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Tolerances for building — Methods of measurement of buildings and building products — Part 1: Methods and instruments

*Tolérances pour le bâtiment — Méthodes de mesure des bâtiments et des produits
pour le bâtiment —*

Partie 1: Méthodes et instruments



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 7976-1 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 — Methods of measurement of buildings and building products —

Part 1 : Methods and instruments

1 Scope and field of application

This International Standard gives some alternative measuring methods for the determination of shape, dimensions and dimensional deviations of buildings and building products which are relevant to fit. The methods can also be applied when accuracy data are being collected in factories or on building sites.

Information is given about deviations of parts of buildings or of building products which can be determined with the equipment described.

The measuring methods concern primarily those objects the faces of which are rectilinear in shape and which have a modulus of elasticity larger than 35 kPa, for example concrete, wood, steel, hard plastic. Building products consisting of glass wool and similar soft materials are not the subject of this International Standard.

Rules for quality control in all stages of measurement such as frequency checks, place, time, etc., are not covered by this International Standard.

Part two of this International Standard gives the position of measuring points to be used in the measurement described in this part.

To facilitate cross-referencing, the same numbering is used in the two parts of this International Standard.

2 References

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

ISO 7078, *Building construction — Procedures for setting out, measurement and surveying — Vocabulary and guidance notes.*

ISO 7976-2, *Tolerances for building — Methods of measurement of building and building products — Part 2: Position of measuring points.*

ISO 8322, *Building construction — Measuring instruments — Procedures for determining accuracy in use —*

*Part 1: Theory.*¹⁾

*Part 2: Measuring tapes.*¹⁾

*Part 3: Optical levelling instruments.*¹⁾

*Part 4: Theodolites.*¹⁾

*Part 5: Optical plumbing instruments.*¹⁾

*Part 6: Laser instruments.*¹⁾

*Part 7: Instruments when used for setting out.*¹⁾

*Part 8: Electronic distance measuring instruments.*¹⁾

3 General

3.1 Methods of measurement

The methods of measurement refer to the main dimensions of building products, distances between such products and their geometrical deviations. They may, however, also be applied to parts and to subdivisions in building products.

The items to be measured should be supported as they will be supported in use. When this is impractical, the support conditions should be agreed in the measuring schedule. If components are measured whilst they are in a manufacturing jig or mould, this should be noted. Flexible components should always be fully supported on a flat surface.

For both compliance measurements and for the collection of accuracy data, the measurement procedure should be significantly more accurate than the permitted deviation specified for the manufacturing or construction process to be measured.

1) At present at the stage of draft.

Arrangements which make it possible to check the accuracy of the measurement procedure are an essential part of the method. (See ISO 8322, parts 1 to 8.)

When recording the result of a measurement the following conditions should be reported where appropriate :

- identification of operator, instrument and time;
- position and attitude of the object being measured;
- temperature and moisture content of the object being measured;
- any other matters pertaining to the measurement.

It is usually possible to measure directly on surfaces cast against a smooth mould. Local defects such as pores, burns and casting blemishes shall be avoided in the measurement. They shall not appear as incorrect sizes, but their presence shall be noted. In the case of a surface with a considerable roughness in relation to the permitted deviations, the measurements can be specified to be made with the aid of sufficiently large position pieces placed on the object of measurement.

At the end of each of clauses 4 to 14, there is a table that specifies the following items for each of the measuring operations in that clause :

- the measuring operation;
- limits of measuring accuracy, in terms of the permitted deviation of the item to be measured;
- the measuring range;
- the measuring instrument or tool which can be chosen.

3.2 Influence of deviations from reference conditions

Variations in the ambient conditions from the specified reference values can give rise to errors in the measured size of a dimension. Temperature, especially direct sunshine, is normally the most significant of these ambient conditions.

Other reference conditions such as moisture content of timber and age of concrete components shall be taken into account where appropriate.

The actual temperature of either the object to be measured or the measuring equipment may be difficult to determine in practice since it is unlikely that either will be at uniform temperature and because temperature differentials within the object to be measured or in the equipment will exist. The most satisfactory solution is to allow both the object to be measured and the measuring equipment adequate time to achieve a stable ambient temperature. This temperature can then be measured and allowance made for any variation from the specified reference temperature.

So far as the measuring equipment is concerned, the most likely sources of heat input are from the handling of the equipment and from differences between ambient temperature and the reference condition. The object to be measured is also affected by ambient temperature and may also be subjected to considerable heating during manufacture.

The reference temperature in this example is considered to be 20 °C. The following symbols are used :

- t_1 is the temperature of object to be measured, in degrees centigrade;
- t_2 is the temperature of measuring equipment, in degrees centigrade;
- a_1 is the coefficient of expansion of object to be measured;
- a_2 is the coefficient of expansion of measuring equipment;
- Δt_1 is the temperature difference from 20 °C of object to be measured ($\Delta t_1 = t_1 - 20$);
- Δt_2 is the temperature difference from 20 °C of measuring equipment ($\Delta t_2 = t_2 - 20$);
- L is the length being measured.

Then the error in measurement ΔL caused by the temperature differentials Δt_1 and Δt_2 is given by :

$$\Delta L = L (a_1 \Delta t_1 - a_2 \Delta t_2)$$

Section one : Measuring methods for those measurements which can be carried out both in factories and on building sites

NOTE — Most of the examples concerning components can also be applied to parts executed on site.

4 Sizes of components

This clause describes examples of instruments and measuring methods for the determination of length, width and thickness of components.

Linear dimensions are determined using measuring instruments (with or without the aid of position pieces) cited in clause 15, where typical errors and precautions needed are also indicated.

Special attention should be paid to tension and temperature when measuring with tapes. A tape tensioner applying the reference tension should be used where specified or when the length to be measured exceeds 10 m. It is recommended that the tape is supported in order to reduce the influence of the temperature of the object to be measured (see figure 1). It should be observed that when the tape rests on a building component or a floor, the temperature of this object of measurement can differ from the measured temperature of the surrounding air and hence cause measuring errors (see 3.2). This error can be reduced by supporting the tape. The correct temperature of the tape can be measured with a contact thermometer.

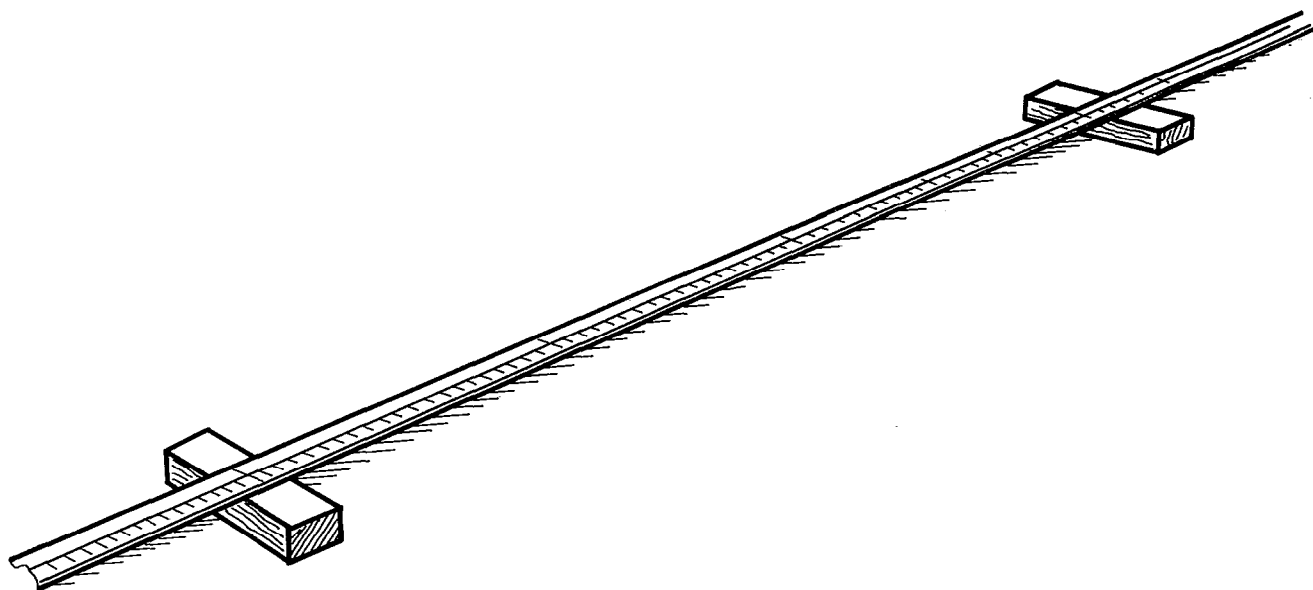


Figure 1

4.1 Length and width

On components which do not have sharply defined edges, position pieces (see clause 15) should be used to improve measuring accuracy. The position pieces should be held or clamped, as necessary for the duration of the measurement, against the appropriate faces of the component in order to define precise edges. An example of the use of corner pieces is given in figure 2.

