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Fire tests on building materials and structures —

Part 21: Methods for determination of the fire resistance of loadbearing elements of construction

ICS 13.220.50

Committees responsible for this British Standard

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Contents

Foreword

This part of BS 476 is published by BSI Standards Limited, under licence from The British Standards Institution.

This standard has been superseded by the current BS EN 1365-1, BS EN 1365-2, BS EN 1365-3 and BS EN 1365-4, but it has been retained based on legitimate need for the standards within non-EU markets.

This Part of BS 476 has been prepared under the direction of the Fire Standards Committee, and describes the specific equipment and procedures for determining the fire resistance of loadbearing elements of building construction. This Part should be read in conjunction with BS 476-20 which describes the general principles for these methods.

This Part has been prepared in such a way as to allow reference to be made to the appropriate method of determining the fire resistance of the designated element by clause number only. Therefore clauses **5** to **8** are self-contained and cross refer to BS 476-20 where necessary.

Methods for determining the fire resistance of non-loadbearing elements that have a finite fire resistance and of components that make a contribution to the fire resistance of a structure are described in BS 476-22 and BS 476-23 respectively.

Methods for determining the fire resistance of external beams and columns are under consideration in the International Organization for Standardization ISO/TC 92, Fire tests on building materials, components and structures.

The general changes made to the methods described in this Part compared with BS 476-8 are described in the foreword to BS 476-20. Appendix A gives guidance and background information that will assist the designer and the testing laboratory to select and evaluate specimens that are more representative of "in use" situations.

Attention is drawn to the Health and Safety at Work etc. Act 1974, and the need to ensure that the methods described in this standard are carried out under suitable environmental conditions to provide adequate protection to personnel against the risk of fire, and/or inhalation of smoke and/or toxic products of combustion.

CAUTION. The mechanical sawing of asbestos cement components attracts the provision of the Asbestos Regulations 1969. Adequate methods exist to control levels of dust during such operations and these are detailed in the Control and Safety Guides[1)] issued by the Asbestos Research Council.

This Part, together with BS 476-20, BS 476-22, BS 476-23 and BS 476-24, supersedes BS 476-8:1972, which is withdrawn. However, the latter will still be made available on request, since it is referred to in the building regulations and other legislative documents.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

[1)] Available from the Asbestos Information Centre, Sackville House, 40 Piccadilly, London W1V 9PA.

1 Scope

This Part of BS 476 describes procedures for determining the fire resistance of loadbearing elements of building construction when subjected to the heating and pressure conditions specified in BS 476-20. This Part provides requirements for specimen selection and/or its design and construction, loading and restraint conditions, equipment, procedures and criteria as they apply to loadbearing specimens. The methods are applicable to beams, columns, floors, flat roofs and walls.

The methods described are not applicable to suspended ceilings protecting steel beams which are described in BS 476-23 (see **A.1**). Owing to limitations imposed by both the furnaces and their method of control, structures employing water cooling techniques are not capable of being evaluated realistically by these procedures.

The methods described are not applicable to assemblies of elements, e.g. wall/floor combinations, although some guidance is provided in Appendix A for tests of this type (see **A.1**).

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 476, the definitions given in BS 476-20 and BS 4422 apply.

3 Test conditions

The test conditions shall be as specified in BS 476-20 except that, in the case of vertical, non-separating elements, the neutral pressure axis may be at a height of up to 2 000 mm above the notional floor level.

4 Apparatus

The apparatus for the test shall be as specified in BS 476-20.

5 Determination of the fire resistance of beams

5.1 General

5.1.1 This clause describes a method for determining the fire resistance of beams with or without an applied fire protection insulation material and unventilated cavities.

5.1.2 Beams that are incorporated in, or which act in, a composite manner with either a floor or a roof construction are normally deemed to be a part of those elements of construction and shall be tested in accordance with clause **7** (see **A.3.1**).

5.2 Test specimen

5.2.1 *Number of specimens.* One specimen shall be tested.

5.2.2 *Size of specimen.* The specimen shall be full size for beams with a span of up to 4 m. For elements that have a span in excess of 4 m, the minimum size of specimen exposed to the heating conditions of the furnace shall be not less than 4 m (see also **5.2.3**).

5.2.3 *Design of specimen or test construction.* When selecting a test specimen or designing a representative construction, the following points shall be considered.

a) If the beam incorporates a mechanical joint along its length, this shall be incorporated as in practice or at mid-span. When joints occur in fire protective claddings, specimens incorporating such protection shall include representative joints (see **A.3.2.2**).

b) Where a beam in practice is only exposed to the effects of fire on three sides, e.g. where the top surface is supporting a floor construction, the specimen shall be provided with an associated construction as in practice. If the construction carried on the top surface of the beam is in continuous thermal contact with the beam, this shall be simulated by a dense aggregate concrete slab of 135 mm thickness. The topping construction shall extend at least 200 mm on each side of the beam.

c) Any associated construction provided to the top surface of the beam for the purpose of a test shall be designed and constructed such as not to provide any significant strength or stiffness to the beam. Any joints in the associated construction, or between the associated construction and any furnace closures, shall be sealed with a resilient gasket of adequate fire performance.

d) If fire protection material is applied or fixed to the beam, this shall be undertaken after the associated construction has been installed, unless in practice the protection is installed before installation of the supported construction. It shall extend over the length of the beam that is to be exposed to the heating conditions of the test, plus sufficient additional length at each end to terminate the protection outside the furnace. Where a void is created within the fire protection system (e.g. hollow box protection to steel beams) this void shall be sealed at the positions where the beam exits from the furnace chamber. The projecting ends of any beam that extend beyond the furnace chamber shall be insulated by wrapping with a single thickness of 100 mm thick mineral wool, with a density of at least 100 kg/m^3.

5.2.4 *Test construction and condition.* The construction and condition of the specimen including any associated construction shall be in accordance with BS 476-20.

5.3 Support and loading conditions

5.3.1 The method used for supporting the ends of the test construction shall be similar to that which would apply in service. When the end conditions are not known, the test construction shall be installed as a simply supported beam.

5.3.2 The magnitude of the test loading taking into account the beam end conditions that apply to the test construction shall be calculated. The recommendations given in BS 476-20 shall be used in determining the test loading (see **A.3.3.2**). The span of the beam, if simply supported, shall be taken as the distance between the supports at the commencement of the test.

5.4 Examination of specimen

5.4.1 Establish the dimensions and relevant properties of the materials used in the manufacture of the test construction in accordance with BS 476-20 (see **A.3.4.1**).

5.4.2 Mount the specimen horizontally on top of the furnace, in its support frame if used, such that it is subjected to the heating conditions of the method in a manner similar to that occurring in practice, i.e. from the underside.

