BS EN 13381-3:2015

BSI Standards Publication

Test methods for determining the contribution to the fire resistance of structural members

Part 3: Applied protection to concrete members

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National foreword

This British Standard is the UK implementation of EN 13381-3:2015. It supersedes DD ENV 13381-3:2002 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee FSH/22/-/12, Fire resistance tests For Protection Systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Test methods for determining the contribution to the fire resistance of structural members - Part 3: Applied protection to concrete members

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Prüfverfahren zur Bestimmung des Beitrages zum Feuerwiderstand von tragenden Bauteilen - Teil 3: Brandschutzmaßnahmen für Betonbauteile

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Foreword

This document (EN 13381-3:2015) has been prepared by Technical Committee CEN/TC 127 “Fire safety in buildings”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2015 and conflicting national standards shall be withdrawn at the latest by October 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes ENV 13381-3:2002.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of 89/106/EEC.

The dimension tolerances regarding the manufacturing of the specimen indicated in the ENV 13381-3:2002 led to tensile stress values of 290 +/- 30 N/mm² in the reinforcement bars depending on the type of structural member. In order to harmonize the mechanical constraint applied on the structural member, the bending moment has been modified to produce the same tensile stress on reinforcement bars equal to 300 N/mm². This value is corresponding to 60 % of the grade of the steel to be used. Due to this approach, the result of tests carried out according to ENV 13381-3:2002 can be taken into account for assessment according to the present document.

In comparison with ENV 13381-3:2002, the following significant changes have been made:

— the bending moment has been modified to be adapted to the thickness of the slab;

— the location of thermocouple used within beams for the calculation of equivalent thickness of concrete is now at 25 mm away from the beam bottom corner instead of 55 mm;

— the graphs to be used for the determination of equivalent concrete thickness for slabs has been improved and extended and is directly available in the standard.

This European Standard is one of a series of standards for evaluating the contribution to the fire resistance of structural members by applied fire protection materials. The other parts of this standard are:

— *Part 1: Horizontal protective membranes*

— *Part 2: Vertical protective membranes*

— *Part 4: Applied protection to steel members*

— *Part 5: Applied protection to concrete/profiled sheet steel composite members*

— *Part 6: Applied protection to concrete filled hollow steel columns*

— *Part 7: Applied protection to timber members*

— *Part 8: Applied reactive protection to steel members*

Annexes A, B and C are normative.

Caution: The attention of all persons concerned with managing and carrying out this fire resistance test is drawn to the fact that fire testing can be hazardous and that there is a possibility that toxic and/or harmful smoke and gases can be evolved during the test. Mechanical and operational hazards can also arise during the construction of test elements or structures, their testing and the disposal of test residues.

An assessment of all potential hazards and risks to health should be made and safety precautions should be identified and provided. Written safety instructions should be issued. Appropriate training should be given to relevant personnel. Laboratory personnel should ensure that they follow written safety instructions at all times.

The specific health and safety instructions contained within this standard should be followed.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard specifies a test method for determining the contribution of fire protection systems to the fire resistance of structural concrete members, for instance slabs, floors, roofs and walls and which can include integral beams and columns. The concrete can be lightweight, normal weight or heavyweight concrete and of all strength classes (e.g. 20/25 to 50/60 for normal strength concrete and for high strength concrete 55/67 to 90/105). The member is to contain steel reinforcing bars.

The test method is applicable to all fire protection materials used for the protection of concrete members and includes sprayed materials, reactive coatings, cladding protection systems and multi-layer or composite fire protection materials, with or without a gap between the fire protection material and the concrete member

This European Standard specifies the tests which are to be carried out to determine the ability of the fire protection material to remain coherent and fixed to the concrete and to provide data on the temperature distribution throughout the protected concrete member, when exposed to the standard temperature time curve.

In special circumstances, where specified in national building regulations, there can be a need to subject the protection material to a smouldering curve. The test for this and the special circumstances for its use are detailed in Annex A.

The fire test methodology makes provision for the collection and presentation of data which can be used as direct input to the calculation of fire resistance of concrete members in accordance with the procedures given in EN 1992-1-2.

This European Standard also contains the assessment which prescribes how the analysis of the test data is to be made and gives guidance to the procedures by which interpolation is to be undertaken.

The limits of applicability of the results of the assessment arising from the fire test are defined together with permitted direct application of the results to different concrete structures, densities, strengths, thicknesses and production techniques over the range of thicknesses of the applied fire protection system tested.

The test method, the test results and the assessment method are not applicable to structural hollow concrete members.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 206, *Concrete - Specification, performance, production and conformity*

EN 823, *Thermal insulating products for building applications - Determination of thickness*

EN 1363-1, *Fire resistance tests - Part 1: General Requirements*

EN 1363-2, *Fire resistance tests - Part 2: Alternative and additional procedures*

EN 1992-1-1, *Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings*

EN 1992-1-2, *Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design*

EN 10080, *Steel for the reinforcement of concrete - Weldable reinforcing steel - General*

EN 12467, *Fibre-cement flat sheets - Product specification and test methods*

EN ISO 13943, *Fire safety - Vocabulary (ISO 13943)*

ISO 8421-2, *Fire protection - Vocabulary - Part 2: Structural fire protection*

3 Terms and definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1363-1, EN ISO 13943, ISO 8421-2 and EN 206 and the following apply.

3.1.1
concrete member
element of building construction which is loadbearing and is fabricated from concrete, defined according to EN 206 and shall contain steel reinforcing bars

3.1.2
fire protection material
material or combination of materials applied to the surface of a concrete member for the purpose of increasing its fire resistance

3.1.3
passive fire protection materials
materials which do not change their physical form upon heating and which provide fire protection by virtue of their physical or thermal properties and may include materials containing water which, on heating, evaporates to produce cooling effects

3.1.4
reactive fire protection materials
materials which are specifically formulated to provide a chemical reaction upon heating such that their physical form changes and in so doing provide fire protection by thermal insulation and cooling effects

3.1.5
fire protection system
fire protection material together with a prescribed method of attachment to the concrete member

3.1.6
fire protection
protection afforded to the concrete member by the fire protection system such that the temperature throughout the depth of the structural member and upon any steel reinforcing bars within it is limited throughout the period of exposure to fire

3.1.7
test specimen
concrete slab or beam test member plus the fire protection system under test

3.1.8
fire protection thickness
thickness of a single layer fire protection system or the combined thickness of all layers of a multilayer fire protection system, excluding the width or height of supporting profiles, clips and other fixings

3.1.9
stickability
ability of a fire protection material to remain sufficiently coherent and in position for a well defined range of deformations, furnace and test specimen surface temperatures, such that its ability to provide fire protection is not significantly impaired

3.1.10
critical temperature
temperature at which failure is expected to occur in steel reinforcement within the concrete at a given load level

3.1.11
lathing
mechanical fixing aids comprising non-combustible wires or similar constructions fixed to the concrete before sprayed fire protection material is applied

3.1.12
adhesive bond promoter
material applied to the surface of the concrete, prior to application of the fire protection material, for promotion of increased bonding

3.1.13
equivalent thickness of concrete
theoretical thickness of concrete which provides the same thermal insulation for a given period of test as does the given thickness of the applied fire protection system

Note 1 to entry: Care shall be taken to ensure when using "equivalent thickness" that in the practical situation the concrete thickness will not be reduced by spalling, etc.

3.1.14
characteristic temperature
average of the mean temperature and the maximum individual temperature [(mean + maximum)/2] for each thermocouple group at equivalent location defined in 9.3.4

3.2 Symbols and units

Symbol	**Unit**	**Designation**
L_{exp}	mm	Length of the test specimen exposed to the furnace
L_{sup}	mm	Centre to centre distance between the test specimen supports
L_{spec}	mm	Total length of the test specimen
W_{exp}	mm	Width of the test specimen exposed to the furnace
h	mm	Thickness of concrete slab or height of concrete beam specimen
l_{sup}	mm	Distance of loading points from the specimen support points
P	kN	Loading applied to the slab or beam test specimen
θ	°C	Characteristic temperature
θ_{crit}	°C	Critical temperature as specified in EN 1992-1-2
d	mm	Depth in concrete
d_{θ}	mm	Depth in concrete at which chosen θ_{crit} is noted
d_p	mm	Thickness of fire protection material: $d_{p(min)}$ is minimum thickness and $d_{p(max)}$ is maximum applied thickness of fire protection material
$\Delta\theta_{CL}$	°C	Temperature rise, as a function of time

d_{cc}	mm	Depth in unprotected concrete slab at which $\Delta\theta_{CL}$ is noted [used in Annex C]
d_{cp}	mm	Depth in protected concrete at which temperature rise $\Delta\theta(d_{cp},t)$ is measured at time *t*
$\Delta\theta(d_{cp},t)$	°C	Temperature rise measured in protected concrete at measured depth d_{cp}
f_y	N/mm^2	Yield strength of steel as defined in EN 10080
ε	mm	Equivalent concrete thickness

4 Test equipment

4.1 General

The furnace and test equipment shall be as specified in EN 1363-1.

4.2 Furnace

The furnace shall be designed to permit the dimensions of the test specimen to be exposed to heating to be as specified in 6.2 and its installation to be as specified in Clause 7.

4.3 Loading equipment

Loading shall be applied according to EN 1363-1. The loading system shall permit loading, of the magnitude defined in 5.3, to be applied along the length and width of the test specimen.

The loading equipment shall not inhibit the free movement of air above the test specimen and no part of the loading equipment, other than at the loading points, shall be closer than 60 mm to the unexposed surface of the test specimen.

5 Test conditions

5.1 General

Test specimens, subjected to predefined loading, are heated upon a furnace in horizontal orientation to provide information on each of the following:

— the temperature distribution within the concrete test member;

— the behaviour of the fire protection system and its stickability;

— the behaviour of the test specimen with respect to specified performance criteria.

It is recommended that the test be continued until the mean temperature upon the main reinforcing bars within the concrete reaches 700 °C, or any single maximum value of 750 °C is recorded, to give the necessary information on the stickability of the fire protection system. However, these temperatures may be modified if requested by the sponsor, with possible consequences on the application field.

If the recommended termination temperatures are not reached after 6 hours test duration, the test shall normally be terminated.

The procedures given in EN 1363-1 and, if applicable, EN 1363-2, shall be followed in the performance of this test method unless specific contrary instruction is given herein.

5.2 Support and restraint conditions

5.2.1 Standard support and restraint conditions

Concrete slab test specimens shall be tested as a simply supported one way structure with two free edges and an exposed surface and span as defined in 6.2.

Concrete beam test specimens shall be tested simply supported. The test arrangement shall provide lateral stability.

The concrete slab or beam test member shall be installed onto the furnace to allow freedom for longitudinal movement and deformation using at one side rolling support(s) and at the other hinge support(s).

The surface of the bearings shall be smooth concrete or steel plates. The width of the bearings shall be the minimum representative of practice.

5.2.2 Other support and restraint conditions

If the support and restraint conditions differ from the standard conditions specified in 5.2.1, these conditions shall be described in the test report and the validity of the test results shall be restricted to those tested.

5.3 Loading conditions

Loading shall be applied to all test specimens.

The magnitude and distribution of the load (P) applied to the specimen shall be calculated taking into account the dead-weight of the specimen (measured or derived by calculation from samples of the components, see 6.5.1) and the weight of load distribution beams or plates, as follows.

The bending moments produced at mid-span of the specimens shall be calculated according to the formula in Annex D, in order to produce a tensile stress in the lower reinforcement bars of the standard concrete test structures equal to 300 MPa.

For concrete slab test specimens the line load shall be symmetrically applied to the test specimen along two transverse loading lines, each one at a distance (l_{sup}) from each of the supports. The proportion of the total load applied at each loading position shall be as specified in Figure 1 (small slab test specimen) and Figure 2 (large slab test specimen). The load shall produce stresses approximating to a uniformly distributed load on the transverse loading lines.

For concrete beam test specimens the line load shall be symmetrically applied to the test specimen by a two point loading system, each one at a distance (l_{sup}) from each of the supports. The proportion of the total load applied at each loading position shall be as specified in Figure 3. The load shall produce stresses approximating to a uniformly distributed load on the transverse loading line.

Point loads shall be transferred to the test specimen through load distribution beams or plates (Figures 1, 2 and 3).

The total contact area between these and the concrete surface of the test specimen shall be as specified in EN 1363-1, provided that the load distribution beam or plate chosen has a flexural rigidity large enough to give the required distribution of the load.

Load distribution beams, for safety reasons, shall have a height to width ratio of < 1.

If the load distribution beams or plates are of steel or other high conductivity material, they shall be insulated from the surface of the concrete test specimen by a suitable thermal insulation material.

Unexposed surface thermocouples shall not be closer than 100 mm to any part of the load distribution system as shown in Figures 1, 2 and 3.

6 Test specimens

6.1 Type and number of test specimens

6.1.1 Type of test specimens

The type of concrete test member used is determined by the type and practical situation to which the fire protection system is to be used, i.e.:

a) fire protection systems to be used on flat, two dimensional concrete members only, such as slabs and walls, are evaluated by carrying out the test on large concrete slabs;

b) fire protection systems to be used on beams and columns only, and subject to three and four sided exposure, are evaluated by carrying out the test on concrete beams;

c) fire protection systems to be used on slabs, walls, beams and columns are evaluated by carrying out the test on both concrete slabs and beams according to a) and b) above;

d) tests may be carried out, in addition to the large scale tests, on loaded small concrete test slabs to provide additional test results for the fire protection system when:

   1) it is to be applied to concrete of higher strength classes to evaluate the spalling behaviour;

   2) the test is carried out to the smouldering curve (Annex A).

Test of intermediate thickness of protection system shall be performed on a loaded large specimen (beam and/or slab) to get representative behaviour of the protection product, especially regarding the stickability and influence of the deformation of the slab or beam on the thermal data.

6.1.2 Number of test specimens

Two full size loaded concrete members (either slabs or beams depending upon the end use as specified in 6.1.1 a) and 6.1.1 b) of the same concrete strength shall be tested.

To one member the minimum thickness of the fire protection system shall be applied and to the other member the maximum thickness. If the fire protection system is only available in a single thickness, then one test on one type of member only shall be carried out at that thickness.

In addition to the mandatory full size tests, following possibilities are available:

— An additional full size slab or beam may be tested with an intermediate thickness of the protection system;

NOTE Such additional test could extend the application field, for instance to get a better result than the direct interpolation method for equivalent concrete thickness, as given in Annex C.

To obtain further data, as defined in 6.1.1 d) loaded small size slab tests may be carried out:

— One such test shall be carried out with a specific thickness of the fire protection system requested by the sponsor to cover in the application field a higher concrete strength (see Clause 15);

— The use of the small slab in the smouldering fire is given in Annex A.

6.2 Size of test specimens

6.2.1 Concrete slabs

The concrete test slabs shall be of the sizes specified in Table 1 and an example is given in Figure 1 (small specimen) and Figure 2 (large specimen).

Table 1 — Sizes of concrete test slabs

	small specimen	large specimen
Exposed length (mm) L_{exp}	≥ 1 300 and ≤ 2 300	4 000 minimum
Span (mm) L_{sup}	≥ 1 500 and ≤ 2 700 (L_{exp}+200) ≤ L_{sup} ≤ (L_{exp}+400) [note]	4 200 minimum (L_{exp}+200) ≤ L_{sup} ≤ (L_{exp}+500) [note]
Specimen length (mm) L_{spec}	≥ 1 700 and ≤ 3 000 (L_{exp}+400) ≤ L_{spec} ≤ (L_{exp}+700)	4 400 minimum (L_{exp}+400) ≤ L_{spec} ≤ (L_{exp}+700)
Exposed width (mm) W_{exp}	≥ 1 000 and ≤2 000	≥ 3 000
Thickness (mm) *h*	(140 -20/+10) for higher strength class of concrete however the concrete thickness and the load shall be adjusted so that the tensile stress in the reinforcement bars is at least 300 N/mm² calculated in accordance with Annex D by updating parameter n to take into account the features of the high strength concrete.	(140 -20/+10)
Position of loading points from support points (mm)	(600 ± 10)	(1 000 ± 10)
The distance between the exposed part of the test specimen and the supports shall be kept as small as possible. For tests of short duration (less than 240 minutes), a distance of 100 mm at either end is recommended. For tests of longer duration, this could be increased to 250 mm at either end, to protect the test equipment from heat damage.		

6.2.2 Concrete beams

The concrete test beams shall be of a size such that an overall exposed length (L_{exp}) not less than 4 000 mm is obtained.

The span (L_{sup}) shall not be greater than the exposed length by more than 250 mm at each end.

The total specimen length (L_{spec}) shall be not greater than the exposed length by more than 350 mm at each end.

The beam shall be of height (450 ± 10) mm and width (150 ± 10) mm.

The position of the loading points from the support points (l_{sup}) shall be (1 000 ± 10) mm.

The beam construction is shown in Figure 3.

6.3 Construction of concrete test specimens

6.3.1 Concrete slab test members

Concrete slab test members shall contain a reinforcing mesh, which may comprise single reinforcement bars tied together with lashing wire or a prefabricated "welded fabric" mesh.

The mesh (placed towards the exposed surface and protected by the fire protection material) shall comprise 10,0 mm diameter ribbed bars for the large slab and 8,0 mm diameter ribbed bars for the small slab. The permitted tolerances on dimensions of reinforcing bars are given in EN 10080.

For the slab test member, an upper mesh, at the unexposed surface, shall be used. It shall comprise 6,0 mm diameter ribbed bars.

Reinforcing bars shall be centred (150 ± 10) mm apart in both directions. The position of the main reinforcing bars with respect to the exposed and unexposed concrete surfaces shall be ensured by the use of spacers, either plastic or concrete, such that the concrete cover obtained is (20 ± 2) mm.