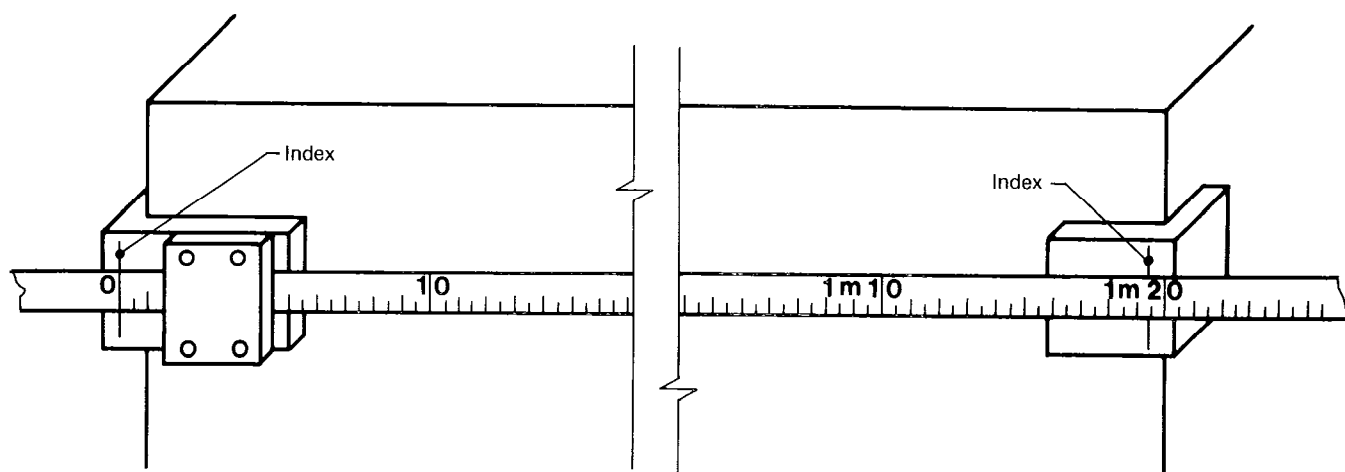
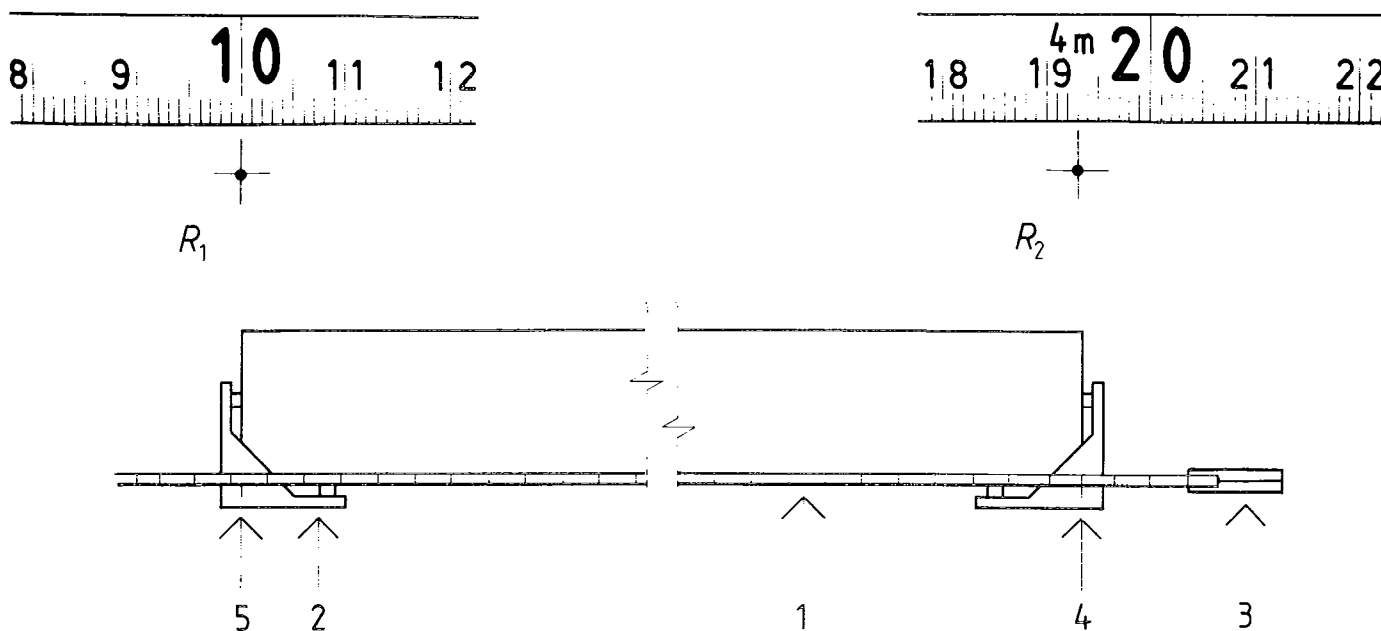


Figure 2



- 1: Tape
- 2: Corner piece
- 3: Tape tensioner
- 4: Reading
- 5: Reading

Example: $R_2 = 4,193$

$R_1 = 0,100$

$L = 4,093$

NOTE — When the zero point is at the end of the tape, readings shall be made in two places.

Figure 3

The result of a measurement between opposite points other than corner points can be used as a rough check of the result of the measurement of straightness deviations. (See clause 6 and figure 4.)

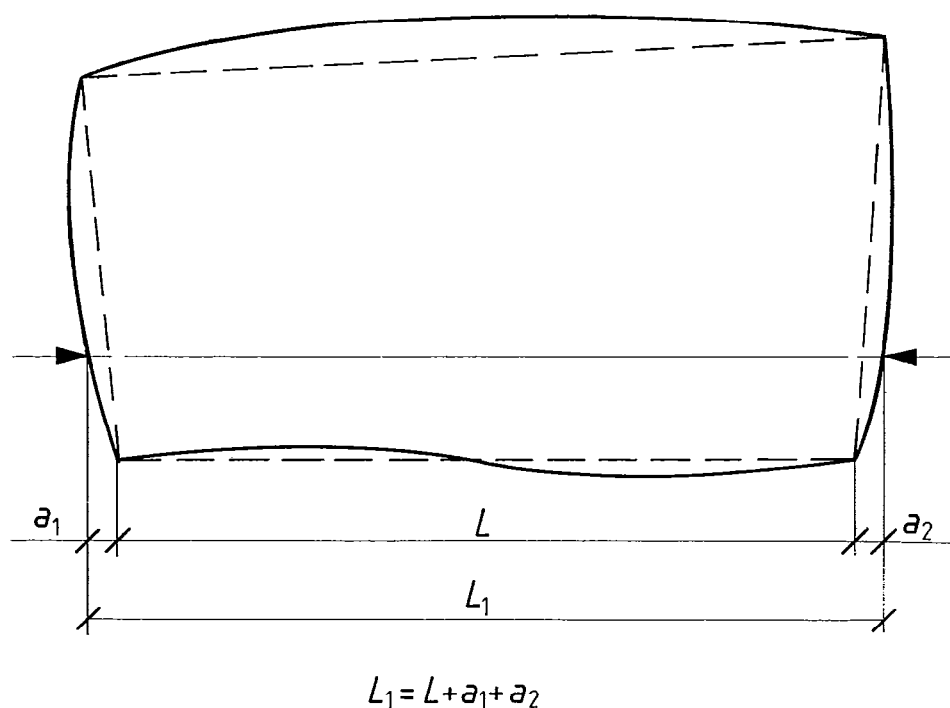


Figure 4

When measurements are made along curved surfaces, errors arise as the curve AB is always longer than the chord AB. Normal accuracy requirements permit readings to be taken to the nearest millimetre. This implies that in practice some amount of curvature can be allowed. (See figure 5.)

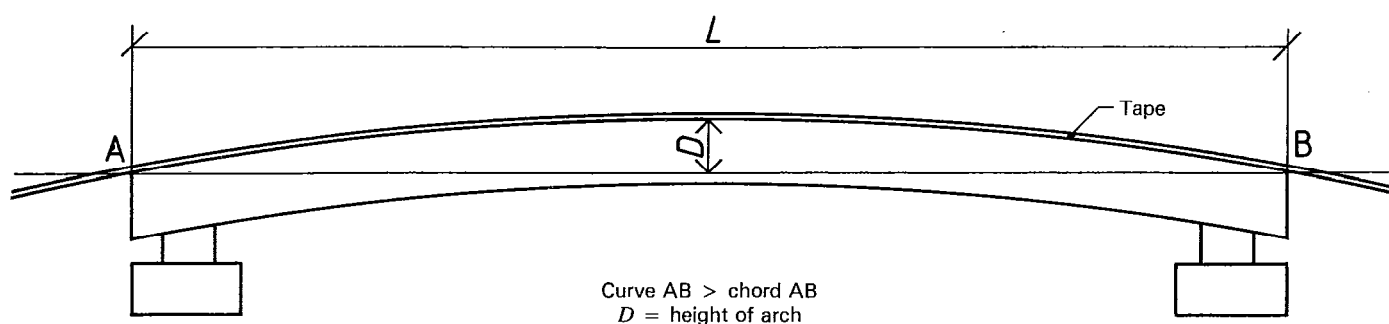


Figure 5

Figure 6 gives a diagram for corrections to be applied when measuring along curved components.

