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Accuracy and tolerance in design and construction — Guide

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages I to VI, pages 1 to 84, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 28 February 2022. It was prepared by Technical Committee B/209, *General building codes*. A list of organizations represented on this committee can be obtained on request to the committee manager.

Supersession

This British Standard supersedes BS 5606:1990, which is withdrawn.

Information about this document

To aid the development of a previous edition of this standard, BSI and the Department of Environment commissioned a survey of dimensional variability on projects where tolerances had been specified. The results of the survey were analysed by the Building Research Establishment and included in that edition of the standard. This data is retained in the current edition in the tables in Annex C.

This is a full revision of the standard, and introduces the following principal changes.

- The examples of issues in Section 2 have been updated.
- Section 3 and Section 4 have been updated to include technology and process changes.
- A clear distinction has been made for the use of accuracy and tolerance as independently definable and required characteristics.
- Clarifications and caveats have been added to the BRE industry performance assessment tables from the 1970s and 1980s (in Annex C), including the importance of not relying on these for an assessment of current practice, i.e. tables of industry performance in relation to manufacturer and assembly, and construction tolerances from the 1970s and 1980s have not been updated, but are retained for historical reference for empirical site/manufacturing performance in that period. The assumptions around dimensional variability in the industry current practice (on- or off-site) need to be assessed without reliance on the legacy tables included in this document for historical example and context.

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It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The guidance in this standard is presented in roman (i.e. upright) type. Any recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

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Section 1: General

1 Scope

This British Standard gives guidance on and provides examples of principles that relate to accuracy and tolerance in design and construction activity for the built environment. It is intended to be a practical guide to assist designers and constructors in determining and managing the risks associated with accuracy and tolerance and taking steps to control them appropriately, which, if unmanaged, can be very significant to cost, time and quality.

The fundamental objective is to provide awareness and advice on ways to avoid problems of inaccuracy or fit arising on-site. The need for such advice on any particular project varies, depending on the character of the project and the materials and methods of construction. This British Standard is designed to be relevant to all types of construction including the most sophisticated ones. Those concerned with an individual project can judge the extent to which each section is relevant to their needs.

This British Standard takes into account the growing importance of off-site construction [e.g. MMC (modern methods of construction)] and the changes in technology (e.g. digital measuring equipment) and processes [e.g. BIM (building information modelling)] since the last edition was issued. However, it also retains previous guidance where it provides essential insight and wisdom which might still be relevant today.

While this British Standard is not a guide to productivity in the construction industry, some of the impacts of accuracy and tolerance on productivity, which can be either potential improvements or lessons to be learnt, have been illustrated in Section 2 by practical examples for user understanding. These are not exhaustive but are intended to highlight how these impacts can be significant, either positive or negative, and that this standard can be used as an important part of the quality planning, management and execution of design and build activity for the built environment (buildings and infrastructure).

This British Standard is designed to support the creation and implementation of a project strategy for accuracy and tolerance and provide practical implementation guidance throughout the life cycle and is supported and supports other important standards and processes. It is intended to be applied to buildings and infrastructure works in design and construction and aims to assist in the following:

a) avoiding or resolving problems of inaccuracy or fit by assessing the dimensional needs of a design regarding tolerances, and then designing and specifying appropriately;

b) assessing the likely achievement of tolerances in construction specified for a particular project, and giving guidance on strategies to verify capabilities and mitigate challenges;

c) providing for monitoring and controlling work during construction to check that it is in accordance with specified dimensional tolerance and accuracy for surveys;

d) aiding digital design and engineering (on- and off-site) including the application of BIM for the built environment; and

e) understanding the importance of the accuracy of surveys undertaken pre, during and post construction works to measure existing features and as-built with the ability to support and verify the achievement of design tolerances and fit.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions of this document[1]. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 6100-11, *Building and civil engineering – Vocabulary – Part 11: Performance characteristics, measurement and joints*

BS 6954-3, *Tolerances for building – Part 3: Recommendations for selecting target size and predicting fit*

BS 7334 (all parts), *Measuring instruments for building construction*

3 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in BS 6100-11 and the following apply.

3.1 building information modelling (BIM)

processes, technologies and skill sets required for the management of information through the whole life cycle of a built asset, from initial design all the way through to construction, operations and maintenance and finally de-commissioning

NOTE BIM is achieved through the definition of information requirements for the organization, asset and project and use of digital technologies for modelling, collaboration and coordination of information and data across multiple disciplines and organizations, which in turn supports quality assurance workflows to enable informed decision making and verify client requirements achievement at each key stage in a project life cycle.

3.2 characteristic accuracy

accuracy, expressed in terms of systematic deviation or standard deviation or both, found by measurement of a representative sample and assumed to be characteristic of the whole

3.3 dimensional control

process for controlling dimensional variability

NOTE Dimensional control includes the creation of datums, survey control, as-built surveys, setting out reference lines and grids and the calibration and checking of survey equipment.

3.4 dimensional variability

range of dimensional deviations from a target or reference size, relative position or location resulting from induced or inherent spatial deviations

3.5 induced spatial deviation

dimensional variability in size, relative position or location from a reference or target size due to a manufacturing, assembly or building process

3.6 inherent spatial deviation

dimensional variability in size, relative position or location from a reference or target size due to environmental and/or operational and loading effects on materials and assemblies

[1] Documents that are referred to solely in an informative manner are listed in the Bibliography.

3.7 reference size

spatial dimension, size, relative position or location of something in a design, from which deviations are measured

3.8 spatial deviation

dimensional variability in size, relative position or location from a reference or target size

NOTE Spatial deviation is typically established by a survey measurement as the difference between the desired value and the actual value at a given time when the survey was undertaken. It is to be considered alongside the spatial measurement accuracy.

3.9 spatial measurement

dimensional values established by survey or setting out process

NOTE Spatial measurement is used to quantify an actual size, dimension, relative position or location.

3.10 spatial measurement accuracy

accuracy of a survey measurement used to quantify the possible difference between an actual dimension, size, relative position or location and the measurement value

NOTE Spatial measurement accuracy is typically expressed as a standard deviation value and confidence statistic having a positive or negative affect on the measurement (i.e. ±"N" mm Std dev or ±"N" mm with 68% confidence). See Annex A for guidance on survey measurement and setting out strategy, specification and risk/challenge management.

3.11 spatial tolerance

permissible dimensional variability from a target or reference size, relative position or location

NOTE 1 Spatial tolerance is typically expressed as a lower and upper limit deviation from the reference or target position.

NOTE 2 It is assumed that the permissible dimensional variability is designed within limits which mean the performance requirements of the design can be met in construction and operation.

3.12 target size

spatial dimension, size, relative position, or location of something in a design, from which deviations would ideally be zero

Section 2: Challenges with accuracy and tolerance associated with the fit of elements and components of construction

4 Challenges and examples

4.1 General

Dimensional variability in construction, whether operations are carried out on a construction site or in an off-site environment, can generate issues of performance and fit. Recognizing and addressing this before manufacture and/or construction is critical to minimize delays and expensive remedial measures when the desired objectives in terms of functionality, durability and appearance are not achieved. These performance impacts can be looked at from three perspectives:

a) functionality: structural integrity is likely to be dependent on achieving certain design parameters, for example, fire stopping is dependent on both continuity and fit;

b) durability (longevity): poorly fitting components might accelerate weathering damage such as corrosion by moisture ingress or compromise fire integrity by exposing fragile materials; and

c) appearance: for example, where panel components that are clearly intended to align fail to do so or where a deficient fit creates unsightly staining.

Examples a) to c) are all important and can be cumulative and interdependent but expectations and relative importance can vary, with emphasis shifting depending on the assembly or building operation, the construction elements affected and the type of project. Accuracy and tolerance should be taken into account to balance this relative importance, including implications on adjacent elements, operations, or other matters such as unintended consequences.

Spatial design parameters and tolerance should be specified such that functionality, durability and appearance are achieved and achievable. For construction, dimensional control is required to verify that the specified parameters and tolerances have been met. In cases where tolerances are small on a particular project or in a particular element of construction, for example:

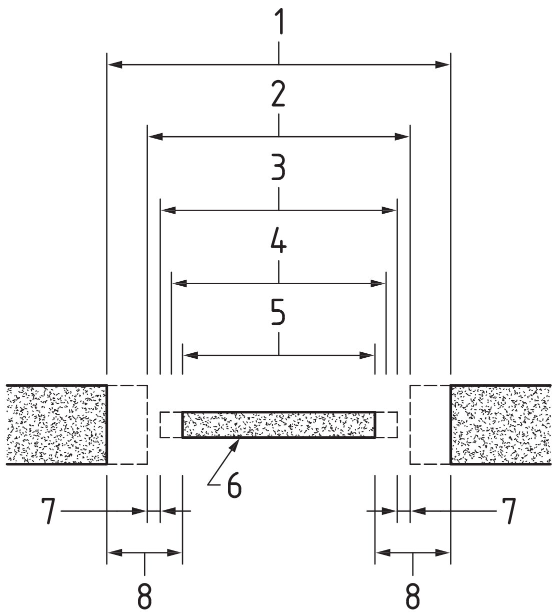
- the casting-in of critical fixings into concrete (functionality); or
- the flatness of a floor finish (longevity and appearance); or
- the gaps between wall tiles (appearance); or
- the misalignment of structural connections for sub-assemblies manufactured off-site, such as roof, floor or wall cassettes (appearance and functionality);

this should be made clear, documented and communicated.

Strategies for managing and mitigating these challenges are critical during the construction stage. For example, one strategy might be to remove as many constraints on fit as possible, perhaps by providing for adjustability of fixing so that fine adjustment of position can be made. Whatever the desired outcome, there should be a planned methodology from factory to site and consideration given to the costs and implications of trying to achieve the design parameters related to spatial fit and performance.

Figure 1 illustrates the principles involved in considering the interaction of components in relation to tolerances and fit. The principle applies in all planes and in relation to location and is often expressed in terms of horizontal or vertical dimensions, shapes, sizes and spaces. Further examples of common issues are given in Clause **6** .

Figure 1 — *Example of dimensional variability aspects in construction of components, spaces and joints*



Key

1	Max. space between components	5	Min. component size
2	Min. space	6	Component
3	Max. component size	7	Min. joint size
4	Target component size	8	Max. joint size

Accuracy reflects the certainty of dimensional control including surveying and setting out. The principle applies in all planes and in all axes in relation to location and spatial dimensions.

Annex A includes some examples of issues associated with these elements of a survey strategy and an example industry table of specifying survey accuracies for spatial measurements for surveying, setting out or verification of as-built tolerances independently of equipment or method used. Table C.3, which was provided to support the original BRE studies of construction accuracy in 1975–76 and 1985–88, is included in Annex C for information purposes only and should not be used as a specification or for current industry norms.

4.2 Strategies for the management of critical issues

The most straightforward way to reduce tolerance risks is to coordinate from a very early stage of a project to ensure that tolerances between related elements are compatible.

Tolerance information (e.g. tolerance values, dimensional and geometric properties of components, tolerance risks etc.) should be communicated between stakeholders with the aim of ensuring that components fit and function properly.

Tolerance risks can be mitigated with effective identification, planning, communication, collaboration, coordination and control.

4.3 Identification

Tolerance requirements should be captured at early project stages.

The class of tolerances applied to tolerance requirements should be selected with the aim of ensuring stability and serviceability.

Connections with a high risk of tolerance problems should be identified in the early project stages.

Tolerance risks with potentially negative effects on dimensional and geometric accuracy of components and assemblies and their functions should be proactively identified.

The severity of tolerance risk should be estimated using qualitative, quantitative or semi-quantitative approaches.

4.4 Planning

Solutions to mitigate tolerance risks, especially tolerance risks with high severity, should be generated based on factors such as site conditions, labour availability/skills, schedule constraints, incurred costs, manufacturability, etc.

Tolerance values should be collected from appropriate reference documents, manufacturers, designers and contractors.

Realistic tolerance values should be specified based on the capability and competence of manufacturing and construction teams to obtain a certain level of accuracy, consequences of tolerance risks, cost of manufacturing and construction.

Tolerance analysis should be performed, including scenarios with maximum and minimum ranges.

The impact of combined deviations on components and sub-assemblies should be evaluated (serviceability analysis).

The sequence of assembly process and its impact on the geometric accuracy of components and sub-assemblies should be determined.

The compatibility of the specified tolerances of adjoining components in sub-assemblies should be checked (tolerance coordination).

The measurement plan which includes information such as the accuracy of the survey process, the responsibility to verify deviations of components with the specified tolerances, and the list of specified tolerances should be prepared and communicated with parties.

4.5 Communication

Tolerance information (e.g. permitted deviations, used reference documents, prepared measurement plan) should be communicated clearly between designers and construction teams via specifications, drawings and other means, as appropriate, including digital data exchange.

4.6 Control

Deviations achieved on-site should be measured and their impact on the performance requirements should be assessed.

5 Digital technology considerations

5.1 General

With the application of BIM (building information modelling) processes, the importance of accurate survey information using an agreed project grid to coordinate design and construction, and the dimensional control for setting out and verification of as-built positions should be recognized and defined from the earliest stage of the project and throughout the life cycle to hand over and operation. This requirement should be included in the employer’s information requirements or exchange information requirements (EIR) and the supplier’s BIM execution plan (BEP), as well as in specifications and scope for surveying and setting out works and monitoring/assurance checks. Where BIM processes are not being formally applied, this information should be included in relevant appointment documentation, including the information standards, the information production methods and procedures as well as scopes of work.

The level of graphical and non-graphical detail required during different design development stages, from concept to detailed design, can impact spatial accuracy and tolerance management in design. Accordingly, a building designed within a 3D environment should allow for maturing of spatial tolerances as a design maturity grows.

Although the terminology is evolving, digital information creation for design and construction introduces requirements to specify the level of graphical information needed for a design at different stages of development. At the detailed design and construction handover stage this information can be at its highest and can start to include information for future operations and maintenance.

Where BIM processes are utilized on projects, the BEP should address how identification, planning, communication and control of tolerance risks can be achieved. BIM approaches can also be used to design out potential accuracy and fit issues prior to manufacture and test the tolerance management plans and setting out strategies within the context of the planned build sequence.

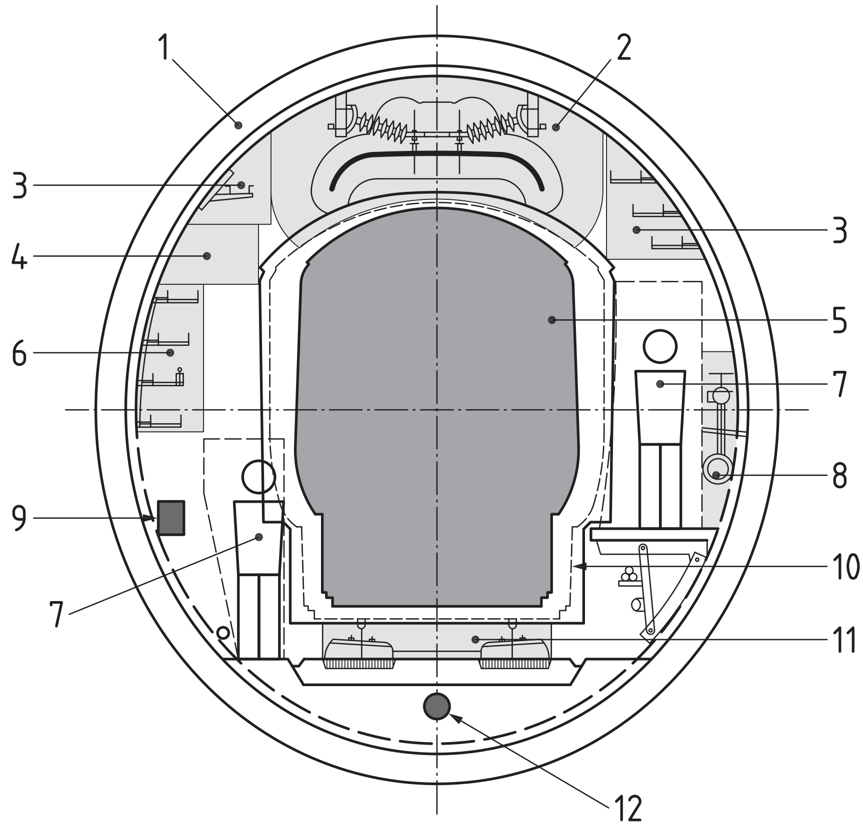
5.2 Examples

It is possible using BIM processes to combine the structural frame with the curtain wall design models to establish any spatial coordination issues during the design supported by software applications. In this example, maximum “out of tolerance” of the structure can be established to assist in the façade design, especially where the façade and structure are complex shapes where 3D modelling can, for instance, accurately position support brackets on the primary structure and eliminate design issues before fabrication commences.

Although the use of advanced measurement techniques in manufacture and on-site, e.g. laser scanning, and using precise methods of production, such as robotic assembly, can bring about improvements, dimensional and geometric variations can still be problematic due to the underlying issue of discrepancies between precise factory-made components and large site tolerances, as well as geometric effects due to building movement.

Design processes, methodologies, specialist software and relevant standards can enable project stakeholders to define exacting and precise design and construction tolerances. These can then be validated through clash avoidance/detection and co-ordination processes within software applications, as well as the application of a volume strategy which allocates spaces and buffer areas around disciplines or key elements of designs (i.e. structural frame, service zones). Figure 2 shows an example of a volume strategy used in rail tunnel design.

Figure 2 — *Volumes within a tunnel design for spatial co-ordination*



Key

1	Tunnel structure	7	Emergency walkway
2	Overhead line electrification	8	Water system
3	Electrical system	9	Communications systems
4	Signage	10	Kinetic envelope
5	Train	11	Track system
6	Signalling system	12	Drainage system

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6 Surveying and setting out

6.1 Site survey information

6.1.1 General

Given the complex and sometimes fragmented nature of construction supply chains and the number of disciplines, people's competence measurement processes, tools and systems involved in the design and build process, it is not surprising that issues arising from dimensional control in surveying and setting out accuracy are common. Risks and issues need to be managed effectively, otherwise they can easily manifest into quality, performance and programme issues with adverse consequences.

One of the first criteria of any building or construction project is to assess the existing site information, spaces, features and potential constraints where the works are to be constructed. These constraints can include existing boundaries, buildings and other visible features, as well as less visible features such as underground services and geology, and invisible features such legal boundaries and planning constraints (e.g. land ownership, rights of way, wayleaves, right to light, regulated distances, spaces or heights). Environmental constraints such as flood risk can be an important input to tolerance requirements for design and construction. Finally, the need to assimilate design into existing facilities or buildings for refurbishment, renovation or renewal creates an early demand for precise information to enable new design and construction spatial requirements to be integrated accurately.

Once the information is collated and combined spatially on a common project grid and coordinate system, the design and construction (including manufacturing) process can commence. The setting out and dimensional control for assembling components on- and off-site needs to be managed throughout the construction process to ensure the project runs as seamlessly as possible.

6.1.2 Examples

Previous editions of this British Standard included details of survey planning and specification, along with survey accuracies for certain types of equipment. Due to changes in technology and digital processing of surveys, it is now preferable to refer to professional body industry guidance on surveying techniques, grids and accuracies and generate a project survey strategy. The following list provides an outline of the principle types of challenges a survey strategy seeks to address.

a) Lack of consistency in survey and setting out coordinates, grids and linear referencing (e.g. chainage).

b) Inadequate accuracy in dimensional control for surveying and setting out (on- and off-site assembly).

c) Poor specification of 3D survey requirements and digital representation of features (over and underground).

d) Poor survey supplier or operative performance and assurance (on- and off-site assembly).

e) Difficulties with undertaking surveys safely or accessing sites and facilities (site hazards and difficult environments).

f) Lack of access or awareness to survey information available (including technology barriers, communication, distribution and notification issues).

g) Lack of understanding or appreciation of survey information usefulness and risk (including lack of understanding of the accuracy, currency and completeness of information).

Annex A provides further information and guidance on the surveying issues and specifications.

6.2 Structural elements

6.2.1 General

Tolerance risks associated with dimensional and geometric tolerance variability (tolerance problems) in structural elements are often addressed on-site during the construction phase of projects using ad hoc strategies and trial-and-error methods. Failure to consider how the combination of geometric changes and tolerances in structural elements which manifest themselves during construction can considerably increase the cost of construction and maintenance, cause delays and increase material wastage if this is not taken into account during the design phase.

No geometrically sized or positioned components absolutely meet their specified size or position. The difference between the actual and nominal dimension is termed a geometric deviation.

Geometric deviations are a manufacturing and assembly issue and are determined by the accuracy with which individual elements in the overall structure are manufactured and how accurately they are brought together on- or off-site.

Geometric deviations include deviations relating to specific geometric size or position (e.g. floor thickness, length of beam, etc.) and deviations relating to specific geometric properties (e.g. flatness of concrete slabs).

Geometric changes in structural elements occur over time as a result of deflection, drying shrinkage, temperature effects, foundation movement, or other factors.

To design a structure that is fit for the use for which it is intended, and is compatible with the associated building fabric, the designer should take into account:

a) the geometric changes associated with the structure, and individual structural elements, due to actions (e.g. forces applied to the structure), material properties and geometry; and

b) the permitted geometric deviations for the structure, and individual structural elements, related to the manufacturing and construction of those elements.

Geometric changes should determine the difference between the initial and final position of any relevant points on structural elements, such as node points, and should take into account any free movements allowed by the structure, such as bolt slip in oversize holes of steel connections.

The designer should define limits for both the geometric changes (e.g. deflection limits) and the geometric deviations (e.g. geometric tolerances) in response to the intended function of the structure. Geometric deviations are different, and additive to, geometric changes.

Different limits for geometric changes (e.g. deflection limits) might be required to suit different building uses, or at interfaces between the structure and non-structural components (e.g. cladding, panelling units, pipework, lift well, stairwell).

6.2.2 Examples and typical issues

Figure 3 illustrates how the combination of geometric changes and geometric deviations should be taken into account by the designer to define appropriate limits compatible with the associated building fabric. The example in the figure relates to the design of a structural edge beam supporting a cladding mullion on a cantilevered angle bracket.

The final position of the mullion support(s) compared to its nominal position would need to take into account:

a) the vertical deflection of the new edge beams from the applied loads (geometric change);

b) the vertical deflection of the angle brackets due to applied load (geometric change);

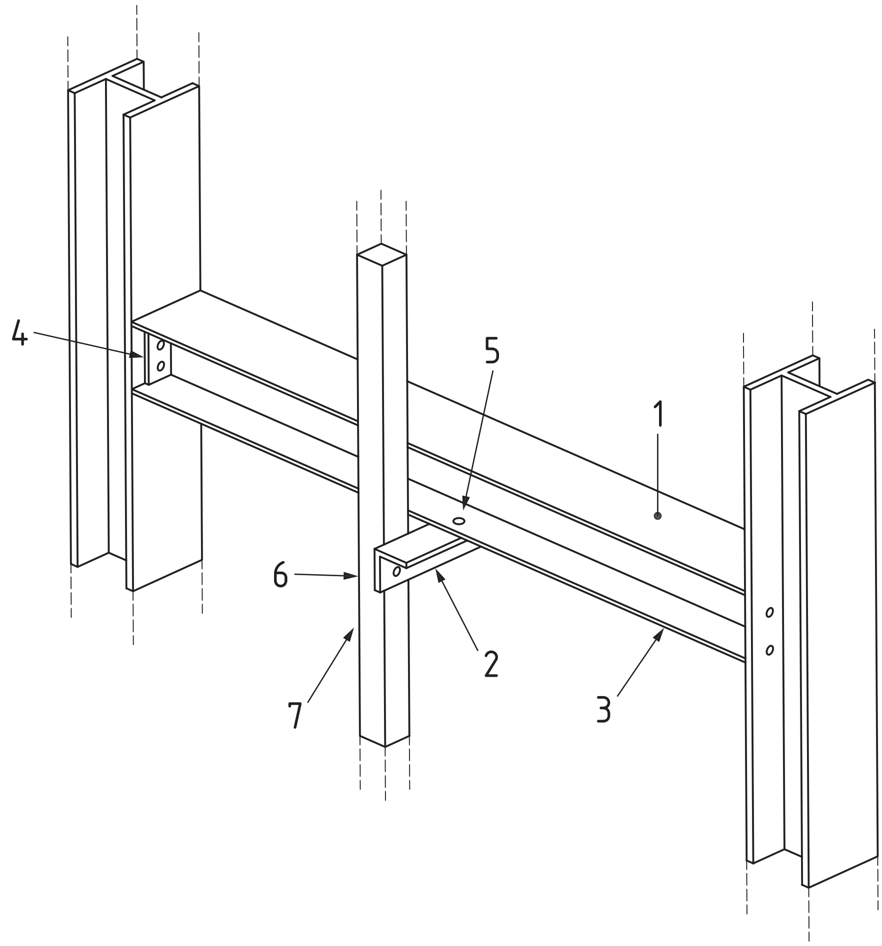
c) the rotational deflection of the new edge beams due to the eccentric nature of the loading on the edge beam (geometric change);

d) the geometric tolerance of the position of the new edge beam (which might require consideration of the geometric tolerance of the supporting columns) (geometric deviation);

e) the geometric tolerance of the holes between the angle brackets and the new edge beam (geometric deviation); and

f) the geometric tolerance of the holes between the angle brackets and the mullions (geometric deviation).