The actual position of the main reinforcing bars at the exposed and unexposed surfaces and the position of the thermocouples specified in 9.3 shall be accurately adjusted just before the casting of the concrete member.

6.3.2 Concrete beam test members

Each concrete beam test member shall contain four ribbed reinforcing bars of 12 mm diameter, fixed with 8,0 mm diameter stirrups at (200 ± 10) mm centres. The permitted tolerances on dimensions of reinforcing bars are given in EN 10080.

The position of the 12 mm reinforcing bars with respect to the concrete surface shall be ensured by the use of spacers, either plastic or concrete, such that the concrete cover obtained is (25,0 ± 2) mm.

The actual position of the reinforcing bars at the concrete surface shall be accurately measured and recorded after the test at the positions of the thermocouples specified in 9.3. This shall be achieved by cutting the concrete beam into at least two pieces through or close to the required positions.

6.3.3 Fabrication of concrete test members

Slab and beam concrete test members shall be prepared in a smooth surfaced framework made from steel or timber. To facilitate release of the slab or beam from the framework, soluble oils or emulsions shall be used. The actual material used for this purpose shall be detailed in the test report.

Waxes, insoluble oils or other release agents may be used within this test method but they shall be subject to restricted application (see Clause 15) and each release agent intended to be used shall be separately assessed.

In order to avoid the collapse of the beam or slab test specimen during the test, fixtures to which hangers are attached may be provided on the unexposed side. These fixtures shall not interfere with the applied load.

6.3.4 Application of fire protection material (except ceiling) to concrete test member

The fire protection material shall be uniformly applied to the concrete, as in practice, including any required fixing aids, e.g. lathes, meshes and wires or adhesive bond promoters, and in the same manner for both maximum and minimum fire protection thickness.

The fire protection material shall extend over the full exposed surface(s) of beams and slabs, and be applied prior to the application of the test load.

Where a fire protection system creates a small cavity between the concrete and the fire protection material, e.g. when the supporting profiles are directly fixed onto the slab or beam, the ends shall be sealed with fire resistant material to prevent any flow of hot gases out of the cavities.

Fixing profiles for board type fire protection systems can be orientated in both longitudinal and transverse directions of the test specimen. Fixing profiles orientated in the longitudinal direction, for each line of fixing profiles, shall include a joint between boards at mid span with a tolerance of ± 50 mm.

Fixing profiles orientated in the transverse direction shall include joints between boards in accordance with the following:

Large slab specimens	At least one transverse joint positioned not further than 500 mm from the transverse axis.
Small slab specimens	At least one transverse joint positioned not further than 100 mm from the transverse axis.
Beams	At least one joint shall be positioned at mid-span, or as close to mid-span as is possible on both sides and base of the beam.

6.3.5 Installation of a ceiling below the concrete slab

The test specimen shall reproduce the conditions of use, including junctions between membrane and walls and edge panels, joints and jointing materials and be installed from below by the same method and procedures as given in the installation manual, or in written instructions, which shall be provided by the sponsor.

It shall be fitted with all the components for hanging, expansion and abutting, plus any other fixtures which are to be defined by the sponsor, with a frequency representative of practice.

For horizontal protective membranes which are suspended from the structural building member by hangers, the suspension system and the length of the hangers shall be representative of practice.

For self-supporting horizontal protective membranes which are fixed to the perimeter walls, the supporting system shall be representative of practice.

The profiles bearing the various panels shall be installed against each other without any gap, unless a gap (or gaps) is required for design purposes. In this case the gap (or gaps) at the junctions of main runners shall be representative of that to be used in practice and shall be installed within the main runners and not at their ends.

The profiles within the test specimen shall include a joint representative of joints to be used in practice in both longitudinal and transverse directions.

The horizontal protective membrane shall be fixed according to normal practice on all four edges, either directly to the furnace walls or to a test frame. A test frame, where used, shall be fixed directly to the horizontal structural building member being protected, or to the furnace walls.

If the construction or properties of the horizontal protective membrane are different in the longitudinal and transverse directions, the performance of the specimen may vary depending upon which components are aligned with the longitudinal axis. If known from experience, the specimen shall be installed so as to represent the most onerous condition by arranging the more critical components parallel to the longitudinal axis. If the more onerous condition cannot be identified, two separate tests shall be carried out with the components arranged both parallel and perpendicular to the longitudinal axis.

6.4 Composition of test specimen component materials

6.4.1 Concrete

The concrete in the test specimen shall normally be of type 25/30 to 30/37 [LC/C/HC] (light-weight between 800 kg/m^3 and 2 000 kg/m^3, normal-weight between 2 000 kg/m^3 and 2 600 kg/m^3 or heavy-weight concrete greater than 2 600 kg/m^3) according to EN 206 and EN 1992-1-1, although other grades within the strength range 20/25 to 50/60 may be used, (see the Scope).

The concrete shall be prepared from siliceous aggregates, of maximum aggregate size of 20 mm, and Portland cement. The composition and properties of the concrete used shall be appropriate to those defined in EN 206 and EN 1992-1-1.

Other non-siliceous and lower density aggregates are permitted, but the applicability of the results of the assessment will be restricted according to Clause 15.

The consistency of the wet concrete shall allow for good compaction and smooth surface. The consistency shall be of type S3 or F3 determined in accordance with EN 206.

6.4.2 Steel reinforcement

The steel reinforcement bars used shall be ribbed and shall be of grade B500 (to EN 10080) or comparable European Standard grade (see EN 10080) with f_y = 500 N/mm^2. The permitted tolerances on the dimensions of reinforcing bars are given in EN 10080.

6.4.3 Fire protection system

The generic description of the fire protection system and its major components shall be specified by the sponsor, including at least the name, dimensions, the expected nominal density, thickness and moisture content according to European Technical Specifications (European Standard or ETA).

6.5 Properties of test materials

6.5.1 General

The actual material properties of the test specimen component materials shall be determined, according to EN 1363-1 and using appropriate product test standards, on test materials or test samples conditioned as described in Clause 8.

6.5.2 Concrete

The concrete strength of all batches of concrete used shall be measured at intervals during conditioning (see Clause 8) and on the day of the fire test according to one of the methods specified in EN 206.

The density and moisture content of all batches of concrete used shall be measured at intervals during conditioning and on the day of the fire test using small samples prepared at the same thickness and at the same time and from the same materials as each concrete member to be tested. These small samples, of size 200 mm ± 5 mm × 200 mm ± 5 mm × thickness ± 5 of test sample shall have been covered, after preparation, on five sides with a water impermeable membrane, the top surface exposed, and conditioned with the concrete test member as specified in Clause 8. The method used to prepare and condition these test samples shall be reported.

The dimensions of the concrete member measured before application of the fire protection material together with weight of reinforcement and the final concrete density may be used to calculate the dead-weight contribution of the concrete to the calculation of load.

6.5.3 Steel reinforcement

The grade of steel bars used for reinforcement shall be confirmed either by measurement to appropriate standards or by certificate of conformity, against the specification given in 6.4.2, which shall be provided by the supplier.

6.5.4 Fire protection materials

The actual thickness, density and moisture content of the fire protection materials shall be measured and recorded, at the time of test, either directly upon the fire protection material or materials or on special test samples taken by the laboratory. These shall be conditioned as defined in Clause 8. The measurement procedures appropriate to different types of material are given in Annex B.

The thickness of a board or panel type fire protection material shall not deviate by more than 15 % of the mean value over the whole of its surface. The mean value shall be used in the assessment of the results and the limits of applicability of the assessment. If it deviates by more than 15 %, the maximum thickness recorded shall be used in the assessment.

The thickness of a sprayed or coated passive type fire protection material shall not deviate by more than 20 % of the mean value over the whole of its surface. The mean value shall be used in the assessment of the results and the limits of applicability of the assessment. If it deviates by more than 20 %, the maximum thickness recorded shall be used in the assessment.

The density of fire protection material applied to the concrete at minimum and maximum thickness shall be recorded. The average between mean values of the density of the fire protection material at minimum and maximum thickness shall be used in the assessment of the results of the test, unless the difference between this average value and the mean values at minimal and maximal thickness is greater than 15 % of the average value, in which case the maximum mean density value recorded shall be used.

For reactive fire protection materials, the average primer thickness should be first measured and then subtracted from the total average primer and reactive coating thickness. The resulting permitted thickness tolerances excluding primer and topcoat shall be in accordance with the requirements of EN 13381-8.

6.6 Verification of the test specimen

An examination and verification of the test specimen for conformity to specification shall be carried out as described in EN 1363-1.

The properties of the materials used in the preparation of the test specimen shall be measured using special samples, where necessary, as defined in 6.5 using the methods defined in Annex B.

The sponsor shall verify that the fire protection material has been applied correctly and in the case of sprayed or coated materials ensure, by methods appropriate to the material, that it is of the design composition and specification.

7 Installation of the test construction

7.1 Concrete large slab test specimens

The test construction, comprising the concrete slab test member, any supporting construction or test frame and the fire protection system, shall be installed onto the furnace to allow freedom for longitudinal deflection and movement, according to 5.2.1.

Special attention shall be given to the choice of size of the test specimen according to the expected duration of the test (see 6.2.1) and to insulation of the supports carrying the slab against the influence of heat.

Care shall be taken to ensure that during installation of test specimens onto the furnace, or as a result of any movement occurring during the test, the fire protection system is not subjected to any expansion or restraint stresses contrary to its use in practice.

7.2 Concrete small slab test specimens

The test construction, comprising the concrete slab test member, any supporting construction or test frame and the fire protection system, shall be installed onto the furnace to allow freedom for longitudinal deflection and movement, according to 5.2.1.

Special attention shall be given to the choice of size of the test specimen according to the expected duration of the test (see 6.2.1) and to insulation of the supports carrying the slab against the influence of heat.

Care shall be taken to ensure that during installation of test specimens onto the furnace, or as a result of any movement occurring during the test, the fire protection system is not subjected to any expansion or restraint stresses contrary to its use in practice.

7.3 Concrete beam test specimens

The test construction, comprising the concrete beam test member, any supporting construction or test frame and the fire protection system shall be installed onto the furnace to allow freedom for longitudinal deformation and movement, according to 5.2.1. Special attention shall be given to insulation of the supports carrying the beam against the influence of heat.

The loaded beams shall be provided with a lightweight concrete topping. The topping to the beam shall be a layer of mineral fibre insulation board placed between the lightweight concrete topping and the top of the beam. This insulation board shall have a thickness of 10 mm to 15 mm and a nominal density of (350 ± 50) kg/m^3. It shall have a width equal to the width of the top of the beam.

Care shall be taken to ensure that during installation of test specimens onto the furnace, or as a result of any movement occurring during the test, the fire protection system is not subjected to any expansion or restraint stresses contrary to its use in practice.

8 Conditioning

The test construction and test samples taken for the determination of material properties (specified in 6.5) shall be conditioned according to EN 1363-1. Material properties shall be determined according to methods specified in 6.5, Annex B and EN 1363-1.

The minimum conditioning time for concrete slabs and beams shall be 90 d.

9 Application of instrumentation

9.1 General

The instrumentation for the measurement of temperature, furnace pressure and deformation shall comply with the requirements of EN 1363-1.

9.2 Instrumentation for measurement of furnace temperature

9.2.1 Slab specimens

Plate thermometers of the type specified in EN 1363-1 shall be provided to measure the temperature of the furnace. They shall be uniformly distributed, with at least one centrally placed within every 1,5 m^2 of the exposed test specimen surface area, the exposed area being the nominal area measured in the plane of the specimen.

The plate thermometers shall be oriented so that side 'A' faces the floor of the furnace and shall be positioned (100 ± 50) mm below the underside of the protective material. For test specimens with less than 6 m^2 exposed area, a minimum of four plate thermometers shall be used.

9.2.2 Beam specimens

The furnace temperature in the region of each loaded beam test specimen shall be measured by plate

thermometers, placed at locations at 1/5, 2/5, 3/5 and 4/5 of the heated length of the loaded beam, with two plate thermometers at each location, one on each side of the beam at a distance of 100 mm ± 10 mm of the beam.

The plate thermometers shall be positioned at a distance of 500 mm below the soffit as shown in Figure 8.

The plate thermometers shall be oriented so that for half their number side ‘A’ faces the floor of the furnace and for the other half, side ‘A’ faces the longer side walls of the furnace. The distribution of the different orientations shall be such that there shall be equal numbers facing the floor and the wall on each side of the beam.

At the commencement of the test these thermocouples shall be positioned as specified in EN 1363-1.

9.3 Instrumentation for the measurement of test specimen temperature

9.3.1 General

Thermocouples for measuring temperatures upon the exposed surfaces of the concrete beneath the fire protection material, on the reinforcing bars and within the concrete shall be of the double glass fibre insulated bare wire type specified in EN 1363-1 and be positioned and fixed as specified in EN 1363-1.

To provide protection against damage when casting concrete, the wire of such thermocouples may be encased within a secondary casing, which shall be chosen such that it will not affect the temperature history of the thermocouple throughout the test. Such thermocouples shall be new when used for this test. See Figure 4.

Drilling of holes and applying thermocouples in these holes is not permitted.

Thermocouples for measuring temperatures upon the unexposed surface of the concrete shall be of the copper disc type specified in EN 1363-1. They shall be positioned and fixed as specified in EN 1363-1.

9.3.2 Large and small concrete slab test specimens

Thermocouples shall be provided to permit measurement and recording of the surface and internal temperatures of the concrete and its reinforcement.

These thermocouples shall be as given below and shown in Figures 1, 2, 3 and 4:

i) five thermocouples fixed on the unexposed upper face of the slab, (numbers 1 to 5). These shall not be closer than 100 mm to any part of the load distribution system;

ii) thirteen thermocouples at the concrete surface, beneath the applied fire protection system, on the exposed lower face of the slab, with a minimum of one per m^2 (five only indicated in figures as thermocouples numbers 6 to 10).

   They shall be on the following locations:

   — a thermocouple opposite each unexposed surface thermocouple specified in (i) above;

   — a thermocouple opposite each reinforcement bar thermocouple specified in (iii) below;

   — a thermocouple opposite each measurement station designated a, b or c in (iv) and (v) below.

   Such thermocouples shall be installed by fastening to the mould in which the concrete is cast, with a non-combustible tape (e.g. ceramic tape) with moderate adhesive properties before the concrete is cast (see Figure 7). Care shall be taken when removing the concrete slab from the mould that the tape releases from the mould and the thermocouple is not damaged;

iii) five thermocouples fixed on the longitudinal reinforcement bars, (numbers 11 to 15), the hot junction of which shall be positioned midway between two transversal bars and in the central zone of the slabs between the loading points. The hot junction of the thermocouples shall be spot welded to the bottom of the bars and between the ribs on the bars.

NOTE The bottom location is the worst.

iv) for the small slabs, three sets of five thermocouples shall be introduced into the body of the slabs, (designated a, b and c in Figure 1).

v) for the large slabs, three sets of five thermocouples shall be introduced into the body of the slabs, (designated a, b and c in Figure 2).

The thermocouples in cases iv) and v) above shall be located between the loading points and shall be rigidly mounted on tensioned U-shaped 5 mm diameter bars fixed to the upper reinforcing bars in order to guarantee their spacing at 15 mm centres.

Such thermocouples shall be fixed to the 5 mm U-shaped bars isothermally for 50 mm. The hot junction is angled away from the U-shaped bar such that it is between 5 mm to 10 mm away from and below the bar (on the exposed side during the test) and positioned accurately at the required depth. Thermocouple fixing bars and thermocouples shall be spaced 50 mm apart at each measurement station throughout the depth of the slab (see Figure 4).

9.3.3 Beams

Thermocouples shall be provided to permit measurement and recording of the surface and internal temperature of the concrete and its reinforcement. These thermocouples shall be located as given in Figure 3, in each of three cross sectional areas situated at:

Area Y: central section located at ½L_{exp}.

Area X: (600 ± 100) mm from one side of the central section, between two stirrups.

Area Z: (600 ± 100) mm from the other side of the central section, between two stirrups.

Thermocouples within each cross sectional area shall be as follows and as given in Figure 3.

i) three thermocouples (numbers 1 to 3 shown in Figure 3) fixed to the concrete surface, beneath the applied fire protection system. These thermocouples shall be located and fixed according to the principles of the methodology of 9.3.2 (ii);

ii) three thermocouples fixed to the stirrups, (numbers 4 to 6 shown in Figure 3). These thermocouples shall be located and fixed according to the principles of the methodology of 9.3.2 (iii);

iii) two thermocouples fixed on the lower reinforcement bars, (numbers 7 to 8 shown in Figure 3). These thermocouples shall be located and fixed according to the principles of the methodology of 9.3.2 (iii) but in the diagonal direction;

iv) four thermocouples positioned centrally within the beam, (numbers 9 to 12 shown in Figure 3). These thermocouples shall be located and fixed according to the principles of the methodology of 9.3.2 (iv/v);

v) two thermocouples shall be fixed to the upper surface of the concrete beam, one midway between cross sectional areas 1 and 2 and the other midway between areas 2 and 3, (numbers 13 and 14 shown in Figure 3). These thermocouples shall be located and fixed according to EN 1363-1.

9.3.4 Equivalent locations as referred to in 11.2 are:

Slabs:

— upon unexposed upper surface of the concrete - 5 thermocouples;

— upon exposed lower surface of the concrete - 13 thermocouples minimum;

— upon longitudinal reinforcement bars - 5 thermocouples;

— within concrete at each of 4 depths (small slab only) - 3 thermocouples;

— within concrete at each of 5 depths (large slab only) - 3 thermocouples.

