/2, ISO 1803/1 and ISO 1803/2.

Parts 3 and 4 of ISO 3443 have been produced to meet the need for internationally agreed methods of relating accuracy, tolerances and fit in the determination of sizes for components and construction (and, in ISO 3443/4, joints). Two distinct needs are identified, though both share common ground.

There is thus a need to provide generally applicable expressions relating accuracy, tolerances and fit, that can be drawn upon, either :

a) to identify optimum target sizes for standard components, where each type of component has a variety of applications, or

b) to identify appropriate limits of size for components, whether standard or not, for application in a specific building.

Both needs can be met by expression of substantially the same relationships between the factors affecting fit, and in principle either standard might be pressed into service to meet either aim. In practice, however, each is structured to serve its particular purpose.

Joints in more than one dimension are however only considered in this part of ISO 3443.

Part 3 of ISO 3443 is structured to meet the aims in a) above. It provides procedures for selecting target sizes (formerly "work sizes") for components, or *in situ* works, such that joint clearances will be within their required limits with a known probability of success.[1] The procedures deal with the relationship between the following factors:

1) accuracy of components and *in situ* work;

2) sizes of components and *in situ* work;

3) joint clearances;

4) probability of fit;

and they can be used whether 2), 3) or 4) above is the unknown to be calculated. The procedures assume that values for 1) above have been established by measurement surveys and relate target sizes to co-ordinating sizes using the concepts of "extension" and "deduction"; see 4.4 and 4.5.

The procedures also enable a target size to be calculated for any standard component, such that the component will have an optimal probability of fit in all its applications.

Worked examples are given in annex B.

ISO 3443/4 is structured to meet the needs in b) above. It is therefore concerned primarily with the design of buildings in which components (including standard components) are used, and is aimed primarily at building designers who, as engineers, can be expected to be mathematically and statistically competent. It is to meet these aims that this part of ISO 3443 deals with

— methods for predicting deviations and specifying tolerances to obtain a particular desired total accuracy in an assembly,

— the effect of specified tolerances on expected size variability,

— the basis for optimization of tolerances for each particular assembly and its elements.

ISO 3443/4 presupposes calculations only for assemblies with elements of one dimension, such as beams and columns, for the sake of simplicity. However, tables for common cases with elements of two and three dimensions (panels, etc.) are given in the annex.

1 Scope

This part of ISO 3443 indicates some general principles and one method for predicting deviations in composite systems and specifying tolerances for the constituent elements in order to meet functional requirements and tolerance specifications for the assembly.

2 Field of application

This part of ISO 3443 applies to tolerances and deviations in all kind of assemblies and other systems composed of elements, within the building industry.

1) ISO 3443/3 deals with accuracy in terms of target size and limits of size (e.g. upper and lower limits of component size). Alternatively, accuracy can be defined in terms of permitted deviations in relation to a reference size — usually identical with the target size. See ISO 1803/1.

3 References

ISO 1791, *Modular co-ordination — Vocabulary*.

ISO 1803/1, *Building construction — Tolerances — Vocabulary — Part 1: General terms.*

ISO 1803/2, *Building construction — Tolerances — Vocabulary — Part 2: Derived terms.*[1)]

ISO 3443/1, *Tolerances for building — Part 1: Basic principles for evaluation and specification.*

ISO 3443/2, *Tolerances for building — Part 2: Statistical basis for predicting fit between components having a normal distribution of sizes.*

ISO 3443/3, *Tolerances for building — Part 3 : Procedures for selecting target size and predicting fit.*[1)]

ISO 3443/7, *Tolerances for building — Part 7 : General principles for approval criteria, control of conformity with dimensional tolerance specifications and statistical control — Method 2.*[1)]

ISO 4464, *Tolerances for building — Relationship between the different types of deviations and tolerances used for specification.*

4 Definitions

For the purpose of this part of ISO 3443, the definitions given in ISO 1791 and ISO 1803/1 apply with the following additions.