Figure 3 — *Example of interface tolerances between edge beam and cladding*



Key

1	New edge beam	5	Geometric tolerance of the holes between the angle bracket and the new edge beam
2	Angle bracket	6	Geometric tolerance of the holes between the angle bracket and the mullion
3	Rotational deflection of new edge beam	7	Mullion
4	Geometric tolerance of the position of the new edge beam		

6.3 Cladding and façades to external walls

6.3.1 General

The failure to take into account the tolerances and the potential out of vertical alignment of the primary structure, such as a steel frame, concrete frame and brick or blockwork backing wall, can result in either the unitized or stick system curtain walling system clashing and causing installation issues. The dead load and live load deflections should be taken into account in the design as this can cause issues such as buckling, slippage, misalignment and excessive movement of the façade causing joints to open or close and ultimately not allow the system to drain properly and keep the curtain wall water and airtight.

Non-load-bearing external walls should be isolated from movement of the supporting primary structure to eliminate the risk of inducing/transferring loads into them which they have not been designed to accommodate. Loads such as wind and thermal in the external wall should be able to accommodate expansion and contraction against the structure, which can impact on accuracy and fit issues between joints and junction areas.

Cladding which presents unbroken planes needs special care. Brackets, fixings, supporting nibs and ties should allow not only for deviations in floor edges, beams and columns at one level but also deviations of adjacent slabs and columns and those across the whole façade as these affect local and overall accuracy of the wall.

Deviations to be taken into account should include those arising from transfer of reference marks vertically and horizontally, setting out the façade from the reference marks and alignment of floor edges and columns. The total effect should be assessed statistically.

With systemized wall construction, the components should be positioned to achieve the required overall length and required elevation relative to each floor. Deviations of elevation are greater where the wall is standing on the ground floor slab rather than hung from the primary structure at each storey. Penetrations through the wall arising from external features such as balconies, external structural members, external lift wells and ventilation openings have deviations (and tolerances) associated with them that should also be taken into account.

Support bracketry fixed into either cast insert in masonry or concrete or hole and plate provisions in primary steel should be designed to accommodate the potential "out of tolerance" structure. Holes in steelwork can be designed to be slotted, façade brackets can be designed to be adjustable in different orientations. It is critical to design to worst case "out of tolerance" of the primary structure and this normally can be established by fully understanding the movement and tolerances report of the primary structure including erection tolerances of steel and concrete frames. The *National structural steelwork specification* [1] and *National structural concrete specification* [2] are often referenced and used as a basis to develop a project-specific movement and tolerances report. On some projects there is the opportunity to survey the as-built structural or supporting frame before manufacture of the external wall; however, it is likely that modern curtain walls on new build projects have very long design and fabrication lead times and therefore have to be designed and procured well before the structure is built. This can lead to larger adjustable connection details which should be carefully designed such that the façade is installed in the design intent position. On more complex structures and façade interfaces, the primary structural tolerances might have to be tighter than the allowances normally permitted in the *National structural specifications* [1, 2] but this can sometimes incur additional costs to meet the desired architectural intent if not captured and addressed early in the design.

6.3.2 Two cladding scenarios to a primary steel structure

6.3.2.1 Scenario 1: Walls mounted outboard of the primary structure

For out-of-plane fit, fixings and brackets should be provided with a range of adjustability at least equal to the total range of expected deviation. If ultimately fixings and brackets have to be modified to enable construction to be executed, it is normally easier to design an extended bracket than to resolve a clash. It is good practice to design walls with a clearance between the wall and the primary structure to reduce the risk of the primary structure elements intruding into the cladding zone.

For in-plane fit, joints should be designed to allow adjustment in plane to achieve the required overall length to fit across adjacent floors and be tailored around penetrations. It should be anticipated that these joints might be required to permit movement and also accommodate deviations with the adjoining primary structure as constructed which, when merged, can allow any specified movement to take place without failure of the system.

6.3.2.2 Scenario 2: Walls mounted within the primary structure

It is common practice to construct a wall as a stud or SFS (structural framing system) back wall positioned between floor slabs and clad with a sheathing board and supporting an external surface of panels, brickwork or render.

The ability to adjust the plane of the surface relative to the back wall depends on the exact form of façade construction and might be severely limited, particularly in the case of a render finish direct to insulation.

The allowable deviation of the stud or SFS from the slab edge should be taken into account. These are normally designed with a nominal projection over the slab edge; this can be reduced or extended to accommodate deviations in the positions of the floor edges, but this adjustment is often insufficient to fully accommodate the deviations. Ultimately, an SFS back wall can be supported off the floor edge on additional brackets.

The floor slab should not project so far forward that it prevents the correct installation of sheathing boards. It should be taken into account that cavities are required to hold the specified thickness of insulation, and a drained and ventilated cavity of the specified depth is required behind a rainscreen. Similar considerations apply to walls constructed of blockwork, brickwork or stone supported on the slab edge or on a shelf bracket mounted on the slab edge.

6.4 Concrete floors

In deriving the levels for a structural floor, the specified minimum thickness of in-situ flooring is applied over the highest point of the structural floor (see Figure 4).

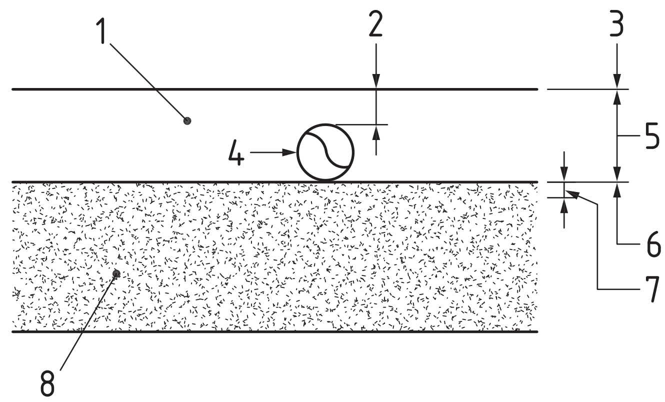
As types of flooring of differing thicknesses can occur in adjacent areas of the same floor, the finished floor level is normally taken as the datum.

The thickness specified should allow for deviations from the designed structural level, for deflection and for the effect of dead load on camber as well as for conduits, ducts, crossovers and junction boxes.

The tolerance for flatness needs to include both the construction methodology and the structural creep over the design life of the building to enable the performance to be maintained (e.g. the appearance of sensitive floor coverings, or the verticality of equipment positioned directly on the floor).

Recommended tolerances in the surface finish of in-situ floorings are given in BS 8204-1 for surfaces to receive a covering and in BS 8204-2 for concrete wearing surfaces.

Figure 4 — *Diagrammatic section showing screed accommodating trunking and range of deviations involved*



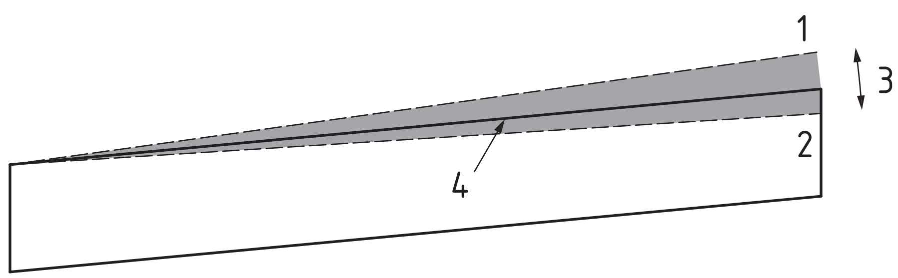
Key

1 In-situ screed floor
2 Minimum cover requirement
3 Finished screed level
4 Trunking
5 Target thickness of screed = minimum thickness required + diameter of trunking + deviation in level of structural slab (see Table 1)
6 Structural floor level
7 Range of deviation of structural slab
8 Structural floor slab

6.5 Flat roofs

Flat roofs should be designed to allow water to drain while avoiding the risk of ponding. Required designed falls should be calculated to allow tolerance for the compounded effects of deviations in the level caused by any element of the supporting construction, deflection of the deck and potential structural movement over the design life of the building. Figure 5 shows the type of tolerance specification for a fall or slope of roof that still retains its required performance requirements (e.g. gradient tolerance to distribute rainfall from surface at a required rate, or minimize risk of ponding due to deflection).

Figure 5 — *Sloped floor with tolerance expressed in gradient variation*



Key

1 Maximum gradient of fall
2 Minimum gradient of fall
3 Overall tolerance of gradient
4 Fall as designed

6.6 Lift wells

NOTE Lift wells are also known as lift shafts.

6.6.1 General

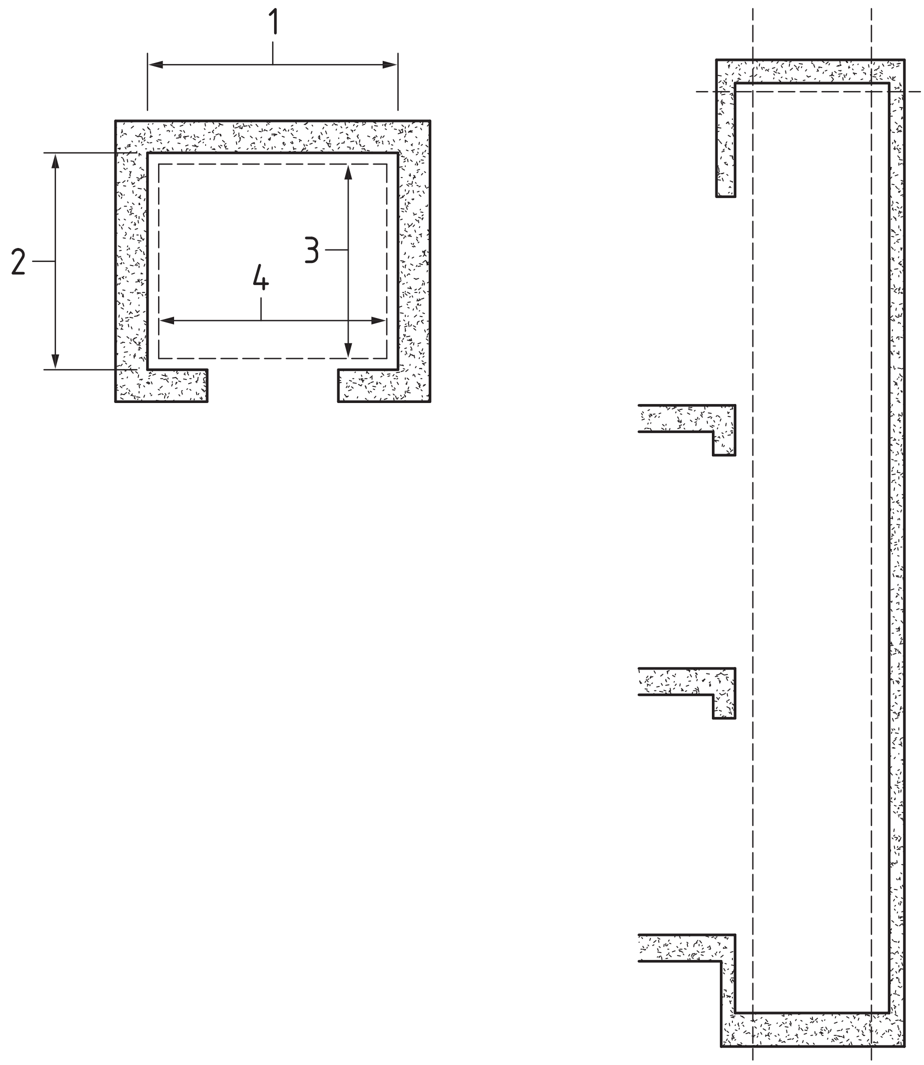
Lifts need to move vertically through a building, and the car and landing door equipment are a critical interface. Therefore, the plumbness of the well and the alignment of the landing openings are of paramount importance. It is also important to build the well to a high degree of verticality, i.e. plumb. Decreased dimensions are likely to result in the lift not being able to be installed.

Lift well dimensions are specified in standards such as BS 5655-6 and BS ISO 8100-30 with a zero negative tolerance and a positive tolerance to reflect this need. See Figure 6 for guidance regarding the specification of sizes for lift wells.

Lift well dimensional tolerances used for initial planning should be no greater than those in BS ISO 8100-30. Once the requirements of the lift installer are known, lift well dimensional tolerances should reflect the requirements of the lift installer.

Figure 6 — *Target sizes of lift well*

Dimensions in millimetres



a) Plan of lift well b) Section through lift well

Key

1 Target size (Ww + 15)

2 Target size (Wd + 15)

3 Min. size (Wd $^{-0}_{+30}$)

4 Min. size (Ww $^{-0}_{+30}$)

Ww Lift manufacturer's minimum lift well width

Wd Lift manufacturer's minimum lift well depth

NOTE 1 Lift manufacturers sometimes specify the sizes of the lift well with the tolerance expressed in the form $^{-0}_{+30}$ *. Since actual sizes are, for practical purposes, distributed equally about the target size (see Annex C) it follows in this instance that the target size for the length and width of the lift well is minimum size +15 with a tolerance of ±15.*

NOTE 2 These values are included by way of example and are not project or asset type specific, which are confirmed by the designer and manufacturer.

6.6.2 Examples and typical issues

In forming the structural openings in concrete walls to lift wells, allowance for masking or packing should be provided to enable doors to be aligned vertically with each other in elevation, by increasing the width and height of the openings, and by reducing the size by means of packings after the doors have been located correctly.

Since door openings might not line up one above another in section through the well, adjustments should be allowed for in the width of linings to jambs to mask inaccuracies. As the height of the lift well increases, the difficulty in getting door openings to line up one above the other increases also; therefore, in lift wells higher than 60 m, the width of structural openings to receive lift doors should be increased by an appropriate amount (see Table C.1).

It is important to facilitate the alignment of landing sills; one way of doing this is by providing, at each landing, an independent threshold, the position of which can be adjusted.

To achieve integrated fire protection of the lift landing door entrances (including any architraves) and the structural opening of the lift well front wall (brick, blockwork, concrete, etc.), it is very important that clearances between the lift entrance and the structural opening, above, below and to the sides of the lift entrance, are maintained within the limits supplied by the lift installer.

6.7 MEP services

6.7.1 General

6.7.1.1 Pipework

Deviations occur in the manufacture of pipework and conduit assemblies and in the location of inlets and outlets connected to the structure. The in-situ connection should be designed to accommodate the predicted total of deviations from all sources and this can include off-site manufactured assemblies.

6.7.1.2 Ductwork

The sizes of apertures for ducting, including allowance for insulation, joints, flanges, junctions, crossovers, firestops, valves and fixing lugs, should be detailed by the designer.

The order of installation and the space needed for access to install, operate and maintain equipment should be taken into account. When insulation is to be applied to the duct after installation, sleeves should be inserted at the point where the ducting passes through the structure. Tolerances specified for the sizes of the openings to be left should allow ventilating grilles or diffusers to be fitted and for flanges to mask the joints and/or packings.

6.7.2 Example

6.7.2.1 Piped supply functions

The pipework for piped supply systems can have manufacturer’s fabrication variances that should be taken into account.

It is usual practice to run pipework together in banks; therefore, as well as the manufacturing tolerances, the bracketry and wall/floor transits (for making good or fire stopping) should be accounted for. Bends, valves, automatic air vents (AAVs), pipe/fire collars and insulation with their associated tolerances should also be taken into account.

6.7.2.2 Electrical power and lighting functions

Electrical power distribution is usually carried out by cabling individually run or in multiple runs on/in containment (i.e. cable basket/cable tray or ladder/conduits/trunkings).

These various types of cable and containment types come in several sizes and profiles, each with respective manufacturer's tolerances, and the proposed installation method(s) and their associated accessories (e.g. clips, saddles, bracketry, flanges, bends, tees, crossovers etc.) and how they fit within the building structure should be taken into account.

Installations through walls/floors might need transits for making good or fire stopping.

Outlets and accessories in the majority of instances require recessing (or semi-recessing) and by the nature of their relative size the tolerances required are small. However, careful consideration of the mounting box depth is required and its impact on the integrity of the structure strength once the recess is formed.

Lighting installations might require recessing (or semi-recessing) into the structure. In these instances, tolerances are required for the body of the luminaire with the flange or bezel of the fitting masking the opening.

6.8 Windows, doors and panelling units

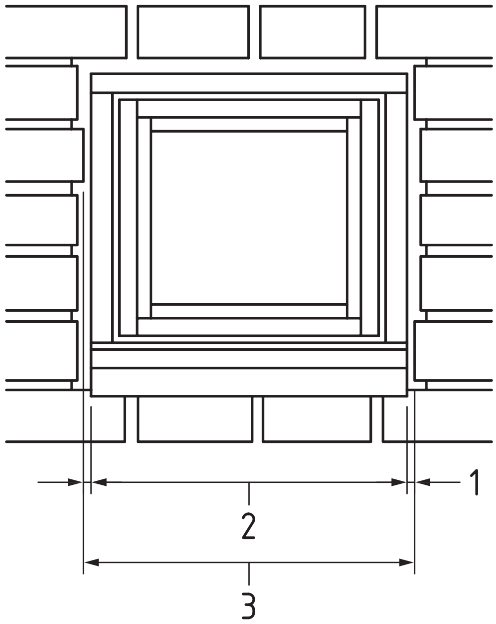
6.8.1 General

Windows, doorsets and panels are generally installed into pre-formed openings that can be formed with greater precision by using jigs or templates. Any inaccuracies in the openings should be allowed for in the sizing of the component taking into account the width of joints between the component and the surrounding structure. There should be sufficient clearance to allow the window, doorset or panel to be positioned without distortion, to allow for any in-service thermal movement where required, and to enable the joint to be sealed against the ingress of air and water. Additional considerations might be needed for fire doors. Where the widths of the joints become too wide, they should be masked by cover strips. Overlapping joints, e.g. where a window is installed behind the face brickwork, can accommodate inaccuracies but variations in the visible margins around the component, e.g. window jamb, might be more apparent and therefore less acceptable than wide joints. See Figure 7 and Figure B.1 to Figure B.3 in Annex B for tolerance interfaces in window openings.

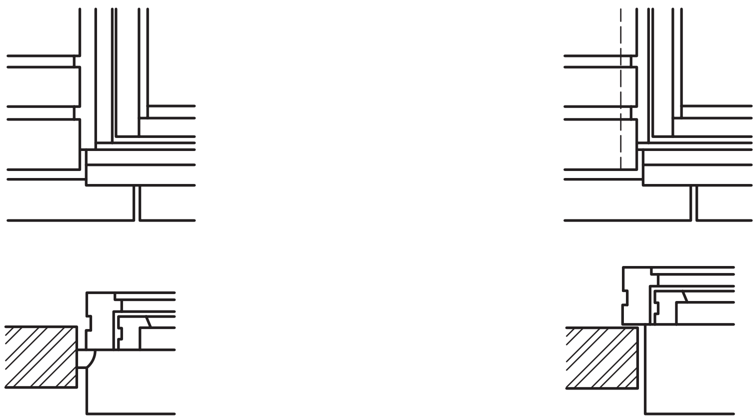
6.8.2 Examples and typical issues

It is also challenging to control structural tolerances where these are not formed before window and door manufacture needs to commence due to long lead times and the programme does not allow for site surveys and measurements to be taken. The design should be coordinated such that the jointing around the perimeter can be detailed to accommodate the as-built structural openings, the window manufacturer's tolerance and the aesthetic and functional requirements of the installation. Figure 7 shows interface options which might allow the aesthetic impacts of tolerances to be resolved.

Figure 7 — *Window opening and frame to wall interface variations*



a) Window elevation and fit



b) Gap masked by cover strip

c) Window behind face brickwork

Key

1	Installation clearance	3	Minimum opening width
2	Frame width		

6.9 Prefabricated partitions

6.9.1 General

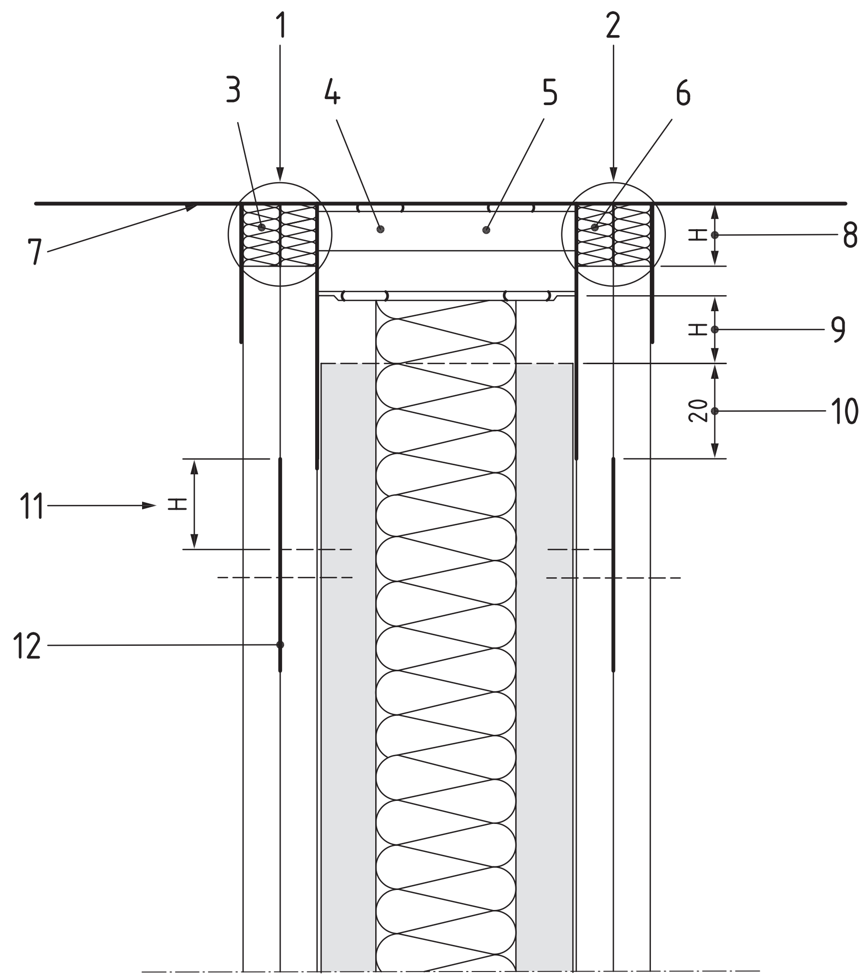
When partitions are to be fitted between previously constructed items, problems of fit can arise. It should be determined that the particular system specified can accommodate any tolerance in the floor and ceiling level and is capable of maintaining the performance requirements specified for a particular project. Small openings such as gaps, cracks or holes can compromise fire integrity and conduct airborne sounds, significantly reducing sound insulation.

6.9.2 Example

Deflection heads (see Figure 8) in partition systems might be required when there is a need to allow for movement (up, down or both) within the structure at the head of a partition.

Where appropriate, tested and robust detailing should be implemented. All detailing should accommodate the predicted total of deviations in the structure, adjacent components and in the partition.