Beams (examples referenced to Figure 3):

— upon unexposed upper surface of the concrete - 2 thermocouples;

— upon exposed lower surface of the concrete - 3 thermocouples, one in each of areas X, Y and Z (e.g. thermocouple 2);

— upon exposed lateral surfaces of the concrete - 6 thermocouples, two in each of areas X, Y and Z (e.g. thermocouples 1 and 3);

— upon lower stirrup bars - 3 thermocouples, one in each of areas X, Y and Z (e.g. thermocouple 5);

— upon lateral stirrup bars - 6 thermocouples, two in each of areas X, Y and Z (e.g. thermocouples 4 and 6);

— upon lower reinforcement : 6 thermocouples, two in each of areas X, Y and Z (e.g. thermocouples 7 and 8);

— within the concrete at beam top - 3 thermocouples, one in each of areas X, Y and Z (e.g. thermocouple 9);

— within the concrete at beam centre - 3 thermocouples, one in each of areas X, Y and Z (e.g. thermocouple 10);

— within the concrete at beam lower quadrant - 6 thermocouples, two in each of areas X, Y and Z (e.g. thermocouples 11 and 12).

9.4 Instrumentation for the measurement of pressure

Equipment for measuring pressure within the furnace shall be provided, located and used as specified in EN 1363-1.

9.5 Instrumentation for the measurement of deformation

A suitable means of measuring the vertical deformation at mid-span and at each of the loading lines relative to the supports shall be provided, located and used as specified in EN 1363-1 for loaded concrete slabs and beams.

9.6 Instrumentation for the measurement of applied load

Instrumentation for the measurement of the load applied to large concrete slabs and beams shall be provided and used as specified in EN 1363-1.

10 Test procedure

10.1 General

Carry out checks for thermocouple consistency and establish data points for temperature as specified in EN 1363-1 before commencement of the test and the procedures defined in 10.2 to 10.7.

10.2 Furnace temperature and pressure

Measure and record the furnace temperature using the thermocouples defined in 9.2 and the furnace pressure in accordance with the procedures and frequency specified in EN 1363-1.

Control the furnace temperature according to the data received from the furnace temperature measurement thermocouples to the criteria of EN 1363-1.

Control the furnace pressure to the criteria of EN 1363-1.

10.3 Application and control of load

Using the procedures of EN 1363-1 apply a constant load to the slab or beam test specimen, of magnitude in accordance with 5.3, throughout the test period until a deformation of $^{L_{sup}}/_{30}$ is reached, or when the rate of deflection exceeds that given in EN 1363-1. at which point the load shall be removed.

Hangers, when used to avoid collapse of the test specimen, shall not influence the deflection when the load is removed.

10.4 Temperature of test specimen

Measure and record the temperature of the test specimen upon the exposed and unexposed surfaces of the concrete and within the concrete, using the thermocouples specified in 9.3 at intervals not exceeding 1 minute.

10.5 Deformation

Using the procedures of EN 1363-1, for the loaded slab or beam test specimens, identify an initial deformation datum point, relative to the supports, before application of the load. Then apply the test load and measure the zero point for deformation after applying the load and before commencement of heating. Monitor the deformation and rate of change of deformation continuously throughout the test. Record the results according to EN 1363-1.

10.6 Observations

Wherever practical, monitor the general behaviour of the test specimen, especially the protective material, throughout the test and record the occurrence of cracking, fissuring, deterioration, delamination or similar behaviour as described in EN 1363-1 and also spalling of concrete, if so.

10.7 Termination of test

All tests should provide thermal data up to the maximum temperature required for the scope of the assessment.

When the load has been removed it shall be necessary to continue the test until the mean temperature recorded on reinforcement bars exceeds the design steel temperature (e.g. 550 °C for beams and 650 °C for slabs), or the duration of the test exceeds the maximum time period agreed with the sponsor (with a maximum of 6 h).

Otherwise terminate the test when one or more of the reasons for termination which are specified in EN 1363-1 occur.

11 Test results

11.1 Acceptability of test results

It is possible that within any test apparently erroneous results may occur through failure of thermocouples, incorrect assembly of the test specimen, etc. If any results are to be disregarded, i.e. become invalid, the laboratory, in consultation with the sponsor, shall justify this and apply the following rules:

Slabs:

— upon unexposed upper surface of the concrete – at least 4 of the 5 thermocouples;

— upon exposed lower surface of the concrete – at least 10 of 13 thermocouples;

— upon longitudinal reinforcement bars – at least 3 of 5 thermocouples;

— within concrete at each of 4 depths (small slab only) – at least 2 of 3 thermocouples;

— within concrete at each of 5 depths (large slab only) – at least 2 of 3 thermocouples.

Beams (examples referenced to Figure 3):

— upon unexposed upper surface of the concrete – both thermocouples;

— upon exposed lower surface of the concrete – at least 2 of 3 thermocouples, one in each of areas X, Y and Z (e.g. thermocouple 2);

— upon exposed lateral surfaces of the concrete – at least 4 of 6 thermocouples, two in each of areas X, Y and Z (e.g. thermocouples 1 and 3);

— upon lower stirrup bars – at least 2 of 3 thermocouples, one in each of areas X, Y and Z (e.g. thermocouple 5);

— upon lateral stirrup bars – at least 4 of 6 thermocouples, two in each of areas X, Y and Z (e.g. thermocouples 4 and 6);

— upon lower reinforcement – at least 4 of 6 thermocouples, two in each of areas X, Y and Z (e.g. thermocouples 7 and 8);

— within the concrete at beam top – at least 2 of 3 thermocouples, one in each of areas X, Y and Z (e.g. thermocouple 9);

— within the concrete at beam centre – at least 2 of 3 thermocouples, one in each of areas X, Y and Z (e.g. thermocouple 10);

— within the concrete at beam lower quadrant – at least 4 of 6 thermocouples, two in each of areas X, Y and Z (e.g. thermocouples 11 and 12).

11.2 Presentation of test results

The following shall be reported within the test report:

a) the results of measured dimensions and actual material properties, especially the properties of the concrete and the thickness, density and moisture content of the fire protection together with those values to be used in the assessment, according to 6.5;

b) the individual results of all furnace temperature measurements and the mean of all individual furnace temperature measurements, taken as specified in EN 1363-1, graphically presented and compared with the specified requirements and tolerances given in EN 1363-1;

c) the individual results of all furnace pressure measurements and the mean of all individual furnace pressure measurements, taken as specified in EN 1363-1, graphically presented and compared with the specified requirements and tolerances given in EN 1363-1;

d) the individual results and the mean of all individual results of all temperature measurement thermocouples at equivalent locations given in 9.3.4, all graphically presented. Evidence of compliance with the validity criteria of 11.1;

e) the individual results and the mean of all individual results of all the deformation measurements, specified in 10.5, all graphically presented. If the load is removed according to 10.3 the time at which this occurred;

f) observations made and the times at which they occur shall be reported.

These results (b to e) may be presented as a selection of the measured data sufficient to give a history of the performance of the test specimen according to EN 1363-1.

These results may also be prepared and printed in tabular form and/or presented upon computer media. In the latter case this shall be prepared in an appropriate, secure "read only" format to prevent alteration. Only data maintained in the laboratory files shall be used in the assessment

12 Test report

The test report shall include the following statement:

"This report provides the constructional details, the test conditions, the results obtained and the interpolated data obtained when a specific form of construction together with a specific fire protection system was tested following the procedures of EN 13381-3. Any deviation with respect to thickness and density of fire protection, concrete and reinforcing steel type and geometry could invalidate the test result".

In addition to the items required by EN 1363-1, the following shall also be included in the test report:

a) the generic description and accurate details of the fire protection system;

b) full details of the test specimens including application method;

c) description of the fabrication of the concrete member, any surface preparation or treatment, including releasing oils, etc., used during its fabrication. Description of the preparation and conditioning of the concrete according to 6.5.2. Description of the conditioning of the test construction and its installation onto the test furnace;

d) the results of the measurements obtained in 11.2 a) to e) during the tests presented in graphical format (and any other optional format), as required in 11.2;

e) if possible a description of significant behaviour of the test specimen observed during the test period, including observations of the time(s) and magnitude of any detachment of fire protection material;

f) the magnitude of the load applied to each test specimen, as a function of time, and if removed (loaded beams and columns), the time at which this occurred;

g) the reason, on the basis of 10.7 of this test method, for the termination of the test and the time elapsed when the test was terminated;

h) the results of any other testing carried out such as the smouldering fire (slow heating curve) test as described in Annex A should be reported separately;

i) details of the calculations used to determine the test load;

j) a statement of the validity of the test results according to the principles of 11.1.

13 Assessment

13.1 General

The assessment method details the means whereby the results of temperature measurement and observations made throughout the test are used to provide the following:

a) the relationship between concrete temperature, time and thickness of fire protection;

b) the equivalent thickness of concrete, related to thermal insulation criteria;

c) information on stickability and exposure time.

The data obtained by continuing the test after removal of the load can only be used for the assessment of non-loadbearing floors or non-loadbearing walls.

From the temperature data collected and reported in 11.2 and Clause 12, the following shall be identified:

— the graphs of the mean of all individual temperatures for each thermocouple group at equivalent location defined in 11.2 d);

— the graphs of the individual thermocouples giving rise to the highest individual temperature for each thermocouple group at equivalent location defined in 11.2 d).the graphs or tables of the characteristic temperatures for each thermocouple group at equivalent location defined in 11.2 d) calculated according to 3.1.14.

These results shall be used as the characteristic temperature in the assessment under 13.2 and 13.3.

13.2 Concrete slabs

For each thickness of fire protection system tested, profiles of measured characteristic temperature vs. depth in concrete upon or within the concrete slab test member shall be plotted at thirty minute intervals, for each thermocouple group at equivalent location as defined in 11.2 d), as shown in Figure 5. These profiles are obtained by connecting the concrete depth – versus – critical temperature points with straight lines.

Alternatively, exposed and unexposed surface characteristic temperatures and internal concrete characteristic temperatures may be plotted on the same diagram, joined by interpolating curves to give a characteristic temperature profile throughout the test specimen at any time. Characteristic Temperature profiles on reinforcing bars shall be plotted separately in this case.

The value used for depth shall be the distance of the thermocouple from the surface of the concrete slab, beneath the fire protection material.

From this information the depth d_θ at which a series of limiting temperatures, $\theta_{crit,}$ of 300 °C, 350 °C, 400 °C, 450 °C, 500 °C, 550 °C, 600 °C and 650 °C is observed, shall be recorded at 30 min intervals.

The values of d_θ shall be plotted on a graph against the thickness of fire protection system to give a relationship of time period for a given critical temperature in steps of 50 °C .

The plotted results shall be joined with a straight line as shown in Figure 6.

Alternatively, the values of d_θ can be plotted on a graph against the critical / limiting temperature to give a relationship of thickness of fire protection for a given time period in steps of thirty minutes.

The plotted results shall be joined with a straight line.

13.3 Concrete beams

For each thickness of fire protection system tested, profiles of measured characteristic temperature vs. depth upon or in the concrete beam test member shall be plotted at thirty minute intervals, as shown in Figure 5, along the diagonal axis and sets of thermocouples (equivalents between brackets).

— Diagonal axis comprising thermocouples (7 and 8), (12 and 11), (10) (see Figure 3).

Alternatively, temperatures on the above diagonal axis may be plotted on the same diagram, joined by interpolating curves, to give a temperature profile throughout the test specimen at any time. Temperature profiles on reinforcing bars shall be plotted separately in this case.

The value of depth used shall be the distance, along the depth axis, of the thermocouple from the exposed surface of the concrete beam, beneath the fire protection material.

From this information the depth d_θ at which a series of limiting temperatures, $\theta_{crit,}$ of 300 °C, 350 °C, 400 °C, 450 °C, 500 °C, 550 °C, 600 °C and 650 °C is observed, shall be recorded at 30 min intervals.

The values of d_θ shall be plotted on a graph against the thickness of fire protection system to give a relationship of time period for a given critical temperature in steps of 50 °C .

The plotted results shall be joined with a straight line as shown in Figure 6.

The values of d_θ shall be plotted on a graph against the critical / limiting temperature to give a relationship of thickness of fire protection for a given time period in steps of thirty minutes.

The plotted results shall be joined with a straight line as shown in Figure 6.

13.4 Insulation

The assessment for insulation shall be carried out according to EN 1363-1.

13.5 Stickability

a) Assess the time when, or if, the maximum temperature recorded on the exposed surface of the concrete (after reaching 200 °C) is more than 50 % above the mean value of all temperatures recorded on the surface:

   1) for a transient period (and then returns to normal);

   2) continuously, for the remainder of the test.

b) Assess the time when, or if, significant detachment (area > 0,25 m²) of the fire protection system occurs from the recorded observations.

The occurrence of a combination of a) 2) or b) shall be assessed as loss of stickability.

13.6 Equivalent thickness of concrete

The procedures for the determination of the equivalent thickness of concrete slabs and beams are given in Annex C.

14 Report of the assessment

The report of the assessment shall include the following:

a) the name and address of the body providing the assessment and the date it was carried out.

   Reference to the name and address of the test laboratory, the unique test reference number(s) and report number(s);

b) the name(s) and address(es) of the sponsor(s). The name of the manufacturer of the product or products and the manufacturer or manufacturers of the test construction;

c) the generic description of the product or products, particularly the fire protection system and any component parts (where known). If unknown this shall be stated;

d) general description of the fabrication of the concrete member, any surface preparation or treatment, including releasing oils, etc., used during its fabrication. General description of the fixing details of the fire protection system. General description of the conditioning of the test construction and the installation of the test construction onto the furnace;

e) general description of the test specimen with drawings, including the dimensions of the test specimen and photographs and written instructions, provided by the sponsor;

f) the composition and measured properties, especially density, thickness and moisture content, of components of the test specimen which are required to be determined and their method of determination;

g) graphs or tables of characteristic temperature derived according to 13.1.

h) results of influence on loadbearing capacity derived in accordance with 13.2 and 13.3:

1) the characteristic temperature vs. depth upon or within the concrete slab or beam test member plotted at thirty minute intervals;

2) the depth d_θ upon or within the concrete slab or beam (test member at which limiting temperatures, $\theta_{crit,}$ of 300, 350, 400, 450, 500, 550, 600 and 650 °C were calculated by linear interpolation at 30 min intervals using the data indicated in i) as shown in Figures 5 and 6 (introduce an example of table instead); this depth has to be the location of the bottom line of the reinforcement bar for the slab and the location of the bottom line of the reinforcement bar on the diagonal for the beam.

i) a statement on insulation performance according to the criteria of 13.4 [EN 1363-1];

j) a statement on stickability and the time at which any significant detachment of the fire protection system occurred, according to the criteria of 13.5;

k) the results of the measurement and determination of equivalent thickness of concrete versus fire protection thickness and measured temperature (test duration) for slabs and beams according to Annex C.

15 Limits of applicability of the results of the assessment

15.1 The results of the assessment from the fire protection system tested in horizontal orientation on concrete slabs are applicable, to all concrete slabs and walls with fire exposure from one side only, in both horizontal and vertical orientation.

The results of the assessment from the fire protection system tested in horizontal orientation on concrete beams are applicable, as tested, to all beams and columns exposed to fire from more than one side, in use in both horizontal and vertical orientation provided that:

a) the method of fixing and application is the same as that tested;

b) the influence of fire from more than one side on temperature distribution has been calculated according to EN 1992-1-2 and considered within the assessment;

c) if there was a cavity between the structural member and the protection product, the cavity height can not be reduced. The fire protection capacity of the horizontal protective membrane can be nullified by the presence of combustible materials in the cavity above the membrane. The applicability of the results of the assessment is limited according to the quantity and position of such combustible materials within that cavity during the fire test. The amount of combustible material permissible in the cavity is given in national regulations.

15.2 The results of the assessment are applicable to concrete members in which the density is within the range 0,85 to 1,15 times that tested.

15.3 The results of the assessment are applicable to concrete members in which the concrete strength is equal to or one strength grade higher than that tested according to EN 206. When a small slab loaded according to Table 1 and made of higher strength class of concrete is tested with a specific thickness of protection and no spalling occurs, the result of the assessment is applicable to concrete members with a strength class of concrete up to the highest strength class that is tested within the small slab. In this case, the range of applicable thicknesses of protective product is restricted from specific thickness tested as requested by the sponsor (see 6.1.2) to the maximum thickness covered by the assessment.

15.4 The results are applicable to pre-stressed structures provided that rules indicated in EN 1992-1-2 are respected.

15.5 Where the concrete test specimen is prepared with siliceous aggregates, the results of the assessment are applicable to concretes made with any type of aggregate. If the test specimen is prepared with non-siliceous aggregates, the results of the assessment are limited to concretes made with the type of aggregate tested.

15.6 The results of the assessment for beams are applicable to all concrete beams with a equal or higher width as that tested and with a equal or higher height as that tested. It is possible to decrease the height provided the section surface remains the same or is higher, by increasing the width.

15.7 The results of the assessment are only applicable to fire protection systems where the fixing and jointing systems are the same as that tested.

15.8 The results of the assessment from a test using a single layer fire protection system are applicable only to single layer fire protection systems.

The results of the assessment from testing a double or multi-layer fire protection material are applicable to that material in a double or multi-layer format, provided that the number of layers is not greater than tested and the composition of layers is unchanged.

15.9 The maximum permitted thickness of the total protection: up to 5% above the maximum thickness tested on a loaded element.

The minimum permitted thickness of the total protection: up to 5% below the minimum thickness tested on a loaded element.

If only one thickness of protection system was tested, the results of assessment are applicable only to this thickness.

15.10 The results of the assessment from testing sprayed fire protection systems applied with lathing or wire mesh secured to the concrete slab are only applicable to members incorporating the same type of lathing or wire mesh.