5.4.3 Position the furnace control thermocouples as specified in BS 476-20 at not less than two thermocouples for each metre length of test construction, or part thereof, with not less than six thermocouples for beams of less than 3 m span. Distribute the thermocouples uniformly with no thermocouple closer than 500 mm from the furnace wall so that their hot junctions are 100 ± 10 mm horizontally away from the sides of the specimen and level with the soffit of the beam including any applied protection, with a tolerance of ± 10 mm.

NOTE The position of the hot junction should not vary by more than 50 mm from this position during test.

5.4.4 When the timing control thermocouple is not one of the furnace temperature control thermocouples, install a timing thermocouple as specified in BS 476-20.

5.4.5 Position at least one pressure sensing head in the furnace such that the pressure conditions in the furnace are measured and controlled in accordance with BS 476-20, at a position 100 mm below the top of the beam or the soffit of the topping construction.

Ensure that the pressure sensing head(s) does not interfere with the deflection of the test construction.

NOTE The head is not required to be maintained at a fixed distance from the surface of the specimen during test.

5.4.6 If additional measurements are to be made of the temperature of any part of the test construction not related to the criteria, fix any thermocouples that have not been built into the specimen in accordance with BS 476-20 (see **A.3.4.2**).

NOTE As these beams are not separating elements there is no requirement to attach surface temperature monitoring thermocouples nor is there a need to set up the ambient temperature measuring equipment.

5.4.7 Install the equipment to measure the maximum vertical deflection of the specimen. For simply supported constructions assume this to be at mid-span but for non-symmetrical constructions or unevenly distributed loading, take deflection measurements at more than one position in order to determine the maximum deflection.

5.4.8 If the ends of the test construction require any special provisions to achieve an initial fixity, attach any equipment and/or apply any forces as required.

5.5 Test procedure

5.5.1 Carry out the loading procedure in accordance with BS 476-20. Record the time prior to the commencement of the heating that the loading is completed.

5.5.2 Monitor the specimen for loadbearing capacity and make observations of the behaviour of the specimen in accordance with clause **9** of BS 476-20:1987.

5.6 Criteria of failure, expression of results and test report

5.6.1 *Criteria of failure.* The fire resistance of loadbearing horizontal elements without any separating function shall be determined with respect to loadbearing capacity. The criteria of failure shall be as given in **10.2.3** of BS 476-20:1987.

5.6.2 *Expression of results.* The result shall be stated in terms of the elapsed time, to the nearest minute, between the commencement of heating and the termination of heating or failure to satisfy the criterion of loadbearing capacity in accordance with BS 476-20.

NOTE An example of the method of expressing the results is given in **A.11** of BS 476-20:1987.

5.6.3 *Test report.* The test report shall include the result (see **5.6.2**) and any observations, including the mode of failure, together with the other requirements given in clause **12** of BS 476-20:1987.

6 Determination of the fire resistance of columns

6.1 General

6.1.1 This clause describes a method for determining the fire resistance of fully exposed columns used as separate elements of construction. The column may be provided with an applied fire protection media with or without an unventilated cavity.

6.1.2 Columns that are incorporated in, or that act in, a composite manner with a wall construction are deemed to be a part of those elements of construction and shall be tested in accordance with clause **8** (see **A.4.1**).

6.2 Test specimen

6.2.1 *Number of specimens.* One specimen shall be tested. Where the column may be used in practice with different end restraint conditions or different slenderness ratios, more than one test may be necessary to establish the effects of these conditions.

6.2.2 *Size of specimen.* The specimen shall be full size for columns with a height of up to 3 m. For elements that have a height in excess of 3 m, the minimum size of specimen exposed to the heating conditions of the furnace shall be not less than 3 m. The overall height shall be such as to allow a capping and the loading equipment to be fixed at each end with adequate protection from the furnace atmosphere and from the conduction of excessive heat through the specimen.

6.2.3 *Design of specimen or test construction.* When selecting a test specimen or designing a representative construction, the following points shall be considered.

a) When joints occur in fire protection claddings, any specimen that incorporates such protection shall include representative joints.

b) The specimen shall be essentially straight. Where suitable material design codes exist, any non-linearity shall be within the specified tolerances. Where no such codes exist, material selection or the manufacturing process shall be such that the specimen has a linearity representative of that to be found in practice.

c) The ends of the specimen shall be adequately designed and detailed for the proper transmission of the test load from the loading platens to the specimen with the required conditions of fixity. Provision shall be made for the attachment of protecting collars at each end of the specimen. These shall be designed to provide location and an adequate means of sealing with the furnace walls and shall be suitably attached and supported so that they remain effective and in position throughout the heating period. The method adopted to provide the seal shall allow the test specimen to move within the furnace walls without significantly affecting the load transmitted from the loading rig to the specimen or the fixity at the ends of the specimen (see **A.4.2.1**).

d) Provision shall be made for the proper positioning and alignment of the specimen in the rig and for ensuring uniform distribution of the loading over the ends of the specimen.

6.2.4 ***Test construction and condition***

6.2.4.1 The test construction shall be manufactured in accordance with BS 476-20.

6.2.4.2 Operations required by this method, such as the provision of protection at the ends of the specimen and the installation of thermocouple measuring junctions for monitoring internal temperatures, shall be undertaken at appropriate stages during the construction.

6.2.4.3 The condition of the test construction, including the associated collar and capping (see **A.4.2.2**) shall be in accordance with BS 476-20.