Figure 8 — *Example section of deflection head, standard head and sole detail*

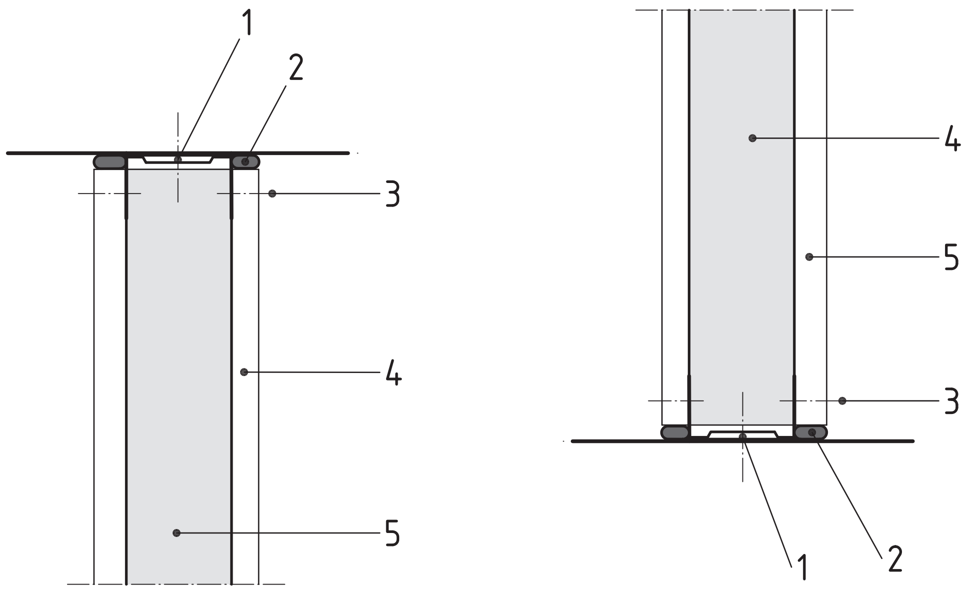


a) Deflection head

Key

1	Mineral wool and cloaking angle	8	Boards cut short of soffit by deflection amount
2	Intumescent acoustic sealant	9	Studs cut short of track by deflection amount
3	Rock mineral wool	10	Minimum 20 mm overlap of stud and track
4	Packers cut precisely to track width	11	Allow deflection amount as minimum between track and fixing
5	Use head deflection table to select packers	12	Screw fix flat strap between outer board layer and substrate
6	Intumescent acoustic sealant		
7	Cloaking angle		

Figure 8 — *Example section of deflection head, standard head and sole detail (continued)*



b) Standard head c) Sole detail

Key

1 U Track fixed at max. 600 mm centres
2 Intumescent acoustic sealant
3 Screw fix plasterboard to track
4 Board to suit required performance 5 mm shorter than floor to ceiling height
5 C Stud cut 5 mm shorter than floor to ceiling height

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6.10 Stairs

6.10.1 General

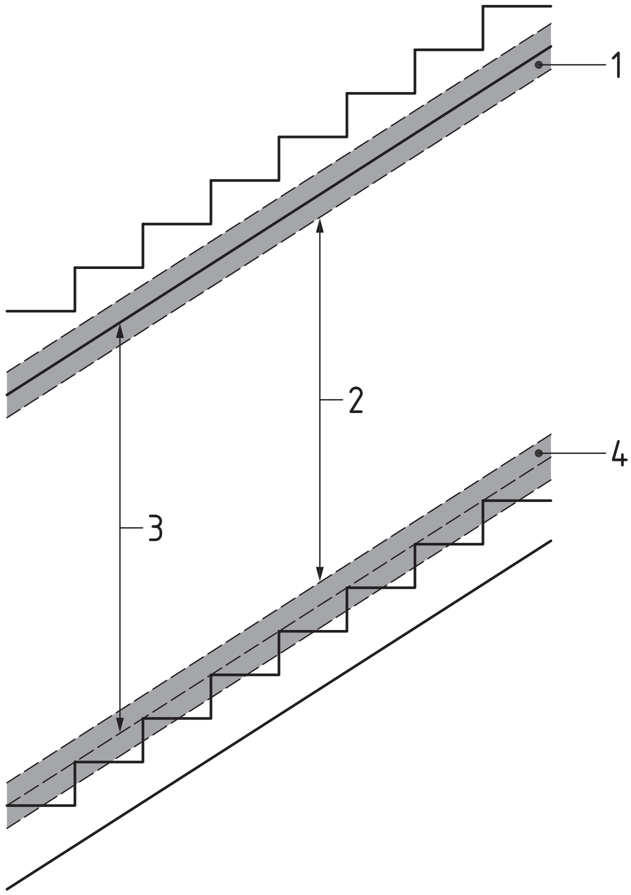
Staircases typically contain off-site fabricated elements. The overall achieved tolerances of the installed staircase are affected by the tolerances of the in-situ work and the manufacture tolerances of the stair. The structural and architectural design should take into account problems of fit in particular in relation to floor openings and storey heights, as well as the vertical tolerances of any adjacent walls. In some cases, floor deflection might be a consideration.

6.10.2 Examples

Stairs made of in-situ concrete typically require screed to achieve an acceptably even rise and going (depth of step).

To achieve key design dimensions, the compounded effect of a range of tolerances should be taken into account. In relation to headroom, lateral tolerances of stair placement (in the direction of the stair) are amplified by the tangent of the angle of the stair as shown in Figure 9.

Figure 9 — *Staircase headroom*



Key

1 Tolerance allowance relating to soffit

2 Required headroom

3 Designed headroom so that required headroom is achieved

4 Tolerance allowance for stair

6.11 Furniture and fittings

6.11.1 General

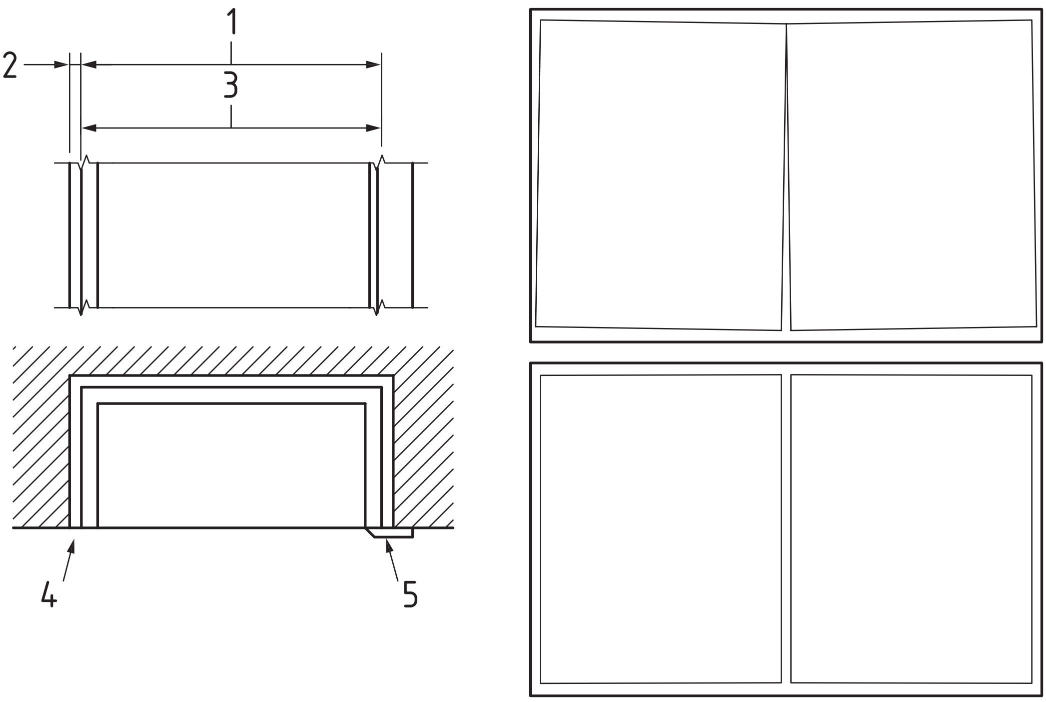
Deviations of the structure into which fitted furniture is to be installed can lead to problems of fit or alignment of carcases. The aesthetics of the furniture, once installed, should not be affected by uneven lines and irregular positioning of supports, shelves or doors.

6.11.2 Examples

When items of furniture are designed to fit between surfaces, e.g. positioned into a recess, sufficient clearance should be allowed to enable the item to be manoeuvred into position taking into account any deviations in the surfaces. The resulting gaps between the item and the surrounding structure might need to be caulked and large gaps might need to be disguised by cover strips [see Figure 10a)].

The fit and alignment of doors can be overcome by mounting them on the face of the carcass and using adjustable hinges. In Figure 10b) the initial install is shown on the top and the adjustment possible in hinge design to align on the bottom.

Figure 10 — *Tolerances and adjustment for aesthetic alignment of cabinet doors*



a) Recess tolerance with cover moulding to conceal b) Adjustment of cabinet doors

Key

1 Minimum width of recess

2 Installation clearance

3 Width of furniture

4 Open gap or sealed

5 Cover moulding

6.12 Flora elements

6.12.1 General

Although landscaping might not previously have been seen as an important construction activity in the critical path, its importance in sustainable development and to successful architectural and environmental performance requirements of construction projects is now recognized and continues to increase. Moreover, planning conditions and exacting articles of national and local planning guidelines and law can mandate certain accommodations in design, for which retention of existing vegetation or amenity planting is delivered, or environmental visual impact is measured and mitigated and reasonable objections to a development are satisfied. Changing climate in recent years has also seen necessary upscaling of drainage infrastructure and the introduction of landscaped sustainable urban drainage systems (SUDS) for residential sites greater than ten units in number. This has introduced landscaped open drainage in SUDS on an appreciable scale and planting schemes in keeping with the maintenance of open drainage and integrated planting with a high social value.

The organic and dynamic nature of planted features – both over and underground – and their potential to impact the built assets raises many important considerations for spatial tolerance in design and construction, as well as constraints related to preservation and conservation, where green assets are already existing.

It is also important to take into account the life cycle of these features: their requirement to grow or be maintained in proximity to other assets and their impact on carbon and other environmental constraints such as natural drainage and geotechnical impact, noise, light and wind.

6.12.2 Examples demonstrating design function and typical issues

6.12.2.1 Tree preservation and environmental management (existing)

A planting specification typically includes a management plan of five years spanning that period of growth and a significant degree of variance. Tree preservation orders imply that protected trees on a site need growth space to be factored into design in the same way that trees planted anew need that accommodation. Collars and frames at floor level or higher need to fit the species, and the surface or feature being protected, and not present a hazard.

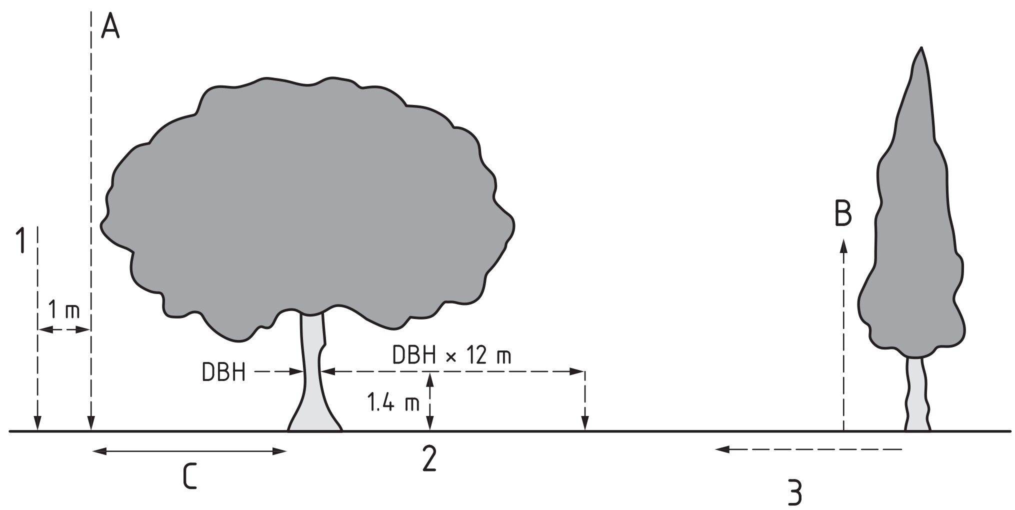
Planting in bulk to deliver a cheap but consistent coverage of the site might mean modular planters and semi-automatic watering systems, so tolerances in both the planter designs and the drainage need to be observed, especially when palleted in large numbers with a wide range of variance in the schema.

6.12.2.2 Classical landscape design

The wrong tolerance for future growth in trees in building design compromises the planting of a large tree (trees) in an internal atrium and the structures around it.

Rights to light can also be compromised by adverse tree planting, which should not be altered from the original design without some assessment of the effects. Fundamental metrics need to be observed for both the tree itself and the environment and visual amenity around it, such as the tree protection zone (TPZ) pertaining to the space that mature trees need to be afforded. See Figure 11 and Figure 12, which relate to the unseen matter of tree roots (structural root zone – SRZ).

Figure 11 — *Calculating the tree protection zone (TPZ)*



Key

1 Method 1: TPZ = Canopy, drip line + 1 m

2 Method 2: TPZ = tree diameter at breast height (DBH) × 12

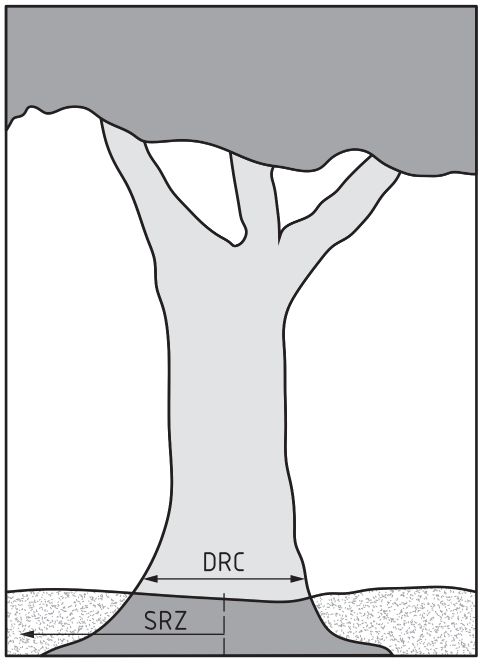
3 Method 3: TPZ = ½ × tree height (for tall, narrow trees)

A Canopy drip line

B Half of tree height

C Canopy radius

Figure 12 — *Calculating the indicative structural root zone (SRZ) of uncontrolled tree roots*



DRC = Diameter above root crown (trunk diameter in metres, measured immediately above root crown or buttress)

SRZ radius = (DRC × 50)^0.42 × 0.64

NOTE The SRZ for trees with trunk diameters (DRC) <0.15 m is 1.5 m.

Individual trees are seen as soft landscape/not structure and are often not measured with the same rigour as hard features. The depth of tree roots is not easily ascertained in respect of retrospective/found asset surveys and damage from subsidence and heave, when they are planted in the wrong place or removed in bulk, can also have consequences.

The drainage pathways around trees are critical for securing lifelong good growth in the first five years after planting in the growing medium and soil integrity through the planting site.

Managing the root bowl development of trees can be designed for with root-training containment systems which require precise placement, as they are often water fed with irrigation pipework systems and planted with the support of underground earth anchor systems first introduced in the mid-1980s. Atypical growth that could not be envisaged in the original design is a possible outcome that can clash with surrounding structures, but a thorough tree specification and species selection, as exhibited in specifiers guides, limits the designed-for issues of fit and suitability for the scheme.

There is a generic formula to inform the indicative structural root zone (SRZ) that should be avoided in works around existing trees and planted trees without root containment systems, commercial root barriers, or naturally occurring root barriers. The SRZ needs to be protected in order that the stability of the tree is not undermined and the tree falls over (see Figure 12).

The healthy growth factor of trees in respect of their surface dimensions is characterized by the tree protection zone (TPZ).

Section 3: Designing to achieve good fit and assembly

7 Dimensional variability and target size

In any production process dimensional variability and deviation from target size are inevitable. The size and shape of buildings or building components seldom, if ever, equal exactly those specified or shown on the drawings.

Inadequate provision in the detail design of tolerances appropriate to the building being designed can create construction and assembly difficulties. These difficulties often lead to unsatisfactory performance and appearance of the building or structure, which can be onerous and expensive to overcome.

Taking a realistic view of the dimensional variability in manufacture and construction assists the process of arriving at details that can be achieved in practice and that avoid details with unnecessary or difficult-to-achieve spatial tolerance requirements.

Experience has shown that practical measures, such as the following, can be taken to avoid common problems.

a) The visual effects of inaccuracies should be minimized; for example, in a run of storey-height panels, each of which might vary in width within the stated tolerances, the position of each can be adjusted on-site to achieve regular joint widths. Uneven joints are far more noticeable than irregular panel sizes.

b) The sizes of timber and structural steel sections are commonly described by nominal values that differ significantly from their work sizes. Design should be based on actual sizes.

c) Fixings that have critical locations should have allowance made in the design and construction for dimensional adjustment and guided alignment (e.g. error proofing in design, manufacture and assembly).

d) Fixings cast in situ or pockets for fixings, such as lift guides, should be avoided as far as possible by using fixings which do not require preformed holes.

e) When constructing tall modular structures, it is important to launch them from a flat and level base with a tight tolerance. For example, a modular stair tower on a concrete foundation might benefit from having an accurately located and levelled frame on the foundation before assembling the constituent modules.

8 Spatial tolerances

8.1 Aims

Spatial tolerances should be determined at the outset of each project so that:

a) the practicality of the design details in relation to fit can be assessed;

b) the appropriate tolerances, reflecting the needs of the design and performance, can be specified; and

c) compliance with tolerances during construction and assembly can be monitored and quality assured and managed.

8.2 Factors affecting spatial tolerances

Tolerances should take account of the following:

a) the character and appearance of the building;

b) the dimensional requirements imposed by regulation or statute;

c) the nature of the proposed construction (traditional or skeletal frame, type of cladding, type of fenestration, building services, etc.);

d) type of details likely to be needed for the proposed construction (façade treatment, jointing systems, waterproofing, finishes, etc.);

e) method of construction (e.g. traditional, high tech, modular, in situ, precast, off-site);

f) induced spatial deviation; and

g) inherent spatial deviation.

8.3 Procedure for specifying spatial tolerances

Tolerances should be specified as follows:

a) identify areas where dimensions are likely to be critical for the satisfactory performance of the design and clearly identify in which direction these tolerances are allowable (e.g. +0 mm/−10 mm for a critical level or height not to be exceeded);

b) choose design details that avoid problems of fit and minimize the number of tolerance constraints;

c) select reasonable and achievable tolerance targets based upon planned methods and expected practice;

d) verify available methods, materials, and techniques for special requirements of fit and assembly;

e) make provision in joints to accommodate the build-up of individual dimensional variabilities;

f) discuss the tolerance requirements in consideration or consultation with all parties involved in the building process as soon as feasible to enable understanding of the design intentions, development of building details and a positive commitment to achieving fit; and

g) explore the DFMA (design for manufacture and assembly) possibilities to remove avoidable tolerances for manufacture of components and adjustment in assembly.

9 Basic information and analysis of dimensional variability

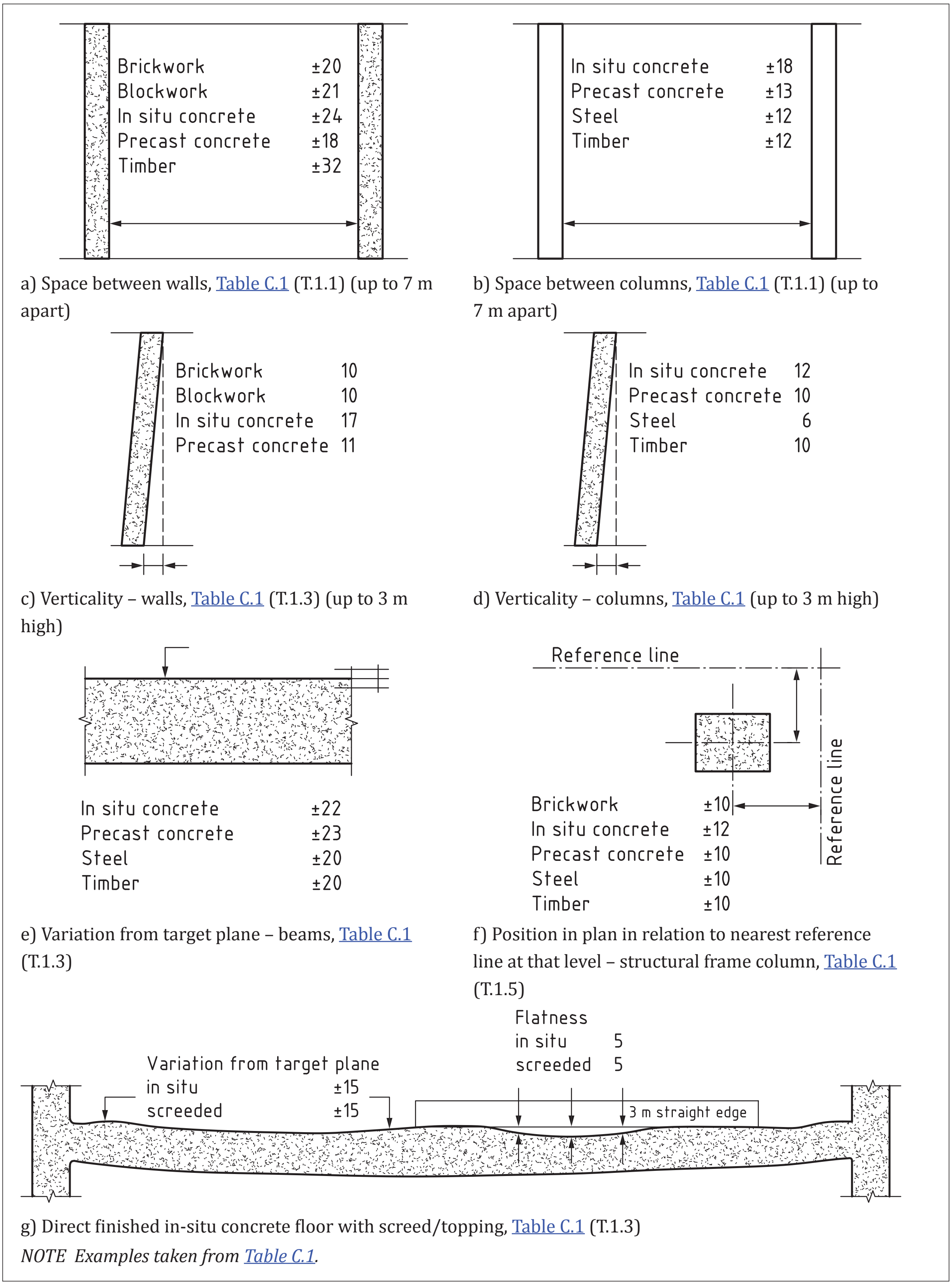
9.1 Range of deviations associated with items of construction

Table C.1 in Annex C gives historical values of a range of dimensional deviations for several items of construction and materials.

These values are from a survey of industry site practice by the BRE in 1975–78 for site construction and from 1985–88 for manufacturing practice and are provided for example only (see notes in annexes). The values include the contributions of all the constituent variabilities in, for example, bow, twist, verticality, camber etc. and are based on the characteristic accuracy values given in Table C.4 in Annex C.

For those items of construction which were not part of the BRE measurement survey, an estimated deviation value is given in Table C.1. Some diagrammatic examples of the range of deviations from Table C.1 are given in Figure 13.

Figure 13 — *Examples of deviation limits associated with items of construction*



a) Space between walls, Table C.1 (T.1.1) (up to 7 m apart)

b) Space between columns, Table C.1 (T.1.1) (up to 7 m apart)

c) Verticality – walls, Table C.1 (T.1.3) (up to 3 m high)

d) Verticality – columns, Table C.1 (up to 3 m high)

e) Variation from target plane – beams, Table C.1 (T.1.3)

f) Position in plan in relation to nearest reference line at that level – structural frame column, Table C.1 (T.1.5)

g) Direct finished in-situ concrete floor with screed/topping, Table C.1 (T.1.3)

NOTE Examples taken from Table C.1.

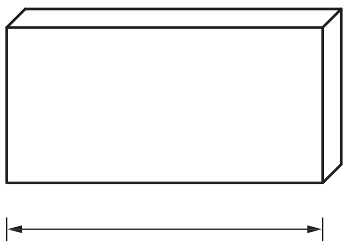
9.2 Range of deviations associated with manufactured components

Table C.2 in Annex C gives values of a range of deviations for several manufactured components and materials historically used in construction. The values assume usual manufacturing techniques, the use of conventional materials of the required quality, current standards of workmanship and the appropriate level of dimensional quality control at the time. These are provided for context and information and do not represent current practice (see notes on annexes).

For those types of dimension which were not part of the measurement survey, an estimated value is given. If no value is given, the information could be obtained from a relevant product/material British Standard where it might be described in terms of permissible (permitted) deviations to establish a spatial tolerance for them.

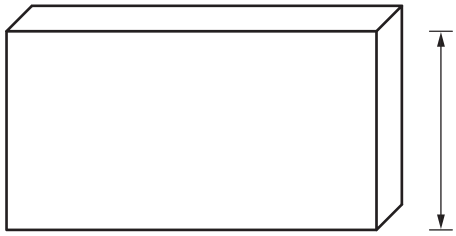
Some diagrammatic examples of the range of deviations from Table C.2 are given in Table 1 to Table 11.