15.11 The results of the assessment from testing sprayed fire protection systems, with or without lathing or other mechanical fixing aids and with or without the use of adhesive bond promoters, are only applicable to members in which the fire protection material, mechanical fixing aids (if used) and the adhesive bond promoter (if used) are the same as that tested.

15.12 The results of the assessment from testing sprayed materials or glued materials applied to concrete surfaces where release from the mould has been facilitated using soluble oil or soluble emulsions, are valid for all types of soluble oil or soluble emulsion release agents.

Where the test results were obtained using wax, non-soluble oil or non-soluble emulsion release agents, or other materials to release the concrete from the mould, the result shall be restricted to that tested.

If the fire protection material is to be applied only to surfaces which have been cleaned completely by sand blasting then the result is valid for all types of soluble and insoluble oil or emulsion release agents, providing sand blasting is applied.

16 Additional limits of applicability of the results of the assessment for suspended ceilings used as protection system

16.1 Height of the cavity

Fire resistance obtained by direct application shall be applicable to cavities with equal or greater height than that tested.

16.2 Exposed width of test specimen

Where the exposed width in the test is less than 3 000 mm the results shall not be applicable to structures of width greater than that tested.

16.3 Properties of the horizontal protective membrane

The result of the assessment is only applicable to the horizontal protective membrane construction tested and at the density and thickness tested ±5%.

Components of supporting steel frame and installation conditions shall be the same as those tested.

16.4 Size of panels within the horizontal protective membrane

Where panels are produced in a range of sizes and if the minimum and maximum sizes are tested, in separate tests, then the results giving the lowest values are directly applicable to all intermediate sizes.

16.5 Fixtures and fittings

If the test was performed without fittings and fixtures, the result is not applicable to membranes with fittings and fixtures. A separate test including the fixtures and fittings as defined in 6.2 shall be required. Fixtures and fittings at intermediate spacings may be directly applied as a result of this additional test.

Test results on membranes containing fittings and fixtures with their own suspension devices may be applied to membranes containing such suspension devices provided the distribution does not exceed those tested.

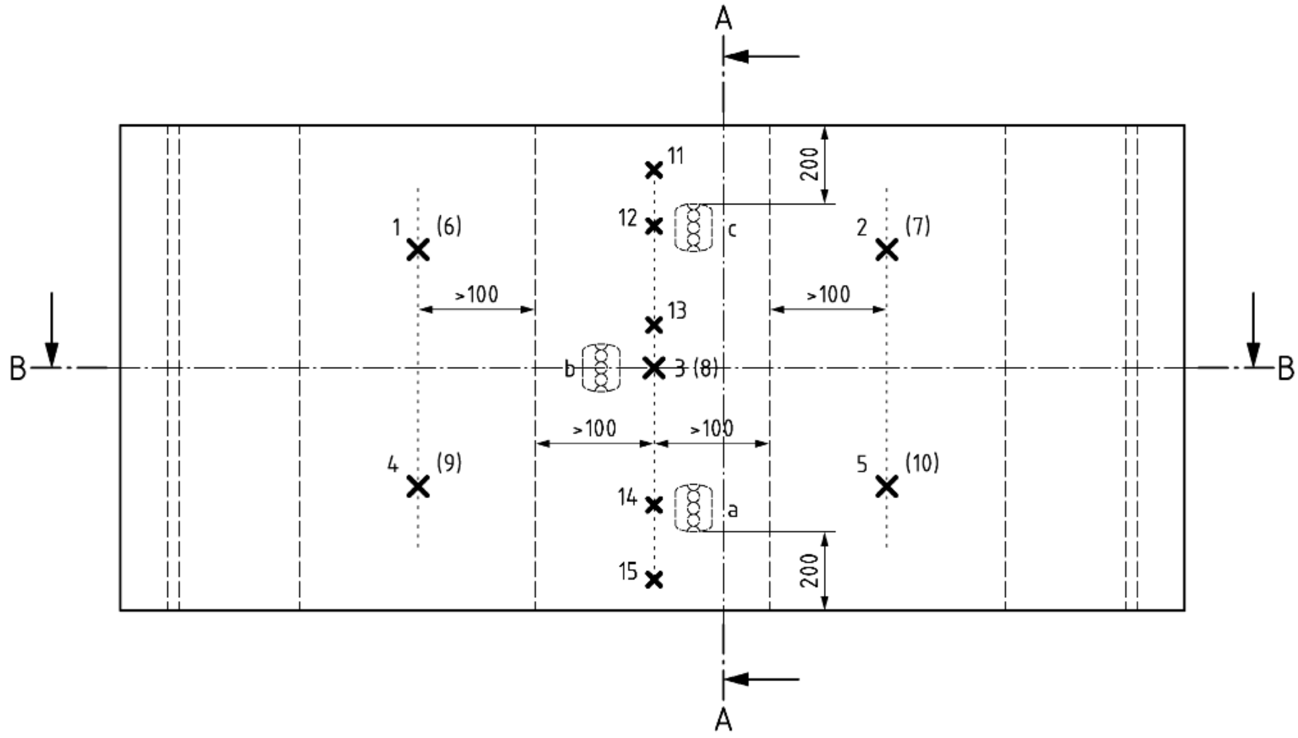
The total area occupied by fixtures and fittings related to the area of the membrane lining is not increased and the maximum tested opening area is the lining is not exceeded.

If the test was performed with fittings and fixtures, the result is not applicable to membranes without fittings and fixtures

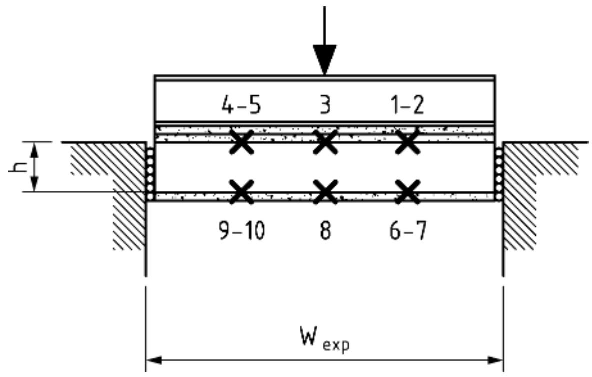
16.6 Gaps between grid members and test frame or walls

Test results obtained with no expansion gap between grid members and the test frame or furnace walls shall be applicable to practical situations where such gaps are used, providing these are no greater than 5 mm in size.

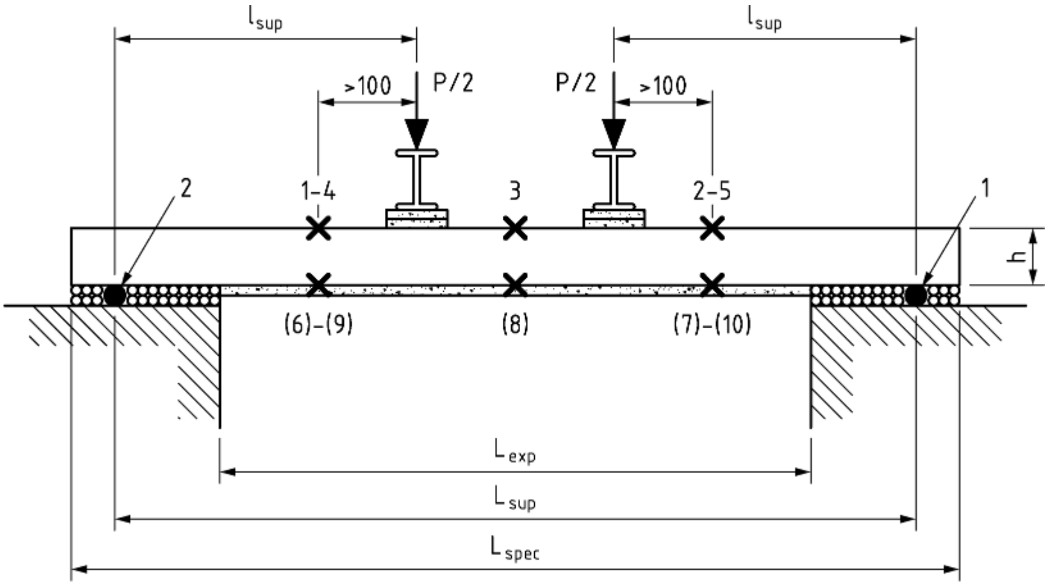
Dimensions in millimetres



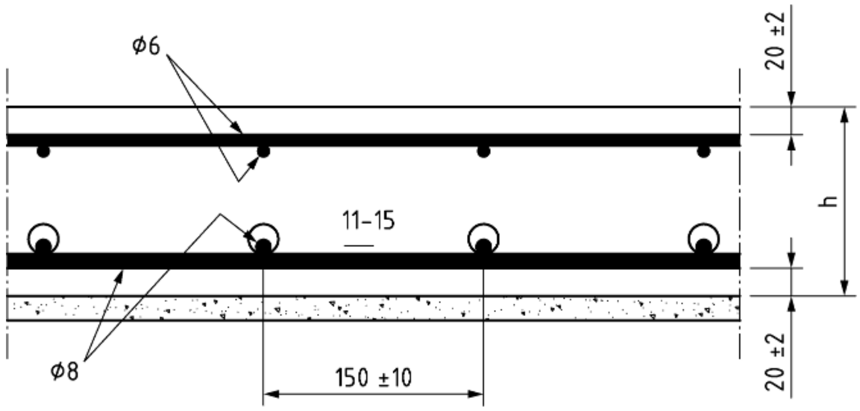
a) Horizontal view



b) Cross section A-A



c) Cross section B-B



d) Location of the reinforcement bars

Key

1 roller support

2 hinge support

X 10 thermocouples on concrete face

a b c thermocouples grids with 5 thermocouples, see Figure 4

11-15 thermocouples on reinforcement bars

1 300 mm ≤ L_{exp} ≤ 2 300 mm

1 000 mm ≤ W_{exp} ≤ 2 000 mm

1 500 mm ≤ L_{sup} ≤ 2 700 mm(L_{exp} + 200) mm ≤ L_{sup} ≤ (L_{exp}+ 400) mm

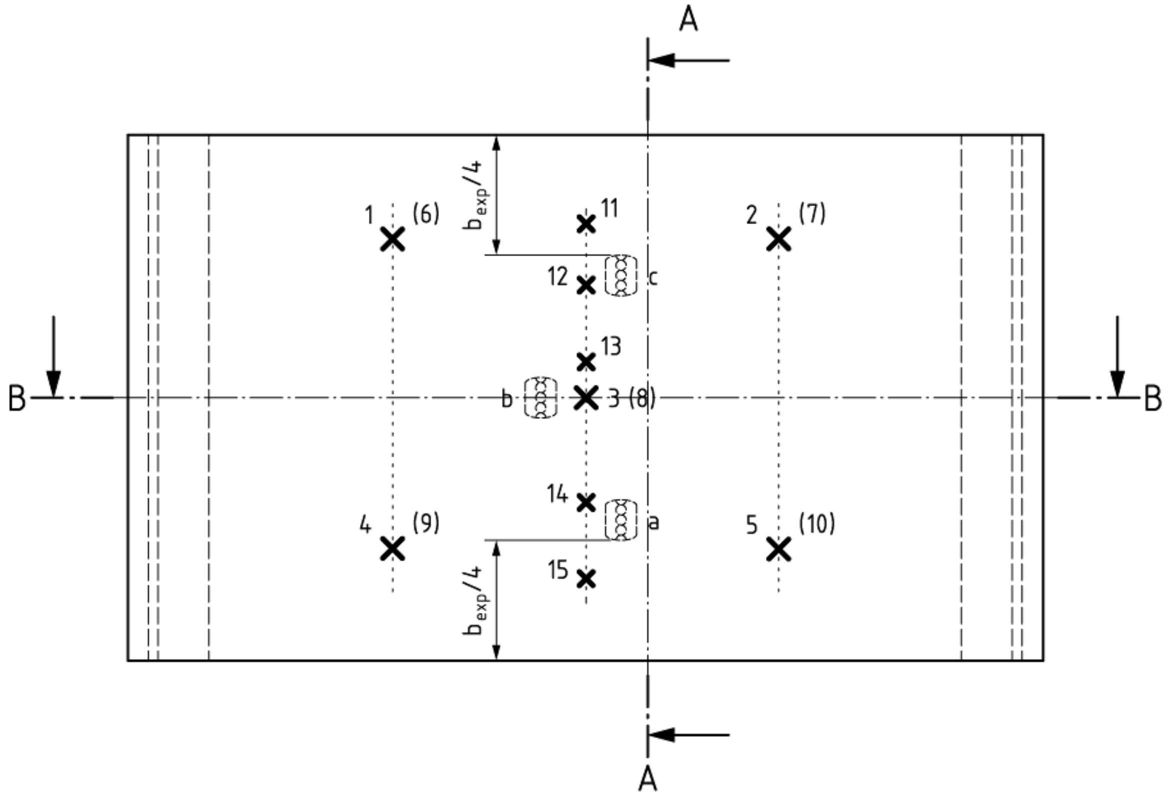
(L_{exp} + 400) mm ≥L_{spec} ≤ (L_{exp} + 700) mm