6.3 Support and loading conditions

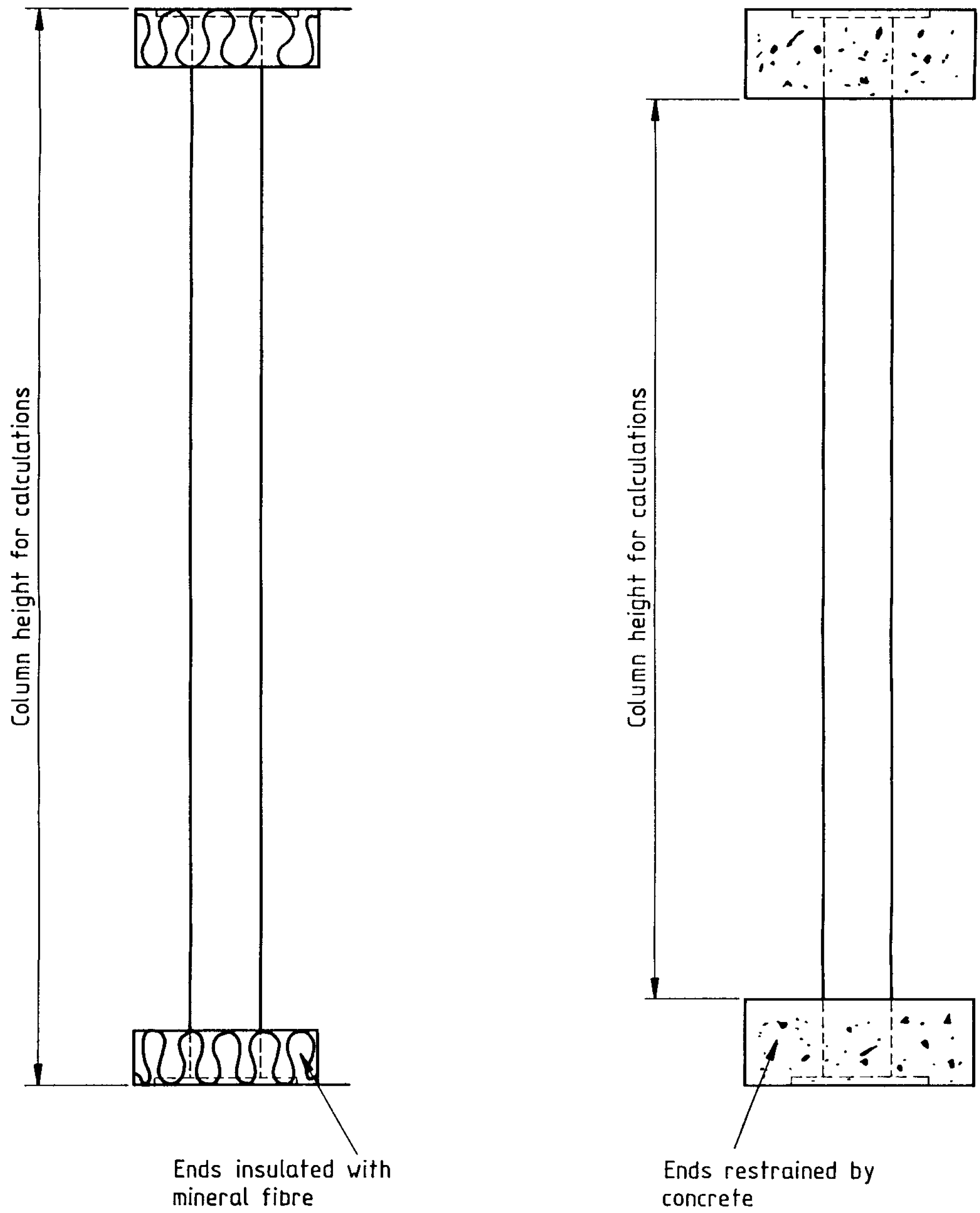
6.3.1 The specimen shall normally be tested with fixed end conditions as in practice but shall be free to expand during the test. Adequate provision shall be made in the design of the loading rig to ensure that fixed end conditions are maintained throughout the test. If a test construction is to be tested under any other conditions of fixity, e.g. pin ended, adequate provision shall be made to ensure that the required end conditions are maintained throughout the test.

6.3.2 The test loading shall be calculated on the basis of axial loading unless otherwise specified (see **A.4.3.2**).

6.3.3 When calculating the test loading for a column, the overall height of the specimen shall be used when restraint is applied to the ends of the specimen only [see Figure 1 (a)].

When restraint is applied along the height of the specimen, e.g. by the use of concrete collars, the height of the column shall be assumed for calculation purposes to be the distance between the restrained area [see Figure 1(b)].

The test load shall be calculated taking into account the relevant buckling length.



(a) Restraint applied to ends only

(b) Restraint applied along height of column at ends

Figure 1 — Calculation of test load for columns

6.3.4 The magnitude of the test loading shall be calculated taking regard of the end conditions applied to the test construction.

6.4 Examination of specimen

6.4.1 Establish the dimensions and relevant properties of the materials used in the manufacture of the test construction as specified in BS 476-20.

6.4.2 Mount the test construction essentially as in practice into a loading rig that is capable of applying an axial load taking care to ensure that a good contact is made between the loading platens and the ends of the column. Enclose the rig and the specimen in the furnace chamber.

6.4.3 Install any other thermocouples required to provide information relating to the internal or surface temperatures of the test construction.

NOTE As these columns are not separating elements there is no requirement to set up ambient temperature measuring equipment.

6.4.4 Install at least six furnace control thermocouples inside the furnace in pairs on opposite sides of the specimen at approximately 1 m vertical centres.

Position the hot junctions of these thermocouples such that at the commencement of heating they are 100 mm ± 10 mm from the respective faces of the column, and not closer than 400 mm to the top or bottom of the furnace and do not vary from these positions by more than 50 mm during the test.

6.4.5 When the timing control thermocouple is not one of the furnace temperature control thermocouples, install a timing control thermocouple as specified in BS 476-20.

6.4.6 Position at least one pressure sensing head in the furnace, so as not to interfere with the deflection of the column, such that the pressure conditions are measured and controlled in accordance with **3.2** of BS 476-20:1987.

6.4.7 Install the equipment required for determining the axial deformation of the test construction.

6.5 Test procedure

6.5.1 Carry out the test procedure in accordance with BS 476-20 applying the test loading not less than 15 min before the commencement of heating.

6.5.2 Monitor the specimen for loadbearing capacity and make observations of the behaviour of the specimen in accordance with clause **9** of BS 476-20:1987.

6.6 Criteria of failure, expression of results and test report

6.6.1 *Criteria of failure.* The fire resistance of a loadbearing vertical element without any separating function shall be determined with respect to loadbearing capacity. The criteria of failure shall be as given in **10.2.3** of BS 476-20:1987 (see **A.4.5**).

6.6.2 *Expression of results.* The result shall be stated in terms of the elapsed time to the nearest minute, between the commencement of heating and the termination of heating or failure to satisfy the criterion of loadbearing capacity.

NOTE An example of the method of expressing the result is given in **A.11** of BS 476-20:1987.

6.6.3 *Test report.* The test report shall include the result (see **6.6.2**) and any observations, including the mode of failure, together with the other requirements given in clause **12** of BS 476-20:1987.

7 Determination of the fire resistance of floors and flat roofs

7.1 General

This clause describes a method for determining the fire resistance of floors, flat roofs up to 10° pitch and other horizontal loadbearing separating elements with or without unventilated cavities that are required to withstand exposure to fire from their undersides. The fire resistance of floor or flat roof constructions incorporating beams as composite constructions shall be evaluated by these methods (see **A.5.1**). The test is not applicable to elements with ventilated cavities.

7.2 Test specimen

7.2.1 *Number of specimens.* When a floor or flat roof, as a separating element, is only required to resist fire from one direction, one specimen shall be tested.

7.2.2 *Size of specimen.* The specimen shall be of such dimensions that at least 4 m × 3 m is exposed to the furnace or full size if the element is smaller (see **A.5.2.1**). The size of the individual components used in the manufacture of the test construction shall be nominally the same as the element it represents (see **A.5.2.2**).