Table 1 — *Overall size: Length [Table C.2 (T.2.1)]*



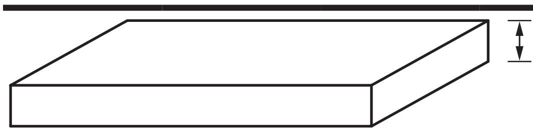
Length measured	**Precast reinforced concrete**	**Precast prestressed concrete**			**Fabricated steel**	**Timber all lengths**
		Stop end plated	**Formed or extruded**	**Inverted T-beams**		
m	mm	mm	mm	mm	mm	mm
Up to 2	±6	±6	—	—	—	—
2 to 6	±9	±9	—	—	—	—
6 to 10	±12	±12	—	—	—	—
Up to 10	—	—	±18	±15	—	—
10 to 20	—	—	—	±25	—	—
20 to 30	—	—	—	±35	—	—
All lengths	—	—	—	—	±5	Frames ±4 Panels ±5 Doors ±3

Table 2 — *Overall size: Width or height [Table C.2 (T.2.1)]*



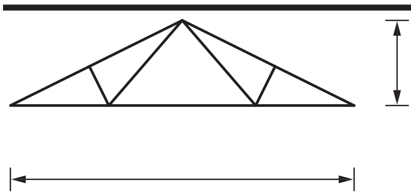
Width or height measured	Precast reinforced concrete	Precast prestressed concrete			Fabricated steel	Timber all strengths
		Stop end plated	Formed or extruded	Inverted T-beams		
m	mm	mm	mm	mm	mm	mm
Up to 0.25	±4	—	—	±8	—	—
0.25 to 1.25	±6	—	—	±12	—	—
Up to 1.25	—	±8	—	—	—	—
1.25 to 4.00	±8	±14	—	±16	—	—
All widths	—	—	±8	—	—	Frames ±4 Panels ±4 Doors ±3

Table 3 — *Overall size: Thickness or depth [Table C.2 (T.2.1)]*



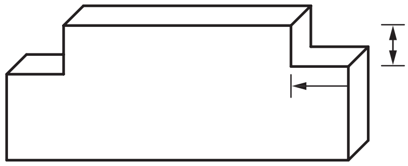
Thickness or depth measured	Precast reinforced concrete	Precast prestressed concrete			Fabricated steel	Timber all lengths
		Stop end plated	Formed or extruded	Inverted T-beams		
m	mm	mm	mm	mm	mm	mm
Up to 0.50	±6	±7	±10	±6	—	—
0.50 to 1.5	±8	±7	±10	±6	—	—

Table 4 — *Overall size: Length and height to apex: Timber roof trusses*



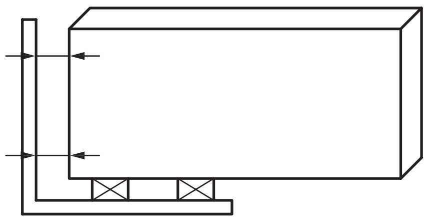
Type of dimension measured	Deviation
	mm
Length	±15
Height to apex	±6

Table 5 — *Shape: Position and size of cut outs and extensions [Table C.2 (T.2.2)]*



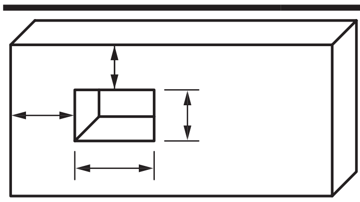
Cut outs measured	Precast reinforced concrete	Precast prestressed concrete		
		Stop end plated	Formed or extruded	Inverted T-beams
m	mm	mm	mm	mm
Up to 0.50	±6	—	±17	±17
0.50 to 10	±12	—	±17	±17

Table 6 — *Shape: Squareness [Table C.2 (T.2.2)]*



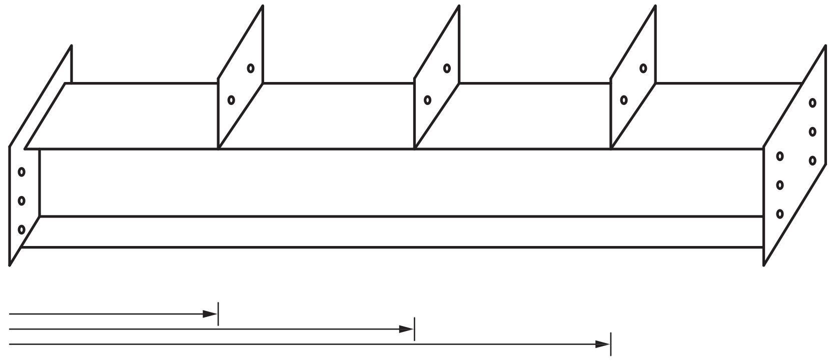
Type of dimension measured	Deviation	
	Precast reinforced concrete	Precast prestressed concrete
	mm	mm
Squareness	±6	±12

Table 7 — *Shape: Internal holes [Table C.2 (T.2.2)]*



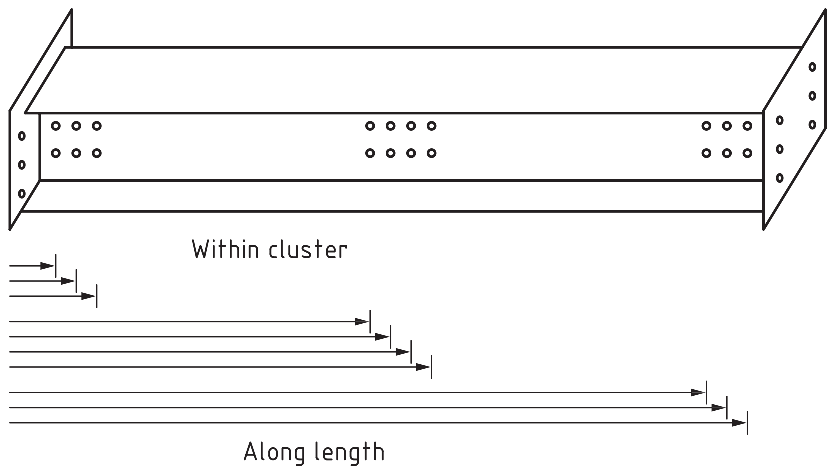
Type of dimension measured	Precast reinforced concrete	Precast prestressed concrete	Timber frames and panels
	mm	mm	mm
Internal holes	±15	±15	Door ±5 Windows ±5

Table 8 — *Connections: Position of cleats or fixing plate [Table C.2 (T.2.3)]*



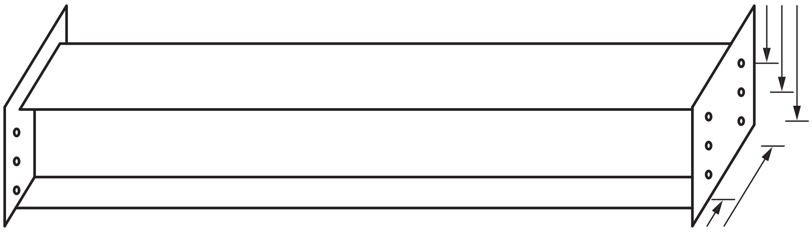
Position of cleats or fixing plates measured	Precast reinforced concrete	Precast prestressed concrete	Fabricated steel
m	mm	mm	mm
Up to 2	±6	±9	±5
2 to 10	±14	±18	±5

Table 9 — *Connections: Position of centres of bolt holes [Table C.2 (T.2.3)]*



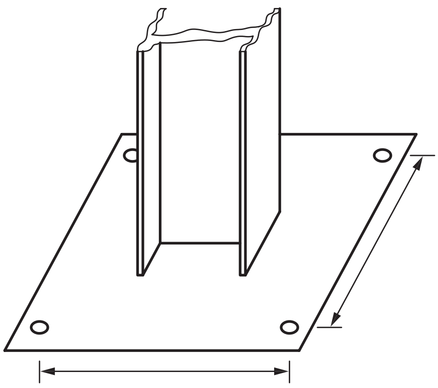
Type of dimension measured	Precast reinforced concrete	Precast prestressed concrete	Fabricated steel
	mm	mm	mm
Along length	±9	±11	±5
Across width	±9	±11	±3
Within cluster of holes	±3	±3	±2

Table 10 — *Connections: Position of centres of bolt holes within welded end plates [Table C.2 (T.2.3)]*



Type of dimension measured	Fabricated steel
	mm
Along length	±4
Across width	±4
Within cluster of holes	±2

Table 11 — *Connections: Position of centres of bolt holes [Table C.2 (T.2.3)]*



Type of dimension measured	Fabricated steel
	mm
In relation to other holes	±4

9.3 Range of deviations associated with setting out and measurement processes

Setting out can involve making linear and angular measurements, controlling verticality and establishing and transferring horizontal and vertical datums, control points and grid lines. For each of these tasks the accuracy achieved depends both on the measuring instruments and ancillary equipment used, as well as on the knowledge, skill and conscientiousness of the parties responsible for setting out and quality control.

Frequently there are a range of measuring instruments which can be used for the task with differing accuracy capabilities. The instruments and process of measurement chosen need to be of a higher order of accuracy than the tolerance being verified.

Annex A contains an example table of how to specify survey accuracies regardless of instrument or technique user (i.e. performance specification).

Table C.3 in Annex C indicates the range of deviations which were including in the BRE historical (1970s and 1980s) study of accuracy in the use of measuring instruments (available at the time) assuming reasonable care was exercised. The accuracy of survey instruments should be checked periodically in accordance with BS 7334 (all parts).

The accuracy of reference lines, points and levels, which in practice are used to set out features and verify tolerances, should be determined in combination with the equipment accuracy examples in Table C.3 and Annex A, to establish if actual tolerances of built features have been achieved. This includes the site surveying control grid accuracy. This is because the accuracy of survey measurements needs to be higher than the tolerances being measured to verify the tolerance has been achieved. Establishing how much higher depends on the size of the tolerance and confidence needed to prove it has been achieved [i.e. 68% (1 sigma), 95% (2 sigma), 99.7% (3 sigma) etc.] and this should be part of the specification.

9.4 Range of deviations associated with inherent spatial deviations

Inherent deviations result from the physical properties of the materials used and include thermal movements, moisture movements, elastic deformation due to both dead and applied loads, e.g. deflection, creep.

These inherent deviations can be reversible or irreversible and appropriate provision should be made for these movements when they are significant.

The provision for these movements depends on the design concepts, joint details, materials for construction involved and their predicted behaviour as well as the sequence of construction, particularly in vary large structures and tall buildings where variance can occur during assembly (e.g. coaxial shrinkage and foundation settlement).

10 Assessing the dimensional needs of a design

10.1 General

The spatial tolerance appropriate for design components or assemblies can vary considerably and should take into account the following scenarios.

a) For sophisticated structures which have sensitive alignment or positional requirements, a complex or constrained process of assembly, a high performance visual or functional need, it is important to resolve all problems concerning tolerances and fit in advance. This might entail the construction of a full-scale mock-up to prove the design and make reasonable provision for variability at critical interfaces. The cost of this exercise should be balanced against the cost of the consequences of lack of fit and/or delay.

b) Where components are combined, the effects of the dimensional variability of the separate components and the connections that go into making up the detail should be assessed as a whole. Some examples of the calculation of combined spatial tolerances are given in Annex B.

c) Where maximum or minimum sizes are required to conform to statutory requirements, the target size should be set so that when the tolerance is taken into account, the actual size does not fall outside the maximum or minimum size permitted (e.g. +0 mm/−10 mm for a critical level or height not to be exceeded).

d) The due environmental or loading effects of inherent spatial deviations should be taken into account, as these can impact the construction or operational stages.

e) Where process of assembly or combination of built components has limited complexity or interaction with each other, and has limited inherent deviation impacts then the industry expected dimensional variability for in-situ or off-site assembly and manufactured components should be taken into account as the minimum consideration for establishing spatial tolerances.

The following steps should be followed to make appropriate provision for dimensional variability for a particular design. References to the tables created during the BRE studies in the 1970s and 1980s and included in Annex C are referred to here to provide examples for how tolerances can be established. However, this should not be used as a standard and the designers and users need to establish an appropriate approach to establishing dimensional variability and tolerances for their specific designs.

10.2 Step 1: Consideration of the dimensional variability of primary elements of construction

The example from the historical BRE survey given in Table C.1, Annex C shows the dimensional variability of site construction (see **8.1**). Figure 14 shows examples of the range of deviations given in Table C.1. From this table an assessment could historically be made of the necessary allowances, and provision could then be made in the design details to accommodate components; for example, brick cladding around frame, or factory-made components which have to be fitted within a structure constructed or erected on-site.

10.3 Step 2: Consideration of the dimensional variability of manufactured components

The example from the historical BRE survey given in Table C.2, Annex C shows the dimensional historical variability of manufactured components (see **8.2**). Table 1 to Table 11 show some examples of the range of deviations given in Table C.2. Up-to-date and other examples not covered in this table should be obtained from manufacturers or empirical tests and analysis where these are important considerations. Other information not covered in this table can be obtained from specialist manufacturers. Manufactured items are likely to possess a higher order of accuracy than those constructed on-site, but nevertheless their variability needs to be provided for in the final assessment of combined fit.

10.4 Step 3: Assessment of combined deviation limits

For a particular design detail, joint or interface, the total deviation can be accommodated in three steps.

Step 3.1: the total induced deviation DL_t can be found by:

a) obtaining the corresponding separate induced deviation DL_1, DL_2 etc., from Table C.1 or Table C.2 or other sources; and

b) calculating the total induced deviation DL_t by finding the square root of the sum of the squares of each individual induced deviation thus:

$$DL_t = \sqrt{\left[(DL_1)^2 + (DL_2)^2 + \ldots \right]}$$

Examples and guidance for calculations are given in Annex B, and are illustrated in Figure 1, Figure 4, Figure 6, Figure 14 and Figure 15, for some common design situations for which the achievement of fit might be critical. In addition, reference can be made to BS 6954-3 for full procedures relating target sizes and joint clearances.

Step 3.2: the total inherent deviation DT_t can be found by:

c) obtaining the corresponding separate inherent deviation DT_1, DT_2 etc., for changes in temperature, moisture content, deflection etc. from other sources; and

d) calculating the total inherent deviation DT_t by summing any individual inherent deviations thus:

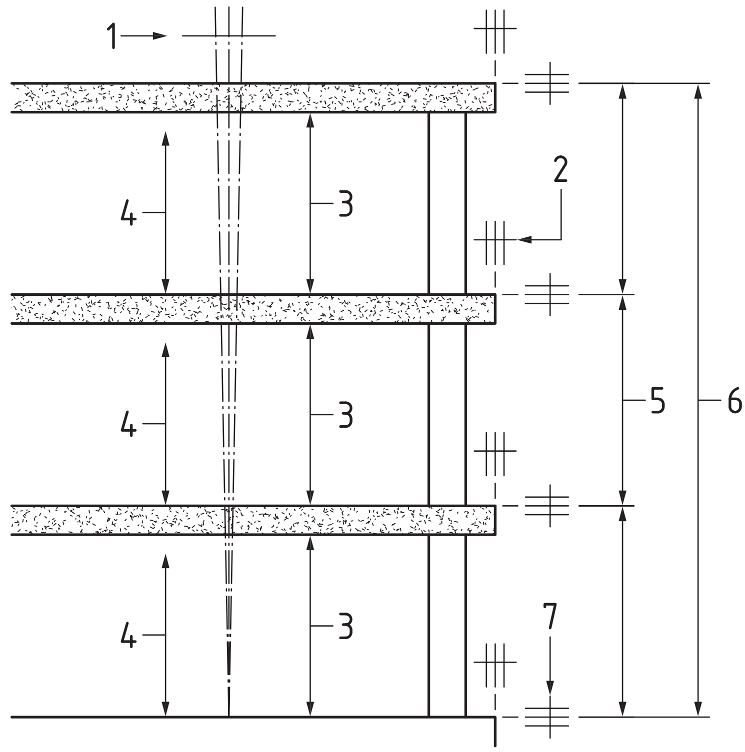
$$DT_t = DT_1 + DT_2 + \ldots$$

Step 3.3: The total deviation D_t can be found by:

e) calculating the total deviation D_t by summing the total induced deviation and the total inherent deviation together thus:

$$D_t = DL_t + DT_t$$

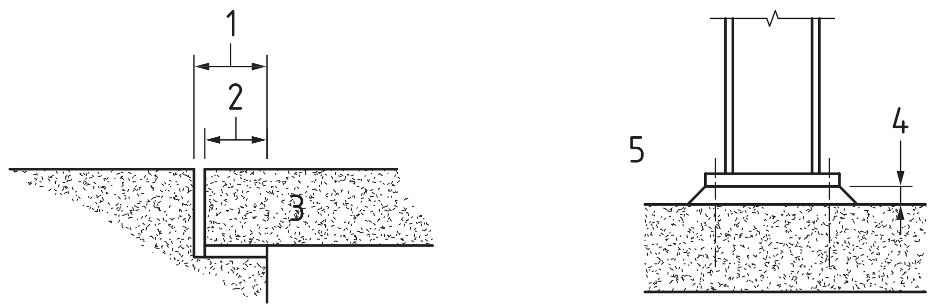
Figure 14 — *Diagrammatic section showing total height, minimum floor to ceiling height, floor edge line and level variability, and vertical setting out variability*



Key

1	Vertical setting out variability	5	Floor to floor height
2	Floor edge variability	6	Total height
3	Target size	7	Floor level variability
4	Minimum dimension		

Figure 15 — *Minimum bearings and dry packings*



a) Minimum bearings b) Dry packings

Key

1 Allowance for variability of space between elements, in addition to minimum bearing
2 Min. bearing requirement
3 Prefabricated component
4 Allowance for variability of level, in addition to minimum required for grout
5 Dry packing or grout

10.5 Evaluation of design proposals

Checks should be made to verify that the individual and combined deviations established in steps 1, 2 and 3 (in **10.2**, **10.3** and **10.4**) meet the needs of the design, construction and operation (i.e. the whole life cycle of the asset).

Checks should also be made against the overall aims given in **8.1** to determine if these aims have been effectively satisfied. Particular attention should be given to the following points.

a) Design of joints and connections: The joint is the medium where the variabilities due to both induced and inherent deviations can be absorbed. Guidance on the selection of jointing methods is given in BS 6093 for structures, claddings, openings in walls, roofs, floors and services passing through building elements.

b) Detail drawings and graphical information: Detail drawings, which is taken to mean digital drawings, models and graphical data, should be prepared for each type of joint or connection and communicated in appropriate formats and scales to indicate the interrelation of all parts of the connection. The detail drawings should allow for the effect of individual or combined deviations as calculated in **9.4**.

c) Adjustability: Adjustability should be provided in the design, for accommodating the tolerances for manufactured components/units (precast cladding, curtain walling, precast construction etc.) to the range of deviations applicable to site construction (see Table C.1 for historical examples). Levelling bolts, bracket systems and careful detailing allow both vertical and elevational variabilities to be absorbed and eliminate conflict between the coarser site constructed tolerances and the finer manufactured tolerances.

d) Mock-ups and trials (real or virtual rehearsals): The construction of mock-ups or trials of the detailed design and construction should be taken into account to enable satisfactory fit to be achieved. This consideration is of particular value in complex construction, or where the assembly programme for the project is critical, or where the tolerances required by the nature of the design are particularly demanding for either manufacture or site construction.

Explicit consideration, at the design stage, of details to absorb the dimensional variabilities of building components, materials and processes allows for the development and production of design details which consistently perform satisfactorily.

11 Specifying spatial tolerances

Spatial tolerances should be specified which reflect the following:

a) the dimensional tolerance needs of the design; and

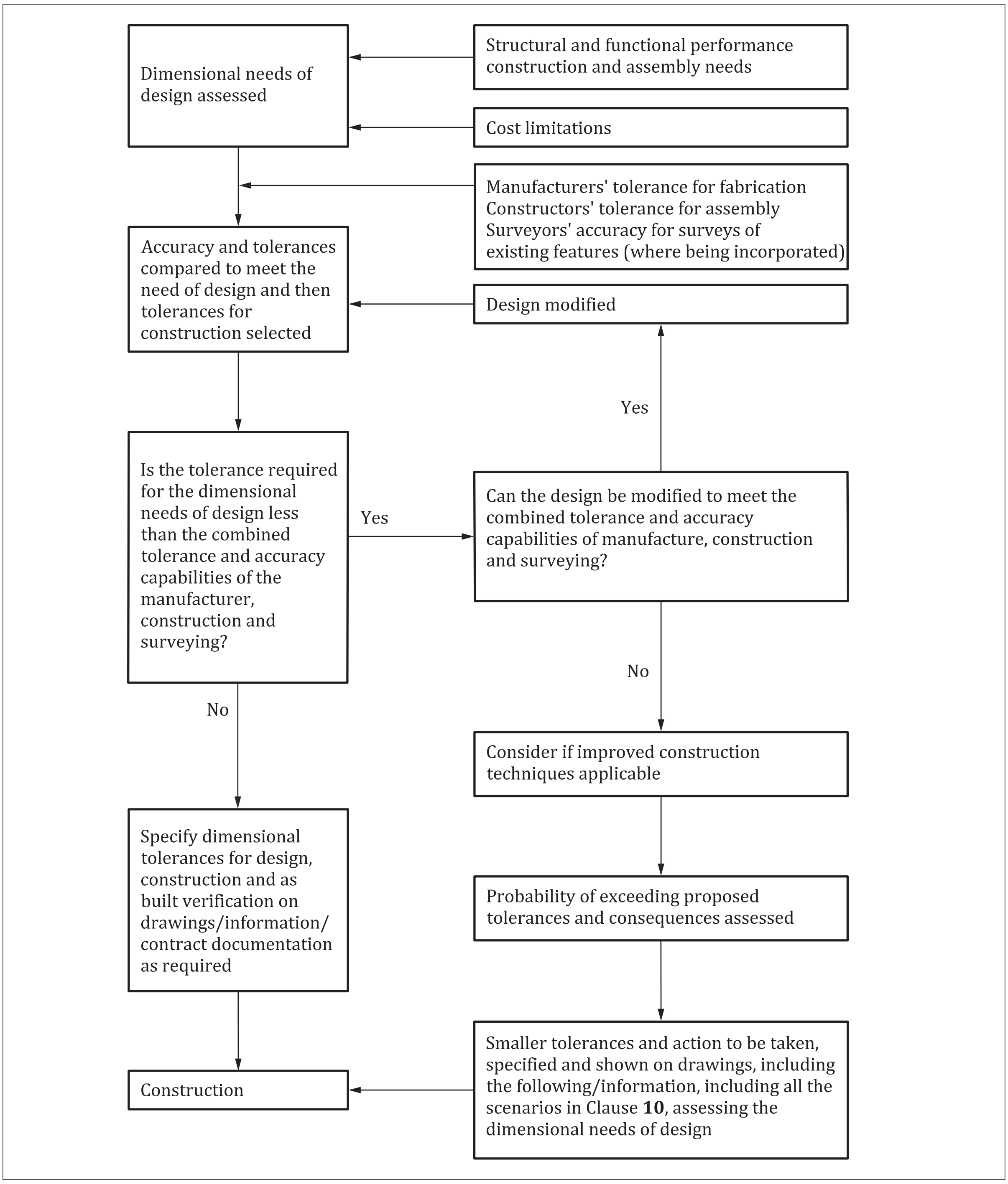
b) the requirements of the various elements and components of the construction.

When special spatial tolerance is required for particular details, joints and interfaces, dimensions with their associated permissible deviations from target size should be shown on the drawings (both digital models and drawings and hard copy where required) and in the specification. See Figure 16 for guidance concerning the establishment of spatial tolerance and dimensional needs of a design.

The need to specify trials and to carry out the construction of mock-ups for particular areas or items of the construction should be taken into account.

Project specifications should include specific requirements for monitoring compliance, including the assurance requirement that spatial measurement accuracy achieved can confirm any dimensional deviation or tolerance with appropriate confidence (see Clause **14**).

Figure 16 — *Process flow chart for designing to achieve good fit and assembly*



Section 4: Construction considerations

12 Consideration for achieving spatial tolerance in construction

To aid compliance with the tolerances specified for a particular project, attention should be given to the following:

a) assessment of the constructional details for constraints on tolerance and practical achievement of fit, e.g. for structural frame and components, claddings and finishes, and ability of operatives and equipment to align and position components in the place assembly;

b) consideration of the physical space and sequence of assembly and working areas to bring components together within the required tolerances and ability to verify this by spatial measurement (physically or remotely) including obstructions;

c) identification of those areas of a project where the constructional details and dimensions are critical;

d) planning and establishment of appropriate dimensional control, setting out, systematic monitoring, recording and reporting procedures on-site;

e) monitoring of the spatial accuracy achieved during construction and the achievement of permissible tolerances, including the need for independent verification and interface checking between interdependent disciplines, contractors and components; and

f) understanding the uncertainty associated with spatial measurement accuracy and specifying the appropriate confidence of measurements (e.g. 1-, 2- or 3-sigma, equivalent to 68%, 95% or 99.7% accuracy of measurement confidence respectively).

13 Sources of induced spatial deviations

13.1 Induced spatial deviations in the surveying and setting out processes

Sources of induced deviations in the setting out process include the following:

a) inability to measure, set out or check with absolute accuracy the position, size or location of existing features and components;

b) inaccuracy in the measurement equipment itself; and

c) inaccuracy in the site survey datums (horizontal and vertical) which effect the position of survey measurements or setting out dimensional grid lines established from them.

13.2 Induced spatial deviations in manufacturing and construction

Sources of induced deviations in manufacturing and construction (due to the material from which a component or element is made, and the manufacturing process) include the following:

a) inaccuracy in moulds, jigs or other equipment influencing a manufactured size before and during component manufacture; and

b) deviations, in size or shape of components, which arise during the manufacturing process and which cause dimensional variability between similar finished products which are intended to be identical.

13.3 Induced spatial deviations in the erection and assembly process

Sources of induced deviations in the erection and assembly process include:

a) inability to locate building components exactly on setting out marks;

b) insufficient adjustability in fixings, e.g. clearance should be present in bolt holes to enable the bolts to pass through;

c) inaccuracy present in measuring instruments [for assembly], particularly those for obtaining verticality;

d) inability to position components in controlled manner due to lack of appropriate and stable handling equipment, particularly for heavy objects; and

e) variability of dimensions of temporary works such as the of shape in formwork; deflection of formwork and the settlement of its supports and props.

13.4 Inherent spatial deviations

Inherent spatial deviations are very difficult to control and therefore should be taken into account with care when designing tolerances to accommodate them. These include factors such as:

a) progressive loading of structures and buildings during construction and commissioning;

b) environmental impacts such as temperature, sunlight, moisture and loading from rain, snow and wind;

c) ground movement; and

d) behaviour of structures and buildings during use and occupancy changes.

14 Control of spatial tolerances and target size

14.1 Monitoring

Errors occurring early in the construction process and not discovered at the time can be difficult and expensive to rectify later. Therefore, checking should be systematic and should be undertaken throughout the manufacturing and construction stages starting with setting out, kickers, shuttering, jigs (including off-site manufacture), position in line, level, assembly and final construction.

Particular attention should be given to the monitoring of construction in areas where the work of following trades, or prefabricated components, would be affected in appearance or performance.

Off-site or manufactured component dimensions relevant to fit should be measured as early as practicable after manufacture begins and the process should be monitored and corrected as necessary so that subsequent components are consistent with each other and the tolerances required.