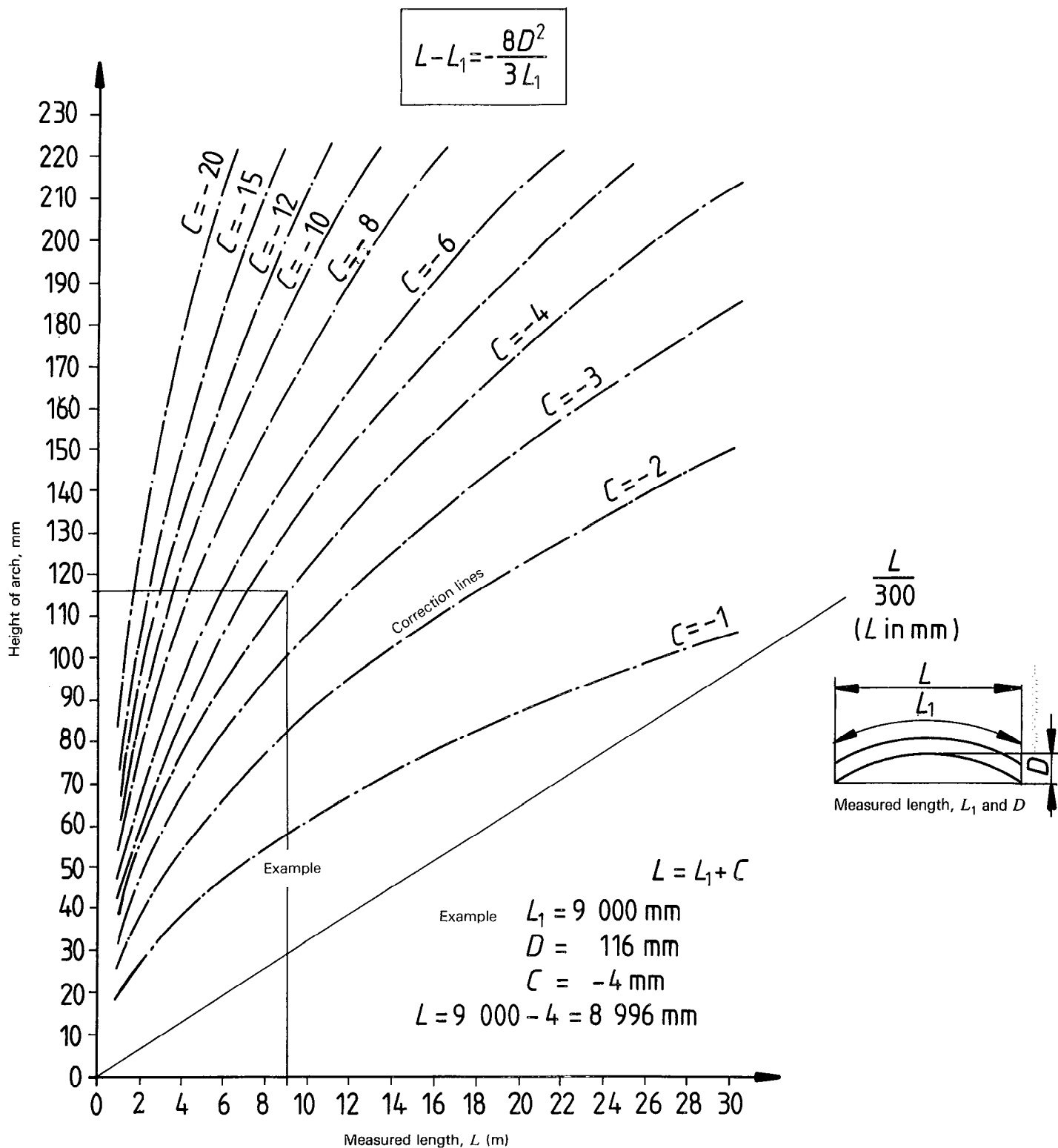


Figure 6

4.2 Thickness or depth

Thicknesses (or depths) of components are determined using instruments cited in clause 15 and in principle carried out in the same way as described in 4.1.

When necessary, corner- and/or edge-pieces should be used.

Instruments with a large contact surface are used for materials with an uneven surface.

Thickness shall be measured perpendicular to at least one of the surfaces of the component. (See figure 7.)

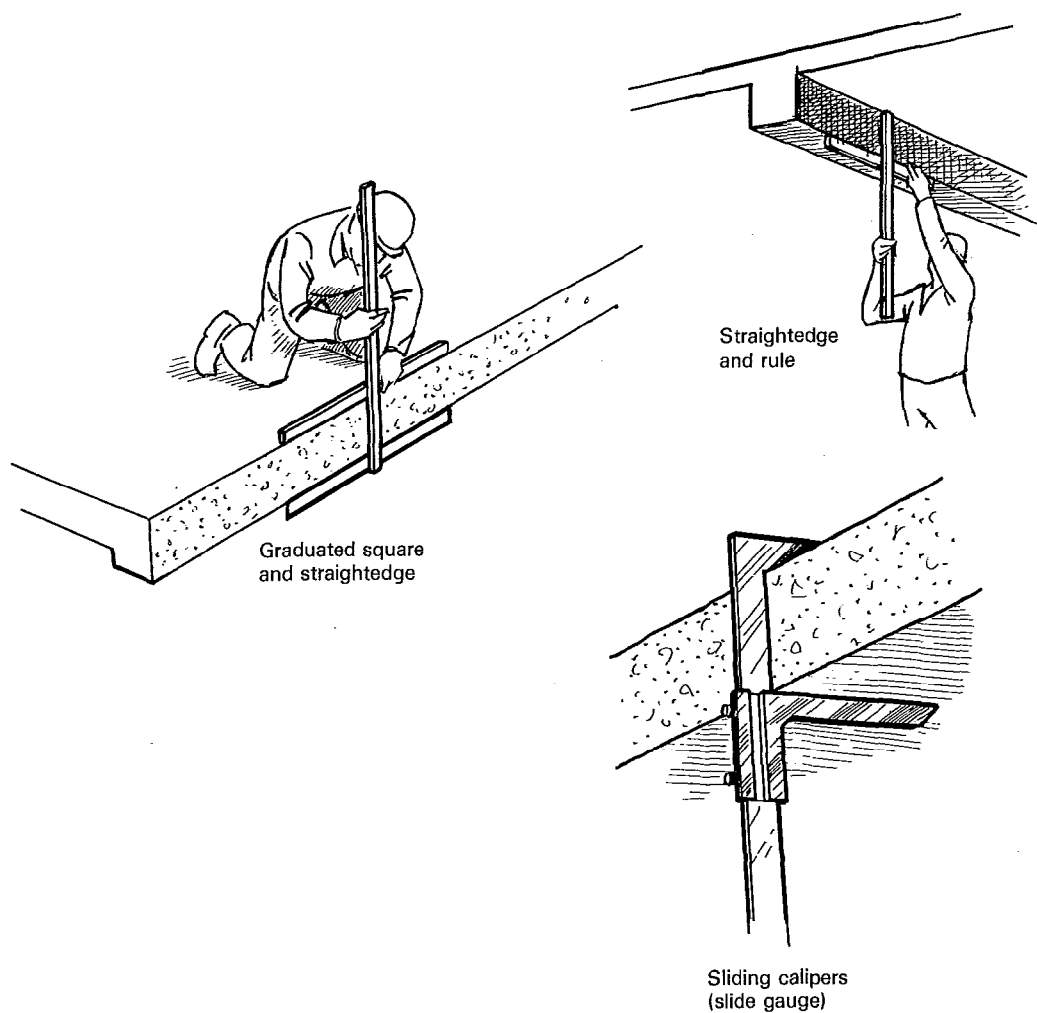


Figure 7

4.3 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed :	Measuring range	Measuring instrument or tool
1	2	3	4
Lengths and widths of components (4.1)	± 3 mm ± 3 mm ± 5 mm	< 1 m < 3 m 3 to 10 m	Retractable steel tape Calibrated steel tape Calibrated steel tape
Thickness of components (4.2)	$\pm 0,5$ mm ± 1 mm ± 2 mm ± 3 mm ± 5 mm	$< 0,1$ m 0,1 to 0,5 m 0,5 to 2,0 m < 1 m $< 0,5$ m	Caliper Caliper Caliper Retractable steel tape Measuring rod and two boning rods

5 Squareness (perpendicularity) of components

This clause describes examples of instruments and measuring methods for the determination of deviation from squareness (right-angle), but can in principle be applied to any angle.

According to ISO 4464 the angular deviation is described as the difference between an actual angle and the corresponding reference angle.

Figure 8 shows angular deviations expressed in gon or degrees [figure 8a)] or as offsets [figure 8b)].

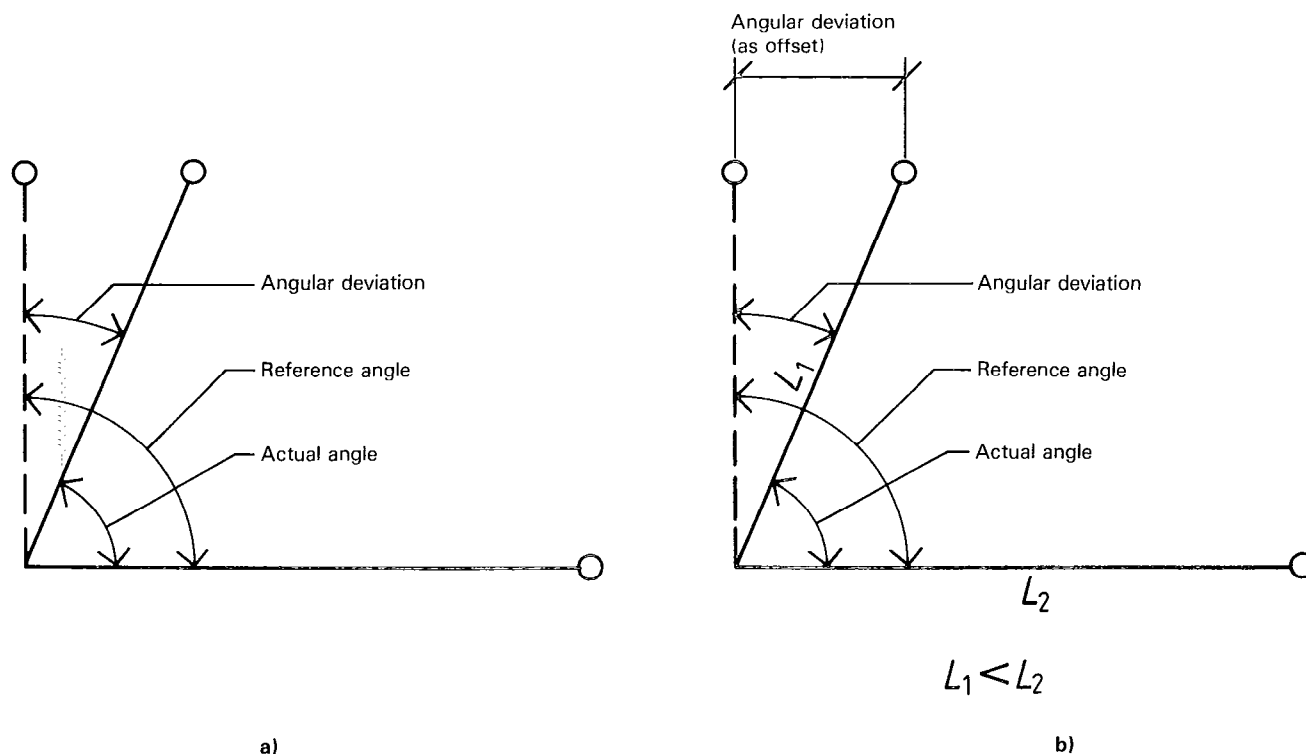


Figure 8

If alternative b) is put into practice, the angular deviation shall be determined from the shorter side of the angle and shall be measured perpendicular to the corresponding side of the reference angle.

Parallelism deviation, which is another form of angular deviation, is dealt with in 5.2.

Angular deviations are determined using instruments and tools given in chapter 15, with or without the aid of position pieces.

Three methods are described for the determination of deviations from a right-angle in building products. The method chosen depends on the size of the object of measurement.

In figure 9, if b and $c < 1\,200$ mm, a square is used as shown in figure 11. Otherwise, a measuring telescope is used (see 5.1.3) or diagonal measurement (see 5.1.2) is made. Diagonal measurement, however, may only be used when the permitted deviation of the right-angle is more than 5 mm per metre.