7.2.3 *Design of specimen or test construction.* When selecting a test specimen or designing a representative construction, the following requirements shall be satisfied.

a) Floors and flat roofs often include mechanical joints in the element for purposes of either erection, construction or expansion. Even though such joints may occur at greater than 3 m centres, the test construction shall incorporate any such joint. In the case of expansion joints the size of the joint shall be realistically related to the use of the specimen. If more than one jointing method is utilized in a particular form of construction, it may be possible to incorporate more than one joint in a construction in which case care shall be exercised in order to ensure that the specimen is valid for the element being evaluated.

b) Floors and flat roofs incorporating cavities shall have their cavities sealed.

c) Floors and flat roofs often incorporate diffuser grilles, light fittings and associated wiring. Where these form an integral part of the element then the test construction shall incorporate them in a representative manner.

NOTE When the fittings are not an integral part of the element but may be fitted subsequently in a manner that may have an adverse effect on the fire resistance of the element, these should be subject to a separate test.

7.2.4 ***Test construction and condition***

7.2.4.1 The test construction shall be manufactured in accordance with BS 476-20.

NOTE When additional information is required with respect to either cavity or individual component temperatures, the thermocouples to be used for this purpose may be installed during manufacture of the test construction (see **A.5.4.2**).

7.2.4.2 The condition or the state of cure of the test construction and any associated construction shall be in accordance with BS 476-20.

7.3 Support and loading conditions

7.3.1 When the test specimen is full size, it shall be subjected to similar edge and end restraint conditions as it would have in practice.

7.3.2 When the test specimen is full span but of reduced width, the test construction shall be subjected to similar end conditions to those that exist in practice. Edges shall be unsupported and free from thermal restraint.

7.3.3 When the test specimen is smaller than full size and/or where the intended support conditions are unknown, the test construction shall be tested, simply supported and without restraint against thermally induced movement. Where more onerous test conditions can be identified they shall be used. Where the support conditions are not specified, the specimen shall be tested as a one-way spanning simply supported construction.

7.3.4 When the test specimen is smaller than full size but represents an element that is structurally continuous, the test construction shall be simply supported but shall be free from restraint against expansion.

7.3.5 The magnitude of the test loading shall be calculated taking into account the support conditions. The recommendations given in BS 476-20 shall be used in determining the test loading (see **A.5.3**). The span of the floor or flat roof, if simply supported, shall be taken as the distance between the supports at the commencement of test.

7.4 Examination of specimen

7.4.1 Establish the dimensions and relevant properties of the materials used in the manufacture of the test construction in accordance with BS 476-20 (see **A.5.4.1**).

7.4.2 Mount the test construction, carried within its loading support frame if used, essentially horizontally on top of the furnace such that it is subjected to heating from the underside. Where the test construction is mounted other than horizontally, e.g. a flat roof of up to a 10° pitch, this shall be stated in the test report.

7.4.3 Position the furnace control thermocouples at not less than one thermocouple to every 1.5 m^2, or part thereof, of the exposed surface area, with a minimum of four for specimens of less than 6 m^2 with the exposed surface area being the nominal area measured in the plane of the specimen. Distribute the thermocouples uniformly ensuring that no thermocouple is closer than 500 mm from the furnace walls or closer than 300 mm from any vertical surface, and with the thermocouple hot junctions at 100 ± 10 mm from the horizontal surface of the specimen, at the start of the heating period, and ensure that they do not vary by more than 50 mm during the test.

7.4.4 Position at least one pressure sensing head in the furnace such that the pressure conditions in the furnace are measured and controlled in accordance with BS 476-20, at a position 100 mm below the surface of the specimen, so that it does not interfere with the deflection of the test construction during the test.

NOTE The pressure sensing head is not required to be maintained at a fixed distance from the surface of the test construction during the test.

7.4.5 Fix five surface temperature monitoring thermocouples, in order to measure the mean unexposed face temperature rise, to the upper surface of the construction including any insulating material that may be used, e.g. on a roof structure. When the thermocouples are to be attached to the upper surface of any fibrous or resilient insulation material, use the thermocouple weight described in BS 476-20. Position the thermocouples with one placed approximately in the centre of the specimen and one approximately in the centre of each quarter section, taking account of the requirements of **C.4.1.3.2** of BS 476-20:1987. None of the five thermocouples shall be fixed over joints in the construction where the thermocouple could be heated by the possible flow of hot gases.

7.4.6 Attach additional thermocouples, as required, in order to determine the temperature at points on the upper surface where the temperature is likely to be higher than elsewhere, due to the presence of joints, more conductive components or lower levels of insulation at positions other than those specified above, either in the same manner or in the normal manner as described in BS 476-20.

7.4.7 Where additional measurements are to be made of the temperature of any part of the test construction not related to the criteria, fix any thermocouples that have not been built into the specimen as described in BS 476-20 (see **A.5.4.2**).

7.4.8 Locate in position, and attach if necessary, the equipment required for measuring axial deformation with reference to supports at the anticipated point of maximum deflection. Where this point cannot be predetermined, take more than one deflection reading.

7.4.9 If the ends of the test construction require any special provisions to achieve an initial fixity, attach any equipment and/or apply any forces as required.

7.5 Test procedure

7.5.1 *General.* Carry out the test procedure in accordance with BS 476-20, applying the test loading not less than 15 min before the commencement of heating.

7.5.2 *Loadbearing capacity.* Monitor the test construction for loadbearing capacity and make observations of the behaviour of the specimen in accordance with clause **9** of BS 476-20:1987.

7.5.3 *Integrity.* Monitor the unexposed face of the test construction for integrity in accordance with clause **9** of BS 476-20:1987.

7.5.4 ***Insulation***

7.5.4.1 Measure the temperature rise of the unexposed face for evaluation of insulation in accordance with clause **9** of BS 476-20:1987 for both the mean temperature rise and the maximum temperature rise using the thermocouples specified in **7.4.5** and **7.4.6**.

Use the measurement from the roving thermocouple, when employed, and from the additional fixed thermocouples only for determining the maximum temperature rise.

7.5.4.2 If during the test a thermocouple is known to be heated directly by gases passing through the construction from the furnace, for example owing to the occurrence of shrinkage, cracking or distortion, do not use the readings obtained from it for the purpose of determining compliance with the criteria of either mean or maximum unexposed face temperature rise and report this fact. If more than two of the thermocouples that are intended to be used in determining the mean temperature rise are affected, do not assess the specimen for compliance with the criteria for mean temperature rise and report this occurrence.

7.6 Criteria of failure, expression of results and test report

7.6.1 *Criteria of failure.* The fire resistance of a loadbearing floor or flat roof shall be determined with respect to load-bearing capacity, integrity and insulation. The criteria of failure shall be as given in **10.2**, **10.3** and **10.4** of BS 476-20:1987.