Aspects that should be taken into account include the following:

a) agreed monitoring and control procedures including measuring sequences and number of elements and components to be monitored [for example, guidance on setting out can be obtained from BS 5964 (all parts)];

b) guidelines given in BS 7307-1 and BS 7307-2 indicating methods of measurement of building and building products, which can be used to standardize the monitoring procedure;

c) method of use, calibration, checks and accuracy capability of measuring instruments, which should be appropriate to achieve the spatial tolerances specified (see **8.3**);

d) supervision, verification and checking of the erection process and capability and capacity of operatives and equipment provisioned such that components are placed in position within the tolerances specified for the project; and

e) verification and check procedures for manufacturing jigs and equipment including calibration processes.

14.2 Dimensional control

Dimensional control should be achieved by:

a) checking that measured results are within the tolerances specified for the project (see **14.1**);

b) identifying sources of induced spatial deviations (see Clause **13**);

c) understand and allow for inherent spatial deviations (see **13.4**);

d) taking appropriate corrective action (see **14.5**).

14.3 Recording

The dimensions measured should be systematically recorded for the following purposes:

a) checking the achieved dimensions as built are within the specified tolerances;

b) preparing as built records and handover information (including digital drawings, models and digital twins) showing the measurements achieved in practice and the deviations from the target size;

c) validating characteristic accuracy of processes which are being relied upon during the project to consider updates and lessons learned to be applied to current or future works;

d) to support quality assurance, auditing and compliance checks; and

e) regulatory requirements (if applicable).

14.4 Presentation of dimensional tolerance and accuracy data

Guidance is given in BS 7308 concerning the principles on which the presentation of dimensional accuracy data should be based and the format in which this data should be presented for defined items of construction and manufactured components.

14.5 Corrective action

Corrective action in respect of work that does not conform to the tolerances specified for a project can include:

a) rectification of work already done;

b) adjustment of methods or materials used;

c) increasing supervision at identified sources of inaccuracy; and

d) adjustment of design and/or details.

14.6 Preventive action

Systematic checking as the work proceeds including progressive as-builts is essential to make sure that the adopted methods, monitoring and control systems are appropriate and are being conformed to, and where not being conformed to, subsequent works can be informed and appropriate adjustments made.

Preventive action can be indicated from an assessment of the results of the monitoring, particularly at the initial stages of each process. This allows the problems to be identified and addressed at an early stage.

It should be determined where statistical process control can be applied to construction (particularly related to machine-repeatable activities including manufacturing processes) and on-site repeatable works that benefit from being frequently controlled.

Annex A (informative) Surveying and setting out strategy

A.1 Principles of a survey strategy

*COMMENTARY ON **A.1***

A survey strategy and the challenges it can address are outlined here with simple examples of the consequences of issues arising. In relation to BIM processes, these requirements can be captured formally in the employer information requirements or exchange information requirements (EIR) and responded to in the suppliers/appointed parties BIM execution plan (BEP). Notwithstanding, the following sections outline the principal challenges to be addressed by a survey and setting out strategy which helps address the challenges and issues related to accuracy and tolerance in construction.

A.1.1 Consistency in survey and setting out grids, coordinates and chainage

Building and engineering works are invariably designed and set out in 1:1, although for key sources of information a national grid mapping system is used which is not 1:1. This is caused by the need to allow for the fact the earth is curved, and nations need to provide a projected or flattened map to users over large areas of land.

It is also the case that building and engineering works might require spatial reference systems which are not based on coordinates to locate, measure and set out aspects of work. For example, it is common in road and rail projects to use chainages (linear references) and in building to use internal grids and reference lines and datums throughout the site and buildings.

Failing to retain overall integrity across the entire project area, the site grid and coordinate system, and align properly to it for setting out or surveys can result in many costly mistakes or misfits (e.g. misaligned connections across and within structures, buildings or services, overlapping site legal boundaries, inadequate height for flood risk or floor to floor spaces, misaligned modular components, re-work of designs which are not at 1:1 scale, inability to fit buildings or components on-site or retain clearances needed for roadways, access routes or planning constraints).

Maintaining and checking the physical coordinate system markings (survey control points) and verifying the relationship to transferred datums, chainages and reference grid lines, as well as to other survey information is essential to a survey strategy and project success.

A.1.2 Survey and setting out accuracy

Specifying the correct survey accuracy varies for each task and purpose the information is used for. It is particularly important in a design context as the stages of design progress. The accuracy suitable to positioning/setting out existing site features such as roads and landscaping are unlikely to be as high as the accuracy required to set internal structures or M&E services in most cases. Equally the survey accuracy required to prove design tolerances have been set out correctly or achieved in reality need to be higher than the tolerances they are verifying. It is for this reason that establishing the accuracy of an overall site grid and datums is likely to require the highest accuracy proportionally to any other survey task or use, and nearly all other survey and setting out accuracies are affected by it. A simple example of an issue is failing to establish the height datum on each floor accurately enough to the next floor where a stair or landing component, or cladding component can no longer fit correctly.

A.1.3 3D survey and digital representation (over and underground)

Traditionally surveys were carried out in two dimensions (X,Y plans) with height added as a textual piece of information or a separate drawing (e.g. elevation, section) and sometimes with height captured from a separate capture exercise such as levelling.

Although traditional techniques of 2D plus height are used and still relevant, increasingly survey capture and processed digital outputs are being generated in 3D directly, with immersive capture of the site features, i.e. laser or Lidar scanning, which captures thousands of points per second, or photogrammetry/videogrammetry techniques which can also be used to extract immersive (continuous) 3D data on features imaged.

This creates a challenge for digital representation and visualization in traditional ways, such as looking at a floor plan when a wall is not vertical as it creates multiple extents in a 2D view. Another example is understanding underground utilities surveys when represented as single lines although pipes etc. have bottom, top and extents also (they are not single line objects in reality).

Establishing the right level of information and detail in 2D and 3D digitally should be taken into account in surveys so that mistakes or misinterpretations are avoided. Increasingly allowing access to the immersive survey information (such as point clouds or photo imagery) to verify the extracted 2D or 3D digital information is important in making the best practical use of modern surveys, although this requires special software and often high-performance computer capabilities.

It is also important that, once captured and extracted, the spatial measurement accuracies associated with features extracted and published in surveys are traceable and readable within the digital information. Spatial measurement accuracy issued on paper surveys plots was historically linked to the plot scale and survey legend statement on a printed plan. This is often no longer relevant when surveys are stored digitally (due to the ability to zoom in and out at any scale, turn off title sheets and legend text as well as export data to other files).

Therefore, spatial measurement accuracy of surveys should, where possible, be made explicit in coding, metadata or attributes in digitally issued surveys, as well as in associated legends and textual information, and designers and constructors should be aware of this when assessing tolerances.

A.1.4 Supplier performance and assurance

Surveys and setting out are typically performed by people with specialist skills, whether surveyors or setting out engineers or supervisors. It is essential that the suppliers and undertakers of surveys have processes and procedures for checking their work, recording this and making it available for audit or verification by others. The simplest example is the site survey grid and coordinate control markers and datums. A survey control report (confirming how it was established, to what accuracy and what statistical checks and adjustments were undertaken) should be made available on a project. This includes any transformations from national to local grid or alignment of legacy survey sources which are not on the agreed common site/project grids.

There are regrettably numerous instances of projects commencing on the assumption that the survey information supplied is accurate to a certain value, without any supporting evidence of a survey control report, or verification by the other parties prior to critical decisions affected by accuracy being made. Simple examples include using ordnance survey plans (national mapping) or utility records (provided by utility owners) in early design without understanding their accuracy limitations; commissioning a survey without seeking a survey control report and quality assurance information from suppliers on the accuracy of features captured in the survey information and survey control markers established supplied before sharing this information with others to information design or construction.

A.1.5 Safety and site access

Although a wider aspect of site and construction projects, increasingly surveys require remote access and capture, or to enable others to remotely understand the site without the need to visit, return or undertake additional surveys post-initial site survey. In any survey strategy, undertaking multi-purpose surveys which can be captured remotely (without contact, e.g. scanning) can add value and avoid risks in more people trying to physically survey places which are difficult to reach. Examples include surveying active and operational sites and buildings, roof areas, and as-built progress or information at height which is not easily accessed or reached. Extreme examples include falls or incidents on-site related to surveying in difficult conditions and omissions from surveys due to limited physical access which later clash with designs or works unknowingly.

A.1.6 Information awareness and access

An increasing challenge and potential significant cause of waste and re-work is the lack of awareness and access to survey information on projects. Many of the initial challenges around survey grid consistency and alignment of different sources of spatial information stem from a lack of project and participant awareness (in particular, site operatives and contractors) of available survey information and how it is coordinated and controlled, i.e. datum locations, values and accuracy.

Equally the format and location of information on digital systems can also create an issue with access to it, either permissions to access the location where the information is, or the software tools needed to open, interrogate and use the information. Projects which undertake BIM in accordance with the BS EN ISO 19650 series (formerly BS and PAS 1192) can help resolve this by utilizing a common data environment (CDE) and providing suitable solutions which give access to survey information including guidance on viewing and accessing survey data.

A.1.7 Information usefulness and risk

Accuracy varies according to purpose. So, although last on the list, it is probably one of the most costly risks and issues with the use of survey information. What can it be used for, how reliable is the information, including how accurate it is and if it is likely to have been changed or in need of update or verification since it was created? As-built records are probably the most notorious example of important information which parties struggle to re-use if it can't be trusted or information about its integrity can neither be validated or verified. Issuing critical information such as surveys and stating "for information only" or to be checked on-site, which was the traditional approach, is unlikely to be efficient or effective for a modern construction project. If issued without quality assurance or liability from the source, it is likely to have to be replicated and re-done, or ignored.

Establishing how survey information has been captured, its accuracy, coverage and currency (date of capture), as well as establishing risks around how the features might change over time due to site changes or environmental impacts is an important part of a survey strategy to maintain the right quality of information about surveys.

It is also critical in a digital environment that the tracking, tracing and presentation of accuracy is explicit and discoverable in the survey information provided. Embedding this information into digital attributes, metadata and coding and visible notation is important to knowledge transfer and life cycle information management, along with having a survey strategy which explains the way this can be achieved.

A.2 Accuracy of site surveying

Accuracy of site surveying depends on many factors and to aid the management of accuracy and tolerance in construction it is considered a performance requirement. Table A.1 is an example of a spatial measurement accuracy table produced by an industry body related to the surveying profession (this is due for an industry update). It provides band values for each type of survey specification as the minimum accuracy to be achieved in plan and vertical measurement and a quality value in the terms of sigma (standard error) and confidence associated with that (how many measurements need to achieve this value in a sample check).

Surveying and setting out all require survey control, datums and reference lines, as indicated in Section 4. These are an important consideration for the life cycle of a project where features change and can be disturbed causing replacement or disturbance. Table A.1 is provided as a form of guidance and allows for example specific values to be created where the band values are not desired.

Increasing accuracy requirements in a specification has a consequential impact on the effort to achieve them and this is primarily driven by the spatial tolerances needs of a design. In fact, the accuracy of a survey to prove a tolerance has been achieved needs to be of a higher standard to give confidence in results. Therefore, survey accuracy requirements need to be directly verified against the spatial tolerances they are trying to assure, so that they do not compromise verification or compliance processes.

Table A.1 — *Survey band accuracy table*

Plan/dimension accuracy (X,Y)			**Height/elevation accuracy (Z)** A)			
Band	**1 sigma (68% confidence)**	**2 sigma (95% confidence)**	**Band**	**Accuracy hard detail 1 sigma**	**Accuracy soft detail**	**Example survey types/ uses** B)
A	±2 mm	±4 mm	A	±2 mm	n/a	Monitoring, high accuracy engineering setting out and fabrication surveys.
B	±4 mm	±8 mm	B	±4 mm	n/a	Monitoring, high accuracy engineering and measured building surveys and setting out.
C	±5 mm	±10 mm	C	±5 mm	n/a	Engineering surveying and setting out, high accuracy measured building surveying, heritage recording.
D	±10 mm	±20 mm	D	±10 mm	±25 mm	Engineering surveying and setting out, measured building surveys, high accuracy topographic surveys, determined boundaries, area registration.
E	±25 mm	±50 mm	E	±10 mm	±50 mm	Measured building surveys, topographic surveys, low accuracy setting out, net area surveys, valuation surveys, area registration, utility verification (QL-A) PAS 128 (UK).

Table A.1 — *Survey band accuracy table (continued)*

Plan/dimension accuracy (X,Y)			Height/elevation accuracy (Z) A)			
Band	**1 sigma (68% confidence)**	**2 sigma (95% confidence)**	**Band**	**Accuracy hard detail 1 sigma**	**Accuracy soft detail**	**Example survey types/ uses B)**
F	±50 mm	±100 mm	F	±50 mm	±100 mm	Low accuracy measured building surveys, topographic surveys, high accuracy utility tracing, gross area surveys.
G	±100 mm	±200 mm	G	±50 mm	±100 mm	Topographic surveys, low accuracy measured building surveys, utility tracing surveys, boundary mapping, high accuracy geotechnical, detection (QL-B1) PAS 128 (UK).
H	±250 mm	±500 mm	H	±125 mm	±250 mm	Low accuracy topographic surveys, national urban area mapping, geotechnical mapping, tree surveys.
I	±500 mm	±1 000 mm	I	±500 mm	±1 000 mm	Low accuracy topographic mapping, national non-urban mapping, general boundary mapping, asset mapping, utility survey, detection (QL-B4) PAS 128 (UK).
J	±1 000 mm	±2 000 mm	J	±1 000 mm	±2 000 mm	Low accuracy route/ corridor planning surveys, large area GIS asset mapping.
X Y	Custom		Z	Custom	Custom	To create a customized band, select the nearest band letter below the required value and add as a prefix to XY or Z specifying the required value (e.g. G-XY = ±125 mm plan at 1 sigma).

NOTE This table is reproduced from RICS Measured surveys of land, buildings and utilities [3]. Copyright is claimed in this table. Reproduction of this table and making products from it might infringe that copyright. Details of the copyright owner can be found in the Foreword.

A) Multiply by 2 for 2 sigma values.

B) Example survey types/uses: the table includes examples of users of the types of survey and plot scale output that might be suitable for different accuracies. However, this is not an exhaustive list of examples nor fixed to each band.

Annex B (informative)
Examples of the calculations of tolerances

B.1 General

This annex was included in the 1990 edition of this British Standard and is retained to clarify and draw attention to the legacy BRE studies on accuracy and fit in construction (1975–77) and manufacturing (1986–88).

These studies were used to inform the principles of this British Standard, and a supporting series of standards, BS 6954, were also created to demonstrate how to allow for and calculate tolerances for building. These inputs are still relevant to the principles of this guidance, although the value ranges and practices are potentially significantly out of date.

As an example from those studies, it was found the deviations given in Table C.1 for items of site construction and in Table C.2 for manufactured components, could be used to provide an initial assessment of the likelihood of achieving satisfactory fit during construction. These limits were taken to apply for normal methods of construction and manufacture (at the time of the studies) and are made up of the contributions of the constituent variabilities (including Table C.3, the accuracy of survey instruments at the time).

For instance, these historical studies found the rate of misfit associated with the range of deviations given in Table C.1 and Table C.2 at the time was quoted approximately as:

a) 4.5% (1 in 22) for items of construction; and

b) 1.25% (1 in 80) for manufactured components.

Different rates of misfit have been quoted to take practical account of the repetition which generally applies to the manufacture of components. The differences in these rates of misfit are ignored in obtaining the initial assessments of the likelihood of fit. The estimate obtained assumes the following:

1) the contribution of the systematic deviation is small compared to the total variability;

2) the number of manufactured infill components are few; and

3) the variability associated with the component variability associated with the constructed space.

For those designs for which any of the assumptions 1), 2) or 3) are invalid, or for which a full assessment is needed, should be used to assess the dimensional needs of the design.

The following worked examples in **B.2**, **B.3** and **B.4** are shown for explanation purposes and rely on the legacy tables of industry practice re-published in this edition. They are not to be used to represent current capabilities or standard tolerances, which should be determined specially by any users of this guide for their needs and project circumstances.

B.2 Examples concerned with the insertion of a manufactured component into a prepared space

B.2.1 General

Subclause **B.2.2** is concerned with the insertion of a manufactured component into a space and enables an initial assessment to be made of the maximum and minimum joint size that allows a jointing technique to accommodate a known dimensional variability in space and component size.

B.2.2 Insertion of a window frame into a prepared opening (determining the range of possible joint sizes)

*NOTE Subclauses **B.2.2.1** and **B.2.2.2** deal with construction for fitting timber framed windows into a prepared space between two unplastered, cast in-situ concrete columns.*

B.2.2.1 Single window frame fitted into a prepared opening (see Figure B.1)

Calculate the range of joint sizes when a timber window frame (target size 2 390) is to be fitted into a space between in-situ concrete columns (target size 2 430).

Variability information	Deviations
Space between columns: in-situ concrete: Table C.1 (T.1.1)	±18 mm
Length of component: timber: Table C.2 (T.2.1)	±4 mm
Number of components	1

Calculation of target size of joints:

Target size of joints = $\frac{2430-2390}{2}$ = 20 mm each side

Total deviation in size of joints (see **10.4**) = √ (18^2 ±4^2) = ±18.4 mm

Max. joint size = $20+\frac{18.4}{2}$ = 29.2 mm

Min. joint size = $20-\frac{18.4}{2}$ = 10.8 mm

The jointing technique should be capable of accommodating the maximum and minimum joint sizes, i.e. 30 mm to 10 mm.

If the jointing techniques available cannot accommodate the predicted range of variability, other options can be taken into account, including the following:

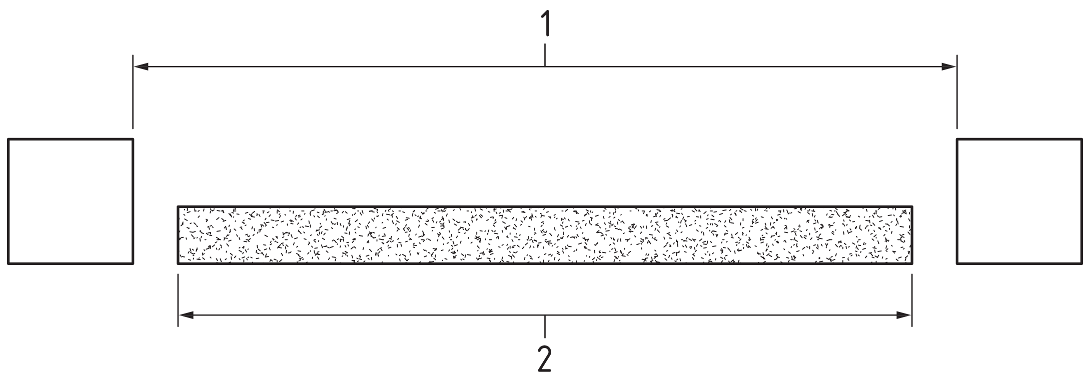
a) amend design to allow window to be fixed to the face of the columns;

b) detail the columns with rebates to accommodate frame (see Figure B.2);

c) use a joint cover strip (see Figure B.3); and

d) use more than one window, thus introducing more joints to accommodate variability (see **B.2.2.2**).

Figure B.1 — *Target sizes for a prepared opening, single window and joints*



Key

1 Opening target size 2 430 mm

2 Frame target size 2 390 mm

Figure B.2 — *Rebated column*

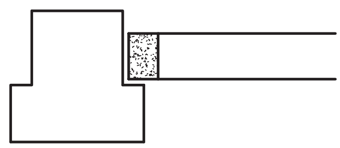
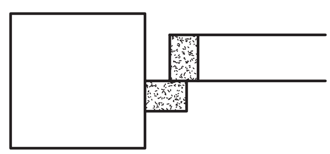


Figure B.3 — *Joint cover strip*



B.2.2.2 Three window frames fitted into a prepared opening (see Figure B.4)

Calculation of target size of joints:

Number of components 3. Number of joints 4.

Total variability in size of joints = $\pm\sqrt{\left(18^2+4^2+4^2+4^2\right)}$ = ±19.3 mm

Target size of joints = $\frac{2430-2391}{4}$ = 9.8 mm each

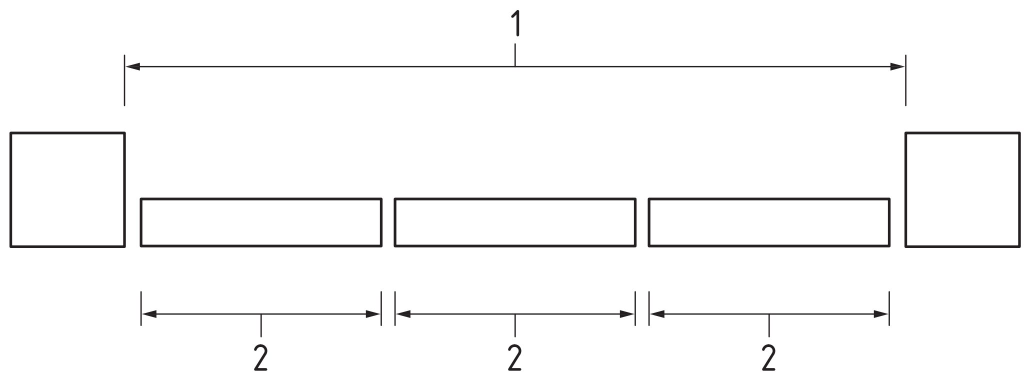
Max. joint size = $9.8+\frac{19.3}{4}$ = 14.6 mm

Min joint size = $9.8-\frac{19.3}{4}$ = 5.0 mm

The jointing technique in this case should be capable of accommodating joint sizes in the range 15 mm to 5 mm.

Similar calculations should be made for vertical dimensions.

Figure B.4 — *Target sizes for a prepared opening, three windows and joints*



Key

1 Target size for opening 2 430 mm

2 Target size 797 mm

B.2.3 Line and level of concrete nibs supporting facing brickwork or other cladding

For the construction of in-situ concrete nibs at the edge of floor slabs supporting facing brickwork six storeys in height (see Figure B.5), the following should be taken into account.

a) Position in plan, calculated tolerance on position of concrete nibs.

1) Ground floor level

Variability information (ground floor)

Setting out nearest reference line from building grid line (Table C.3, T.3.1) = ±5 mm up to 5 m.

Position of face of concrete nib in relation to the nearest building grid line on the same level = ±12 mm (Table C.1, T.1.5). Total tolerance on position of nibs at ground level

$= \sqrt{(5^2 + 12^2)}$ = ±13 mm.

2) Upper floor levels

For first floor level and above, the tolerance for the face of the nib at each floor is influenced by the method used to establish the building grid lines on each floor.

For the purposes of this example, assume that grid lines on the first, second and third floors are to be established from grid lines on the ground floor using a theodolite. Also assume that the grid lines on the fourth and fifth floors and roof are established from the grid on the third floor also using a theodolite.

b) Position in plan, calculated tolerance on position of facing brickwork.

Position of face of brickwork relative to nearest reference line (Table C.1, T.1.5) = ±10 mm.

Total tolerance on position of nib = ±15 mm reference (see above).

∴ Variability of bearing of brickwork on concrete nib = $\sqrt{(15^2 + 10^2)}$ = ±18 mm.

From the calculations of **B.2.3** the following observations can be made.

1) The edge of the concrete nibs can vary by up to ±15 mm from a vertical plane.

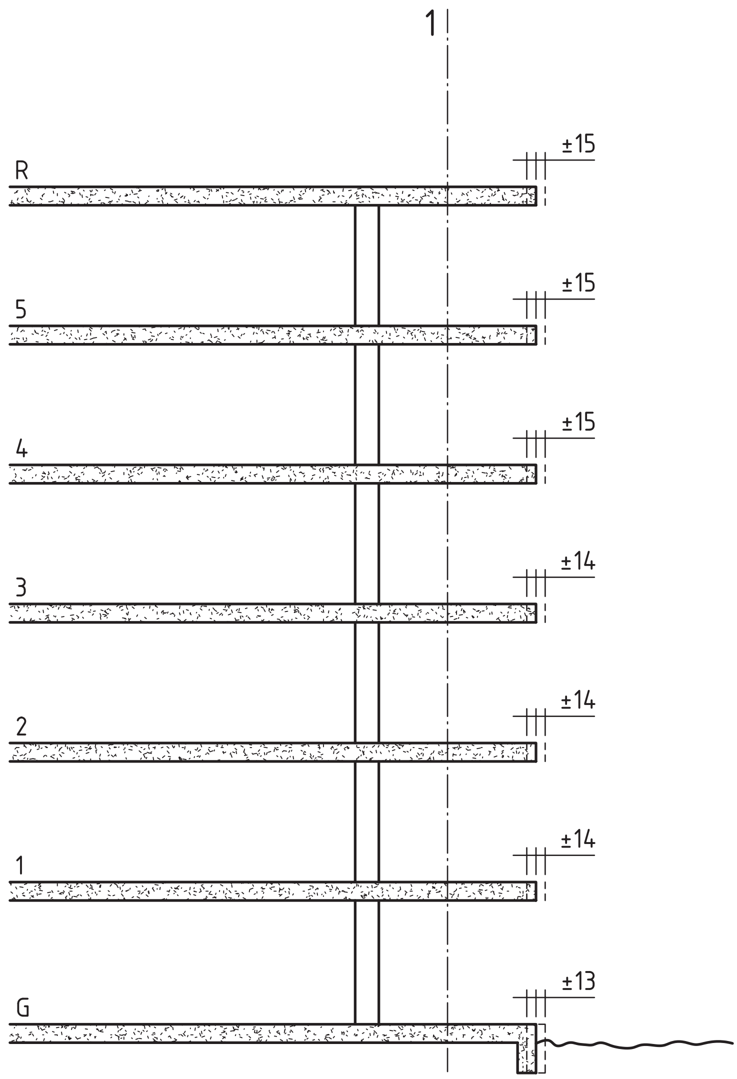
2) The variability of the bearing of the brickwork on the concrete slab edge is ±18 mm. The effect of this reduction in bearing on the stability of the brickwork should be taken into account (see Figure B.6).