4.1 reference size : Size specified in the design, to which deviations and tolerances are related.

NOTES

1 For the purposes of the calculations in this part of ISO 3443, the upper and lower permitted deviations are assumed to be equal. Where this is not so, the mean of the upper and lower limits of size should be taken as the reference size.

2 The term "target size", as defined in ISO 1803/1, is a special case of reference size which normally coincides with the concept of reference sizes as used in this International Standard.

4.2 constituent element in an assembly : Any component, joint, space or set-out distance, etc., which contributes to the observed dimension of the assembly.

NOTE — "Constituent element" is sometimes shortened to "element" in the text.

5 Propagation of deviations in an assembly or other composite system

The reference size B for a given element in an assembly is expressed generally in relation to the other elements in the assembly :

$$B = K_1 B_1 + K_2 B_2 + \ldots + K_i B_i + \ldots + K_n B_n = \sum_{i=1}^{n} K_i B_i \qquad \ldots (1)$$

where

B_i is the reference size of element number i;

K_i is a coefficient determined from the geometry of the assembly and the method of erection.

As seen in the examples below, the normal values for K_i are $+1$, -1, $+\frac{1}{2}$ and $-\frac{1}{2}$.

The actual deviation V from the reference size is then given by :

$$V = \sum_{i=1}^{n} K_i V_i \qquad \ldots (2)$$

where

K_i is the same coefficient from equation (1);

V_i is the actual deviation from the reference size B_i.

Example 1 :

Figure 1 shows an assembly of components erected from the set-out line L with given joint widths to a previously erected component C.

$$B = -B_1 - B_2 - B_3 - B_4 - B_5 - B_6 + B_7$$

$$V = -V_1 - V_2 - V_3 - V_4 - V_5 - V_6 + V_7$$

Example 2 :

If the last component is positioned with the intention of being symmetrical in the remaining space, we have the situation in figure 2.

Now element number 5 represents the departure from symmetry and therefore

$B_5 = 0$, but $V_5 \neq 0$.

$$B = -B_1 - B_2 - B_3 - B_4 - B_5 - B - B_6 + B_7$$

or

$$B = -\frac{1}{2}B_1 - \frac{1}{2}B_2 - \frac{1}{2}B_3 - \frac{1}{2}B_4 - \frac{1}{2}0 - \frac{1}{2}B_6 + \frac{1}{2}B_7$$

$$V = -\frac{1}{2}V_1 - \frac{1}{2}V_2 - \frac{1}{2}V_3 - \frac{1}{2}V_4 - \frac{1}{2}V_5 - \frac{1}{2}V_6 + \frac{1}{2}V_7$$

When the actual deviations are not known, either because they are not measured or because the components have not yet been produced, the deviations are treated as probability distributions.

If V_i is distributed with the expected (mean) value μ_i and the standard deviation σ_i, the respective parameters of the distribution of V are given by :

$$\mu = \sum_{i=1}^{n} K_i \mu_i \qquad \ldots (3)$$

1) At present at the stage of draft.