7.6.2 *Expression of results.* The result shall be stated in terms of the elapsed time to the nearest minute, between the commencement of heating and the time of failure in accordance with BS 476-20 with respect to the three criteria given in **7.6.1**.

When the mean temperature rise has not been determined due to the influence of hot gases (see **7.5.4.2**) the insulation compliance shall be adjudged on the basis of the maximum unexposed face temperature and this shall be clearly stated in the result.

NOTE An example of the method of expressing the result is given in **A.11** of BS 476-20:1987.

7.6.3 *Test report.* The test report shall include the results (see **7.6.2**) and any observations, including the mode of failure, together with the other requirements given in clause **12** of BS 476-20:1987. In addition, the report shall also state the maximum deflection obtained during test and the position at which this occurred.

8 Determination of the fire resistance of walls

8.1 General

This clause describes a method for determining the fire resistance of vertical walls with or without unventilated cavities, which have both loadbearing and separating functions, and which are required to withstand exposure to fire on one face. The fire resistance of wall constructions incorporating columns as composite constructions shall be evaluated by these methods (see **A.6.1**). The test is not applicable to elements with ventilated cavities.

8.2 Test specimen

8.2.1 *Number of specimens.* Walls shall be tested from both sides, i.e. two specimens, unless the wall is entirely symmetrical or unless the weakest direction can be clearly identified or unless the wall is designed to be exposed to a fully developed fire from one side only (see **A.6.2**). If testing is carried out from one side only, i.e. one specimen, the reason for this shall be clearly stated in the report.

8.2.2 *Size of specimens.* The specimen shall be of such dimensions that at least 3 m × 3 m is exposed to the furnace or full size if the element is smaller. The size of the individual components used in the manufacture of the test construction shall be nominally the same as the element it represents.

8.2.3 *Design of specimen or test construction.* When selecting a test specimen or designing a representative construction, the following requirements shall be satisfied.

a) When the wall includes mechanical joints in the element for either erection, construction or as a result of dimensional co-ordination, even though such joints may occur at greater than 3 m centres, the test construction shall incorporate any such joint.

NOTE If more than one jointing method is used in a particular form of construction, it may be possible to incorporate more than one joint in the test construction but if this is done care should be exercised in order to ensure that the specimen remains valid for the element being evaluated.

b) When loadbearing walls are to include doors and/or glazing, these can often have a significant effect on the fire resistance of the wall, and when appropriate this shall be taken into account during the design of the test specimen.

NOTE This may require more than one construction to be tested.

c) Walls often incorporate services; where these form an integral part of the element, the test construction shall incorporate them in a representative manner. When the services and associated fittings are not an integral part of the element but may be fitted subsequently in a manner that may have an adverse effect on the fire resistance of the element, these shall be subject to a separate test.

8.2.4 *Test construction and condition.* The test construction shall be manufactured in accordance with BS 476-20 (see **A.6.2**) and the condition or the state of cure of the test construction and any associated construction shall comply with BS 476-20.

8.3 Support and loading conditions

8.3.1 Where the test specimen is smaller than full size with respect to both height and width, the top and bottom edges shall be unrestrained and the whole specimen, including vertical edges, shall be free to expand during the test (see **A.6.3.1**).

8.3.2 When the test specimen is of full height but reduced width, the test construction shall be subjected to similar end conditions to those that exist in practice and the vertical edges shall be free from any thermal restraint.

8.3.3 When the test specimen is full size, it shall be subjected to similar edge and end conditions as it would have in practice.

8.3.4 The magnitude of the test loading shall be calculated; taking regard of the support conditions.The recommendations given in BS 476-20 shall be used in determining the test loading (see **A.6.3.2**).

8.4 Examination of specimen

8.4.1 Establish the dimensions and relevant properties of the materials used in the manufacture of the test construction in accordance with BS 476-20 (see **A.6.4.1**).

8.4.2 Mount the test construction vertically into a loading frame that has provision for:

a) applying and maintaining mechanically the test loading required;

b) allowing the loading rams to be positioned at specific points or to enable a uniformly distributed load to be applied via spreading beam(s);

c) providing the necessary fixity on the relevant edges of the wall, together with the furnace, if required.

8.4.3 Mount the test construction, carried within its loading support frame if used, vertically in front of the furnace such that it is subjected to the heating conditions of the method.

8.4.4 Position the furnace control thermocouples at not less than one thermocouple to every 1.5 m^2, or part thereof, of the exposed surface area, with a minimum of four for specimens of less than 6 m^2, with the exposed surface area being the nominal area measured in the plane of the specimen. Distribute the thermocouples uniformly ensuring that no thermocouple is closer than 500 mm from the furnace walls, and with the thermocouple hot junctions at 100 ± 10 mm from the vertical surface of the specimen at the start of the heating period, and so that they do not vary by more than 50 mm during the test.

When the wall incorporates a glazed area, ensure that not less than one thermocouple is placed directly in front of a glazed area for every 20 % of the total specimen area that is taken up by glass or glazing.

8.4.5 Position at least one pressure sensing head in the furnace such that the pressure conditions in the furnace are measured and controlled in accordance with BS 476-20, and so that the sensing heads do not interfere with the deflection of the specimen.

8.4.6 Fix five surface temperature monitoring thermocouples to the unexposed face of the specimen in order to measure the mean unexposed face temperature rise. Position these with one thermocouple placed approximately in the centre of the test construction and one thermocouple at the centre of each quarter section.

Do not fix any of these five thermocouples over joints in the construction where the thermocouple could be heated by the possible flow of hot gases.

NOTE When the wall area has more than 50 % glazing, the test construction should be tested as a glazed element in a loadbearing construction and the fixing of the thermocouples should comply with BS 476-22.

8.4.7 Attach additional surface temperature measuring thermocouples at positions other than those specified to determine the temperature at other points on the surface where the temperature rise is likely to be higher than elsewhere due to the presence of joints, more conductive components or lower levels of insulation. Do not use these temperatures for determining the average temperature rise but use them in conjunction with the "roving" thermocouple if necessary, for determining compliance with the maximum temperature rise criteria as specified in BS 476-20.

NOTE When the wall incorporates glazing it may be necessary to fix additional thermocouples to the glazing in order to determine the time at which the use of the cotton pad should be discontinued.

8.4.8 When it is required to obtain additional information with respect to internal temperatures, e.g. cavities or temperatures of individual components, fix any additional thermocouples that have not been incorporated during the construction in accordance with BS 476-20.

8.4.9 Locate in position, and attach if necessary, the measuring equipment to determine both the vertical deformation and the maximum lateral deflection. Where the position of maximum deflection cannot be predetermined, take more than one deflection measurement.

8.4.10 When the test construction is to be examined for the amount of heat being radiated from the surface, position the radiometer in front of the specimen before the start of the test, at such a distance that the field of view of its sensing unit circumscribes the specimen area.