l_{sup} = (600 ± 10) mm

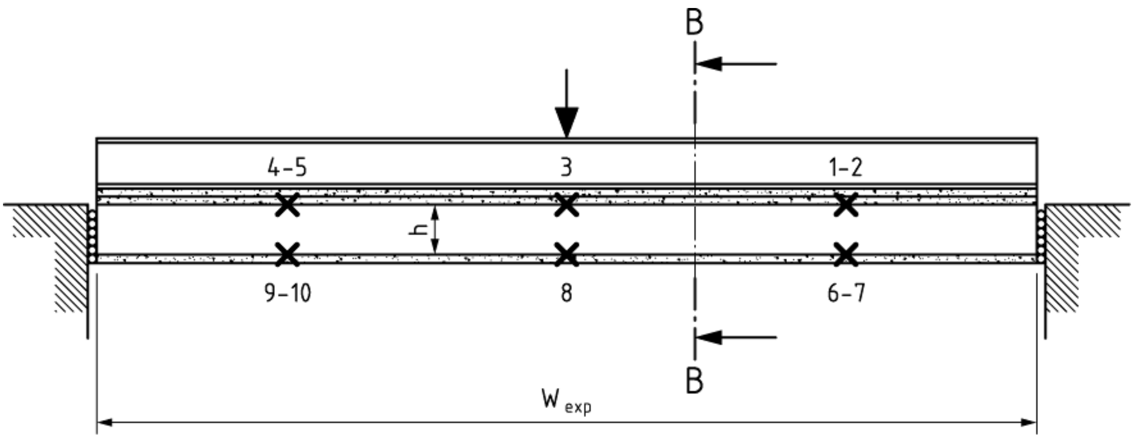
h = (140 - 20/+10) mm

Figure 1 — Construction of small slab test specimen

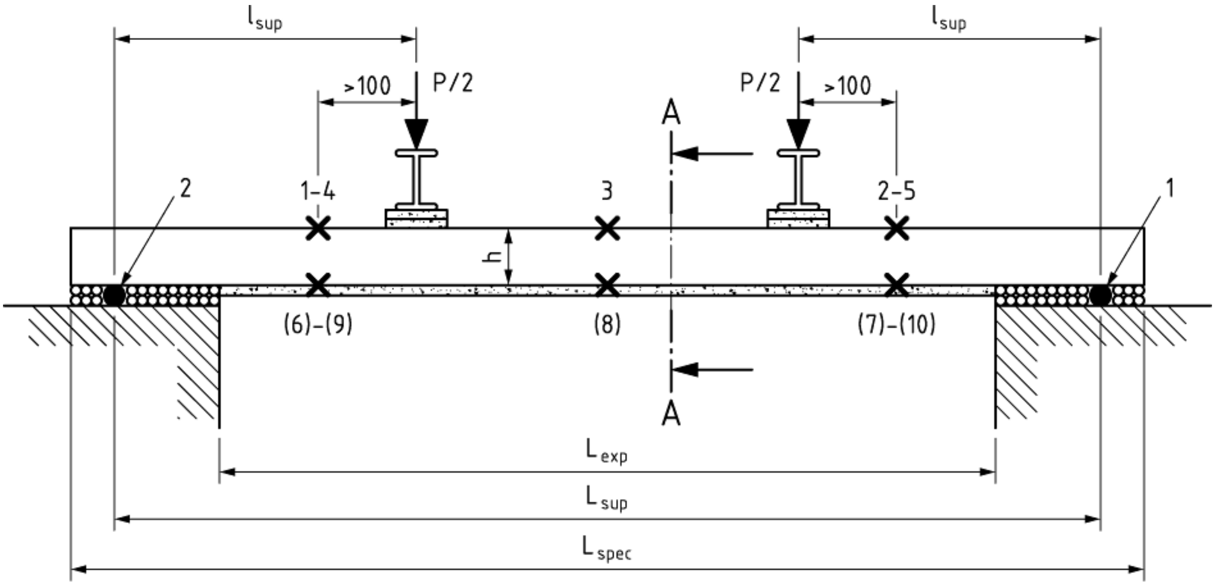
Dimensions in millimetres



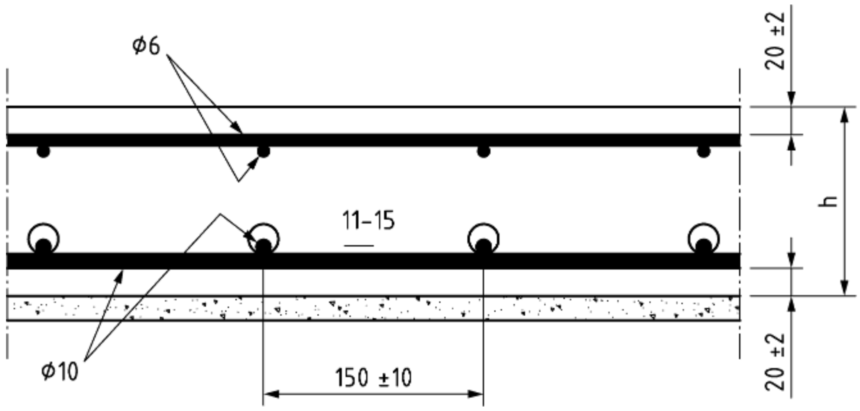
a) Horizontal view



b) Cross section A-A



c) Cross section B-B



d) Location of the reinforcement bars

Key

1 roller support

2 hinge support

X 10 thermocouples on concrete face

a b c thermocouples grids with 5 thermocouples, see Figure 4

11-15 thermocouples on reinforcement bars

L_{sup} ≥ 4 200 mm

L_{exp} ≥ 4 000 mm

W_{exp} ≥ 3 000 mm. refer to 6.2.1 for note

(L_{exp} + 200) mm ≤ L_{sup} ≤ L_{exp} + 500 mm

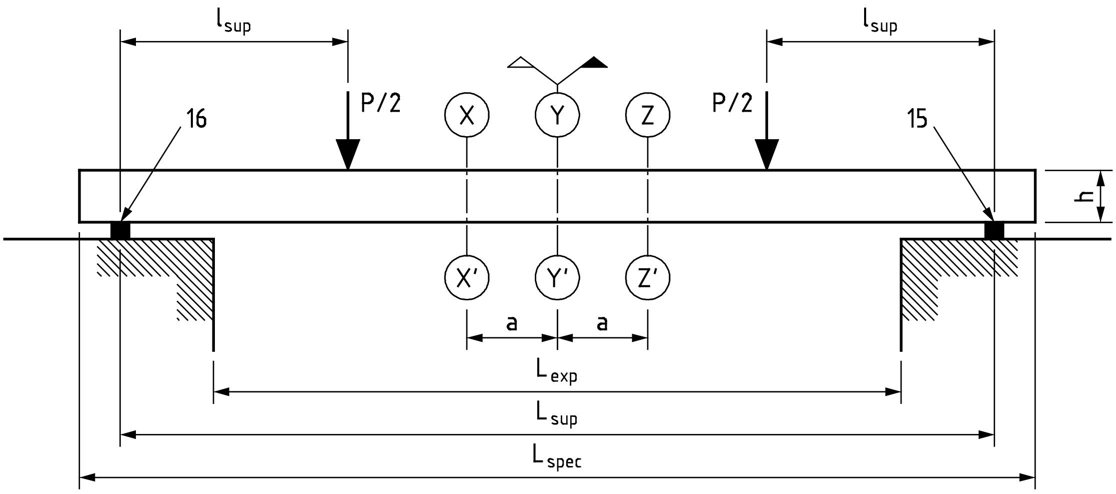
(L_{exp} + 400) mm ≤ L_{spec} ≤ L_{exp} + 700 mm

l_{sup} = (1 000 ± 10) mm

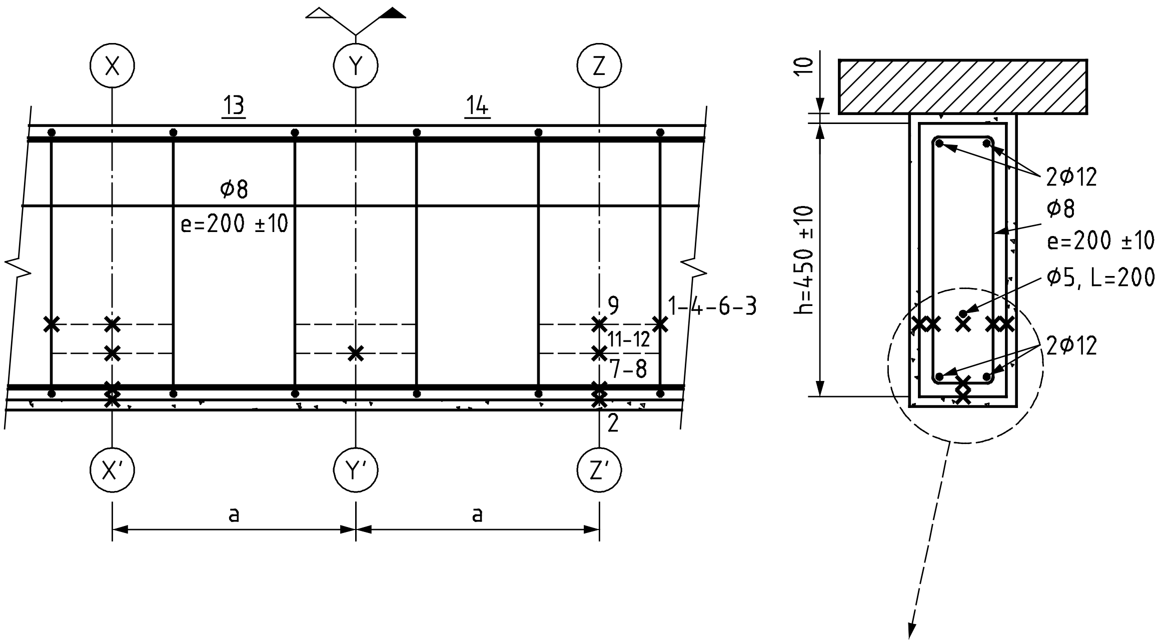
h = (140 -20/+10) mm

Figure 2 — Construction of large slab test specimen

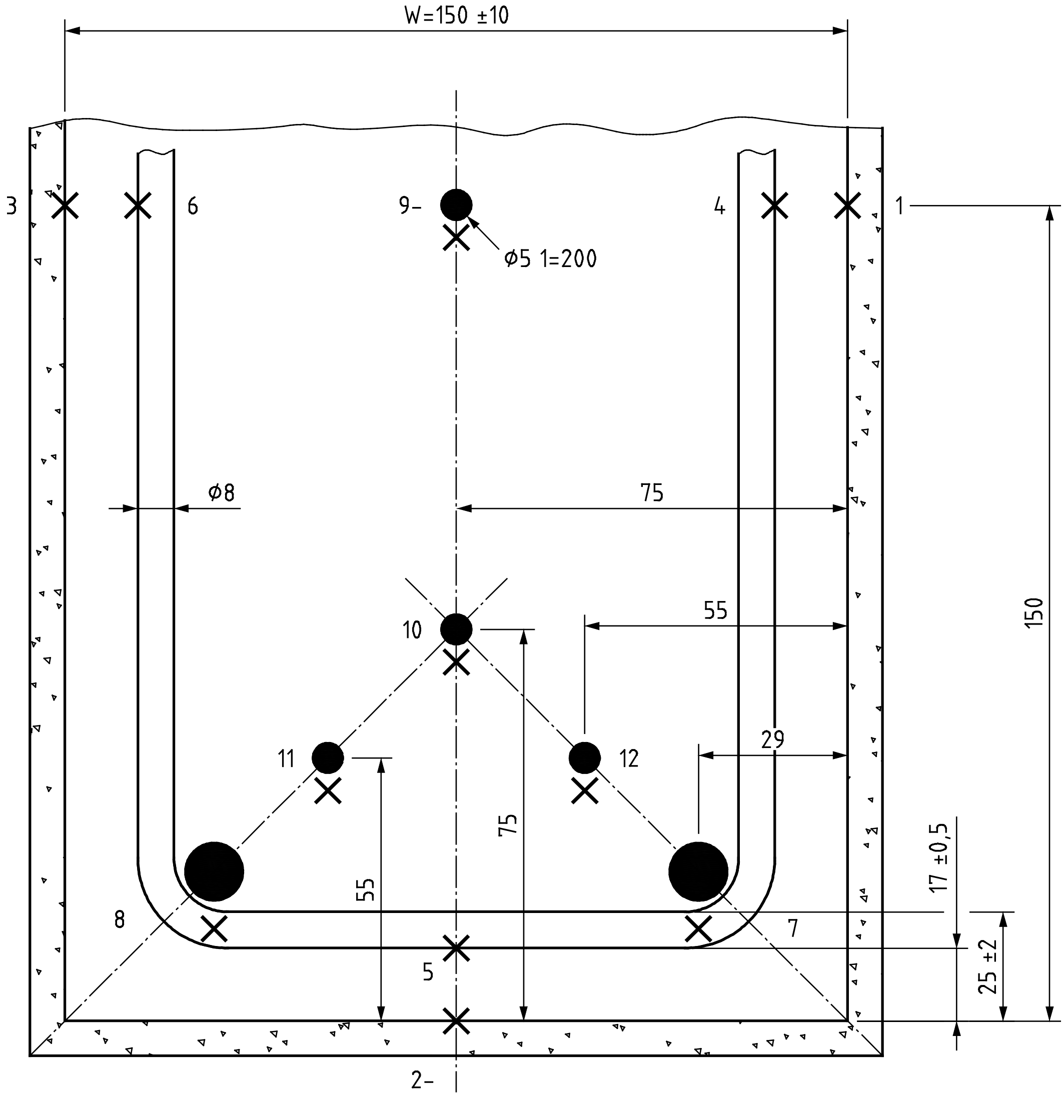
Dimensions in millimetres



a)



b)



c)

Key

1-3 thermocouples on concrete face

4-6 thermocouples on stirrup

7-8 thermocouples on bars

9-12 thermocouples in concrete

13-14 thermocouples on unexposed face

15 roller support

16 hinge support

L_{exp} ≥ 4 000 mm

L_{sup} ≤ (Lexp + 400) mm

L_{spec} ≤ (Lexp + 700) mm

l_{sup} = (1 000 ± 10) mm

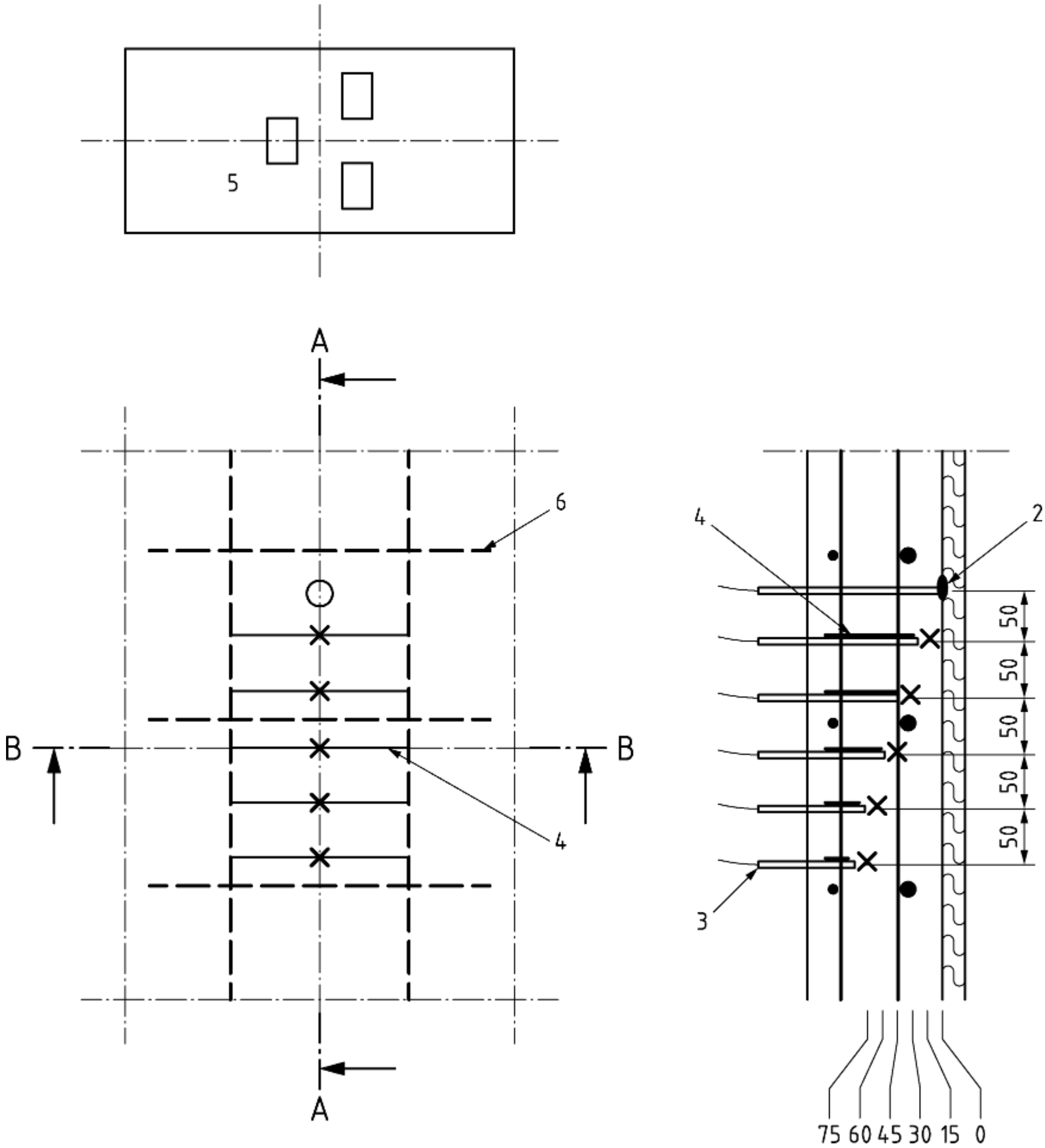
h (beam height) = (450 ± 10) mm

w (beam width) = (150 ± 10) mm

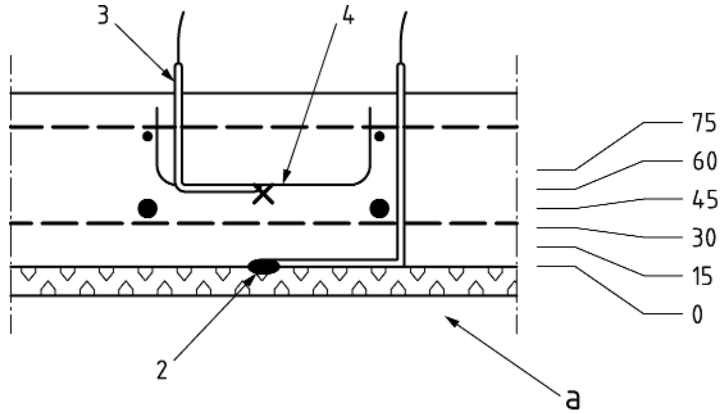
a: (600 ± 100) mm

Figure 3 — Construction of beam test specimen

Dimensions in millimetres



a) Cross section A-A



b) Cross section B-B

Key

1 X = the hot junction of a thermocouple at depth 15, 30, 45, 60 (and 75 mm)

2 ▭ or O = thermocouple fixed to the "exposed" lower surface of the slab

3 thermocouple thread, protected by shrinking tubing

4 steel bar, maximum diameter 5 mm, bent into U-shape and welded to the upper transverse reinforcement bars