The three methods used for determination of angular deviations are explained in the examples below. The deviation is always measured on the shorter leg of the angle and the final result will be the deviation of point B or point C from the required position.

In figure 10, the angles to be measured are those between the lines which connect the corner points (see also figure 16).

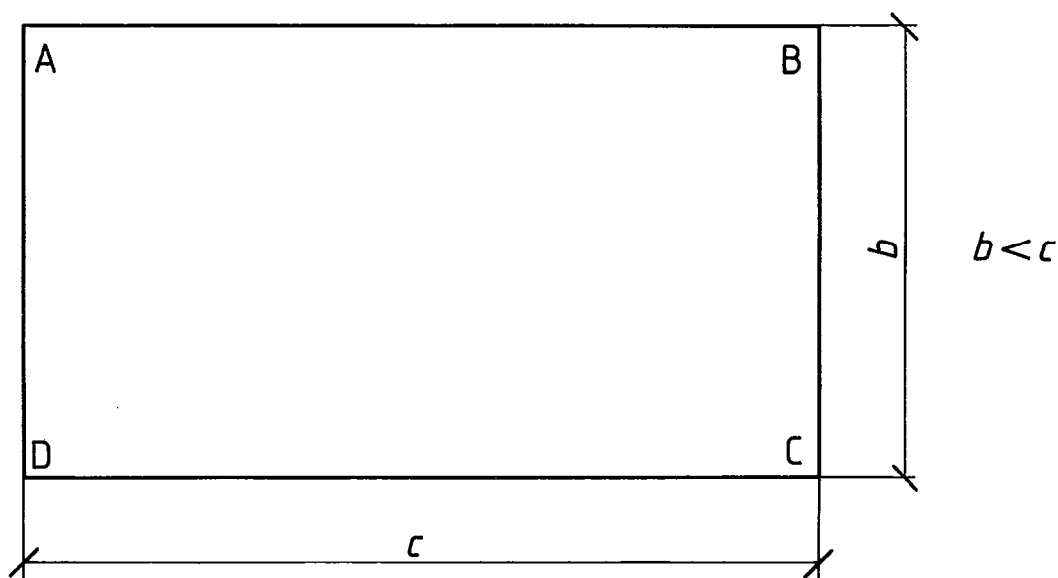


Figure 9

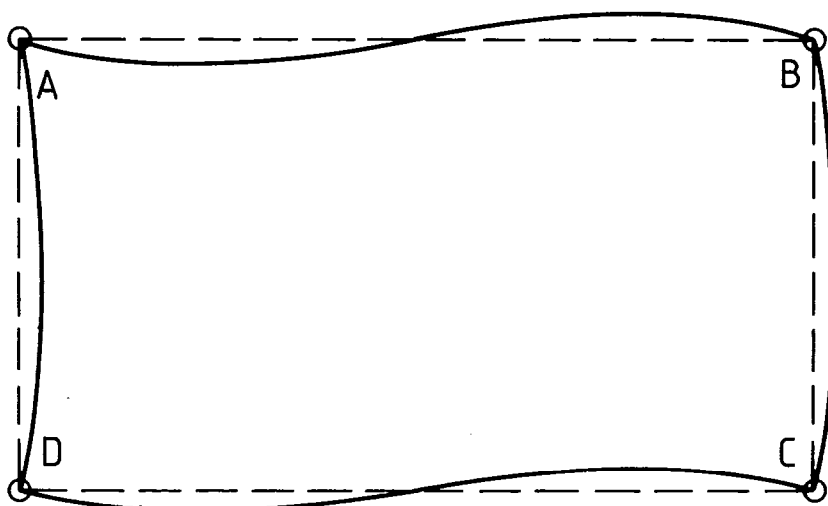
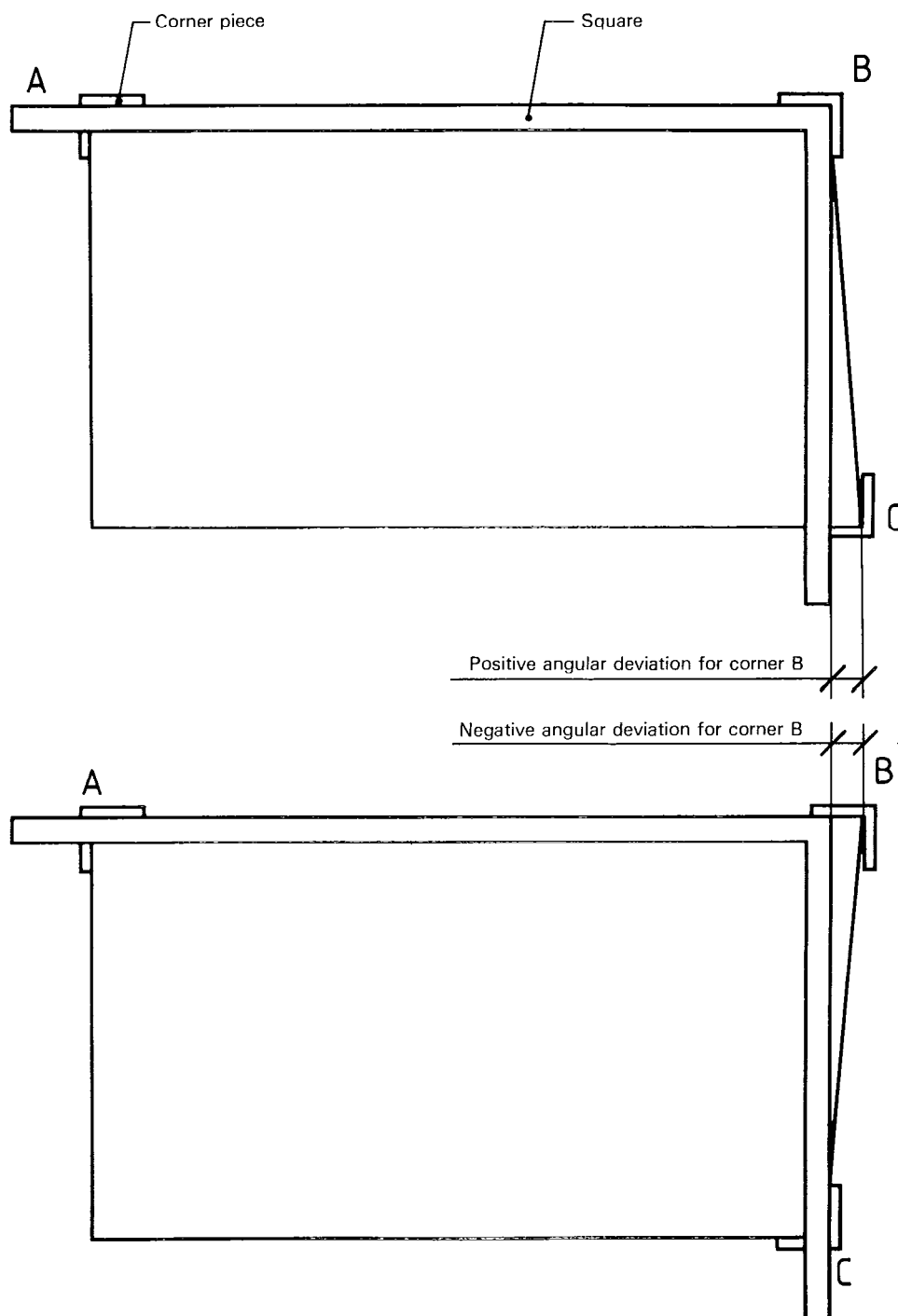


Figure 10

5.1 Angular deviation

5.1.1 Measuring using a square

In figure 11, a square of sufficient size is placed with the longer arm along AB in such a way that the shorter arm touches B or C. The angular deviation of corner B is determined as shown.



Maximum size : 1 200 mm × 1 200 mm
Corner pieces at A, B and C

Figure 11

In figure 12, a square is positioned for measurement of angular deviation. The square rests against the studs S. In order to reduce friction, the arm L_1 is supported on the roller bearing R.

In figure 13, the method in figure 12 can also be used to measure angular deviations on columns.

When using methods shown in figures 12 and 13, the thickness of spacers or studs shall be subtracted from the reading when evaluating the angular deviation.