8.4.11 If the ends or edges of the test construction require any special provisions to achieve an initial fixity, attach any equipment and/or apply any forces as required.

8.5 Test procedure

8.5.1 *General.* Carry out the test procedure in accordance with BS 476-20, applying the test loading not less than 15 min before the commencement of heating.

8.5.2 *Loadbearing capacity.* Monitor the test construction for evaluation of loadbearing capacity and make observations of the behaviour of the specimen in accordance with clause **9** of BS 476-20:1987.

8.5.3 *Integrity.* Monitor the unexposed face of the test construction for evaluation of integrity in accordance with clause **9** of BS 476-20:1987.

8.5.4 ***Insulation***

8.5.4.1 Measure the temperature rise of the unexposed face for evaluation of insulation in accordance with clause **9** of BS 476-20:1987 for both the mean temperature rise and the maximum temperature rise using the thermocouples specified in **8.4.6** and **8.4.7**. Use the measurement from the roving thermocouple, when used, and from additional fixed thermocouples only for determining the maximum temperature rise.

8.5.4.2 If during the test a thermocouple is known to be heated directly by gases passing through the construction from the furnace, for example owing to the occurrence of shrinkage, cracking or distortion, do not use the readings obtained from it for the purpose of determining compliance with the criteria of either mean or maximum unexposed face temperature rise and report this fact. If more than two of the thermocouples that are intended to be used in determining the mean temperature rise are affected, do not assess the specimen for compliance with the criteria for mean temperature rise and report this occurrence.

8.5.5 *Irradiance.* Monitor the unexposed face of any construction that is not designed to satisfy the criteria of insulation by means of the radiometer specified in BS 476-20.

8.5.6 *Deflection.* Monitor the maximum deflection and deformation of the specimen during the course of the test.

8.6 Criteria of failure, expression of results and test report

8.6.1 *Criteria of failure.* The fire resistance of a wall shall be determined with respect to loadbearing capacity of a vertical loadbearing separating element, integrity and insulation. The criteria of failure shall be as given in **10.2** to **10.4** of BS 476-20:1987.

8.6.2 *Expression of results.* The results shall be stated in terms of elapsed time to the nearest minute, between the commencement of heating and the time of failure, in accordance with BS 476-20 with respect to the three criteria given in **8.6.1**.

When the irradiance from the unexposed face of the specimen has been monitored, the mean irradiance shall be reported in a graph or table with respect to time.

The distance from the surface at which these values were obtained shall be given together with the angle of view of the radiometer.

NOTE An example of the method of expressing the results is given in **A.11** of BS 476-20.

8.6.3 *Test report.* The test report shall include the results (see **8.6.2**) and any observations, including the mode of failure, together with the other requirements given in BS 476-20. In addition the report shall state the maximum lateral deflection, and the position at which this occurred, together with the reason for testing from one side only, if applicable.

Appendix A Guidance information

A.1 General

Whilst this Part of BS 476 does not provide a method for the evaluation of the fire resistance of composite constructions of more than one element, e.g. wall-floor assemblies, there is no reason why the test procedures described in this Part cannot be used in the evaluation of three-dimensional constructions, in which case each element should be loaded as in practice and should be individually monitored with respect to compliance with the relevant criteria. It is recommended that the pressure below the soffit of the horizontal element should be controlled to that specified in the standard when evaluating composite constructions, ignoring any shift in the neutral axis that would occur with respect to the vertical element. A rationalization of the furnace control thermocouples may also be made but not less than eight thermocouples should be used for controlling three-dimensional, multi-element tests.

A.2 Furnace and equipment

For further information see **A.2** and **A.3** of BS 476-20:1987.

A.3 Beams

A.3.1 ***General***

Beams in practice frequently support floor slabs or roof decks, and in some applications, the connection between the beam and the supported construction may be such that they act in a composite manner. Clause **5** covers the testing of beams as separate elements, i.e. where in the design of the construction no account has been taken of the composite action that may be achieved because of any connections. If some degree of composite action has been attributed to the construction during its design, then the fire resistance of the beam should be evaluated as part of the complete floor or roof construction. However, it is possible to utilize the fire resistance of a beam, as determined in isolation by this procedure, in the evaluation of the fire resistance of a construction that benefits from composite action.

The fire resistance of beams and steel beams in particular are enhanced by providing them with thermal insulation. The method described allows the effectiveness of such insulation systems to be evaluated as part of the specimen construction, provided that the insulation material is fixed to the beam and/or the supported construction adjacent to the beam. It is not meant to assess the fire protection of beams provided by membrane protection, e.g. by a suspended ceiling.

Whilst the procedures are written with respect to beams that will normally be subjected to bending stresses, the methodology can be adapted to cover the testing of horizontal tie members.

A.3.2 ***Specimen construction***

A.3.2.1 *Size of specimen.* The evaluation of the fire resistance of a beam is concerned with the effect of heat input resulting from attack by a fire to the soffit, sides and perhaps the top surface of a beam, with no account being taken of heat input into the ends of the beam. The cross-sectional size of the beam is, therefore, required to be as in practice, although the span may be reduced providing that the test loading produces the required magnitude of moments.

The specimen will need to be slightly longer than the length required to be exposed within the furnace to enable satisfactory support conditions to be established. However, for simply supported constructions the overall length should be kept to a minimum, e.g. 4 500 mm to allow about 4 200 mm effective span.

A.3.2.2 *Design of specimen.* Whilst beams are unlikely to incorporate structural joints within the span, most joints being made over the vertical supports, certain forms of construction may well incorporate joints, e.g. finger joints in glue-laminated timber beams. Where such joints do exist in practice, a representative number of joints should be included in the construction of the specimen. In practice, situations may occur where the supported construction will have a lower degree of fire resistance than the beam, e.g. a timber floor supported on steel beams, and it will not be possible to test the fire resistance of the steel beam with this supported construction. With the specified concrete topping construction, the concrete should be provided in discrete sections or with continuous reinforcements to remove the possibility of any composite action between it and the steel beam.

The detail at the position where the beam exits from the furnace chamber requires special consideration to ensure that no interference occurs with the specimen at this position during any deflection that may occur in the test.

A.3.3 ***Support and loading conditions***

A.3.3.1 *Mounting of specimen on furnace.* Simply supported specimens should be mounted on at least one roller at one end to allow freedom for longitudinal movement and to remove any fixity induced by frictional resistance.

When a specimen is to be provided with fixity against rotation over its supports, this can be achieved by cantilevering each end over its supports and fixing it in position. The degree of fixity can be determined from the cantilever arm and the force recorded by the load cell resisting the rotation moment.