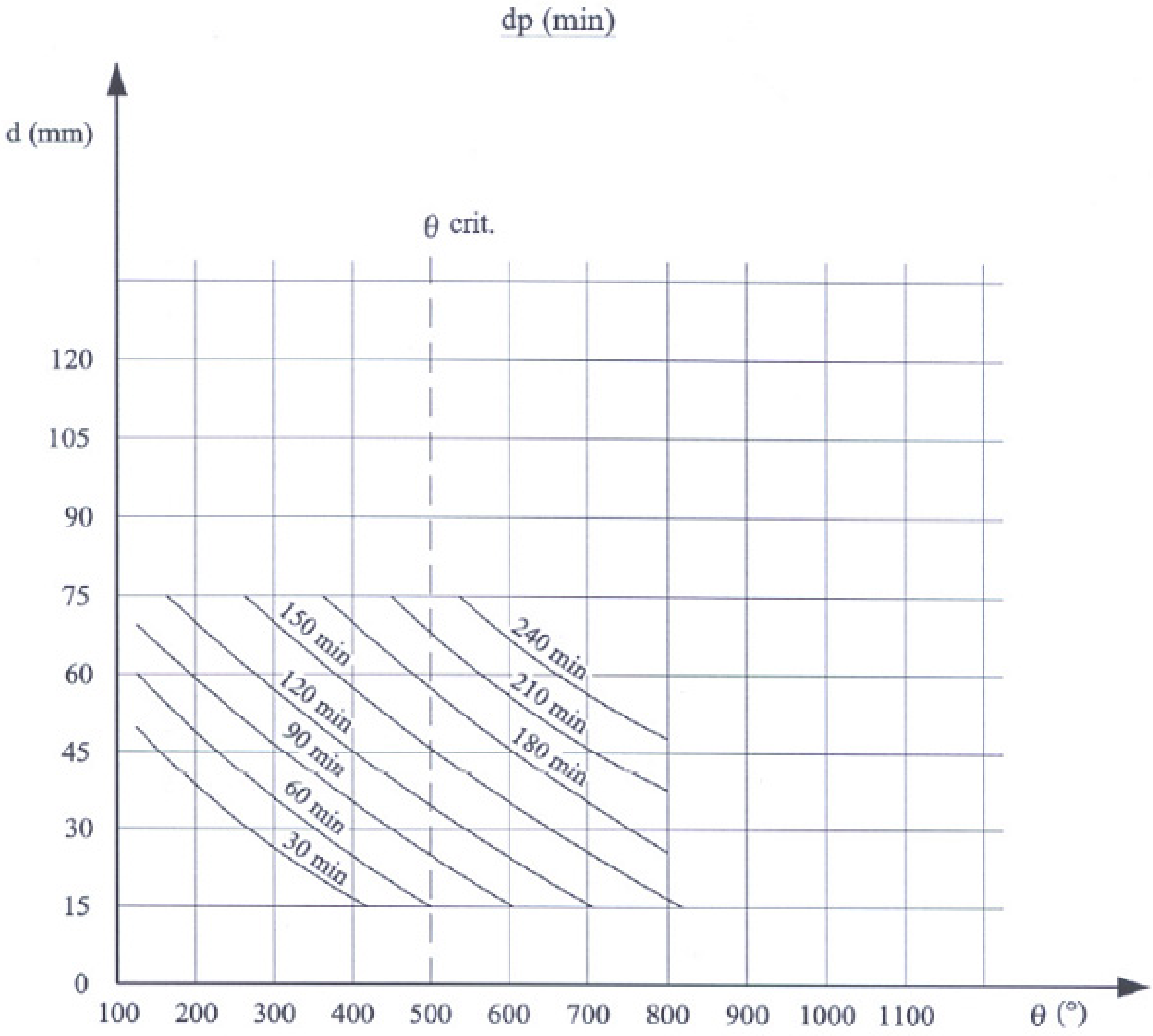
5 concrete slab

6 mesh reinforcement

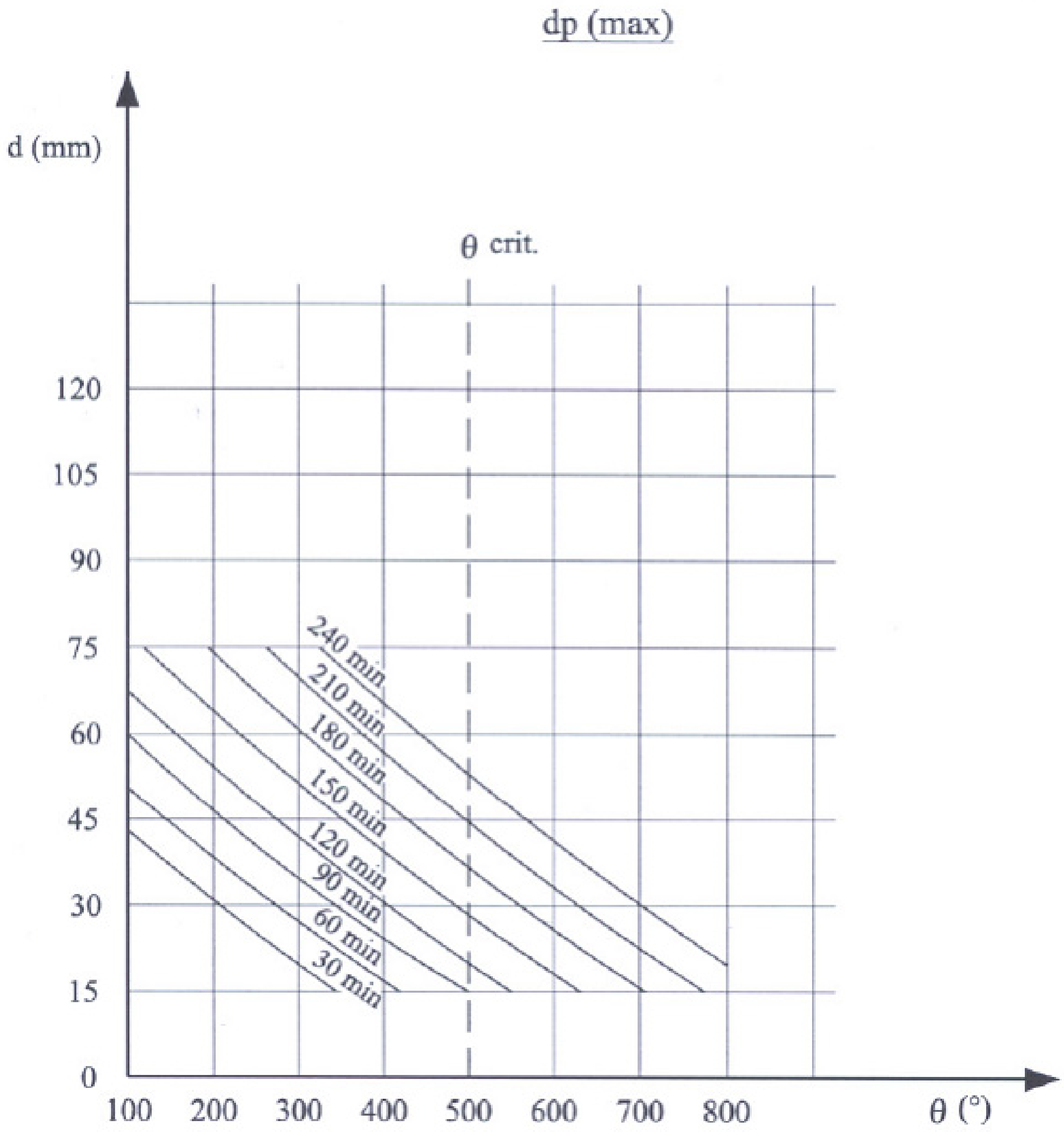
a Note: Only the thermocouple located at depth 45 mm is shown in the figure.

The other ones are mounted in a similar way.

Figure 4 — Thermocouple location and location grids: slab test specimens


dp (min)
d (mm)
θ crit.
120
105
90
75
60
45
30
15
0
100
200
300
400
500
600
700
800
900
1000
1100
θ (°)
150 min
120 min
90 min
60 min
30 min
240 min
210 min
180 min

a)



b)

Figure 5 — Plot of depth in concrete vs. temperature (minimum and maximum fire protection thickness)

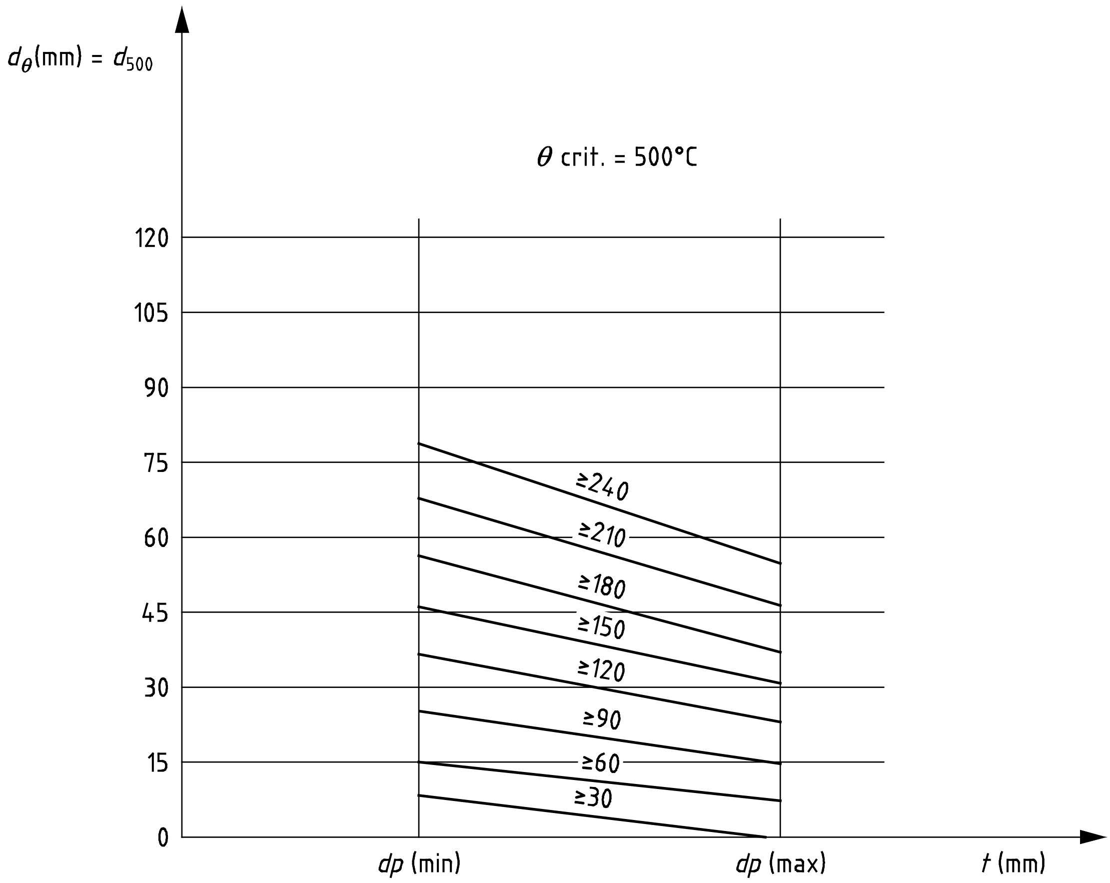
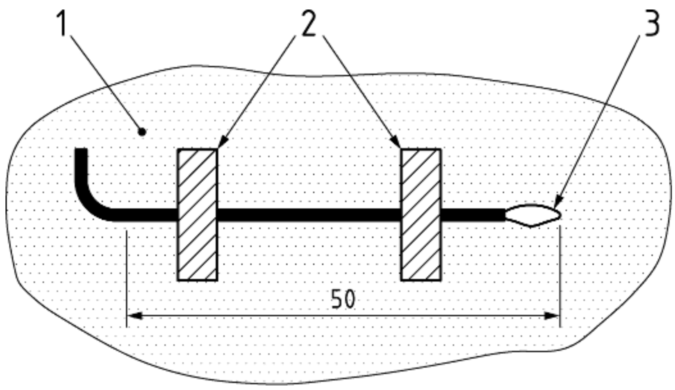
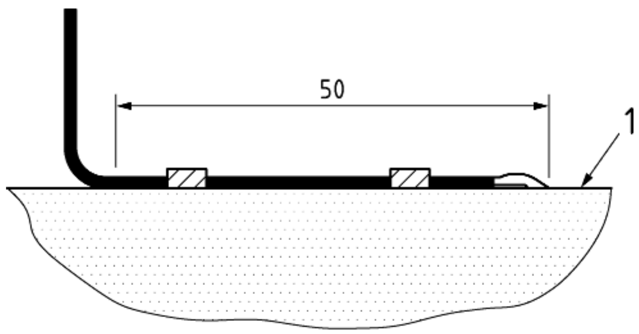


Figure 6 — Plot of fire protection thickness vs. depth d_θ in concrete

Dimensions in millimetres



a) Top view



b) Side view

Key

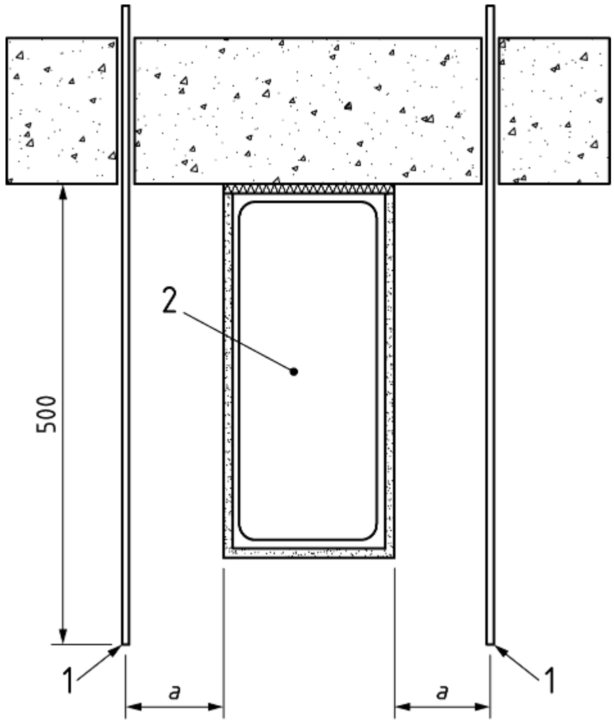
1 mould

2 non-combustible tape, e.g. ceramic tape

3 0,5 mm TC - wire with spot welded hot junction

Figure 7 — Placement of thermocouples at concrete surface

Dimensions in millimetres



Key

1 plate thermocouple

2 concrete beam

a (100 ± 10) mm

Figure 8 — Location of furnace control thermocouples for loaded beams with box protection

Annex A
(normative)

Test method to the smouldering fire or slow heating curve

A.1 Introduction

Fire protection products activated by the heat flux of the fire may be required to be subjected to a test to a smouldering curve (slow heating curve as defined in EN 1363-2), with a rate of temperature increase less than that of the standard temperature / time curve.

NOTE See Council Directive 89/106/EEC, ID No 2: Safety in case of fire, 3.2.4 and 4.3.1.3.4 (b).

This exposure, applicable to reactive fire protection materials, is used only in special circumstances, where it might be expected that the performance of the product when exposed to a smouldering fire might be substantially less than when it is exposed to the standard temperature / time curve, and where such a test is specified in the national building regulations of a Member State of the European Union.

It is not intended to be mandatory for all fire protection materials applied to structural concrete members.

The test is carried out as described in this European Standard and EN 1363-2 where applicable. The test is terminated after 40 min or earlier for reasons given in EN 1363-1.

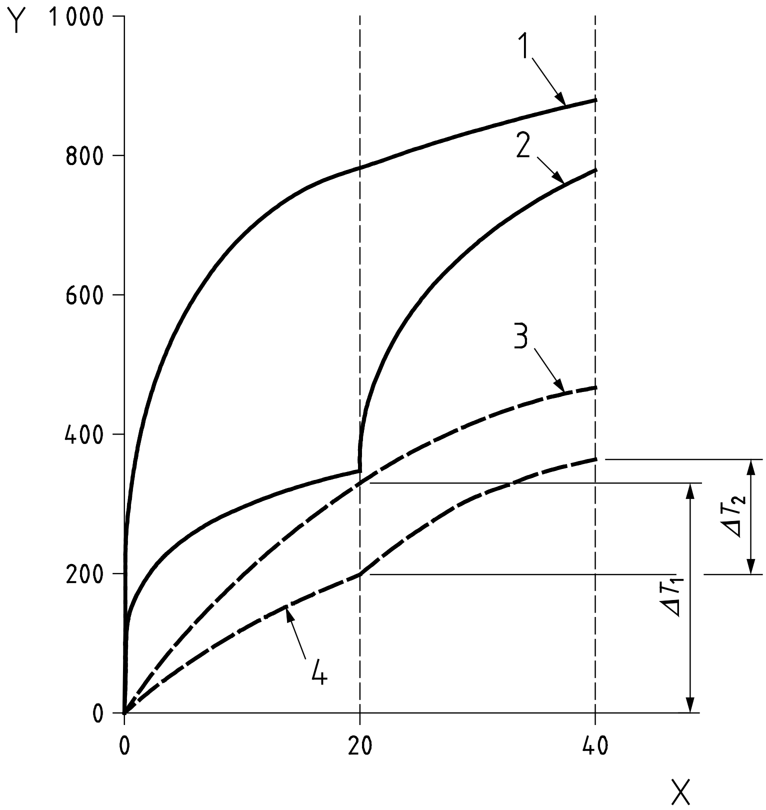
A.2 Evaluation of the results

The characteristic temperature test data obtained for each small slab tested, when subjected to both the standard temperature / time curve (according to the principal test method) and the smouldering curve (this test), shall be compared at each thickness tested, each with the other.

The results from all thermocouples in all comparable locations shall be examined and recorded by tabulation. The results for each comparable location shall be presented graphically, in a manner similar to that given in Figure A.1, and the performance of the fire protection material to the two fire sources compared and recorded.

The values of ΔT_1 and ΔT_2 shall be measured and recorded for all comparable locations.

The results of tests carried out according to the standard temperature / time curve for the particular reactive fire protection material under test shall only be valid and applicable if $\Delta T_1 > \Delta T_2$ in each and every comparable location.



Key

Y temperature (°C)

X time (min)

1 standard temperature/time curve

2 smouldering (slow heating) curve

3 test element temperature to standard temperature/time curve

4 test element temperature to smouldering (slow heating) curve

ΔT_1 temperature rise at a specific location obtained during the test against standard curve fire

ΔT_2 difference between the temperatures obtained during test against the two fire sources

Figure A.1 — Comparison of performance to the standard and smouldering fire curves

Annex B
(normative)

Measurement of properties of fire protection materials

B.1 General

Determination of the thickness, density and moisture content of fire protection materials and other materials used in this fire resistance test is important to the accurate prediction of fire protection performance from the test result. The methods used to establish these properties shall, therefore, be consistent and this annex gives guidance on appropriate procedures to be used.

Any special test samples used to determine thickness, density and moisture content shall be conditioned with the fire test specimen under the conditions described in Clause 8.

Any specific product standard existing for the measurement of such properties shall be followed.

The procedures given in EN 1363-1 shall be followed together with the requirements of B.2 to B.4.

B.2 Thickness of fire protection materials

B.2.1 For board or panel fire protection materials, the nominal thickness of each material shall be measured using suitable gauges or callipers in accordance with EN 12467 or EN 823.

The measurement shall be carried out either on the actual materials during assembly of the test specimen or on a representative special test sample, the minimum linear dimensions of which shall be 300 mm × 300 mm. At least nine measurements shall be made including measurements around the perimeter and over the surface of the material.

The design thickness used in the assessment shall be as described in 6.5.4.

B.2.2 For sprayed passive fire protection materials, the thickness shall be measured using a 1 mm diameter probe or drill, which shall be inserted into the material at each measurement position until the tip of the probe or drill touches the surface of the building element. The probe or drill shall carry a circular steel plate of diameter 50 mm upon it, for accurate determination of the surface level.

The thickness of sprayed or coated passive fire protection material shall be measured in the vicinity between 50 mm to 100 mm away from each of the thermocouples fixed to the surface of the concrete, beneath the applied fire protection system, see 9.3. These locations shall be regarded as the minimum number of thickness measurement points.

For sprayed or coated fire protection materials the design thickness used in the assessment shall be as specified in 6.5.4.