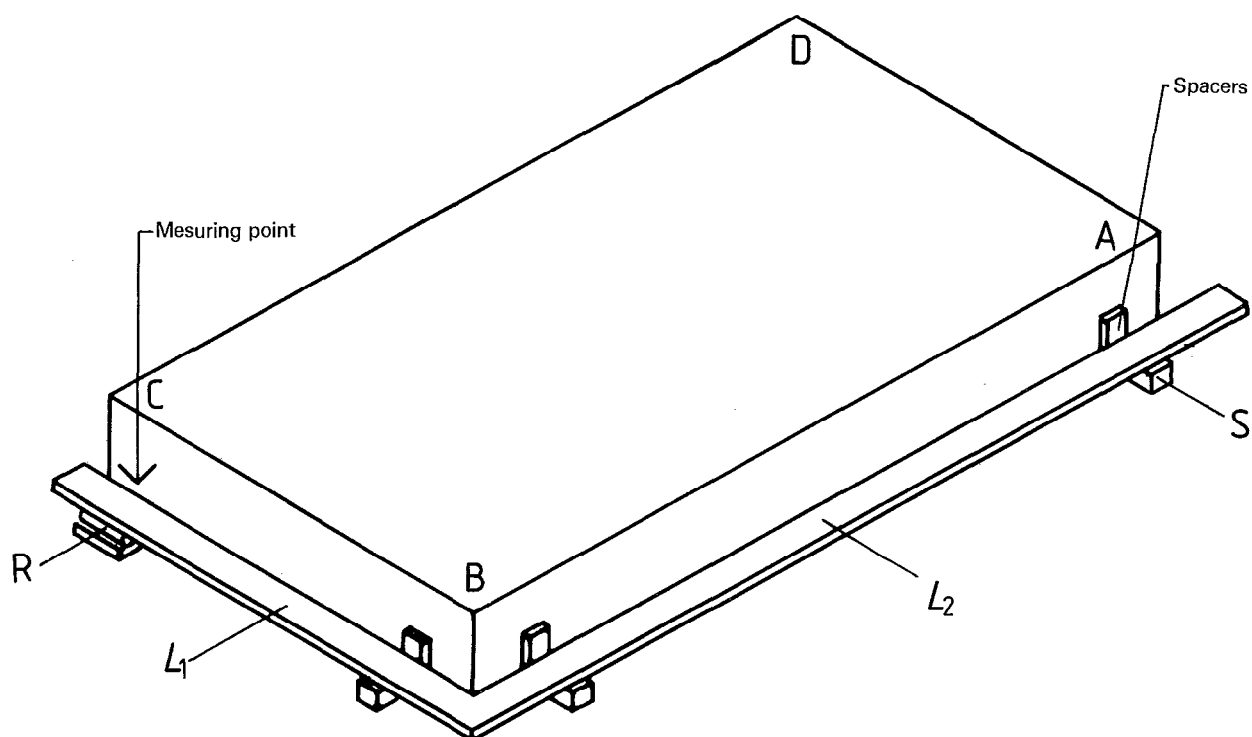


Figure 12

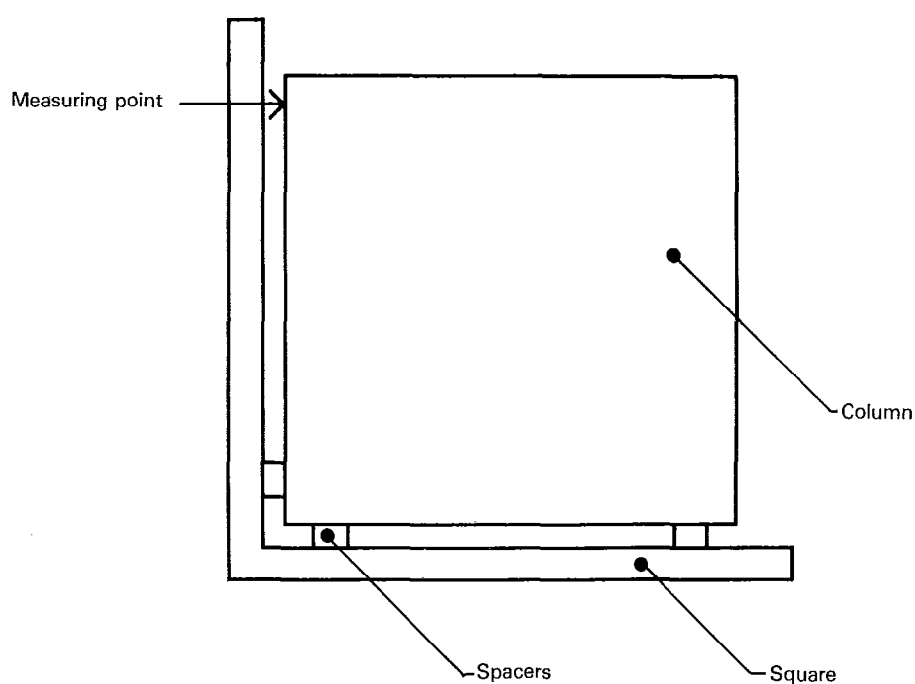


Figure 13

The method in figure 14 can only be used when no straightness deviations occur, as otherwise only the deviations from the right-angle between parts of the surfaces are observed, that is angle ABC and not ABD.

5.1.2 Diagonal measurement

In figure 15, the distances AB, BC and AC are determined with the aid of tapes and corner pieces.

The dimensions of the object to be measured may not exceed the length of the tape and the ratio width/length of the object to be measured shall not be less than 1:2.

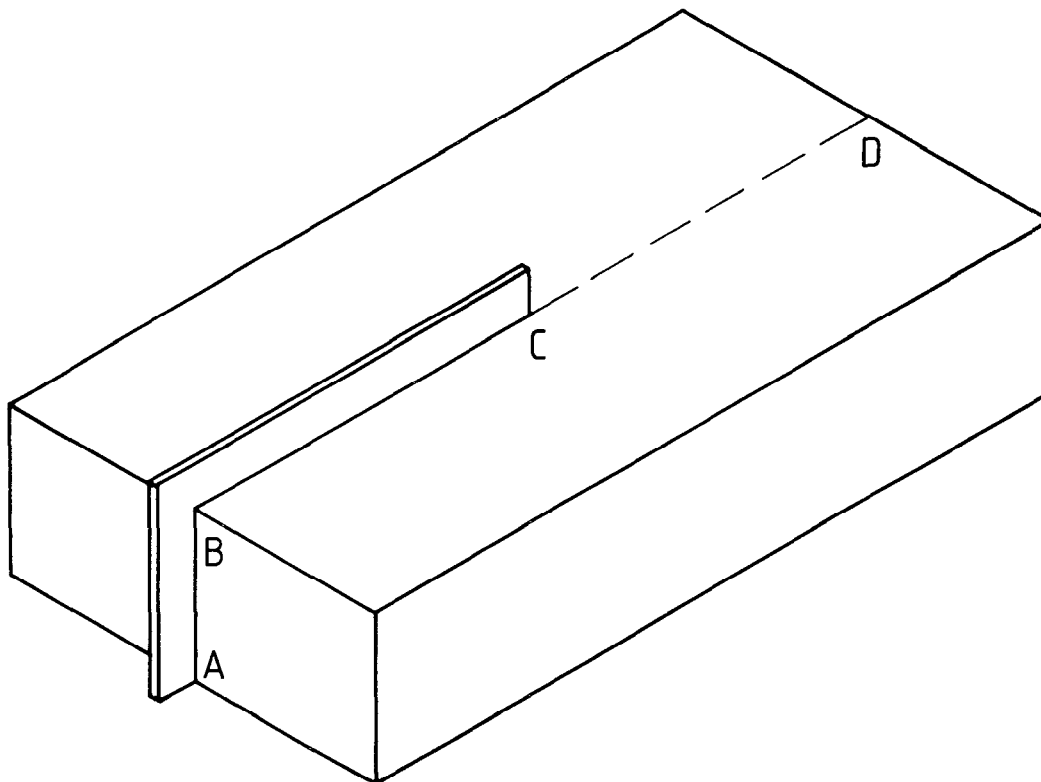


Figure 14

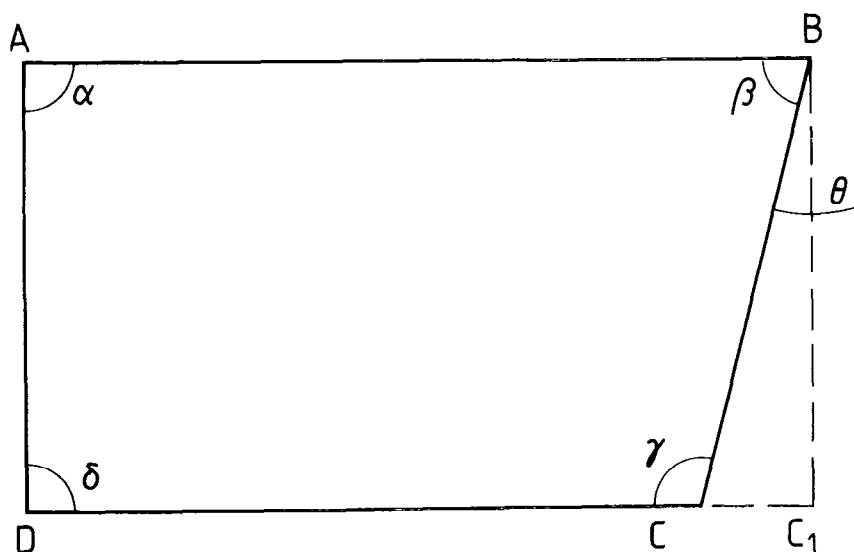


Figure 15

$$CC_1 = \frac{AB^2 + BC^2 - AC^2}{2AB}$$

The angle at point B can be calculated as follows :

$$\cos \beta = \frac{AC^2 - AB^2 - BC^2}{- 2 AB \times BC}$$

This procedure can be repeated for the points A, C and D.

The sum of the angles ($\alpha + \beta + \gamma + \delta$) should be 400 gon or 360° . Any misclosure must be divided equally over the four angles, provided that the misclosure is not more than 0,12 gon ($0,11^\circ = 7'$) for a component of size about 2 000 mm $\times$ 3 000 mm. If the misclosure exceeds this figure, new measurements shall be made.

The angular deviation as an offset (CC_1) can also be determined in relation to the side CB as follows :

$$\beta = 100 \text{ gon} - \theta$$

$$\cos \beta = \sin (-\theta) = \frac{CC_1}{BC} = \frac{AB^2 + BC^2 - AC^2}{2 AB \times BC}$$

or

$$CC_1 = \frac{AB^2 + BC^2 - AC^2}{2 AB}$$

5.1.3 Measuring with a measuring telescope

In figure 16, a measuring telescope is positioned at measuring point B and set at zero towards target A. The instrument is then rotated 100 gon (90°) and the deviation at target C is determined using, for instance, a millimetre-scale placed at this point.