A.3.3.2 *Loading.* When a specimen is to be tested at a span less than that applying in practice, then, for the same loading, different types and magnitudes of stresses will be induced into the specimen than those that will exist in the full size element. The practicability of testing a beam of a specific cross section at a reduced span should be carefully studied to ensure that the critical stresses developed in the test specimen are of the same type that exist in the full size element, e.g. that excessive shear stresses are not being produced by higher loadings over reduced spans. This consideration may influence the choice and method of loading used to develop the required stresses. Since this evaluation is concerned with beams as flexural members, it is important that the bending stress in a simply supported construction equates to that occurring in practice and that this is not compromised by other considerations introduced by the artificial test configurations, e.g. that this stress level is not reduced because of requirements concerned with torsional restraint.

When the test loading applied to a beam is in excess of that which can be applied by means of dead loads, due to instability of the loading weights or possible bridging effects, the specimen should be mounted into a load-restraint frame that:

a) has provision for mechanically applying the test loading;

b) allows loading rams to be positioned at specific positions along the length of the specimen;

c) has the ability to absorb or transfer the reaction forces developed by the loading rams back to the ends of the specimen;

d) with the furnace, is capable of providing the necessary fixity at the ends of the beam.

A.3.4 ***Examination of specimen***

A.3.4.1 *Properties of the materials.* As the cold strength of a simple element, such as a beam, is one of the most important properties of the construction then a greater applicability can be obtained from the test if the test loading is related to the actual strength of the materials used, rather than the typical values available for the material. On fully homogeneous materials such information may be obtained from offcuts and often a loading test at ambient temperature, prior to the fire resistance test, can quantify actual stress/strain relationships. This ambient temperature test should not, however, exceed the elastic limit of the material as this will affect the subsequent yield strength. Other factors that will have a significant effect on the fire resistance are as follows:

a) changes in the cross-sectional area along the length of the beam; checking at several positions is recommended;

b) the density of the beam material, any component parts, or of any protective cladding or applied coating;

c) the average thickness and its variability of any protection material;

d) the moisture content of any hygroscopic materials used in the construction of the beam or any protective coating or cladding.

A.3.4.2 *Temperature measurement.* If the beam is manufactured from metal, e.g. steel or aluminium, or any other inert and homogeneous material where information is available on its properties at elevated temperatures, it will be useful to measure its temperature to assist in the prediction of failure and to enable the result to be used for possible assessment techniques. If the beam is made of concrete, it will be useful to measure the temperature of any reinforcing members and also the temperature gradients throughout the concrete to assist in the prediction of failure and to enable the result to be used for possible assessment techniques.

A.4 Columns

A.4.1 *General*

The method described in clause **6** is only directly applicable to columns that are fully exposed to the fire environment equally on all faces. In practice many columns are built into wall constructions, both internal and external, which have the effect of partially shielding the columns from the full fire exposure. Such columns should, therefore, be evaluated as part of a wall specimen (see clause **8**).

Whilst the procedures are written on an assumption that the test is applied to vertical loadbearing members subjected to compression loads, the method is also appropriate to the evaluation of members subjected to tensile loads, i.e. vertical ties.

A.4.2 *Design considerations*

A.4.2.1 *End conditions.* The permissible load that can be carried by a column depends to a great extent on the end conditions. In slender members of this type, which are assumed to be hinged, even small forces due to friction within the supports may considerably increase the load-bearing capacity. In a fire test an unintentional end restraint may produce a fixity that would have the effect of increasing the fire resistance. Free rotation can generally be achieved by using spherical or cylindrical end supports.

A.4.2.2 *Condition.* Where the end collars comprise concrete casing around the ends of the column, it is important that these are conditioned in a similar manner to the specimen in order to avoid spalling or excessive steam generation.

A.4.3 *Support and loading conditions*

A.4.3.1 *Fixity conditions.* The test should be performed using the conditions that exist on the element in practice but if this is difficult to design, a fire test on a column should be performed with complete fixity and the permissible load (centrally applied) calculated accordingly, taking into account the relevant buckling length.

A.4.3.2 *Loading.* Fire tests on columns are performed, under laboratory conditions, with idealized loading when compared with the loading that may be applied in an actual fire. For instance, it is not possible to reproduce in a test the changes of the end moments that often occur during an actual fire. Nevertheless, the test should accord with reality as far as possible, but it should also produce repeatable and reproducible results.

If the loading and support conditions are clearly defined in practice and these can be reproduced in the test furnace, then the permissible load should be determined taking these factors into account. Where the test conditions are idealized due to the impracticability of reproducing these actual conditions, the test load should be calculated with respect to the conditions applied to the specimen taking into account the effect of the fixity.

A.4.4 *Examination of specimen*

A.4.4.1 *Properties of materials.* As the cold strength of a simple element, e.g. a column, is one of the most important properties of the construction, a greater applicability can be obtained from the test if the test loading is related to the actual strength of the materials used, rather than the typical values available for the material. On fully homogeneous materials such information may be obtained from offcuts and often a loading test at ambient temperature, prior to the fire resistance test, can quantify actual stress/strain relationships. This ambient temperature test should not, however, exceed the elastic limit of the material as this will affect the subsequent yield strength. Other factors that will have a significant effect on the fire resistance are as follows:

a) changes in the cross-sectional area along the length of the column; checking at several positions is recommended;

b) the density of the column material, any component parts, or of any protection cladding or applied coating;

c) the average thickness and its variability of any protective material;

d) the moisture content of any hygroscopic materials used in the construction of the column or any protective coating or cladding.

A.4.4.2 *Temperature measurement.* If the column is manufactured from an inert and homogeneous material, e.g. steel or aluminium, where information is available on its properties at elevated temperatures, the monitoring of internal temperatures assists both with the possible prediction of failure and any subsequent assessments that may be needed. These thermocouples should be fixed to provide as much detail with respect to the temperature profile of the column as possible.

Where composite constructions are used, e.g. concrete filled hollow steel sections, a knowledge of the temperature of the individual materials, as well as the determination of the temperature gradient are both useful with respect to subsequent assessments.

Similarly, thermocouples can be used in order to determine cavity temperatures between columns and any fire protective cladding. Such knowledge may allow the fire protection system to be applied to columns constructed of other materials with different critical temperatures.

Leads from the specimen surface thermocouples should leave the furnace at the lower end.

A.4.5 *Criteria*

The deformation of vertical elements may be due to a combination of thermal expansion and drying shrinkage of the structural components with deformation under load resulting from loss of strength or diminished effective cross-sectional area.

The deformation characteristics of an element composed of one structural material, e.g. a protected structural steel column, are likely to be more predictable than those of an element composed of more than one structural material, e.g. a hollow steel tube filled with concrete.