This example relates to brick cladding but similar considerations apply to other claddings. It is important that sufficient adjustment is provided in fixings to allow the cladding to be brought to a good plane. Adjustment in level should also be provided to enable a good horizontal line to be maintained.

A survey should be made of the edges of the concrete nibs before setting the final position of the brickwork and/or cladding to verify that the bearings and/or connections perform as designed.

The effects of inherent spatial deviations should also be taken into account (see 13.4).

Figure B.5 — *Variability of face line of concrete nibs*



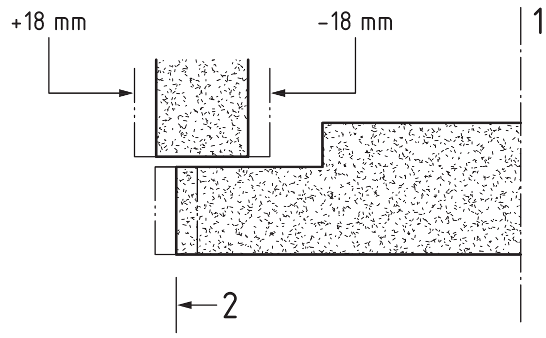
Key

1 Reference line

R Roof

G Ground

Figure B.6 — *Variability of nib in relation to brick face*



Key

1 Reference line

2 Designed position of face of nib

Variability information	Deviations
(1st, 2nd and 3rd floors)	
Transferring a grid line from ground floor (Table C.3, T.3.3)	±5 mm in 30 m height
Setting out nearest reference line at each floor level by tape (Table C.3, T.3.3) from grid line	±5 mm in up to 5 m length
Position of face of nib relative to nearest grid line (Table C.1, T.1.5)	±12 mm
Total tolerance on position of nib (1st, 2nd and 3rd floors)	$= \sqrt{\left(5^2 + 5^2 + 12^2\right)}$ = ±13.9 say 14 mm
(4th, 5th, and 6th floors)	
Transferring grid line ground to third floor	±5 mm
Transferring grid line third to sixth floor	±5 mm
Setting out nearest reference line at each floor level	±5 mm
Position of face of nib relative to nearest reference line	±12 mm
Total tolerance on position of nib	$= \sqrt{\left(5^2 + 5^2 + 5^2 + 12^2\right)}$ = ±14.8 say ±15 mm

B.3 Precast cladding around in-situ column: determining minimum internal dimension of precast cladding to accommodate variability and insulation (see Figure B.7)

Construction of 5 storey in-situ concrete frame with precast cladding to columns. Column target size 300 mm × 400 mm. Minimum cavity cladding to column 50 mm. Storey height 3 500 mm.

For the cladding to fit to the column with a minimum cavity of 50 mm and to produce an acceptable external appearance, account should be taken of the following variabilities.

Variability information	Deviations
Setting out variability	±5 mm
Transfer of grid vertically from base (T.3.3)	–
Setting out nearest reference line (tape) (T.3.1)	±5 mm
In-situ concrete construction variability	±12 mm
Column position on plan from nearest reference line (T.1.5)	–
Column verticality (T.1.3)	16 mm
Column size on plan (T.1.3)	±8 mm
Precast concrete cladding erection/size variability	–
Cladding position on plan from nearest reference line (T.1.5)	±10 mm
Cladding verticality (T.1.3)	14 mm
Cladding size on plan (T.2.1)	±6 mm

Calculation of combined deviation:

Combined deviation (DL_1) due to setting out variability

$DL_1 = \pm\sqrt{\left(5^2 + 5^2\right)}$ = ±7.07 mm (setting out zone)

Combined deviation (DL_2) due to in-situ concrete construction variability

$DL_2 = \sqrt{\left(12^2 + 16^2 + 7^2\right)}$ = ±21.19 mm (in-situ column zone)

Combined deviation (DL_3) due to precast cladding erection/size variability

$DL_3 = \sqrt{\left(10^2 + 14^2 + 6^2\right)}$ = ±18.22 mm (precast cladding zone)

Total combined deviation (DL_t) to establish total variability to be taken into account is given by:

$$DL_t = \pm\sqrt{\left\{\left(DL_1\right)^2 + \left(DL_2\right)^2 + \left(DL_3\right)^2\right\}}$$

$$= \pm\sqrt{\left(7.07^2 + 21.19^2 + 18.22^2\right)}$$

= ±28.82 mm (say 29 mm)

The internal size of the precast cladding unit, providing also the required 50 mm cavity clearance, is given by:

(300 + 50 + 50 + 29)

= 429 mm

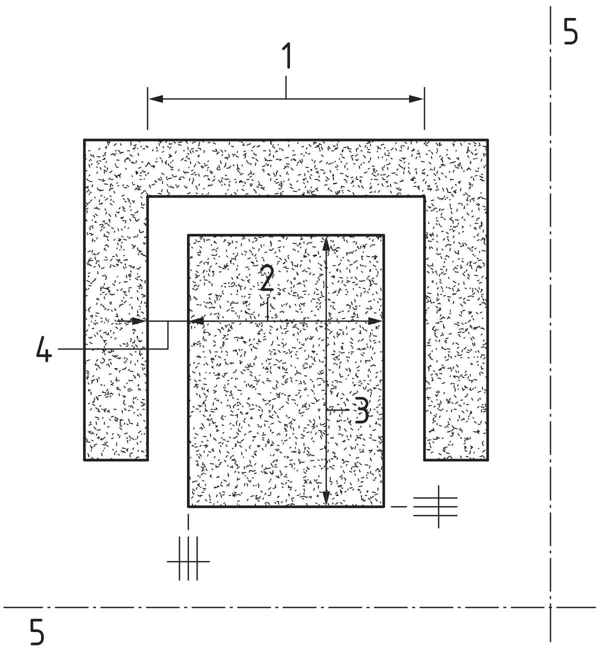
Say for practical dimensioning, 430 mm internal size.

A similar calculation should be carried out to establish the internal size of the cladding unit in the direction at right angles.

Variability information	Deviations
Suspended structural floor before laying screed material (in-situ concrete)	Variation in level from target plane from Table C.1 (T.1.3) ±25 mm
Electrical trunking	Estimated thickness ±0.5 mm
Level of screeded floor material (in-situ concrete)	Variation in datum from target plane from Table C.1 (T.1.3) ±15 mm

Figure B.7 — *Plan showing precast cladding detail around in-situ concrete column*

Dimensions in millimetres



Key

1 Estimate required minimum dimension to accommodate column variability and cavity/insulation

2 Target size 300 mm

3 Target size 400 mm

4 Minimum cavity/insulation requirement 50 mm

5 Reference setting out line

B.4 Calculation of the minimum thickness of screeding to accommodate electrical trunking

Construction of in-situ concrete ground floor slab with 15 mm p.v.c covered electrical trunking covered with a cast in-situ screed (see Figure B.8).

Calculation of target thickness of screed:

Total tolerance = $\sqrt{\left(25^2 + 0.5^2 + 15^2\right)}$

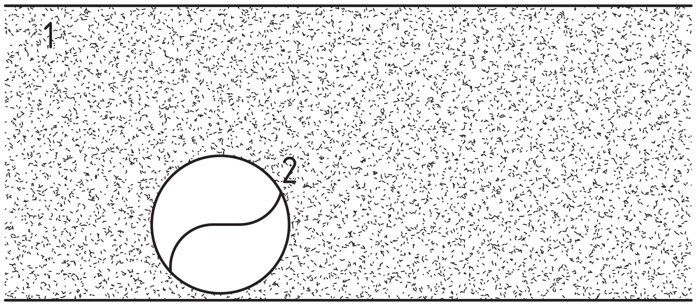
= ±29 mm

Target thickness of screed to be achieved = minimum thickness

+ thickness of trunking

+ 29 mm

Figure B.8 — *Diagrammatic section of screeding*



Key

1 In-situ screed

2 15 mm PVC covered electrical trunking

If the overall thickness of screed is considered excessive the following actions can be taken into account:

a) recess trunking into concrete slab (if design permits); and

b) reduce minimum thickness over trunking but reinforce with mesh.

The possibility that the trunking can cross over other trunking services laid on the slab should be taken into account.

Recommendations given in BS 8203:2017, **6.10** and BS 8204-1:2003+A1:2009, **6.4.5** on pipes and trunking within the thickness of screeds should be taken into account in reaching a solution.

Annex C (informative) Measured values of dimensional accuracy

C.1 Measurement surveys

NOTE This annex is included for reference to source tables referred to throughout the document for estimates of dimensional variability and covers the empirical surveys carried out by the BRE in the 1970s and 1980s. It does not represent current practice for spatial measurement practice and is not to be relied upon for the establishment of specifications for projects accuracy or tolerances – they are retained in this edition for illustrative and historical purposes.

C.1.1 Survey of constructed items

Measurements were made during the Building Research Establishment (BRE) survey (undertaken between 1975 and 1977) of the size and shape of building elements and the space between them for common constructional materials. The standardized methods used for measuring the particular dimensions chosen for the survey are summarized in Annex D.

C.1.2 Survey of manufactured items

Measurements were made by the BRE, between 1986 and 1988, of the size and shape of manufactured components commonly used in building construction for common materials, namely precast concrete (both reinforced and prestressed), fabricated steel and timber.

C.2 Analysis of the measured data

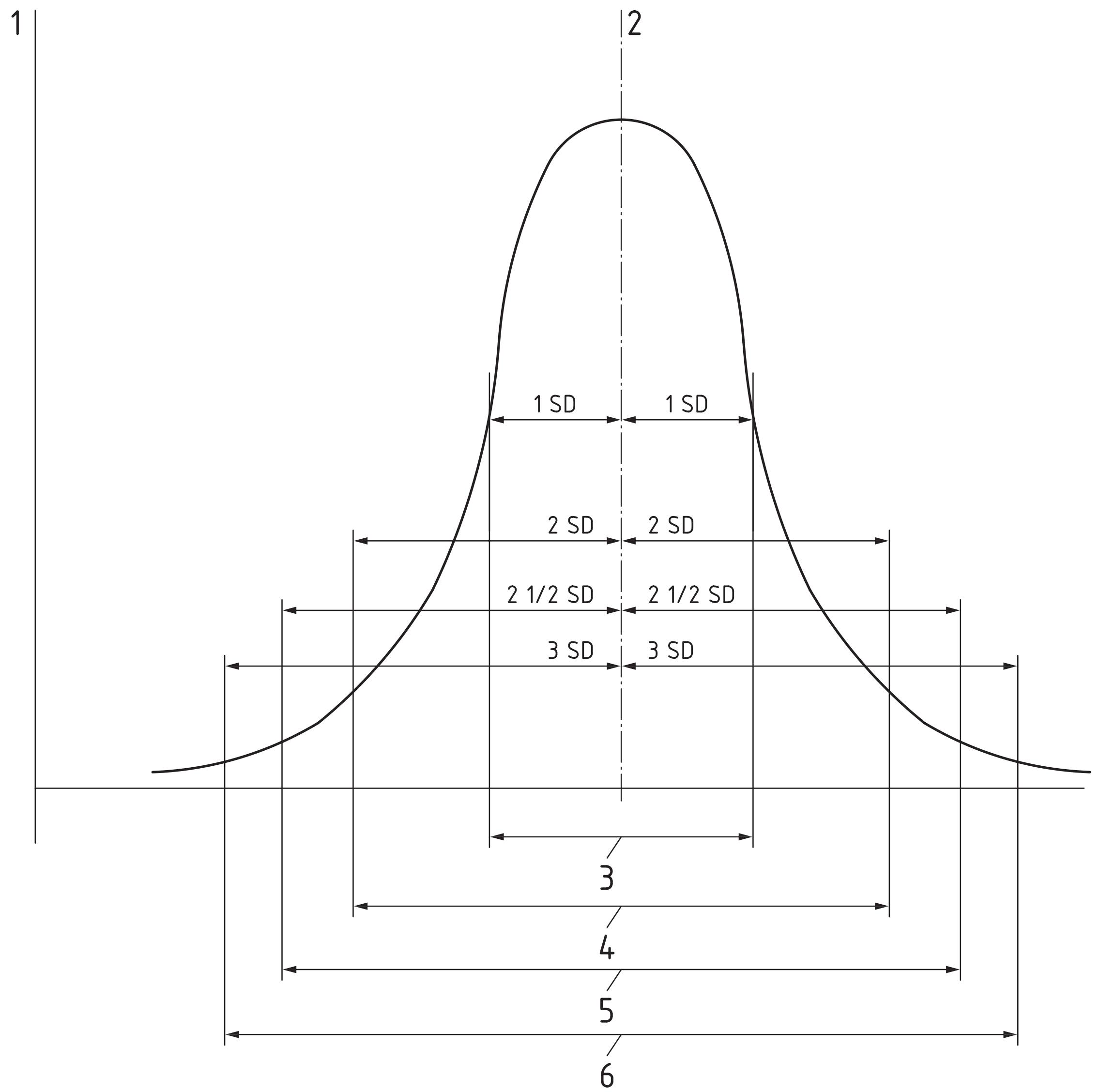
The results of each survey showed that for each construction task, or each manufacturing process, normal methods of working resulted in a consistent pattern of dimensional variability. The variability occurs even when properly trained and fully experienced operatives using the correct procedures, materials and tools make genuine attempts to achieve the specified sizes. It arises because of the physical limitations of the operative and the inherent variability of the materials, tools and measuring equipment used. The magnitude of the variability varies from process to process and is characteristic of the process.

The surveys confirm that the accuracy of a process cannot be improved simply by specifying tighter tolerances. To improve the accuracy characteristic of a process it is necessary to change the method of working by the use of different materials or by the adoption of intrinsically more accurate construction (or manufacturing) and measuring techniques. Such actions are likely to require cost benefit analysis and an awareness of developing technologies and factory capabilities which are constantly improving, e.g. DFMA.

For any given process, the characteristic dimensional variability displays what statistically is known as a "normal" distribution about the mean value (see Figure C.1). The shape of this distribution curve indicates the spread of the values about the mean value. The standard deviation (SD) is a measure of the extent of this spread about the mean value. In some processes, the mean value differs from the target value and this difference is termed the systematic deviation. Characteristic accuracy is expressed in terms of the SD and the systematic deviation ($\bar{x}$).

The shape of the normal distribution curve is such that a range of ±1 SD about the mean value includes 68.27% of sizes, ±2 SD includes 95.45% of sizes, ±2.5 SD includes 98.75% of sizes and ±3 SD includes 99.73% of sizes (see Figure C.1).

Figure C.1 — *Normal distribution of sizes*



Key

1 Number of times value occurs

2 Mean value

3 68.27% included, approx. 1 in 3 falling outside

4 95.45% included, approx. 1 in 22 falling outside

5 98.75% included, approx. 1 in 80 falling outside

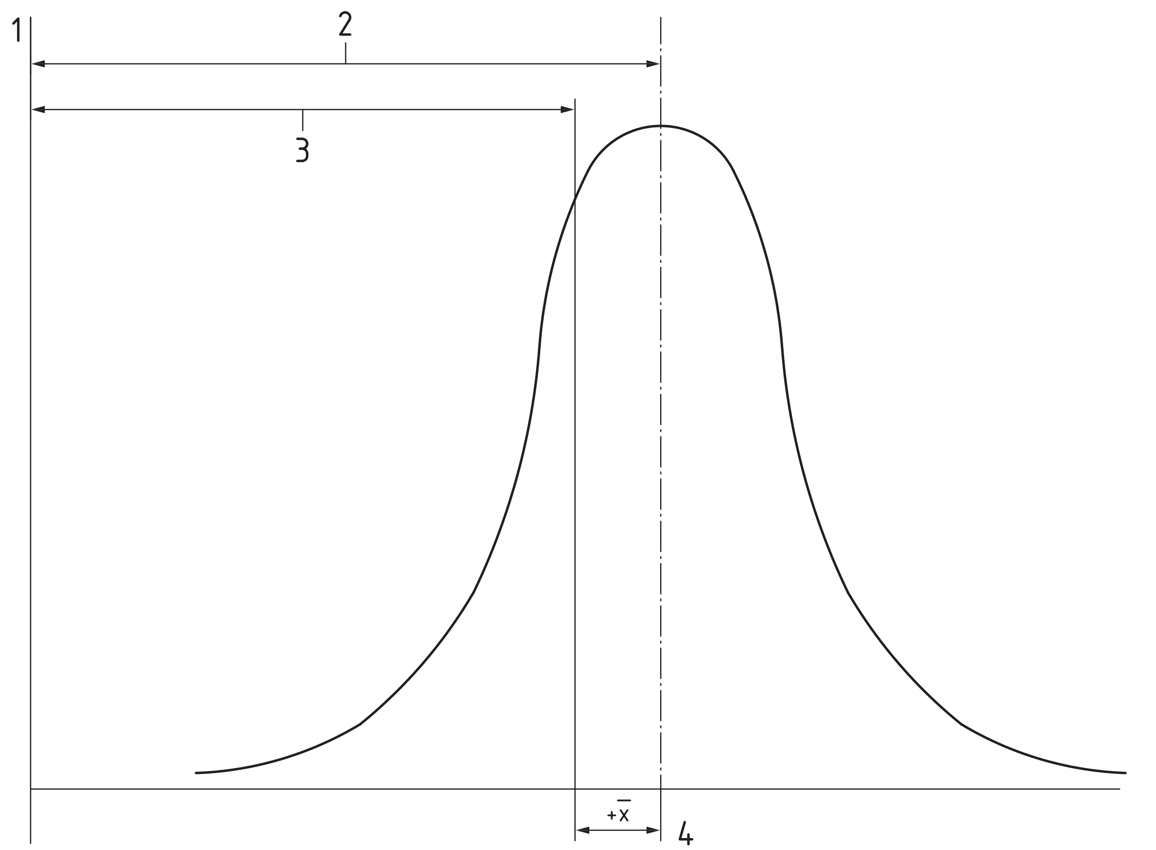
6 99.73% included, approx. 1 in 370 falling outside

C.3 Values of characteristic accuracy for construction and manufacture

Table C.4 presents the survey data as values of characteristic accuracy for each of the items of construction and types of dimension measured. Separate values are given for common materials used in building construction. Similarly, information is given in Table C.5 for manufacture of precast concrete (both reinforced and prestressed), fabricated steel and timber components.

Within Table C.4 and Table C.5, each systematic deviation $\bar{x}$ has been obtained by subtracting the target size from each of the measured sizes. Thus a negative value of systematic deviation indicates a mean size which is smaller than the target size by $\bar{x}$ mm, and vice versa for a positive value systematic deviation. See Figure C.2.

Figure C.2 — *Indication of a systematic deviation of +* $\bar{x}$ *mm from a target size*



Key

1 Number of occurrences

2 Characteristic mean size

3 Target size

4 Systematic deviation from the target size

Table C.1 — *Range of deviations found achievable for construction from BRE Surveys 1975–76 and 1985–88 (98.75% confidence level)*

Item of construction		Location	Construction material					
			Brickwork	Blockwork	In-situ concrete	Precast concrete	Steel	Timber
			mm	mm	mm	mm	mm	mm
T.1.1 space[A)] between elements	Walls up to 7 m apart	At floor	±15	±16	±24	±15	n/a	±27
		At soffit	±20	±21	±24	±18	n/a	±32
	Columns up to 7 m apart	At floor	n/a	n/a	±17	±13	±12	±12[B)]
		At soffit	n/a	n/a	±18	±13	±10	—
	Cased steel columns	At floor	n/a	n/a	n/a	n/a	±16	n/a
		At soffit	n/a	n/a	n/a	n/a	±16	n/a
	Beams and floor slabs	Floor to soffit height	n/a	n/a	±23	±19	—	—
T.1.2 openings	Window or door	Width up to 3 m (not jigged)	±20	—	±14	±11	—	—
		Height up to 3 m (not jigged)	±20	—	±20	±10	—	—
T.1.3 Size and shape of elements and components	Walls	Height up to 3 m	±26	±28	—	—	n/a	—
		Thickness	±20	±19[B)]	±8[B)]	—	n/a	—
		Straightness in 5 m	±5	±6	±9	±6	n/a	—
		Abrupt changes in a continuous surface	—	—	±4[B)]	±3[B)]	n/a	n/a
		Vertically up to 2 m	9	9	11	8	n/a	14
		up to 3 m	10	10[B)]	17	11	n/a	—
		up to 7 m	14[B)]	14	16[B)]	14[B)]	n/a	n/a
		Level of bed joints	±11	±13	n/a	n/a	n/a	n/a
	Columns	Size on plan up to 1 m	—	—	±8	—	—	—
		Vertically up to 3 m	n/a	n/a	12	10	6	10
		up to 7 m	n/a	n/a	16[B)]	14[B)]	8	—
		Cased steel verticality up to 3 m	n/a	n/a	n/a	n/a	10	n/a
		Squareness	n/a	n/a	9	—	—	—
	Beams	Depth						
		(Perimeter beams) up to 600 mm	n/a	n/a	±13	—	—	—
		over 600 mm	n/a	n/a	±20	—	—	—
		(Internal beams) up to 600 mm	n/a	n/a	±12	—	—	—

Table C.1 — *Range of deviations found achievable for construction from BRE Surveys 1975–76 and 1985–88 (98.75% confidence level) (continued)*

Item of construction		Location	Construction material					
			Brickwork mm	Blockwork mm	In-situ concrete mm	Precast concrete mm	Steel mm	Timber mm
		over 600 mm	n/a	n/a	±16	—	—	—
		Level[C]						
		Variation from target plane	n/a	n/a	±22	±23	±20	±20[B]
		Straightness in 6 m	n/a	n/a	10[B]	8[B]	8[B]	10[B]
	Suspended structural floor before laying of screed[E]	Level[D]	n/a	n/a	±25	±28	n/a	—
		Variation from target plane	n/a	n/a	n/a	±31	n/a	n/a
		in-situ or precast slab						
		in-situ topping on precast						
		Structural soffit	n/a	n/a	±19	±18	n/a	—
	Non suspended floor slabs before laying of screed[F]	Thickness	n/a	n/a	±10[B]	—	n/a	n/a
		Level[D]	n/a	n/a	±25[B]	—	n/a	n/a
		Variation from target plane						
	In-situ floorings	Surface regularity[D]						
		Direct finished base slabs, topping and screeds						
		Variation from target plane	n/a	n/a	±15[B]	—	n/a	n/a
		Flatness	n/a	n/a	±5[B]	—	—	—
		Abrupt change across joints	—	—	±2[B]	—	—	—
T.1.4	Building	Length or width up to 40 m	±29	—	±26	±38	±14	—
Overall size on plan	Ground floor slab	Length or width	n/a	n/a	±28	—	n/a	n/a

Table C.1 — *Range of deviations found achievable for construction from BRE Surveys 1975–76 and 1985–88 (98.75% confidence level) (continued)*

Item of construction / Location	Construction material					
	Brickwork	Blockwork	In-situ concrete	Precast concrete	Steel	Timber
	mm	mm	mm	mm	mm	mm
T.1.5 Position on plan in relation to the nearest reference line at the same level						
a) Foundations						
Mass concrete in excavated ground with minimum formwork	n/a	n/a	±50[B]	n/a	n/a	—
Reinforced concrete including rafts, ground beams, column bases, pile caps and strip footings	n/a	n/a	±50[B]	±20[B]	n/a	—
b) Walls	±10[B]	±10[B]	±16[B]	±14[B]	±10[B]	±14[B]
c) Structural frame columns	±10[B]	n/a	±12[B]	±10[B]	±10[B]	±10[B]
d) Lift walls	±10[B]	±10[B]	±12[B]	±10[B]	n/a	n/a
e) Stair wells	±10[B]	±10[B]	±12[B]	±10[B]	n/a	n/a
f) Finished stairs (flight from landing to landing)	n/a	n/a	±12[B]	±10[B]	n/a	n/a
g) Door, window and other openings	±10[B]	±10[B]	±12[B]	±10[B]	n/a	±10[B]
h) Formers for items to be cast or built in	±6[B]	±6[B]	±6[B]	±6[B]	n/a	n/a
i) All other elements above foundations	±10[B]	±10[B]	±12[B]	±10[B]	±10[B]	±10[B]
T.1.6 Dimensions on plan in relation to target sizes						
a) Foundations:						
Mass concrete [as T.1.5a)]	n/a	n/a	±50[B]	n/a	n/a	n/a
Reinforced concrete [as T.1.5a)]	n/a	n/a	±50[B]	±10[B]	n/a	n/a
b) Structural frame length and width up to 8 m	±12[B]	±12[B]	±16[B]	±12[B]	±12[B]	±12[B]
Over 8 m and up to 15 m	±16[B]	±16[B]	±18[B]	±16[B]	±16[B]	±16[B]
Over 15 m and up to 25 m	±18[B]	±18[B]	±20[B]	±18[B]	±18[B]	±18[B]
c) Stairs (structural)[G]						
Length of clear span	n/a	n/a	±14[B]	±12[B]	±12[B]	±12[B]
Width of flight	n/a	n/a	±8[B]	±6[B]	±6[B]	±8[B]
Difference in width of tread or going of consecutive steps	n/a	n/a	±10[B]	±8[B]	±8[B]	±10[B]
Waist thickness measured square to slope of flight	n/a	n/a	±8[B]	±6[B]	±6[B]	±8[B]