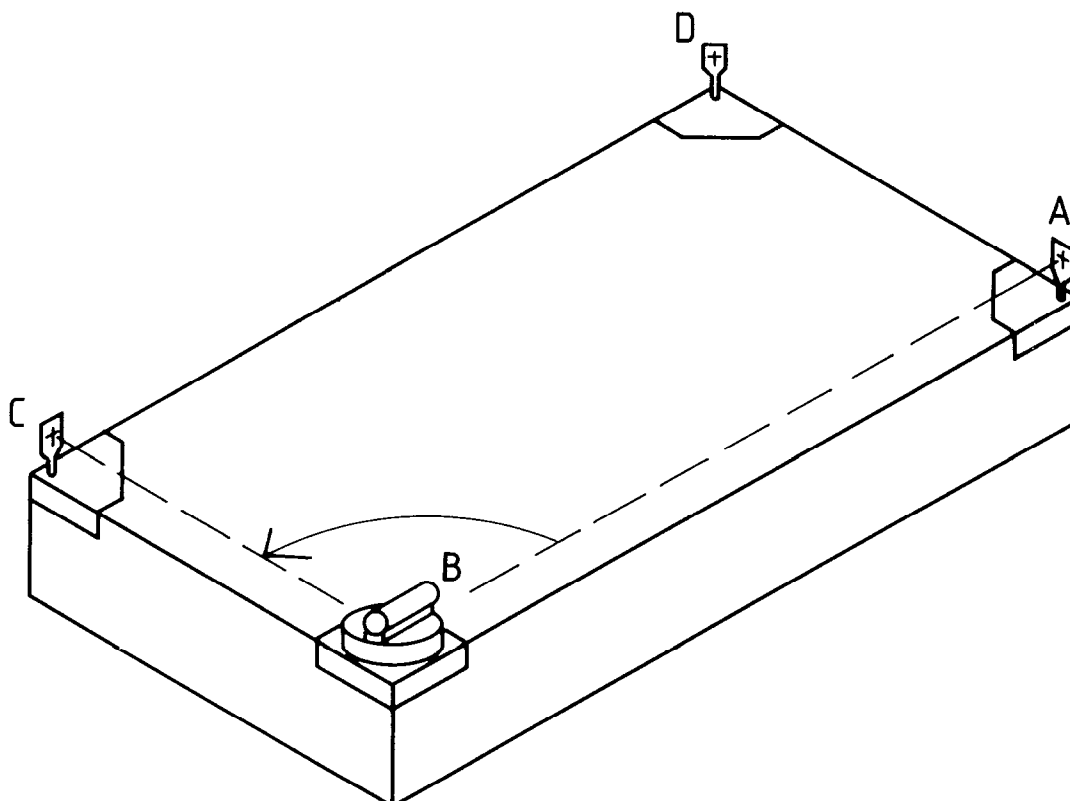


Figure 16

Figure 17 shows a method for the determination of the angular deviation (at B) with the aid of a theodolite (T) the sighting axis of which is brought parallel with BA by turning the theodolite until the readings on the measuring rod (P_1 and P_2) are equal.

The telescope is then turned through 100 gon (90°) and the distances P_3 and P_4 are read off in the telescope from the measuring rod. The distances P_1 to P_4 should range from 500 mm to 1 000 mm. This means that in most cases additional lenses for short-range observation will have to be mounted on the theodolite when reading distances P_1 and P_3 .

The offset angular deviation is in this case positive ($P_3 - P_4$).

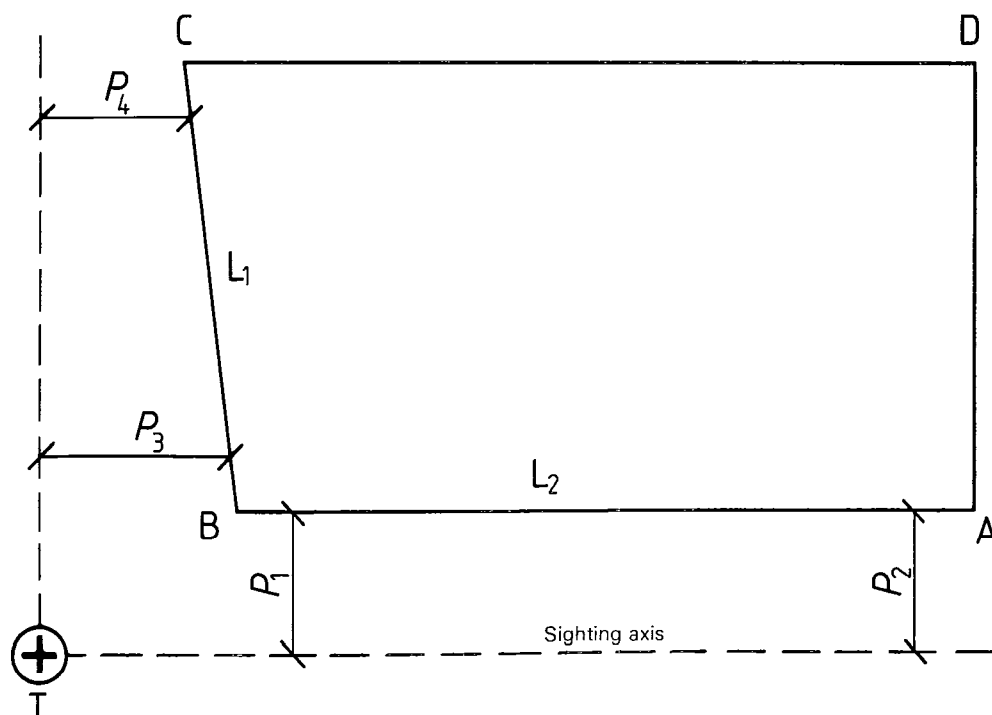


Figure 17

5.2 Parallelism

Parallelism deviation is a form of angular deviation and is the difference between the orientation of the straight line through A and B and the orientation reference line AB_1 through A, parallel to DC (see figure 18). The deviation is measured as the distance between B and B_1 (see ISO 4464).

In figure 18, distances AD and BC are measured from C and D respectively at right-angles to CD, in practice parallel to the edges BC and AD using measuring instruments in accordance with clause 15. The difference between AD and BC is the deviation from the parallel between AB and CD.

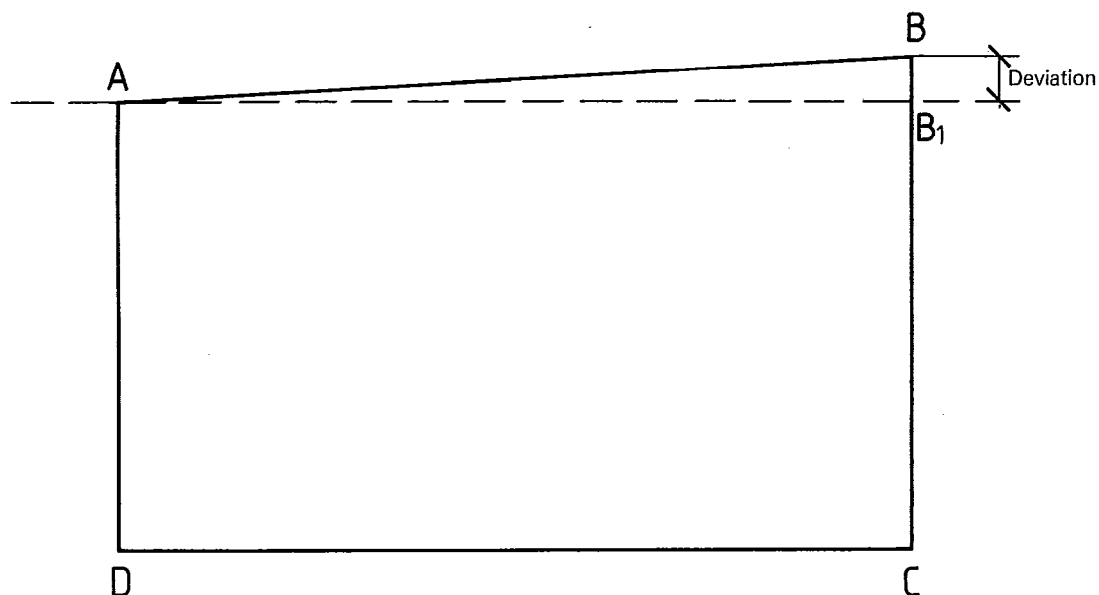


Figure 18

5.3 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed :	Measuring range	Measuring instrument or tool
1	2	3	4
Angular deviation (5.1)	± 4 mm	$< 1,2$ m	Square
	± 5 mm/m	< 30 m	Calibrated steel tape
	± 7 mm	< 30 m	Optical instrument
Parallelism (5.2)	± 2 mm	< 1 m	Caliper
	± 3 mm	< 3 m	Calibrated steel tape
	± 5 mm	3 to 10 m	Calibrated steel tape
	± 5 mm	< 3 m	Measuring rod

6 Straightness and camber of components

This clause describes examples of measuring instruments and tools for the determination of deviations from straightness and from designed camber.

6.1 Straightness

According to ISO 4464, straightness deviation is described as the difference between the actual form of a line and a straight line. The deviations a and b are measured as the distance from points on the actual line to the straight line joining the ends of the actual line, A and B. (See figure 19.)

Straightness deviations are determined using instruments and tools given in clause 15, with or without the aid of position pieces.

The ends of the line, commonly an edge, along which the deviation from straightness is to be measured, are linked either using a string stretched between the two end points, A and B, a straight edge supported by position pieces or the sighting axis of a measuring telescope.

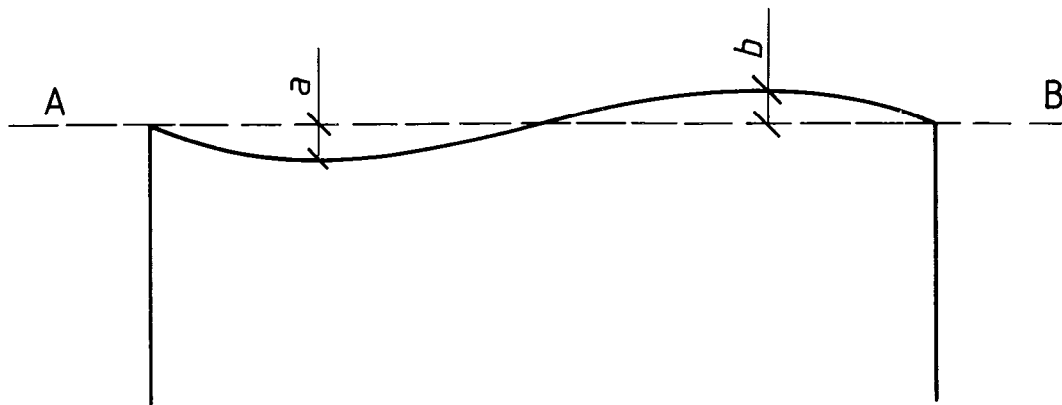
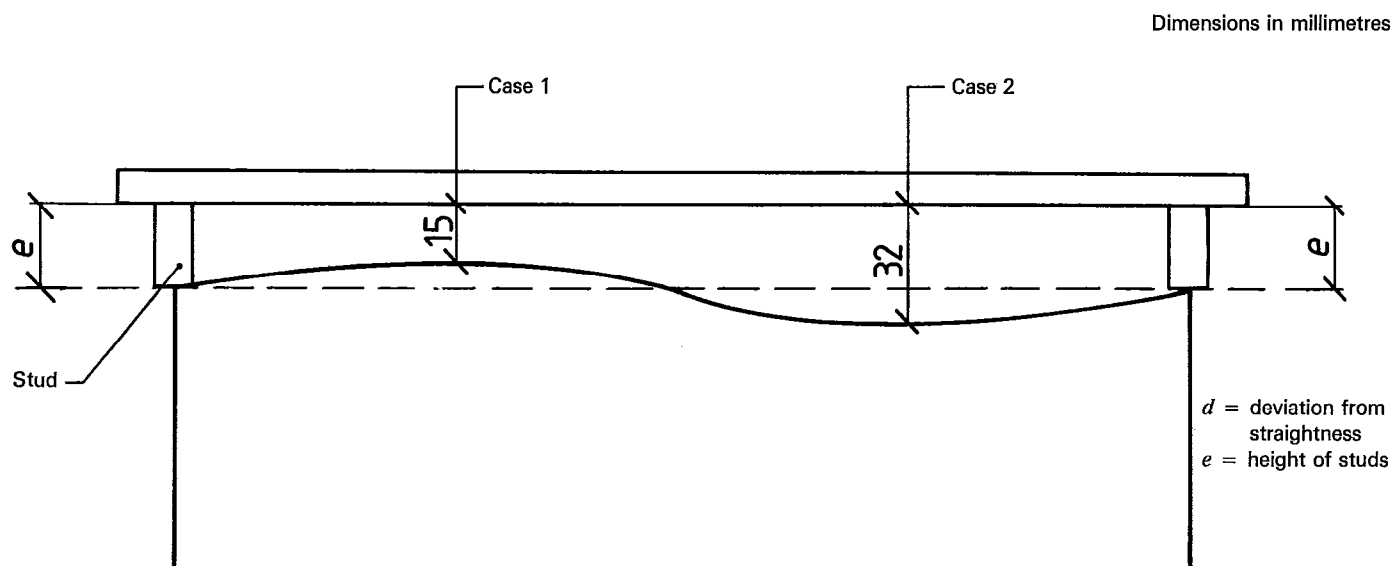