B.2.3 For reactive fire protection coating materials applied to concrete test elements, by spray or coating, the thickness shall be determined by either:

a) Fixing of at least 9 steel plates of size 100 mm × 100 mm and 1 mm thickness to the concrete slab or beam, before the reactive fire protection material is applied. The thickness of the material applied to each of these is measured. These shall not be placed in critical positions with respect to temperature measurement.

b) Interpolation from that measured on a standard steel plate, of size 300 mm × 300 mm, to which the reactive fire protection material is applied at the same time and by the same method as it is applied to the test element. Measurements shall be made at nine points over the steel plate at least, including measurements around the perimeter and over the surface of the material.

   The dry film thickness of reactive fire protection coatings over steel plates (methods a) or b)) shall be measured using an instrument employing either the Electro-magnetic Induction principle or the Eddy Current principle. Reactive fire protection materials applied as coatings typically range from 0,25 mm to 4 mm thickness and the choice of instrument shall be appropriate to the thickness of coating used.

c) Measuring dry film thickness of reactive fire protection materials by interpolation from examination of the wet film applied at the same time and by the same method to a standard steel plate, of size 300 mm × 300 mm, as it is applied to the concrete membrane. Dry film thickness can be measured by:

   1) determining the mass of material applied per unit area and hence applied wet film thickness. Interpolation to dry film thickness using expected mass loss/thickness loss specified by sponsor;

   2) use of wet film thickness combs to give wet film thickness. Interpolation of this using expected thickness loss to dry film thickness.

d) Other verifiable methods proposed by the sponsor.

It is preferable that at least two of the above methods are used for reliability purposes.

For reactive fire protection coatings, the design thickness used in the assessment shall be that defined in 6.5.4.

B.3 Density of applied fire protection materials

B.3.1 General

The density of fire protection material shall be determined from measurements of mass and dimensions using the following:

For board or panel passive fire protection materials, the density may be obtained from values of mass, mean thickness (from nine measurements) and area measured either on the actual materials during assembly or on a representative special test sample, the minimum linear dimensions of which shall be 300 mm × 300 mm. The mass of the board shall be obtained using a balance having an accuracy equivalent to 0,1 % of the total mass of the sample being weighed or 0,1 g (the sample size shall be sufficient such that the minimum sample mass is 100 g) whichever is the greater.

The density of fibrous or compressible fire protection material shall be related to nominal thickness.

B.3.2 For spray applied fire protection materials, the density of the material shall be determined from samples of the material sprayed, from beneath, into two metal trays, horizontally orientated, at the same time as the fire protection system is applied to the concrete test specimen. These two trays shall be of size 300 mm × 300 mm, made from 1 mm thick steel plate. The depth of the trays shall be the same as the design thickness of the spray applied protection.

For each thickness of material two such trays shall be prepared with the material applied to the same thickness as that applied to the concrete. One of these trays is dried to provide a reference for dry density and moisture content. The second tray shall be used to determine the density at the time of test.

The thickness of the specimen within the trays shall be determined at nine points over the surface of the trays according to:

— one at the centre;

— two along each centre to corner axis, equidistant from each other, the centre and the corner.

The mass of the fire protection within the tray shall be obtained using a balance having an accuracy equivalent to 0,1 % of the total mass of the sample being weighed or 0,1 g (the sample size shall be sufficient such that the minimum mass is 100 g) whichever is the greater.

B.3.3 The design density used in the assessment shall in all cases be as defined in 6.5.4.

B.4 Moisture content of applied fire protection materials

B.4.1 The samples and materials used to measure moisture content shall be stored together with and under the same conditions as the test specimens. The measurement of final moisture content shall be made on the day that fire testing takes place.

B.4.2 For board or slab passive fire protection materials, special test samples shall be taken measuring minimum 300 mm x 300 mm and of each thickness of the material used. They shall be weighed and dried in a ventilated oven, using the temperatures and techniques specified in EN 1363-1. The moisture content of the specimen shall be calculated as a percentage of its moisture equilibrium weight.

For gypsum based and similar materials, drying shall take place at (40 ± 5) °C.

Repeated weightings shall be taken until moisture equilibrium or constant mass, (W_2), as defined in EN 1363-1, is reached. The moisture content (W_1 - W_2) of the specimen shall be calculated as a % of its moisture equilibrium or constant mass.

B.4.3 For spray applied passive fire protection materials, the moisture content of the material shall be determined from oven drying of one of the sample trays referred to in B.3.2, for each thickness tested.

They shall be weighed and dried in a ventilated oven, using the temperatures and techniques specified in EN 1363-1. The moisture content of the specimen shall be calculated as a percentage of its moisture equilibrium weight.

Should the product contain, or be based on, gypsum and similar materials, drying shall take place at (40 ± 5) °C.

Annex C
(normative)

Equivalent thickness of concrete

C.1 General

C.1.1 General

Basic data relating to the temperature within an unprotected concrete slab or beam are derived by reference to EN 1992-1-2. The same assessment method is used for determining the equivalent thickness of concrete slabs and beams.

C.1.2 Equivalent thickness of concrete slabs - preliminary data collection

a) The depth in the concrete d_{cc} at which the limiting temperature θ_{CL} is achieved from basic data in an unprotected concrete slab is shown in Figure C.1.

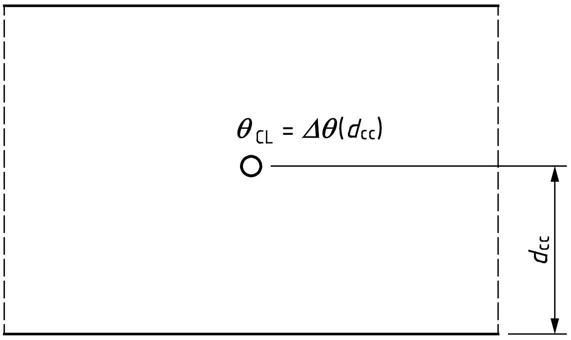


Figure C.1 — Unprotected concrete slab

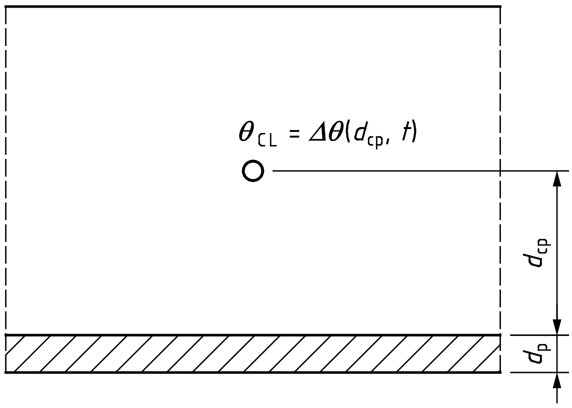


Figure C.2 — Protected concrete slab

b) A thermocouple within a protected concrete slab will at a specified test time t and at a depth d_{cp} within the concrete show a characteristic temperature of $\theta(d_{cp}, t)$ according to Figure C.2. In this test method the thermocouple placed at 15 mm from the exposed surface shall be used to provide data for the determination of equivalent thickness of concrete slabs.

C.1.3 Equivalent thickness of concrete beams - preliminary data collection

a) The depth in the concrete d_{cc}, measured along the axis from the exposed corners of the beam, at which the limiting temperature θ_{CL} is achieved from basic data in an unprotected concrete beam is shown in Figure C.3.

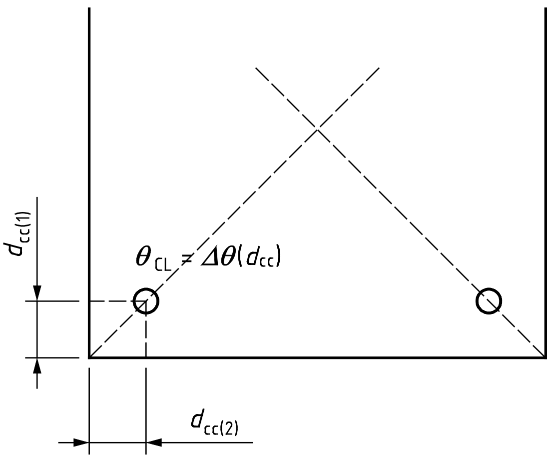


Figure C.3 — Unprotected concrete beam

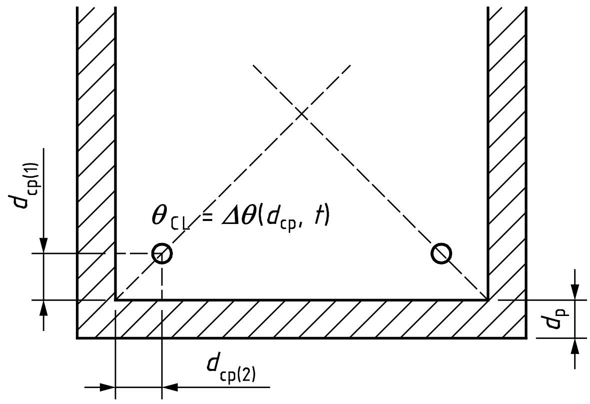


Figure C.4 — Protected concrete beam

b) A thermocouple within a protected concrete beam will at a specified test time t and at a depth d_{cp} within the concrete beam show a characteristic temperature of $\theta(d_{cp}, t)$ according to Figure C.4. In this test method the thermocouple identified as thermocouple 7 or 8 and fixed on reinforcement bars Ø12 (see 9.3.2 and Figure 3) shall be used to provide data for the determination of equivalent thickness of concrete beams.

C.2 Equivalent thickness of concrete slabs and beams - assessment methodology

C.2.1 The graphical presentations shown in Figure C.5 $_{(slabs)}$ and Figure C.6 $_{(beams)}$, derived from EN 1992-1-2, show profiles of temperature vs. depth d_{cc} within the concrete, plotted at 30 min intervals as a function of depth along vertical axis for slabs and as a function of x/y position within the beam from lower corners for beams.

These temperature profiles have been calculated by Finite Element Method, using characteristics for concrete as mentioned in §3.3.2 of EN 1992-1-2, Annex A.

These characteristics where θ is the concrete temperature are as follows :

— ***Specific heat of concrete with moisture content 1,5%:***

$c_p(\theta) = 900$ (J/kg K)	for 20 °C ≤ θ ≤ 100 °C
$c_p(\theta) = 900 + (\theta - 100)$ (J/kg K)	for 100 °C < θ ≤ 200 °C
$c_p(\theta) = 1\,000 + (\theta - 200)/2$ (J/kg K)	for 200 °C < θ ≤ 400 °C
$c_p(\theta) = 1\,100$ (J/kg K)	for 400 °C < θ ≤ 1 200 °C

— ***Thermal conductivity of concrete (lower limit):***

$\lambda_c = 1{,}36 - 0{,}136\,(\theta / 100) + 0{,}005\,7\,(\theta / 100)^2$ W/m K for 20 °C ≤ θ ≤ 1 200 °C

— ***Density of concrete:***

The density of concrete is assumed to vary depending on its temperature influenced by water loss and defined as follows:

$\rho(\theta) = \rho(20\ °C)\ (kg/m^3)$ for 20 °C ≤ θ ≤ 115 °C

$\rho(\theta) = \rho(20\ °C)\cdot(1 - 0{,}02(\theta - 115)/85)\ (kg/m^3)$ for 115 °C < θ ≤ 200 °C

$\rho(\theta) = \rho(20\ °C)\cdot(0{,}98 - 0{,}03(\theta - 200)/200)\ (kg/m^3)$ for 200 °C < θ ≤ 400 °C

$\rho(\theta) = \rho(20\ °C)\cdot(0{,}95 - 0{,}07(\theta - 400)/800)\ (kg/m^3)$ for 400 °C < θ ≤ 1 200 °C

— ***Factors:***

The emissivity related to the concrete surface is assumed 0,7.

The convection factor is assumed 25 W/m².°C

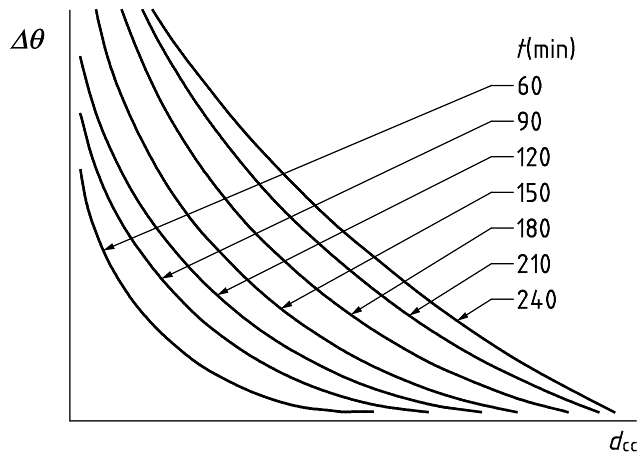


Figure C.5 — Temperatures inside concrete versus depth for slab

Table C.1 — Numerical values to build Figure C.5

Exposure duration	Depth inside concrete slab along vertical axis (mm)																				
(min)	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
30	753	509	344	233	156	107	77	56	42	33	28	24	22	21	21	20	20	20	20	20	20
60	897	683	519	395	301	229	173	131	102	80	64	52	42	36	31	27	25	23	22	21	21
90	971	778	622	497	398	319	255	203	162	129	105	86	72	60	50	43	37	33	29	27	25
120	1021	843	694	571	471	388	320	264	217	178	146	121	101	86	73	62	53	46	40	36	32
180	1089	934	796	678	577	492	420	359	306	261	223	190	161	137	118	102	89	78	68	60	53
240	1136	995	867	754	655	570	496	432	377	328	286	249	217	188	164	142	124	109	97	86	77

Exposure duration	Depth inside concrete slab along vertical axis (mm)																			
(min)	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390	400
30	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
60	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
90	23	22	22	21	21	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
120	29	27	25	24	23	22	21	21	21	21	20	20	20	20	20	20	20	20	20	20
180	47	42	38	35	32	29	27	26	25	24	23	22	22	21	21	21	21	20	20	20
240	69	61	55	50	45	41	37	34	32	30	28	27	25	24	24	23	23	22	22	22

The mechanism for obtaining temperatures within the relevant concrete beam section was the following:

— the tested concrete section (450 x 150 mm) was firstly considered and temperature evolution through it calculated;

— additional calculations were carried out by increasing, each time, the height of the section by 20 mm and the thickness by 2 mm x 20 mm (see Figure C.6);

— this gives the possibility to draw the temperature at the location 1 (25 mm in both directions from the left hand corner) at regular intervals between 30 min and 240 min (Figure C.7).

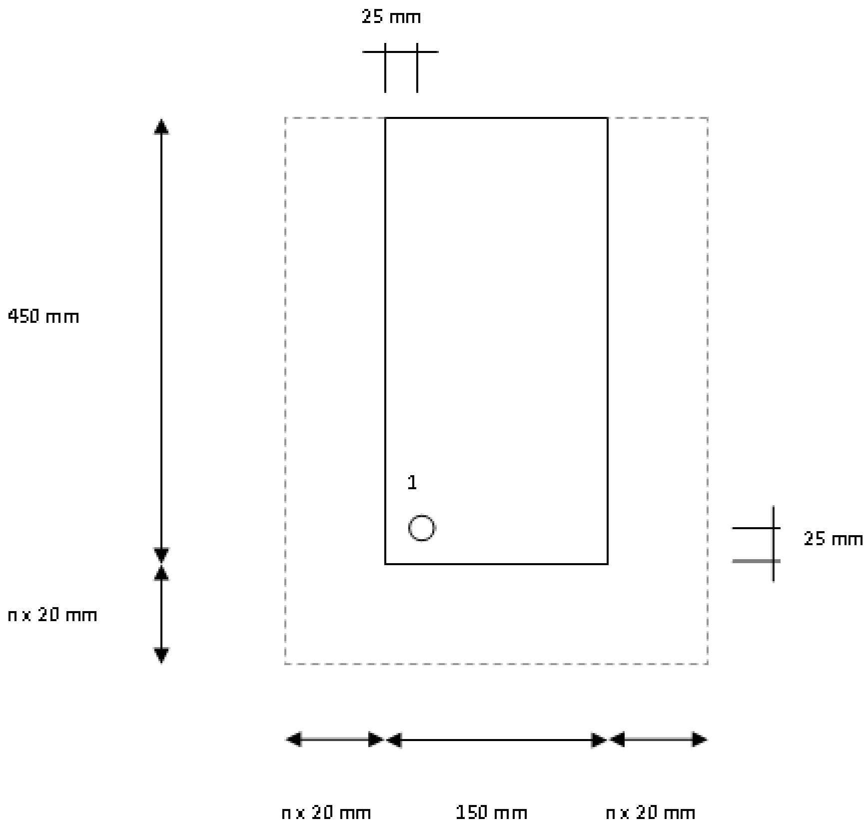
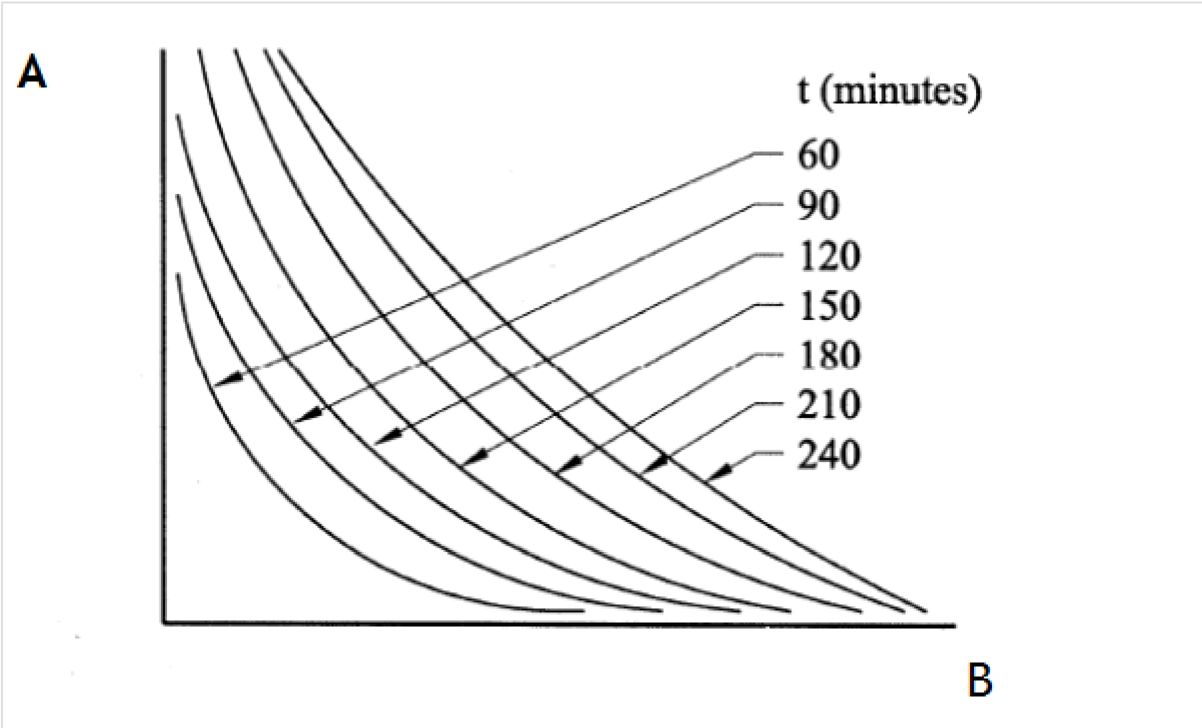