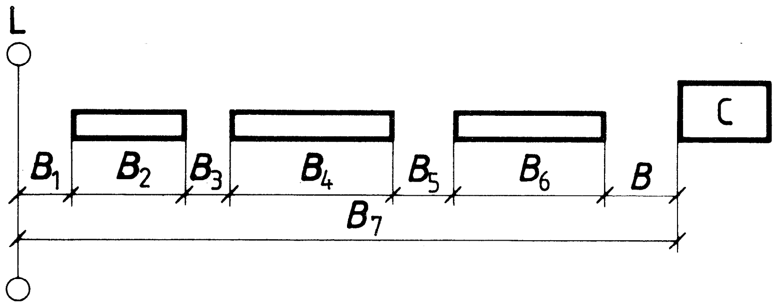

Figure 1 — Illustration of example 1

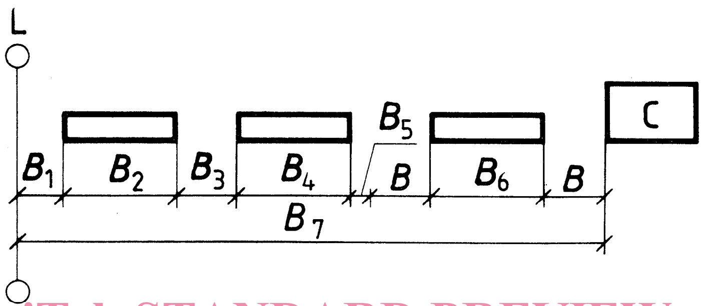

Figure 2 — Illustration of example 2

and

$$\sigma^2 = \sum_{i=1}^{n} (K_i \sigma_i)^2 \qquad \ldots (4)$$

when all deviations are independent (mutually uncorrelated), or :

$$\sigma^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} (K_i \sigma_i) \varrho_{ij} (K_j \sigma_j) \qquad \ldots (4a)$$

when some or all deviations are mutually correlated.

In equation (4a), ϱ_{ij} is the coefficient between the deviations of elements number i and j.

The correlation coefficient will within the field of application of this part of ISO 3443 normally be a number between 0 and 1.

When $\varrho_{ij} \approx 0$, the deviations of elements number i and j are almost independent while $\varrho_{ij} \approx 1$ means that these deviations will always be nearly equal or proportional. Mutual correlation is typical for, for instance, concrete components produced in the same mould, while those produced in different moulds will normally have very little correlation.

Where $i = j$, ϱ_{ij} is always 1.

NOTE — Negative correlation may also occur, for instance when the erection crew increases the joint widths slightly to compensate for undersized components.

When negative joints are not possible, equations (3) and (4) are not strictly correct. This situation is, however, not considered further in this part of ISO 3443.

Equations (1) to (4a) are only strictly correct for assemblies with components in one dimension (for instance beams and columns) where form and angular deviations of the adjacent faces can be regarded as insignificant for the variability of the assembly. Formulae for components in two and three dimensions (for instance wall and floor components) are given in the annex.

Example 3 :

The parameters from example 1 are :

$$\mu = -\mu_1 - \mu_2 - \mu_3 - \mu_4 - \mu_5 - \mu_6 + \mu_7$$

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_4^2 + \sigma_5^2 + \sigma_6^2 + \sigma_7^2$$

The corresponding parameters from example 2 are :

$$\mu = -\frac{1}{2}\mu_1 - \frac{1}{2}\mu_2 - \frac{1}{2}\mu_3 - \frac{1}{2}\mu_4 - \frac{1}{2}\mu_6 + \frac{1}{2}\mu_7$$

$$\sigma^2 = \frac{1}{4}\sigma_1^2 + \frac{1}{4}\sigma_2^2 + \frac{1}{4}\sigma_3^2 + \frac{1}{4}\sigma_4^2 + \frac{1}{4}\sigma_5^2 + \frac{1}{4}\sigma_6^2 + \frac{1}{4}\sigma_7^2$$

Example 4 :

If the deviations of the width of the components are all equally distributed with the same parameters μ_c and σ_c and the deviations of the intended joint width during erection are all distributed with the same parameters μ_j and σ_j, we have from example 1 :

$$\mu_1 = \mu_3 = \mu_5 = \mu_j$$

$$\mu_2 = \mu_4 = \mu_6 = \mu_c$$

$$\sigma_1 = \sigma_3 = \sigma_5 = \sigma_j$$

$$\sigma_2 = \sigma_4 = \sigma_6 = \sigma_c$$

$$\mu = -3\mu_j - 3\mu_c + \mu_7$$

$$\sigma^2 = 3\sigma_j^2 + 3\sigma_c^2 + \sigma_7^2 \qquad \ldots (5)$$

and from example 2 :

$$\mu_1 = \mu_3 = \mu_j$$

$$\mu_2 = \mu_4 = \mu_6 = \mu_c$$

$$\sigma_1 = \sigma_3 = \sigma_j$$

$$\sigma_2 = \sigma_4 = \sigma_6 = \sigma_c$$

$$\mu = -\mu_j - \frac{3}{2}\mu_c + \frac{1}{2}\mu_7$$

$$\sigma^2 = \frac{1}{2}\sigma_j^2 + \frac{3}{4}\sigma_c^2 + \frac{1}{4}\sigma_5^2 + \frac{1}{4}\sigma_7^2 \qquad \ldots (6)$$