Figure 19

6.1.1 Measuring using a straightedge

The length of the straightedge should not exceed 3 m.

Figure 20 shows measurement using a straightedge and corner pieces along the edge of the object of measurement.



Example

The deviation is calculated as follows:

$e = \text{height of studs: } 25 \text{ mm}$

deviation $d = e - \text{reading}$

Case 1: $d = 25 - 15$

$d = 10 \text{ mm (pos.)}$

Case 2: $d = 25 - 32$

$d = -7 \text{ mm (neg.)}$

Figure 20

6.1.2 Measuring using a stretched wire

The method in figure 21 consists of setting up a reference line with a stretched steel or nylon wire, supported at its ends by distance and tensioning pieces. The wire is kept in place by a groove 50 mm from the edge.

The aim of the distance and tensioning pieces is to keep the wire at a predetermined distance from the corners of the object of measurement and to ensure that it does not touch the surface.

6.1.3 Measuring using a measuring telescope

The methods described in 5.1.3 for a measuring telescope used in the determination of angular deviation can also be used to determine the straightness of components.

6.2 Designed camber

The methods described in 6.1.1 to 6.1.3 can also be used to determine deviations from designed camber.

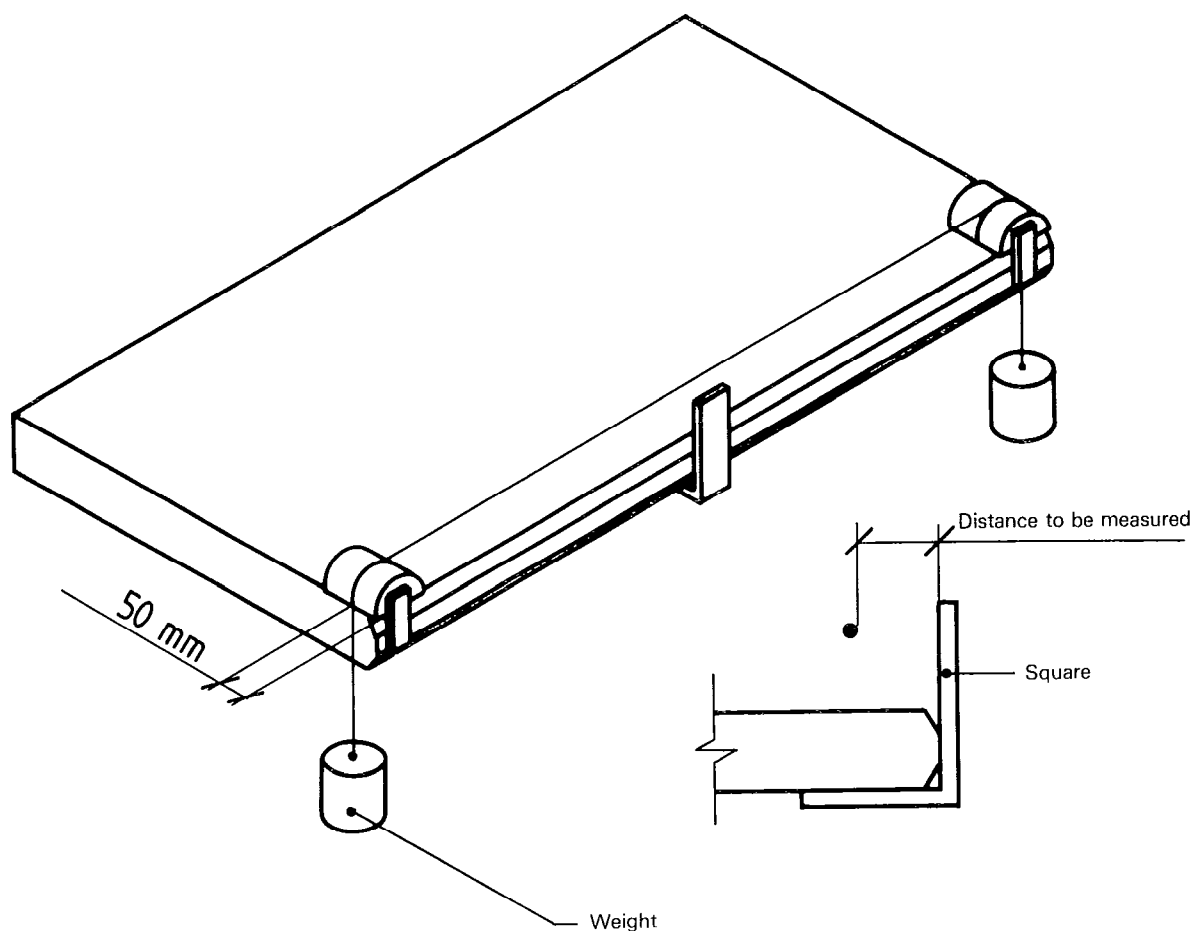


Figure 21

6.3 Accuracy table

Measuring operation	When values for permitted deviation specified for object exceed :	Measuring range (measuring length)	Measuring instrument or tool
1	2	3	4
Deviation from straightness and designed camber (6.1 and 6.2)	± 2 mm	< 3 m	Measuring wedge (< 30 mm), straightedge and corner pieces
	± 3 mm	< 3 m	Rule, straightedge and corner pieces
	± 2 mm	< 2 m	Measuring wedge (30 mm) and steel or nylon wire (< 10 m) and corner pieces
	± 4 mm	2 to 5 m	
	± 8 mm	5 to 10 m	Rule and steel or nylon wire and corner pieces
	± 3 mm	< 2 m	
	± 5 mm	2 to 5 m	
	± 10 mm	5 to 10 m	

7 Flatness and skewness of components

This clause describes examples of instruments, tools, measuring methods and reference planes to be used for the determination of flatness.

According to ISO 4464, flatness deviation is described as "the difference between the actual form of a surface and that of a plane surface". In the case of local flatness these surfaces are substituted by a line and a straight line respectively. When determining deviations from flatness, it is necessary to decide from which reference plane the deviations of the surface are to be measured.

7.1 Principles of measurement

A reference plane can be defined in many different ways, such as:

- a mean plane of the four corner points;
- a plane determined with the aid of the method of least squares;
- in relation to certain straight lines (local flatness);
- in relation to a box (the box principle);
- a plane through three corner points (skewness).

7.1.1 Mean plane

Flatness deviations on a rectangular surface can, according to ISO 4464, be determined with the help of a mean plane for all four corners. This mean plane will be situated $S/4$ above two diagonally opposite corners and $S/4$ below the other two corners (see figure 22) where S is the degree of skewness determined as shown.

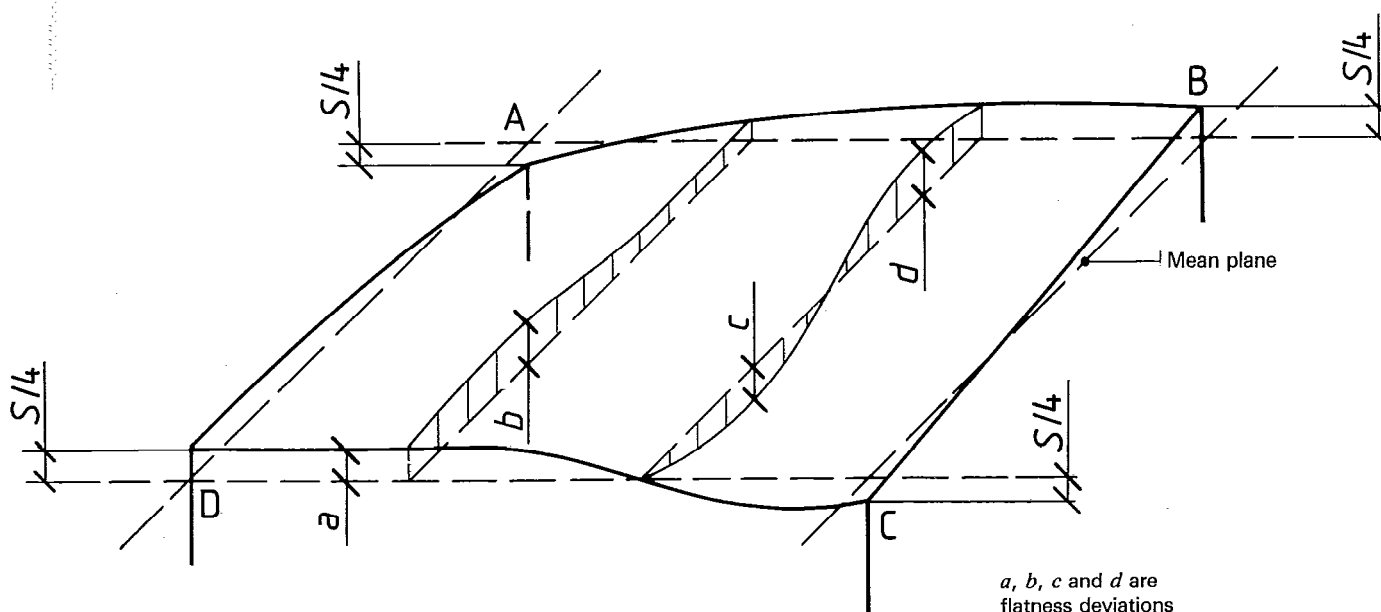


Figure 22

In figure 22, the reference plane is the mean plane passing through $A + S/4$, $B - S/4$, $C + S/4$ and $D - S/4$. The flatness deviations are measured at points all over the surface and not only in sections; the sections in the figure are shown for the sake of simplicity. The surface is scanned in relation to the mean plane. Flatness deviation is expressed positively and negatively by the greatest distance of a point above and below that plane.