Table C.1 — *Range of deviations found achievable for construction from BRE Surveys 1975–76 and 1985–88 (98.75% confidence level) (continued)*

Item of construction	**Location**	**Construction material**					
		Brickwork	**Blockwork**	**In-situ concrete**	**Precast concrete**	**Steel**	**Timber**
		mm	mm	mm	mm	mm	mm
Stairs (finished)[G)]							
Length of clear span		n/a	n/a	±12[B)]	±10[B)]	±10[B)]	±12[B)]
Width of flight		n/a	n/a	±10[B)]	±10[B)]	±10[B)]	±10[B)]
T.1.7 Position in elevation in relation to the nearest reference line							
a) Door, window and other openings including lift landing doors		±15[B)]	± 15[B)]	±15[B)]	±15[B)]	n/a	—
b) Timber components		n/a	n/a	n/a	n/a	n/a	±10[B)]
c) Formers for items to be cast or built in		±10[B)]	±10[B)]	±10[B)]	±10[B)]	n/a	n/a
T.1.8 Levels. Range of deviations in level with reference to the nearest temporary bench mark (TBM)							
a) Foundations							
Mass concrete [as T.1.5a)]							
Formation surface of excavation or blinding concrete		n/a	n/a	±34[B)]	—	n/a	n/a
Upper surface		n/a	n/a	20[B)]	—	n/a	n/a
Reinforced concrete [as T.1.5a)]							
Formation surface of excavation or blinding concrete		n/a	n/a	±30[B)]	—	n/a	n/a
Upper surface		n/a	n/a	±16[B)]	—	n/a	n/a
b) Concrete frame							
Structural roof							
Upper surface height up to 30 m		n/a	n/a	±16[B)]	±20[B)]	n/a	n/a
For each subsequent 30 m		—	—	±8[B)]	±10[B)]	n/a	n/a
c) Steel/timber structural frame							
Base of first erected or constructed member		n/a	n/a	n/a	n/a	±10[B)]	±12[B)]
Top of the steel frame at any storey		n/a	n/a	n/a	n/a	±16[B)]	±20[B)]
Difference in level in any 5 m length measured in that storey		n/a	n/a	n/a	n/a	±6[B)]	±10[B)]

Table C.1 — *Range of deviations found achievable for construction from BRE Surveys 1975–76 and 1985–88 (98.75% confidence level) (continued)*

Item of construction	Location	Construction material					
		Brickwork	Blockwork	In-situ concrete	Precast concrete	Steel	Timber
		mm	mm	mm	mm	mm	mm
d) Stairs (Structural)							
Vertical height of any flight between landings		n/a	n/a	±15[B)]	±15[B)]	—	—
Difference in rise of any consecutive steps		n/a	n/a	±6[B)]	±4[B)]	—	—
Difference in level of tread with the going		n/a	n/a	±4[B)]	±4[B)]	—	—
Per metre width of stair (other widths pro rata with a maximum of 10 mm)		—	—	±5[B)]	±5[B)]	—	—
Stairs finished vertical height of any flight between landings		n/a	n/a	±10[B)]	±10[B)]	±10[B)]	±10[B)]
e) Door, window and other openings including lift landing doors							
Sill and soffit, for each 1 m of width (other widths pro rata with a maximum of 15 mm)		±6[B)]	±6[B)]	±6[B)]	±6[B)]	—	—
T.1.9 Verticality at any point							
a) Lift wells							
Each wall:							
For the first 30 m of height		26[B)]	26[B)]	25[B)]	26[B)]	n/a	n/a
For each additional 12 m of height with a maximum of ±65 mm		6[B)]	6[B)]	6[B)]	6[B)]	n/a	n/a
b) Door jambs							
Plumbness							
For each metre of height with a maximum of 15 mm		4[B)]	4[B)]	4[B)]	4[B)]	n/a	n/a
c) Timber components							
In any 3 m of height		n/a	n/a	n/a	n/a	n/a	8[B)]

NOTE 1 The values in this table are based on the characteristic accuracy values given in Table C.4 and have been obtained by multiplying the measured standard deviations by 2 and adding the value of the measured systematic deviation (disregarding its sign) and rounding to the nearest 1 min.

NOTE 2 The values in this table are based on two standard deviations and on the systematic deviation for each process.

Table C.1 — *Range of deviations found achievable for construction from BRE Surveys 1975–76 and 1985–88 (98.75% confidence level) (continued)*

Item of construction		Location	Construction material					
			Brickwork	Blockwork	In-situ concrete	Precast concrete	Steel	Timber
			mm	mm	mm	mm	mm	mm

A) Values for space between elements take into account variabilities due to position, verticality, straightness/bow and cross section, and should not be combined with values for the latter items.

B) Estimated value.

C) Level variability of beams is measured on the soffit of concrete beams but on the top of steel beams.

D) Variability of surface level can be expressed in two ways. a) Variation from target plane, i.e. variability above and below the target plane (defined with reference to an adjacent TBM) of each of the points levelled. b) Flatness, i.e. "Flatness" of the surface, is defined as the departure from a 3 m straightedge in contact with the floor. This value of flatness is already taken into account in a) above and therefore should not be combined with variation in datum.

E) A suspended structural floor is one designed to span between edge supports.

F) Range of deviations given apply to offices, residential buildings and ordinary industrial ground bearing slabs. Modern high-density warehouses with sophisticated and semi-automated stacking using narrow aisle trucks need higher standards of surface regularity of the floors. Concrete Society TR34 [4] provides valuable guidance on this subject.

G) Check building regulations.

n/a = not applicable.

— = data not available.

Table C.2 — *Range of deviations achieved for manufactured components from 1985–88 BRE Survey – for information only (98.75% confidence level)*

Item	Type of dimension measured	Construction material					
		Precast reinforced concrete	**Precast prestressed concrete**			**Fabricated steel**	**Timber**
			Stop end plated	**Formed or extruded**	**Inverted T-beams**		
		mm	mm	mm	mm	mm	mm
T.2.1 Overall size (see Table 1 to Table 4)	Length						Length up to 6 m:
	up to 2 m	±6	±6	±18	±15	±5	Frames ±4
	2 m to 6 m	±9	±9	±18	±15	±5	Panels ±5
	6 m to 10 m	±12	±12	±18	±15	±5	Doors ±3
	10 m to 20 m	—	—	—	±25	±5	
	20 m to 30 m	—	—	—	±35	±5	
	Length up to 12 m	—	—	—	—	—	Trusses ±15[A)]
	Height to apex	—	—	—	—	—	Trusses ±6[A)]
	Width or height up to 250 mm	±4	±8	±8	±8	—	Frames ±4
	250 mm to 1.25 m	±6	±8	±8	±12	—	Panels ±4
	1.25 m to 4.0 m	±8	±14	—	±16	—	Doors ±3
	Thickness or depth up to 0.5 m	±6	±7	±10	±6	—	—
	0.5 m to 1.5 m	±8	—	—	±6	—	—
T.2.2 Shape (see Table 5 to Table 7)	Position and size of cut outs and extensions up to 0.5 m	±6	—	±17	±17	—	—
	0.5 m to 10 m	±12	—	—	±17	—	—
	Squareness up to 1.2 m	±6	—	—	12	—	—
	1.2 m to 1.8 m	±9[A)]	—	—	—	—	—
	over 1.8 m	±12[A)]	—	—	—	—	—
	Flatness	6[A)] over a 1.5 m length	—	—	—	—	—
	Position of internal holes up to 10 m	±15	±15	—	±15	—	Frames and panels ±5
T.2.3 Connections (see Table 8 to Table 11)	Position of fixing plates or cleats up to 2 m	±6	±9	—	±9	±5	—
	2 m to 10 m	±14	±18	—	±18	±5	—

Table C.2 — *Range of deviations achieved for manufactured components from 1985–88 BRE Survey – for information only (98.75% confidence level) (continued)*

Item	Type of dimension measured	Construction material					
		Precast reinforced concrete	**Precast prestressed concrete**			**Fabricated steel**	**Timber**
			Stop end plated	**Formed or extruded**	**Inverted T-beams**		
		mm	mm	mm	mm	mm	mm
	Position of centres of bolt holes						
	a) along length	±9	±11	—	±11	±5	—
	across width	±9	±11	—	±11	±3	—
	within cluster	±3[A)]	±3	—	±3[A)]	±2	—
	b) in welded end plates	—	—	—	—	±4	—
	within cluster	—	—	—	—	±2	—
	c) in base plates in	—	—	—	—	±4	—
	relation to holes	—	—	—	—	±4	—

NOTE The values in Table C.2 are based on the characteristic accuracy [typical deviations from target size] values given in Table C.5, and have been obtained by multiplying the measured standard deviations by 2.5 and adding the value of the measured systematic deviation (disregarding its sign) and rounding to the nearest 1 mm.

A) Estimated value.

Table C.3 — *Accuracy in use of measuring instruments from BRE survey 1975–76 and 1985–88 – provided for information only*

Measurement	Instrument	Range of deviations	Comment (see also NOTE)
T.3.1 Linear	30 m carbon steel tape for general use	±5 mm up to and including 5 m	With sag eliminated and slope correction applied.
		±10 mm for over 5 m and up to and including 25 m	
		±15 mm for over 25 m	
	30 m carbon steel tape for use in precise work	±3 mm up to and including 10 m	At correct tension and with slope, sag and temperature corrections applied.
		±6 mm for over 10 m and up to and including 30 m	
	Electronic distance measuring (EDM) instruments (short range models) for general use	±10 mm for distances over 30 m and up to 50 m	Accuracies of EDM instruments vary, depending on make and model of instruments.
		±(10 mm ±10 p.p.m.)[C)] for distances greater than 50 m	Distances measures by EDM should normally be greater than 30 m and measured from each end.
	Precise work	±(5 mm ±5 p.p.m.)[C)]	
T.3.2 Angular	Opto-mechanical (e.g. glass arc) theodolite[A)] (with optical plummet or centering rod) reading directly to 20″	±20″ (±5 mm in 50 m)	Scale readings estimated to the nearest 5″. Mean of two sights, one on each face with readings in opposite quadrants of the horizontal circle.
	Opto-mechanical (e.g. glass arc) theodolite (with optical plummet or centering rod) reading directly to 1″	±5″ (±2 mm in 80 m)	Mean of two sights, one each face with readings in opposite quadrants of the horizontal circle.
	1″ opto-electronic theodolite/total station	±3″ (±1 mm in 50 m)	Mean of two sights, one on each face with readings in opposite quadrants of the horizontal circle.
T.3.3 Verticality	Spirit level	±10 mm in 3 m	For an instrument not less than 750 mm long.
	Plumb-bob (3 kg) freely suspended	±5 mm in 5 m	Should only be used in still conditions.
	Plumb-bob (3 kg) immersed in oil to restrict movement	±5 mm in 10 m	Should only be used in still conditions.
	Theodolite (with optical plummet or centering rod) and diagonal eye-piece	±5 mm in 30 m[B)]	Mean of at least four projected points, each one established at a 90° interval.
	Optical plumbing device	±5 mm in 100 m	For an instrument not less than 750 mm long.
	Laser upwards or downwards alignment	±7 mm in 100 m	Four readings should be taken in each quadrant of the horizontal circle and the mean value of readings in opposite quadrants accepted. Appropriate safety precautions should be applied according to power of instrument used.

Table C.3 — *Accuracy in use of measuring instruments from BRE survey 1975–76 and 1985–88 – provided for information only (continued)*

Measurement	Instrument	Range of deviations	Comment (see also NOTE)
T.3.4 Levels	Spirit level	±5 mm in 5 m distance	Instrument not less than 750 mm long.
	Water level	±5 mm in 15 m distance	Sensitive to temperature variation.
	Lightweight self-levelling level	±5 mm in 25 m distance	
	Optical level		
	a) “builders” class	±5 mm per single sight of up to 60 m[B)]	Where possible, sight lengths should be equal.
	b) “engineers” class	±3 mm per single sight of up to 60 m[B)]	
		±10 mm per km	If staff readings of less than 1 mm are required the use of a precise level incorporating a parallel plate micrometer is essential but the range per sight preferably should be about 15 m and should be not more than 20 m. Appropriate safety precautions should be applied according to power of instrument used.
	c) “precise” class	±2 mm per single sight of up to 60 m	
		±8 mm per km	
	Laser level (visible light source)	±7 mm per single sight up to 100 m	
	(invisible light source)	±5 mm per single sight up to 100 m	

NOTE Equipment should be checked periodically in accordance with BS 7334 (all parts).

A) If a single sighting only is made when using a correctly adjusted theodolite to establish an angle the likely deviations are increased by a factor of 3. Therefore, a single sight should not be taken.

B) Value based on measured data.

C) Parts per million of measured distance.

Table C.4 — *Characteristic accuracy values for construction determined from a Building Research Establishment survey from 1975 to 1976*

Item of construction		Location	Data form[A)]	Construction material											
				Brickwork		Blockwork		In-situ concrete		Precast concrete		Steel		Timber	
				$\bar{x}$ [B)]	SD[C)]	$\bar{x}$ [B)]	SD	$\bar{x}$ [B)]	SD	$\bar{x}$ [B)]	SD	$\bar{x}$ [B)]	SD	$\bar{x}$ [B)]	SD
T.4.1 Space between elements	Walls	at floor	b	2.0	6.4	0.9	7.7	1.9	10.8	0.1	7.4	n/a	n/a	−0.8	13.2
		at soffit	b	0.3	9.7	0.5	10.3	2.6	10.5	0.7	8.8	n/a	n/a	2.5	14.6
	Columns	at floor	b	n/a	n/a	n/a	n/a	−1.9	7.3	0.1	6.6	−1.3	5.5	—	—
		at soffit	b	n/a	n/a	n/a	n/a	−0.5	8.9	0.5	6.1	−0.8	4.8	—	—
		Cased steel at floor	b	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	−1.7	7.1	n/a	n/a
		at soffit	b	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	−1.1	7.5	n/a	n/a
	Beams Floor slabs	Floor to soffit height	c	n/a	n/a	n/a	n/a	−2.0	10.7	2.2	8.6	—	—	—	—
T.4.2 Openings	Window or door	Width up to 3 m (not jigged)	p	3.6	8.1	—	—	0.4	6.6	−0.6	5.2	n/a	n/a	—	—
		Height up to 3 m (not jigged)	p	3.2	8.6	—	—	3.7	8.3	−0.1	5.0	n/a	n/a	—	—
T.4.3 Size and shape of elements and components	Walls	Height up to 3 m	m	1.3	12.2	−2.9	12.7	—	—	—	—	n/a	n/a	—	—
		Thickness	o	−2.3	8.6	—	—	—	—	—	—	NA	n/a	—	—
		Straightness in 5 m	L	0.4	2.2	0.1	2.8	−0.3	4.3	−0.2	3.0	n/a	n/a	—	—
		Verticality in storey heights													
		up to 2 m	h	0.3	4.3	0.4	4.4	0.4	5.3	−0.2	3.7	n/a	n/a	−0.7	6.9
		up to 3 m	h	1.0	4.5	—	—	−1.8	7.5	0.6	5.0	n/a	n/a	—	—
		Level of bed joints 3 m	h	0.6	5.1	1.0	6.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Columns	Size on plan of any face, up to 1 m	k	n/a	n/a	n/a	n/a	−0.1	3.9	−0.2	2.6	—	—	—	—
		Verticality in storey heights													
		up to 3 m	h	n/a	n/a	n/a	n/a	−0.8	5.7	0.1	4.8	0.5	2.8	—	—
		up to 7 m	h	n/a	n/a	n/a	n/a	—	—	—	—	0.5	3.6	—	—
		cased steel up to 3 m	h	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.8	4.6	n/a	n/a
		squareness	k	n/a	n/a	n/a	n/a	3.0	3.1	1.5	1.5	—	—	—	—

Table C.4 — *Characteristic accuracy values for construction determined from a Building Research Establishment survey from 1975 to 1976 (continued)*

Item of construction	Location	Data form[A)]	Construction material											
			Brickwork		Blockwork		In-situ concrete		Precast concrete		Steel		Timber	
			$\bar{x}$ [B)]	SD[C)]	$\bar{x}$ [B)]	SD	$\bar{x}$ [B)]	SD	$\bar{x}$ [B)]	SD	$\bar{x}$ [B)]	SD	$\bar{x}$ [B)]	SD
Beams	Depth up to 600 mm	j	n/a	n/a	n/a	n/a	4.2	8.5	—	—	—	—	—	—
	(perimeter beams) over 600 mm	j	n/a	n/a	n/a	n/a	2.7	8.5	—	—	—	—	—	—
	(Internal beams) up to 600 mm	j	n/a	n/a	n/a	n/a	2.5	4.5	—	—	—	—	—	—
	over 600 mm	j	n/a	n/a	n/a	n/a	2.0	6.9	—	—	—	—	—	—
	Level [D),E)]												—	—
	Variation from the target plane of any point on the surface	f, g	n/a	n/a	n/a	n/a	–0.6	10.8	2.3	10.4	4.2	8.1	—	—
[F)] Sus-pended structural floor before laying of screed	Level[E)] (based on 2.5 m grid) Variation from the target plane of any point on the surface	e	n/a	n/a	n/a	n/a	4.2	10.6	–1.5	13.2	n/a	n/a	—	—
	Precast with in-situ topping Level[E)] (based on 2.5 m grid) Variation from the target plane of any point on the surface	e	n/a	n/a	n/a	n/a	n/a	n/a	–3.0	14.2	n/a	n/a	n/a	n/a
Structural soffit	Level[E)] (based on 2.5 m grid) Variation from the target plane of any point on the surface	e	n/a	n/a	n/a	n/a	0.5	9.3	2.2	8.1	n/a	n/a	—	—
Panels	Length	q	—	—	—	—	—	—	—	—	n/a	n/a	–1.3	1.6
	Height	q	—	—	—	—	—	—	—	—	n/a	n/a	–1.4	1.8

Table C.4 — *Characteristic accuracy values for construction determined from a Building Research Establishment survey from 1975 to 1976 (continued)*

Item of construction		Location	Data form[A)]	Construction material											
				Brickwork		**Blockwork**		**In-situ concrete**		**Precast concrete**		**Steel**		**Timber**	
				$\bar{x}$ [B)]	SD[C)]	$\bar{x}$ [B)]	**SD**	$\bar{x}$ [B)]	**SD**	$\bar{x}$ [B)]	**SD**	$\bar{x}$ [B)]	**SD**	$\bar{x}$ [B)]	**SD**
T.4.4 Overall size (on plan)	Building	Length or width up to 40 m	d	0.6	14.0	—	—	2.9	11.5	3.4	17.5	–0.1	6.7	—	—
	Ground floor slab	Length or width	d	n/a	n/a	n/a	n/a	–0.6	13.7	—	—	n/a	n/a	n/a	n/a

NOTE All values are expressed in millimetres and are positive unless otherwise indicated.

A) See Annex D.

B) $\bar{x}$ is, in this standard, the displacement of the mean and is the mean of the values obtained by subtracting the space or work size from all the measured sizes for each item. Measurements were taken to the nearest millimetre.

C) SD is the standard deviation.

D) Level variability of beams is measured on the soffit of concrete beams but on the top of steel beams.

E) Variability of surface level has been expressed by taking into account the variability above and below the target plane (defined with reference to an adjacent TBM) of each of the points levelled.

F) A suspended structural floor is one designed to span between edge supports.

Table C.5 — *Characteristic accuracy values for manufactured components determined from BRE survey, 1988 to 1989*

Item	Type of dimension measured	Construction materials											
		Precast reinforced concrete		Precast prestressed concrete						Fabricated steel		Timber	
				Stop end plated		Formed of extruded		Inverted T beams					
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
T.5.1 Overall size	Length											Length to bm: Panels	
												−0.5	1.9
	up to 2 m	−0.1	2.3	−0.1	2.3	−1.0	7.0	0.3	6.1	−0.3	2.1	Frames	
	2 m to 6 m	−0.3	3.4	−0.3	3.4	−1.0	7.0	0.3	6.1	−0.3	2.1	−01	1.4
	6 m to 10 m	0.5	4.6	0.5	4.6	−1.0	7.0	0.3	6.1	−0.3	2.1	Doors	
	10 m to 20 m	—	—	—	—	—	—	-3.5	8.3	−0.3	2.1	0.1	1.1
	20 m to 30 m	—	—	—	—	—	—	-5.7	12.1	−0.3	2.1		
	Width												
	up to 250 mm	0.6	1.2	0.9	3.1	0.9	3.1	1.3	2.9	—	—	—	—
	250 mm to 1.25 m	0.6	2.1	0.9	3.1	0.9	3.1	0.7	4.8	—	—	—	—
	1.25 m to 4.0 m	0.4	3.0	0.8	5.2	—	—	5.7	4.2	—	—	—	—
	Thickness or depth												
	up to 0.5 m	1.2	1.8	1.2	1.8	0.9	3.6	-0.2	2.5	—	—	—	—
	0.5 m to 1.5 m	2.1	2.8	—	—	—		-0.2	2.5	—	—	—	—
T.5.2 Shape	Position and size of cut outs and extensions up to 0.5 m	0.8	2.5	—	—	2.9	5.6	2.9	5.6	—	—	—	—
	0.5 m to 10 m	−0.5	4.6	—	—	—	—	2.9	5.6	—	—	—	—
	Squareness up to 1.2 m	—	—	—	—	—	—	0.0	3.7	—	—	—	—
	Position of internal holes up to 10 m	−0.7	5.4	−0.7	5.4	—	—	– 0.7	5.4	—	—	Panels and frames	
												1.0	1.8

Table C.5 — *Characteristic accuracy values for manufactured components determined from BRE survey, 1988 to 1989 (continued)*

Item	Type of dimension measured	Construction materials											
		Precast reinforced concrete		Precast prestressed concrete						Fabricated steel		Timber	
				Stop end plated		Formed of extruded		Inverted T beams					
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
T.5.3 Connections	Position of fixing plates or cleats												
	up to 2 m	0.2	2.5	−0.4	3.3	—	—	−0.4	3.3	−0.1	2.0	—	—
	2 m to 10 m	−1.0	5.0	−2.5	5.9			2.5	5.9	−0.1	2.0	—	—
	Position of centres of bolt holes												
	along length	0.7	3.5	0.6	4.0	—	—	0.6	4.0	0.1	1.8	—	—
	across width	0.7	3.5	0.6	4.0	—	—	0.6	4.0	−0.1	1.4	—	—
	within cluster	—	—	—	—	—	—	—	—	0.1	0.9	—	—
	in welded end plates	—	—	—	—	—	—	—	—	−0.1	1.3	—	—
	within cluster	—	—	—	—	—	—	—	—	−0.1	0.9	—	—
	in base plates	—	—	—	—	—	—	—	—	−0.3	1.5	—	—
	in relation to holes	—	—	—	—	—	—	—	—	−0.3	1.5	—	—

Annex D (informative)
The BRE survey of constructed items

COMMENTARY ON ANNEX D

This annex is included for reference to source tables referred to in Annex C and throughout the document for estimates of dimensional variability and covers the empirical surveys carried out by the BRE in the 1970s and 1980s. It does not represent current spatial measurement practice or standard accuracies and is not to be relied upon to create specifications for design or project accuracy or tolerances – they are retained in this edition for illustrative and historical purposes only.

D.1 General

This annex was included in the 1990 edition of this British Standard and is retained here to illustrate how the tolerances and accuracies illustrated in this document from the 1970s and 1980s BRE research studies were gathered and their quality and confidence levels established. While some of these practices might still be relevant, it is the principles and rigorous approach which is the key element of its inclusion.

D.2 Information collected

The nature of the information collected for each of the construction situations included in the survey demanded the use of a variety of measurement procedures. Therefore a series of 15 data forms, labelled "b" to "p" inclusive, were designed (for BS 5606:1978) which included:

a) details of the measurement tools required;

b) recommendations on the measurement techniques to be adopted;

c) details of the type of construction;

d) target sizes;

e) actual sizes; and

f) specified tolerances with reasons.

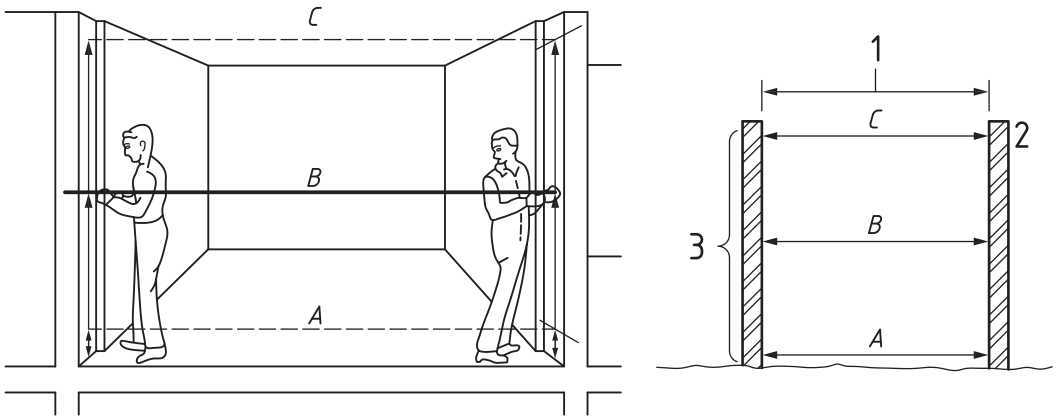
Data from data form "a" (in BS 5606:1978) was used to obtain the relevant construction details for a given site and applied for each type of dimension surveyed on that site.