The calculations above are under the assumption of no mutual correlation.

Example 5 :

If components number 2 and 6 come from the same mould, we might assume a correlation coefficient equal to 1 between these two elements. In the expressions above for the standard deviation, two more terms will be included according to equation (4a), one for $i = 2$ and $j = 6$ and another for $i = 6$ and $j = 2$.

Equation (5) is now

$$\sigma^2 = 3\sigma_j^2 + 3\sigma_c^2 + \sigma_7^2 + \sigma_c^2 + \sigma_c^2 = 3\sigma_j^2 + 5\sigma_c^2 + \sigma_7^2$$

and equation (6)

$$\sigma^2 = \frac{1}{2}\sigma_j^2 + \frac{3}{4}\sigma_c^2 + \frac{1}{4}\sigma_5^2 + \frac{1}{4}\sigma_7^2 + \frac{1}{4}\sigma_c^2 + \frac{1}{4}\sigma_c^2$$

$$= \frac{1}{2}\sigma_j^2 + \frac{5}{4}\sigma_c^2 + \frac{1}{4}\sigma_5^2 + \frac{1}{4}\sigma_7^2$$

6 Prediction of future deviations at the time of design

6.1 Expected value estimated to zero

At the time of design μ_i is supposed to be equal to zero, as there generally is no reason to believe that the said operation or production will have such a stable offset from the reference size that this could be predicted and taken into account many months ahead of the actual occurrence.

Otherwise, if such prediction is possible, the reference size is adjusted accordingly to obtain $\mu_i = 0$. This can be done either by specifying the dimension $B_i - \mu_i$ to the producer or by substituting the value for reference size in equations by the value $B_i + \mu_i$.

As a consequence equation (3) is nullified.

6.2 Estimating the standard deviation of the elements

The standard deviations of the elements can be estimated from previous measurements of the same kind of elements if all the conditions are reasonably invariant.

By specification of tolerances for the deviations and introducing an acceptance/rejection procedure for the elements, reliable information on the future deviations can be obtained from the fact that it is not expedient for any manufacturer or operator to have an appreciable probability of rejection of his work.

The supplier will therefore intend to keep the percentage of defective elements (units) in the production below the value A which the inspection procedure permits (see also ISO 3443/7). So a reasonable estimate of σ_i which tends to be on the safe (higher) side can be determined under the assumption of normal distribution such that A per cent of the elements will have deviations outside the specified tolerance. This is expressed mathematically :

$$\frac{A}{100} = 2 - 2F\left(\frac{T_i}{2\sigma_i}\right) \qquad \ldots (7)$$

where

F is the cumulative normal distribution function;

T_i is the tolerance specified for element i.

It is seen that for a given A the ratio $\frac{T_i}{2\sigma_i}$ is constant, such that

$$T_i = 2t_i\sigma_i \qquad \ldots (8)$$

Table 1 — Values of t as a function of A

A %	t
0,26	3
1,24	2,5
4	2,05
6,5	1,85
10	1,65

6.3 Estimating the correlation coefficients

Elements which have different origins, e.g. components made by different manufacturers, or operations performed by different operators are always non-correlated (see however the note to clause 5). The correlation coefficient is accordingly zero. Elements which derive from the same mould or from another process with very little random variation compared to the tolerance for the elements have very high mutual correlation. The correlation coefficient might therefore, if no further information is available, be estimated to be 1.