The deformation of a structural steel column is likely to indicate expansion as the temperature of the steel rises while the column is well able to support the test loading. Once this initial deformation stage is reached, further expansion will be offset by shortening of the column as the steel deforms under the loading, either locally or as a whole; the apparent expansion will reach a maximum and then reverse. The extent of deformation as the specimen approaches failure is therefore the result of a combination of factors and cannot be used as a reliable criterion of failure even for that simple type of element.

The problem is aggravated with a concrete-filled steel tube. The initial deformation is similar to that of a structural steel column while the tube is carrying the load; as the tube heats rapidly it soon deforms under load and transfers the load to the concrete, but retains sufficient strength to keep the concrete confined. The concrete part of the column continues to support the test load for a considerable time until finally the combination of steel and concrete is no longer able to do so. At this stage, the extent of the deformation in the direction of application of the loading is considerably greater than for a structural steel column.

A timber column shows little initial change in length because it is a poor conductor of heat, and hence the average temperature of the cross-sectional area supporting the load does not alter. After a while, the effective cross section diminishes and deformation in the direction of loading — contraction is observed.

Structural concrete columns expand initially, but the deformation under load soon begins to compensate for the expansion, and the maximum value of expansion against time of heating is much less pronounced than with a steel column.

A.5 *Floors and flat roofs*

A.5.1 General

The criteria specified for evaluating floors and flat roofs are related to the traditional requirements for internal loadbearing floors. These criteria are based on the need to provide a high level of integrity and a low surface temperature on the unexposed face in order to avoid floor coverings and furnishings on the floor above becoming involved in the fire. In the case of a flat roof that is required to resist fire due to the existence of an internal escape route or an adjacent taller building that may be put at risk, the same criteria have been used. As there is unlikely to be such a significant fire risk or fire load on the roof of a building as would exist on an internal floor, the criteria used may not be completely valid for all situations especially the maximum unexposed face temperature. The method is normally limited to the testing of horizontal flat roofs but where the furnace and the loading facilities can accommodate low pitch roofs without compromising the test procedures, then clause **7** is appropriate to the testing of such elements.

A.5.2 *Specimen construction*

A.5.2.1 *Size.* Since the length to be exposed to the furnace is 4 000 mm the specimen will need to be constructed longer than this in order to provide the necessary bearing conditions to be established. For simply supported constructions, however, the bearing area should be kept to the minimum that is compatible with normal use and fixing.

A.5.2.2 *Manufacture of test construction.* As floors are often constructed from many components of nominally the same type and size, e.g. joists and board materials, it is important to ensure that all components used in the construction are of similar size and physical properties. Failure to do so may cause a localized failure.

A.5.3 *Support and loading conditions*

The magnitude of the test loading to be applied to an internal floor should be chosen taking into account the normal considerations of dead load and imposed or live load. In the case of a flat roof the normal design load has to take into account a maximum anticipated snow load which is a significant component of the total load. In calculating the test loading on a flat roof the designer should consider whether it is appropriate for the test load to incorporate the snow load components.

A.5.4 ***Pre-test analysis and setting up of the test construction***

A.5.4.1 *Properties.* In the construction of a joisted floor, using steel or timber joists, it is unlikely that each of the joists will be of identical size. It is important, therefore, not only to determine the average size but also to determine the magnitude of the variation between individual components that are nominally identical.

A.5.4.2 *Temperature measurement.* Unlike beams and columns, which are simple elements, the use of thermal data obtained from inside composite elements such as floors is not so directly applicable with respect to subsequent assessment or calculations. However, a full knowledge of the thermal gradients and individual component temperatures such as joist or cavity temperatures are all of assistance in any subsequent analysis of the performance.

A.6 Walls

A.6.1 ***General***

Some walls, used in practice, act as wide columns which are not designed to provide fire separation, but are required for their loadbearing capacity. In such cases the methods specified in clause **8** may be used but normally the criteria for integrity and thermal insulation are not required. Owing to modern building design, situations can develop in a building, due to open plan design or the provision of doors that are not inherently fire resisting, where a wall that acts as a wide column can be exposed either partially or fully to fire on both faces simultaneously. Very few facilities are capable of exposing a realistic length of walling to fire exposure on both faces simultaneously. However, where the facility does exist, the basic methodology used in evaluating the single face exposure is appropriate for such situations.

A.6.2 ***Manufacture of test construction***

As walls are often constructed from many individual components of nominally similar type and size, e.g. loadbearing stud walls constructed of steel or timber studs, it is important to ensure that all similar components used in the construction are of similar size and physical properties. If differences exist, this may cause a localized failure.

A.6.3 ***Support and loading conditions***

A.6.3.1 *End and edge conditions.* Walls with freely-hinged supports of the loaded edges are rarely used in practice: for experimental purposes full fixity of the bottom as well as the head is recommended. The vertical edges of a test wall should only be restrained if this is justified in practice, i.e. where sections of walling are built between substantial and inert columns that would restrain any lateral deformations.

A.6.3.2 *Loading.* Where columns are used in conjunction with walls that are either non-loadbearing, or only partially loadbearing, then the loading equipment has to be capable of applying the loads only to the loadbearing components or be capable of applying differential loads to each part. Where differential loading is to be applied, this will only be capable of being achieved by separate loading systems or by different sized rams in the case of hydraulically operated loading devices.

The loading frame should have provision for:

a) normally applying mechanically the test loading required;

b) allowing the loading rams to be positioned at specific points or to enable a uniformly distributed load to be applied via load spreading beams that do not permit any bridging of the load to occur, especially if the specimen deforms vertically in an irregular manner;

c) absorbing the vertical reaction forces developed by the loading rams supported such that the direction of loading is maintained vertical throughout the test;

d) together with the furnace, providing the necessary fixity on the relevant edges of the wall.

NOTE Due to the slenderness of a wall, it is unlikely that the specimen can be satisfactorily loaded with dead weights, except in the case of very lightly loaded specimens.

A.6.4 ***Examination of specimen***

A.6.4.1 *Properties.* In the construction of stud walls where several components of similar nominal size are employed in the construction, it is important to determine the average size and also to quantify the variation that exists between individual components.

A.6.4.2 *Temperature measurement.* The behaviour of walls, like that of floors, is not so easily predicted on the basis of thermal information as are beams and columns. A full knowledge of the thermal gradients, individual component temperatures or cavity temperatures are all of assistance in any subsequent analysis of the performance. The fitting of thermocouples to the sides of individual studs, or to the faces of boards or insulation materials, or directly into the cavities will provide a more thorough knowledge of the thermal characteristics.

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Publications referred to

BS 476, *Fire tests on building materials and structures*.
BS 476-*20, Method for determination of the fire resistance of elements of construction (general principles)*.
BS 476-*22, Methods for determination of the fire resistance of non-loadbearing elements of construction*.
BS 476-*23, Methods for determination of the contribution of components to the fire resistance of a structure*.
BS 4422, *Glossary of terms associated with fire*.

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