Techniques used in the BRE construction surveys are illustrated in Figure D.1 to Figure D.14.

The current techniques recommended for measurement are given in BS 7307-1 and BS 7307-2.

The current methods recommended for the presentation of dimensional accuracy data are given in BS 7308.

Figure D.1 — *Distance between walls or columns (from data form b)*



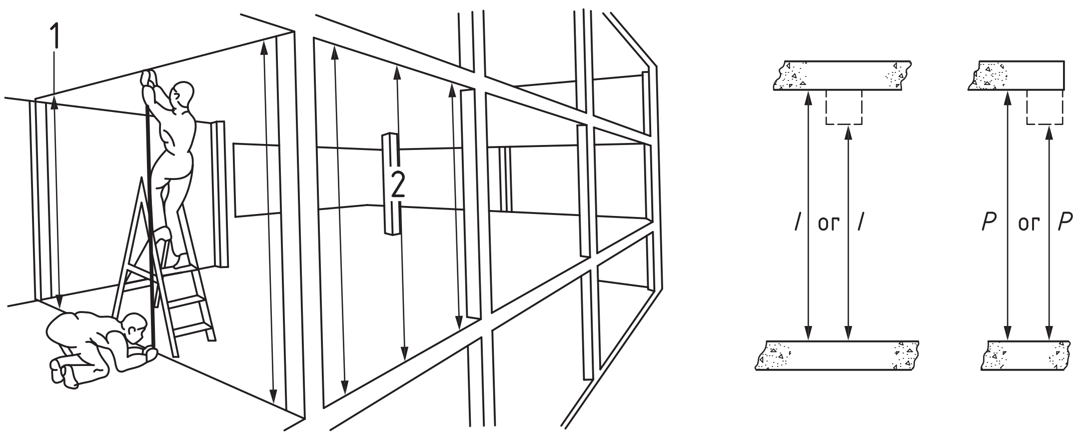
Key

1 Specified dimension

2 Wall/column

3 One storey height between 2 m and 4 m

Figure D.2 — *Distance between floor and soffit in concrete structures (from data form c)*

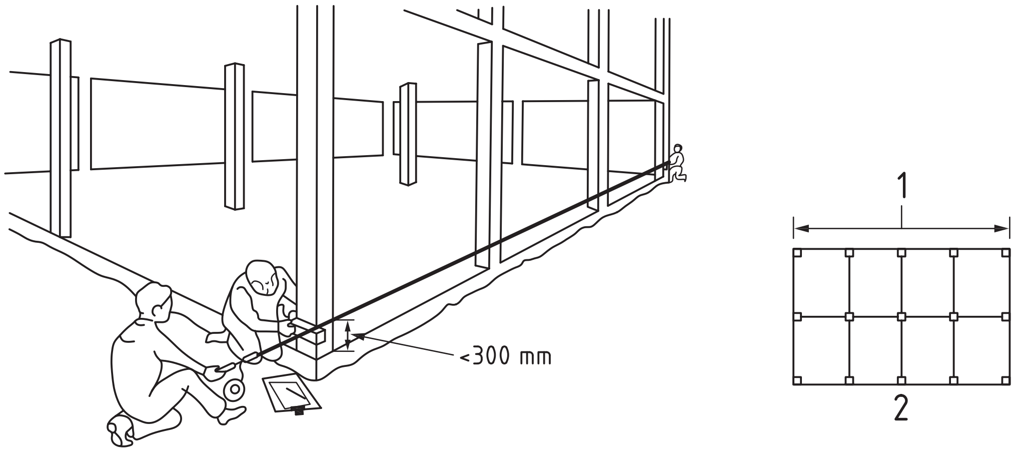


Key

1 Internal opening

2 Perimeter opening *P*

Figure D.3 — *External dimensions of buildings and ground floor slabs (from data form d)*

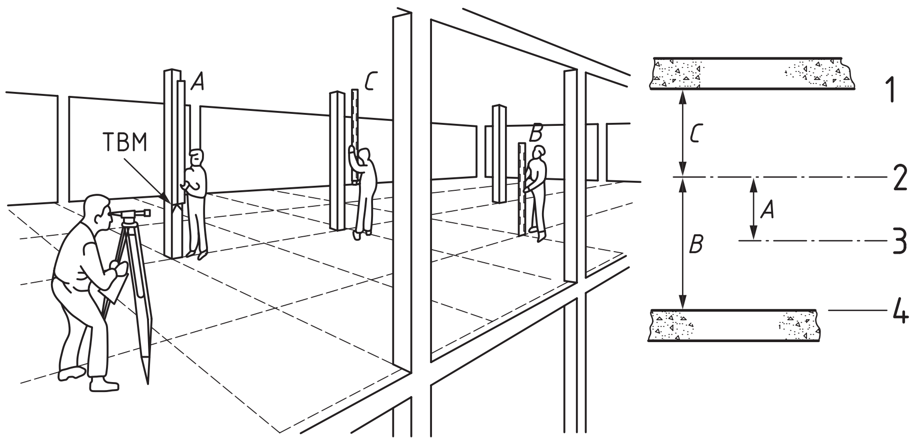


Key

1 Type of dimension intended

2 Building plan

Figure D.4 — *Level of floor and/or soffit of concrete slab (from data form e)*



Key

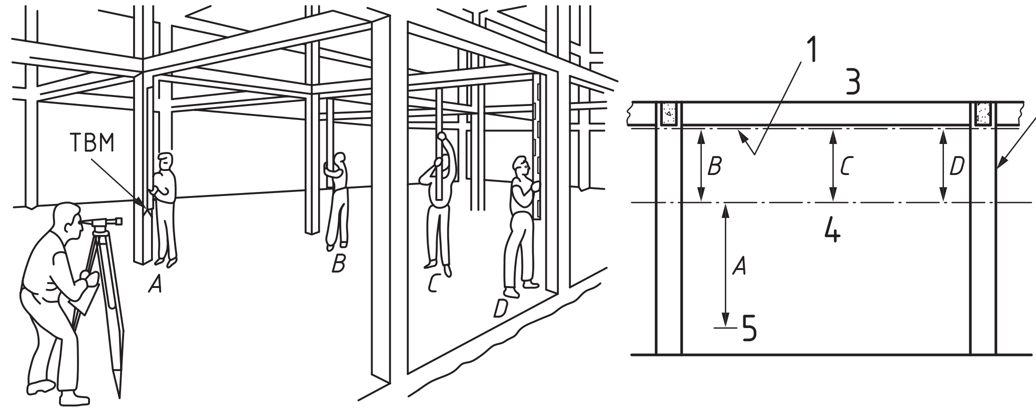
1 Specified structural soffit level

2 Height of level

3 TMB (datum)

4 Specified structural floor level

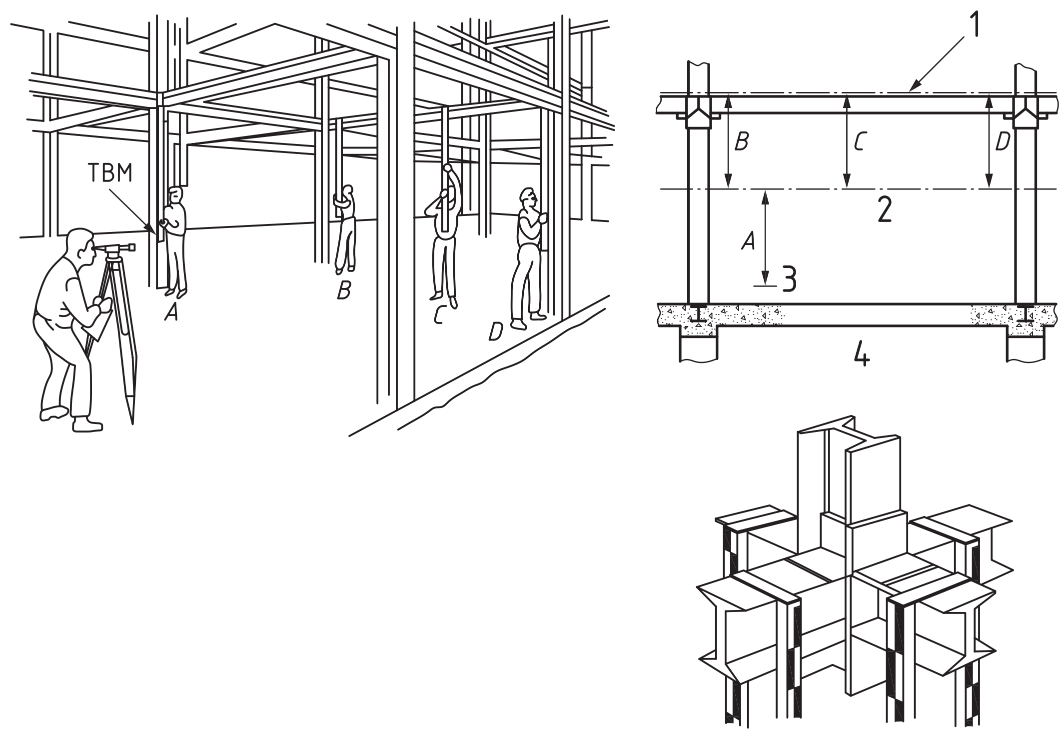
Figure D.5 — *Level of soffit of concrete beams (from data form f)*



Key

1 Specified structural soffit level
2 Wall/column
3 Beam
4 Height of level
5 TMB (datum)

Figure D.6 — *Level of top of steel beams (from data form g)*



Key

1 Specified level to top of beam
2 Height of level
3 TMB (datum)
4 Structural floor

Figure D.7 — *Verticality of walls and columns, i.e. measurement procedure using a plumb-bob (from data form h)*

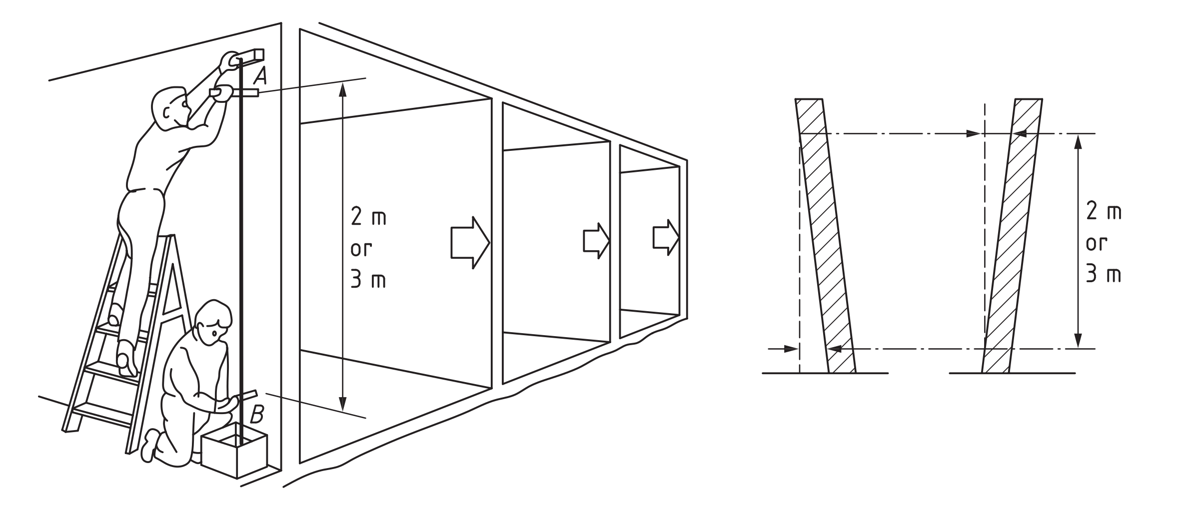
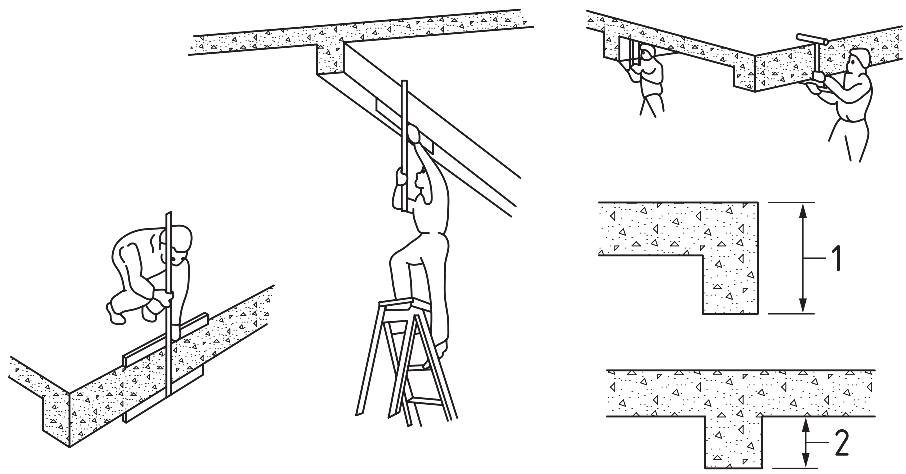


Figure D.8 — *Depth of situ concrete beams (from data form j)*



Key

1 Type A

2 Type B

Figure D.9 — *Size and squareness of concrete columns (from data form k)*

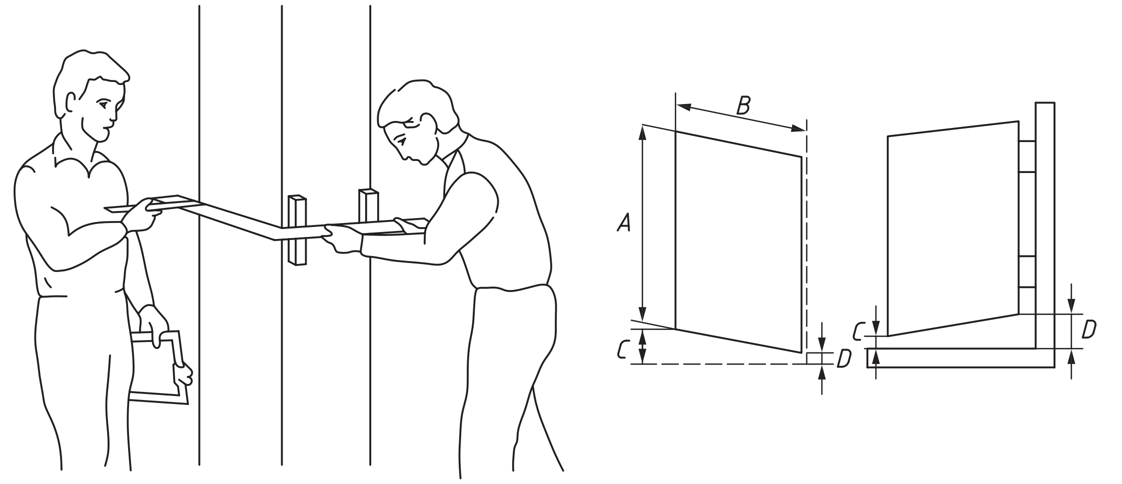
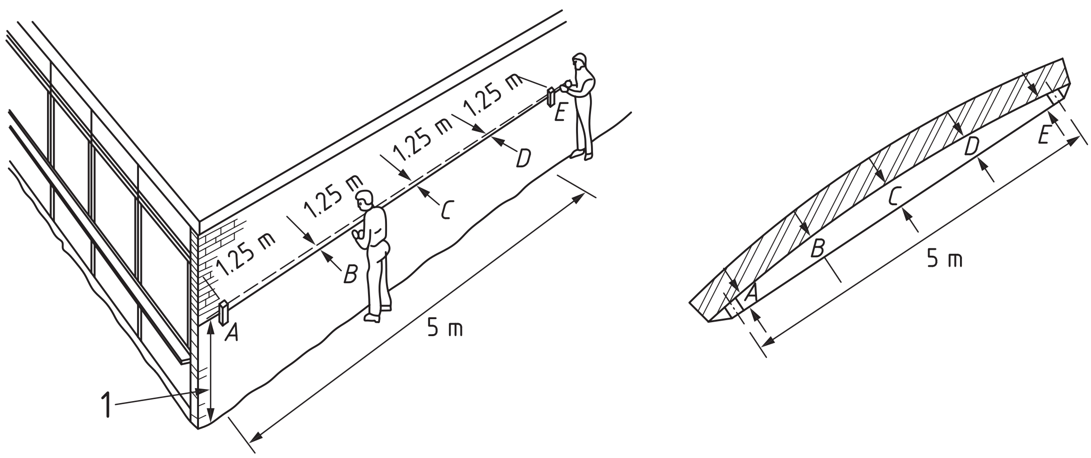


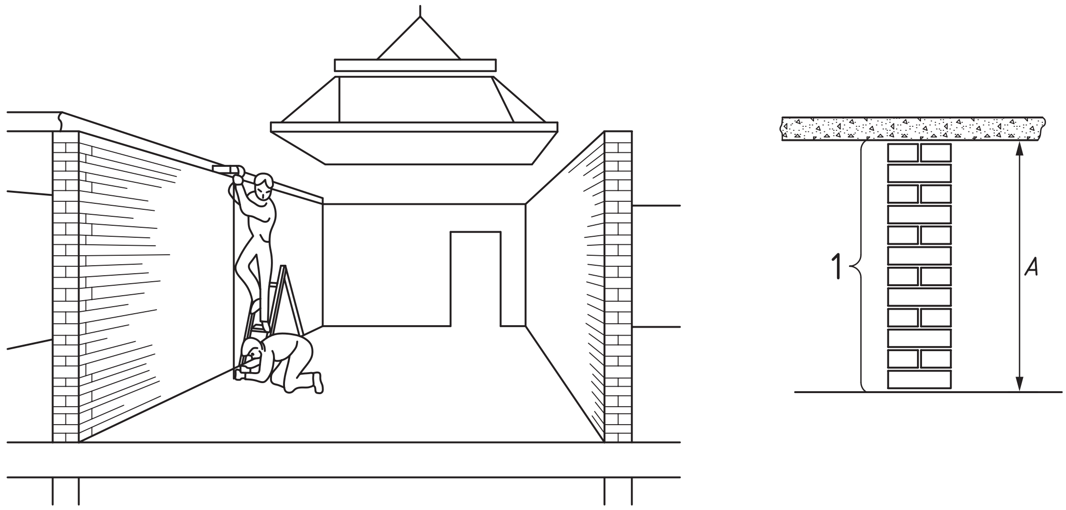
Figure D.10 — *Straightness of walls in any 5 m length (from data form l)*



Key

1 Mid-storey height

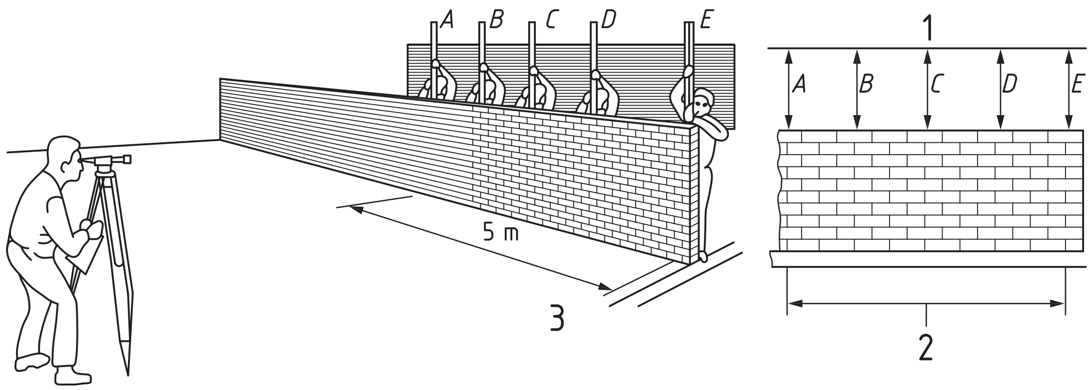
Figure D.11 — *Height of brick or block walls (from data form m)*



Key

1 Specified dimension

Figure D.12 — *Level of bed joints of brick or block walls (from data form n)*



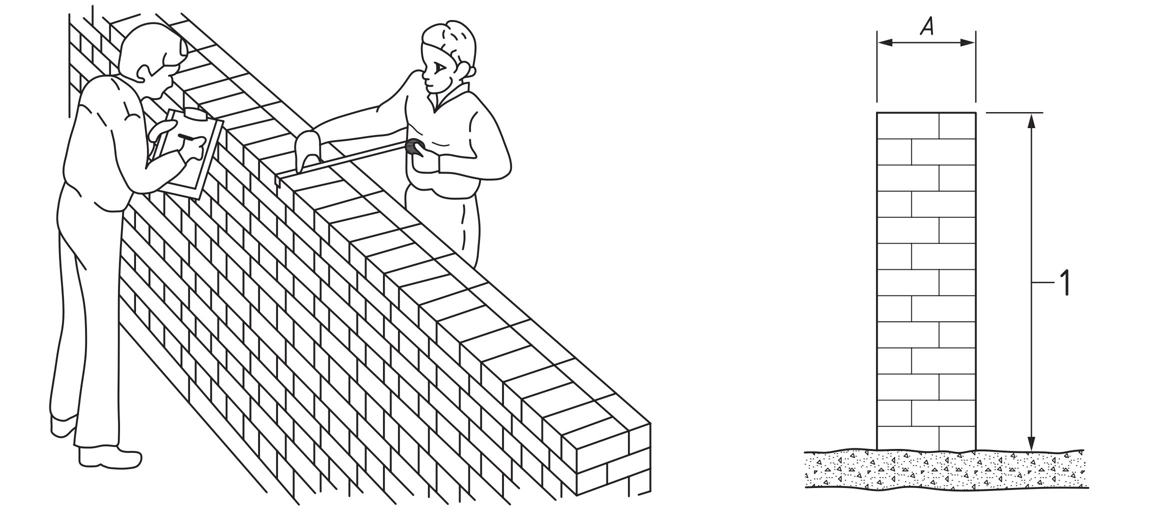
Key

1 Height of level

2 Distance *L*

3 Example shows a 5 m length of wall for wall between 5 m and 10 m long

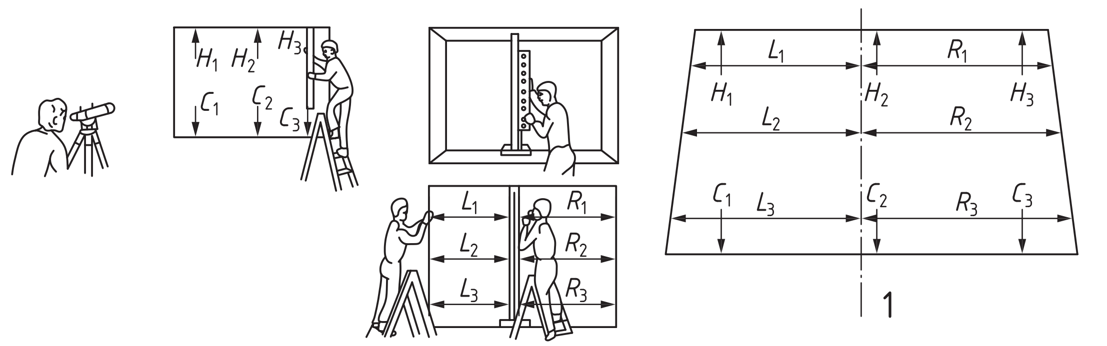
Figure D.13 — *Thickness of brick walls (from data form o)*



Key

1 Mid-storey height

Figure D.14 — *Window and other openings (from data form p)*



Key

1 Timber straight edge as vertical centre line

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BS 5655-6, *Lifts and service lifts – Part 6: Code of practice for the selection, installation and location of new lifts*

BS 5964 (all parts), *Building setting out and measurement*

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Other publications/Further reading

[1] BRITISH CONSTRUCTIONAL STEELWORK ASSOCIATION. *National structural steelwork specification for building construction.* 7th edition. London: BCSA, 2020.[2)]

[2] THE CONCRETE CENTRE. *National structural concrete specification for building construction*. 4th edition. Camberley: Concrete Centre, 2010.[3)]

[3] ROYAL INSTITUTION OF CHARTERED SURVEYORS. *Measured surveys of land, buildings and utilities*. RICS Guidance Note. 3rd edition. London: RICS, 2014.[4)]

[4] CONCRETE SOCIETY. *Concrete industrial ground floors*. TR34. Camberley: Concrete Society, 2018.

2) Available from: www.steelconstruction.org/shop/national-structural-steelwork-specification-for-building-construction-7th-edition

3) Available from: https://construct.org.uk/wp-content/uploads/2020/11/NSCS-Edition-4.pdf

4) Available from: www.rics.org/uk/upholding-professional-standards/sector-standards/land/measured-surveys-of-land-buildings-and-utilities/

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