7.1.2 Method of least squares

A more general definition of flatness is that the reference plane is so constructed that the sum of the surface deviations from that reference plane is zero; i.e. the sum of the positive deviations equals the sum of the negative deviations, and the sum of the squares of these deviations is a minimum (that is, principle of least squares). For such a plane a large number of measurements is required (approximately 16 points on a component of size 4 000 mm × 6 000 mm), while calculations must be done by computer.

It should be noted that the evaluation when using the method of least squares should be entrusted to well qualified personnel.

NOTE — The application of the principle of least squares implies that the calculation result gives the position and the two directions of the reference plane in relation to the measuring plane. Only in those cases

where the surface to be measured is already a part of the erected building can the two directions normally be subject to accuracy requirements.

Figure 23 shows the reference plane to be calculated with the aid of the principle of least squares.

A measure of the quality of the flatness can, by way of example, be specified as:

$$|V_{\text{pos.}}| + |V_{\text{neg.}}| \leq T_{\text{fl}} \text{ mm}$$

where

$V_{\text{pos.}}$ is the largest positive deviation;

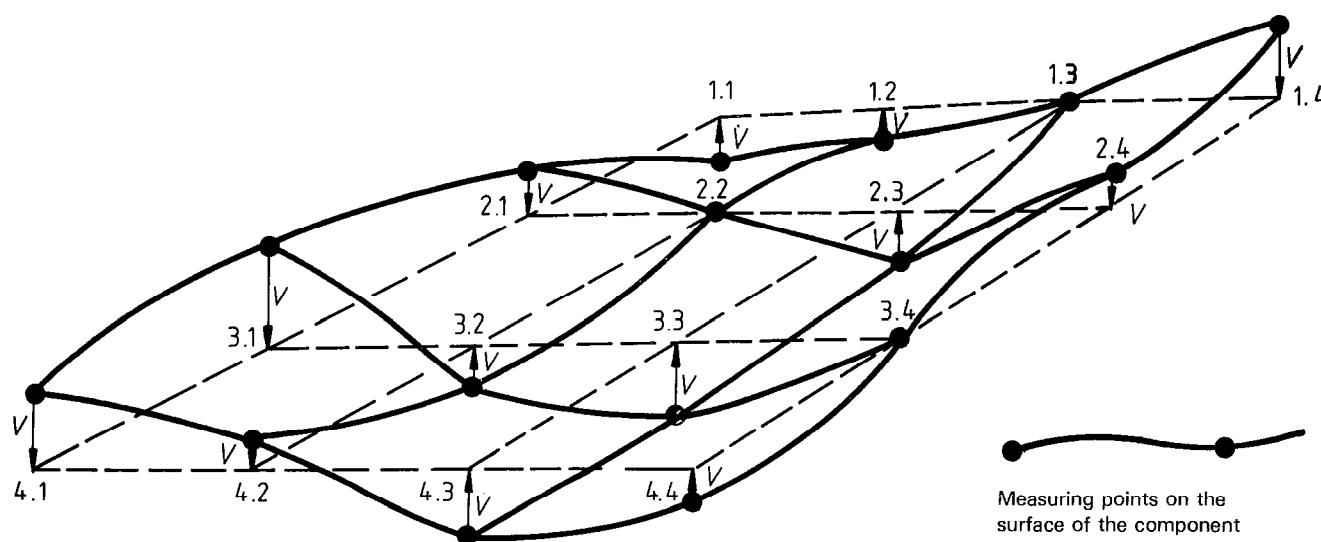
$V_{\text{neg.}}$ is the largest negative deviation;

T_{fl} is the specified flatness tolerance.

7.1.3 Local flatness

Local flatness deviations from certain straight lines in certain directions can be measured.

This method gives a direct measure of local straightness and indirectly an indication of flatness. It is a practical method of checking flatness for many building purposes.



Conditions: $\sum_i V_i = 0$
 $\sum_i V_i^2 = \text{minimum}$
 $(i = 1.1; 1.2; 1.3 \dots 4.4)$

Figure 23

Figure 24 shows flatness deviations a_1 in relation to a reference plane ABCD or deviations a_2 in relation to a straight reference line through the points X and Y on the surface of the component.

7.1.4 The box principle

The box principle may be used to determine flatness deviations. According to ISO 4464, the box principle is described as follows: "The volume to consider is the volume of the space which exists between two theoretical similar parallelepipeds

having the same orientation, one of them being situated inside the other. The distance between the corresponding faces of these parallelepipeds may or may not be equally distributed depending on the tolerance widths which are specified. No point on the surface of the component shall pass beyond this volume."

NOTE — This principle is also applicable when only two dimensions are under consideration. This will probably be the most common situation. (See figure 25.)

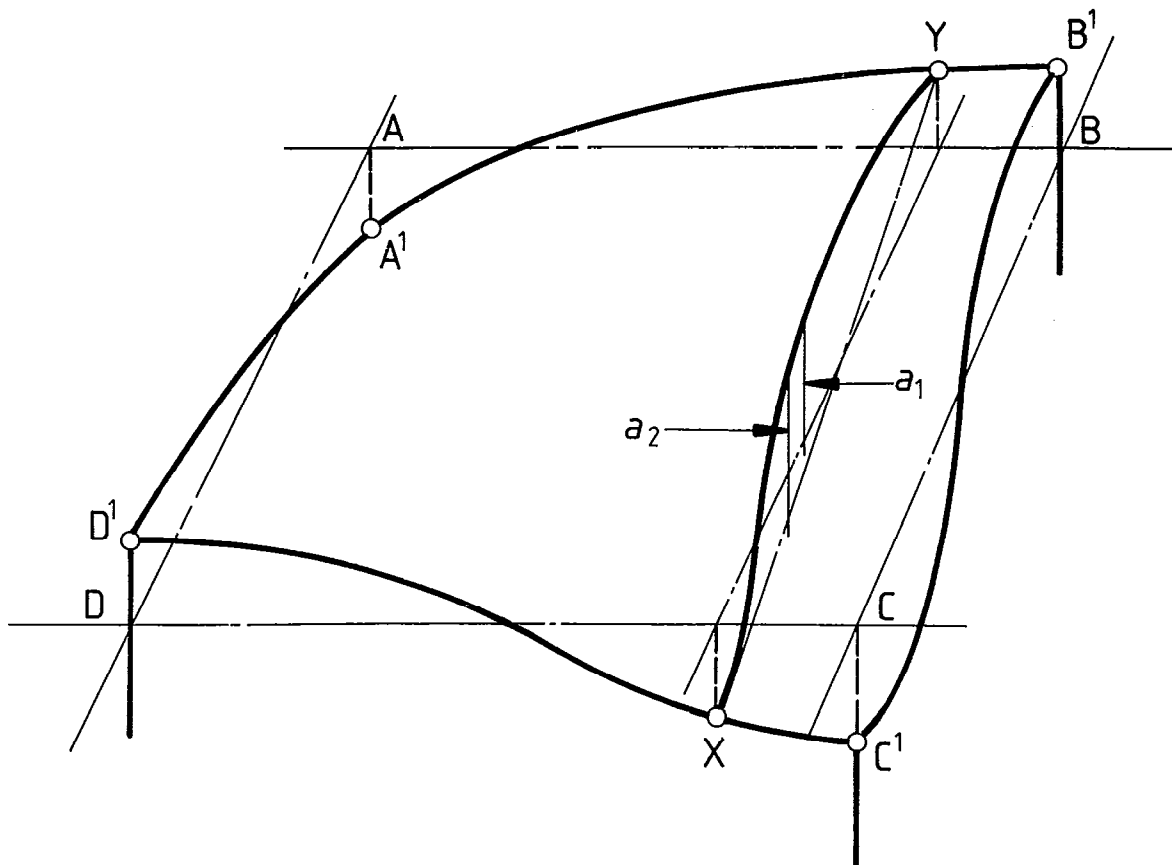


Figure 24

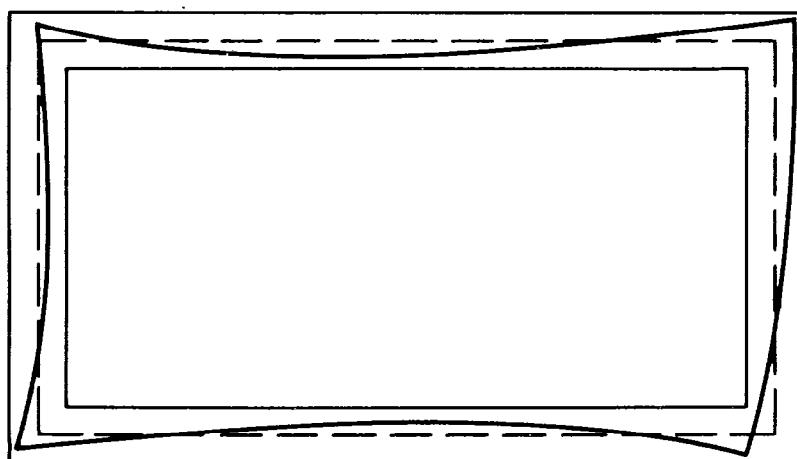


Figure 25