For elements which may be expected to be partly correlated, the correlation coefficient must be estimated from previous measurements or the calculations may be carried out twice, with an upper and a lower guess of the correlation coefficients, to find a reasonable interval of variation for the result.

6.4 Estimating the parameters of the variability of an assembly

The expected value μ is zero according to 6.1 and equation (3).

The standard deviation to be expected is calculated by equations (4) and (4a) from the estimated standard deviations and correlation coefficients of the constituent elements.

If all elements in the assembly are inspected with such sampling plans that permit the same percentage of defective elements, A, the standard deviation of the assembly is estimated as

$$\sigma^2 = \left(\frac{1}{2t}\right)^2 \sum_{i=1}^{n} (K_i T_i)^2 \qquad \text{(uncorrelated case)} \quad \ldots (9)$$

$$\sigma^2 = \left(\frac{1}{2t}\right)^2 \sum_{i=1}^{n} \sum_{j=1}^{n} (K_i T_i)\, \varrho_{ij}\, (K_j T_j) \qquad \text{(correlated case)} \quad \ldots (9a)$$

where t is the common value for t_i.

The deviation of the assembly will in general with a probability of less than A %, A % common for the inspection procedures for the elements, surpass a symmetrical tolerance T given by

$$T^2 = \sum_{i=1}^{n} (K_i T_i)^2 \qquad \text{(uncorrelated case)} \quad \ldots (10)$$

$$T^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} (K_i T_i)\, \varrho_{ij}\, (K_j T_j) \qquad \text{(correlated case)} \quad \ldots (10a)$$

Equation (10) is the basis for the formulae in the annex.

Equation (8) is also valid for the assembly : $T = 2t\sigma$.

If the A-value, or the acceptable probability of exceeding the tolerance limits, is chosen as different for the assembly than that common for the elements, the tolerance T_A for the assembly shall be adjusted as follows :

$$T_A = \frac{t_A}{t} T \quad \ldots (11)$$

where

t_A and t are the proportional constants valid for the assembly and the elements respectively, as shown in equations (8) and (9);

T is the tolerance derived from equations (10) or (10a).

6.5 Components with more than one dimension

Components with more than one dimension are components where the deviations in form and orientation of adjacent faces are significant for the variability of the assembly.

Assemblies with such components are treated in fundamentally the same way as for one dimension, but the calculations are more complicated. This part of ISO 3443 does not provide calculations for more than one dimension, but the user will for many common cases in practical work find the necessary information and formulae in the annex.

The general conditions for the formulae are :

a) no mutual correlation;

b) all $\mu_i = 0$;

c) common probability of exceeding the tolerances for the components and the assembly.

If the deviations are expressed in terms according to ISO 4464, the standard deviation σ_i of the distributed building deviation of components i can in general be expressed as :

$$\sigma_i^2 = a_{im}\sigma_{im}^2 + a_{is}\sigma_{is}^2 + a_{ie}\sigma_{ie}^2 \quad \ldots (12a)$$

where

$$\sigma_{im}^2 = a_{imd}\sigma_{imd}^2 + a_{imo}\sigma_{imo}^2 + a_{imf}\sigma_{imf}^2 \quad \ldots (12b)$$

$$\sigma_{is}^2 = a_{isd}\sigma_{isd}^2 + a_{iso}\sigma_{iso}^2 \quad \ldots (12c)$$

$$\sigma_{ie}^2 = a_{ied}\sigma_{ied}^2 + a_{ieo}\sigma_{ieo}^2 \quad \ldots (12d)$$

The indices mean :

m : manufacturing

s : setting out

e : erection

d : dimension and position

o : orientation

f : form

The coefficients a in equations (12a) to (12d) are zero for non-relevant constituent deviations such as erection deviation for an element assigned to the width of a component.

If the tolerance for the assembly is met with a probability other than that for the constituent elements, this can be taken into account analogous to equation (11) :

$$T_A = \frac{t_A}{t} T$$