Figure C.6 — Concrete beam characteristics



Key

A temperature within concrete

B equivalent thickness of concrete

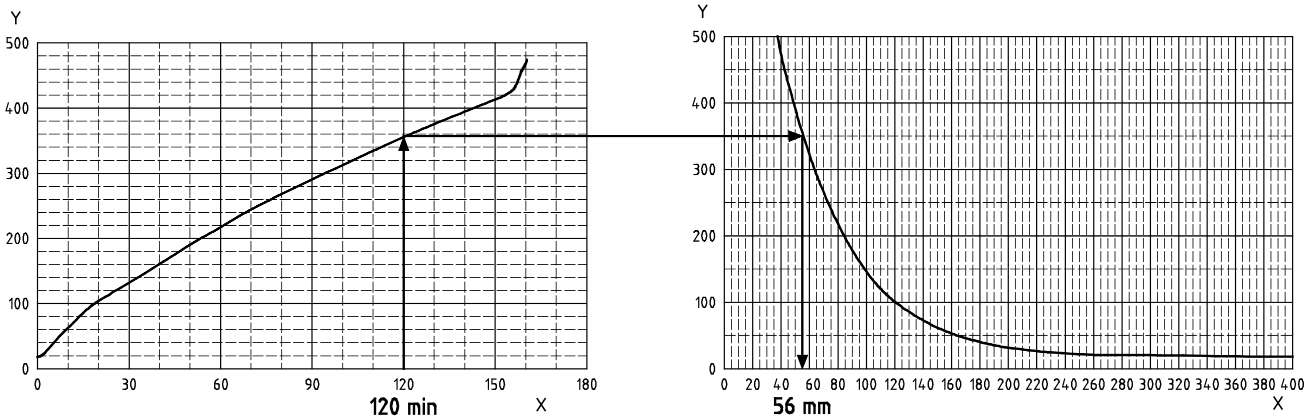
Figure C.7 — Temperatures inside concrete versus equivalent thickness for beam

Table C.2 — Temperature at location 1 with additional equivalent thickness of concrete

Exposure duration	**Additional equivalent thickness of concrete (mm)**										
(min)	**0**	**20**	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**
30	464	233	120	63	35	25	21	20	20	20	20
60	691	444	272	166	107	68	43	31	25	22	21
90	818	588	399	267	179	123	86	59	41	31	25
120	904	695	503	356	251	177	128	94	68	48	36
180	1015	847	664	506	380	286	214	162	124	96	73
240	1087	952	784	625	491	382	298	232	181	143	114

NOTE The column headed 0 in the Additional Equivalent thickness part of the table refers to location 1 in Figure 7 with zero protection. Other columns represents the temperature at location 1 with additional concrete protection. This enables the equivalent concrete protection provided by the actual protection material to be established.

C.2.2 For a given thickness of fire protection, inclusion of measured data for characteristic temperature $\theta(d_{cp}, t)$ obtained at a specific concrete thickness $d_{cp,}$ into selected curves from Figure C.5 $_{(slab)}$ as shown in Figure C.8 $_{(slab)}$ permits the determination by interpolation of the depth d_{cc} in an unprotected concrete slab at which that same temperature $\theta(d_{cp}, t)$ would be found.



Key

X	time (min)	X	concrete depth d_{cc} (mm)
Y	characteristic temperature inside concrete slab at 15 mm deep (°C)	Y	temperature inside concrete slab (°C)

Characteristic temperature recorded at 15 mm deep inside a concrete slab protected by x mm of a protective material,at 120 min of a fire test.

Temperature evolution inside an unprotected concrete slab at 120 min exposure under EN 1363-1.

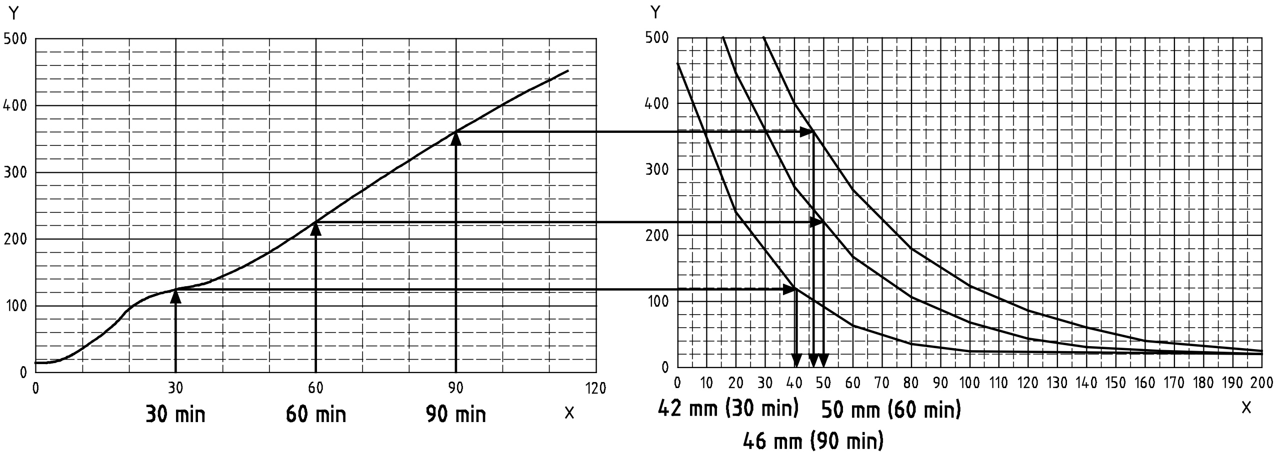
Figure C.8 — Characteristic temperature versus depth for slab

The equivalent thickness of concrete ε, corresponding to x mm of protective material applied under a concrete slab and after 120 mm under EN 1363-1 thermal program, is given by:

$$\varepsilon = [d_{cc\ (unprotected)} - d_{cp\ (protected)}]$$

i.e. in the example $\varepsilon(x, 120min) = [56 – 15] = 41$ mm

C.2.3 For a given thickness of fire protection, inclusion of measured data for characteristic temperature $\theta(d_{cp}, t)$ obtained at a specific concrete thickness $d_{cp,}$ into selected curves from Figure C.7 $_{(beam)}$ as shown in Figure C.9 $_{(beam)}$ permits the determination by interpolation of the depth d_{cc} in an unprotected concrete beam at which that same temperature $\theta(d_{cp}, t)$ would be found.



Key

X time (min)

Y characteristic temperature inside concrete beam at [25,25] mm deep (°C)

Characteristic temperature recorded at [25,25] mm deep inside a concrete beam 150 mm x 450 mm protected by x mm of a protective material.

Key

X equivalent thickness of concrete (mm)

Y temperature inside concrete beam (°C)

Temperature evolution recorded at [25,25] mm deep inside a concrete beam 150 mm x 450 mm protected by x mm of concrete at 30 min, 60 min and 90 min exposure under EN 1363-1.

Figure C.9 — Characteristic temperatures versus equivalent thickness of concrete for beam

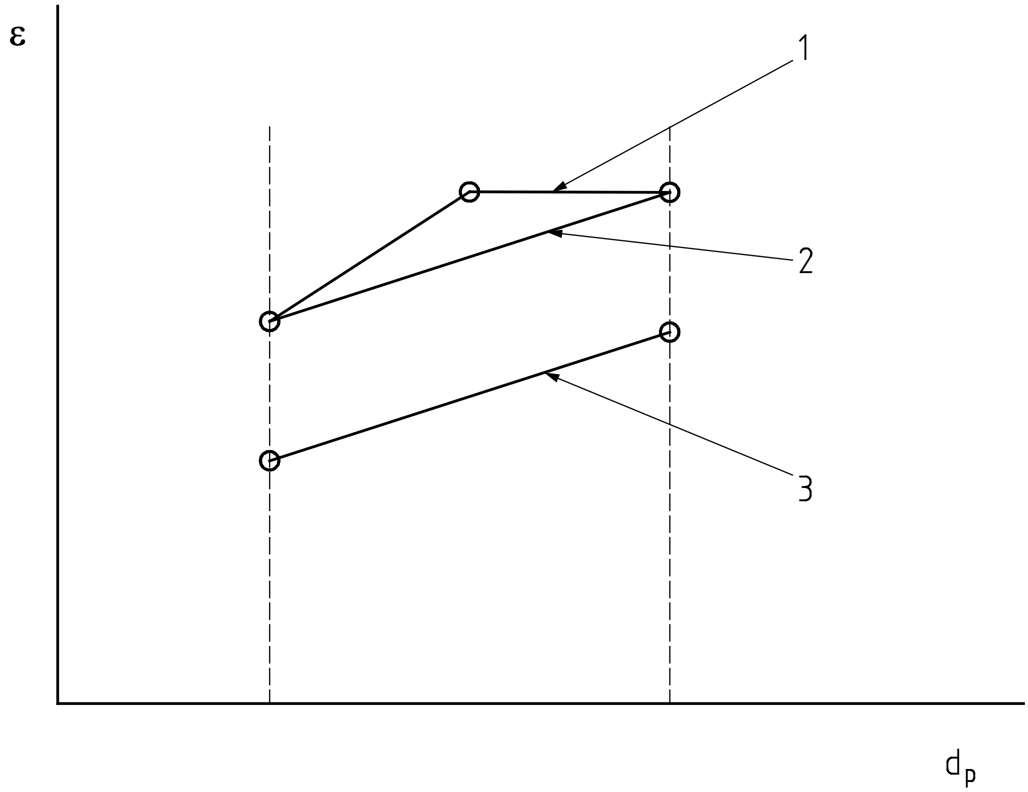
The equivalent thicknesses of concrete, corresponding to x mm of protective material applied on a concrete beam at 30, 60 and 90 minutes under EN 1363-1 thermal program, are given by the X value corresponding to the temperature and duration, i.e. in the example:

— at 30 min $\varepsilon(x, 30min)$ = 42 mm

— at 60 min $\varepsilon(x, 60min)$ = 50 mm

— at 90 min $\varepsilon(x, 90min)$ = 46 mm

C.2.4 The values of equivalent concrete thickness ε can be plotted for each thickness of fire protection tested permitting interpolation of the result as a function of fire duration according to Figure C.10.



Key

1 3 thicknesses tested [t = 120 minutes]

2 2 thicknesses (max/min) tested [t = 120 minutes]

3 2 thicknesses (max/min) tested [t = 90 minutes]

ε = equivalent thickness (mm)

d_p = fire protection thickness (mm)

Figure C.10 — Equivalent thickness versus fire protection thickness for different exposure times (slab or beam)

Annex D
(normative)

Calculation of stresses in standard concrete structures

D.1 General

Minimal dimensions for standard concrete structures to be used for assessment of a protective material are indicated in 6.2 as well as their construction details in 6.3.

Dimensional tolerances are accepted for each type of standard structure.

Consequently, the loading conditions shall be defined according to actual dimensions of standard structure on which the protective material to assess is applied.

The relevant procedure to achieve such adequate loading conditions is described hereafter.

D.2 Relevant concrete structures

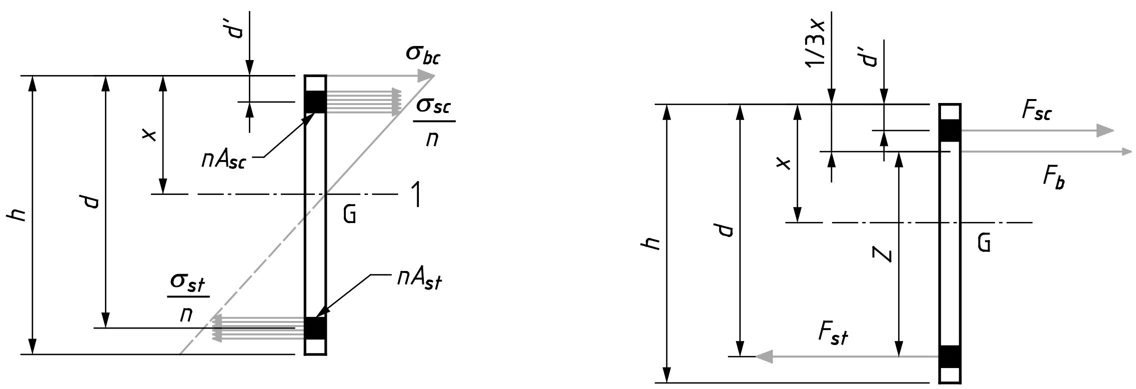
The procedure is dealing with:

— large and small dimensions slabs;

— rectangular beams.

D.3 Distribution of stresses across the section of the concrete structures

The distribution of stresses across the section of a rectangular section can be presented as follows:



Key

1 neutral axis

NOTE Parameters of this figure are defined in D.4.1 and D.4.2.

Figure D.1 — Distribution of stresses across the section of the concrete structures

D.4 Mechanical study

D.4.1 Equilibrium of external forces

The equilibrium of external forces developed on a rectangular cross section and due to bending can be expressed as follows :

$$F_b + F_{sc} - F_{st} = 0 \quad \text{(D.1)}$$

$$\sum M / _{tensilesteel} = M - F_b \times Z - F_{sc} \times (d - d') = 0 \quad \text{(D.2)}$$

where

F_{st}, F_{sc}	forces in reinforcement bars respectively in tensile and compressed parts (N);
F_b	force in compressed concrete (N);
M	bending moment (N.m).

$$F_b = b^x / 2^{\sigma_{bc}} \quad \text{(D.3)}$$

$$F_{st} = A_{st}\sigma_{st} \quad \text{(D.4)}$$

$\sigma = 0$ and $\varepsilon = 0$ (D.5)

D.4.2 Determination of the position of the neutral axis (x)

The position of the neutral axis (x) where σ and ε are equal to 0 can be determined by solving Formula (D.8), on the basis of Formulae (D.6) and (D.7) :

$$F_b + F_{sc} - F_{st} = b \times \frac{x}{2} \times \sigma_{bc} + A_{sc} \times \sigma_{sc} - A_{st} \times \sigma_{st} = 0 \quad \text{(D.6)}$$

$$\frac{\sigma_{bc}}{x} = \frac{\sigma_{st}/n}{(d - x)} = \frac{\sigma_{sc}/n}{(x - d')} \quad \text{(D.7)}$$

i.e. :

$$\frac{b \times x^2}{2} + n \times A_{sc} \times (x - d') - n \times A_{st} \times (d - x) = 0 \quad \text{(D.8)}$$

where

b	width of the section (m);
x	position of the neutral axis (m);
d	position of the reinforcement bars in the tensile part of the concrete section (m);
d'	position of the reinforcement bars in the compressed part of the concrete section (m);

A_{st} total steel section of the reinforcement bars in the tensile part of the concrete section (m²);

A_{sc} total steel section of the reinforcement bars in the compressed part of the concrete section (m²);

σ_{st} stress in the reinforcement bars in the tensile part (N/m²);

σ_{sc} stress in the reinforcement bars in the compressed part (N/m²);

σ_{bc} stress in the concrete in the compressed part (N/m²);

n ratio between Young modulus of steel for reinforcement bars and Young modulus of concrete for class C considered.

For a class C25/30 concrete, coefficient $n = \frac{E_{steel}}{E_{concrete}} = \frac{210.000}{33.200} = 6.325$

D.4.3 Determination of the quadratic modulus

The quadratic modulus of the cross section is equal to :

$$I = I_b + I_{st} + I_{sc} \tag{D.9}$$

where

Compressed concrete $I_b = \frac{b \times x^3}{12} + b \times x \times \left(\frac{x}{2}\right)^2 = \frac{b \times x^3}{3}$

Tensile reinforcement bars $I_{st} = m_{stbars} \times \frac{\pi \times D_{st}{}^4}{64} + n \times A_{st} \times (d - x)^2 \approx n \times A_{st} \times (d - x)^2$

Compressed reinforcement bars $I_{sc} = m_{scbars} \times \frac{\pi \times D_{sc}{}^4}{64} + n \times A_{sc} \times (x - d')^2 \approx n \times A_{sc} \times (x - d')^2$

where

D_{st} is the diameter of the rebar located in tensile part of the concrete section (m);

D_{sc} is the diameter of the rebar located in compressed part of the concrete section (m);

i.e. :

$$I = \frac{b \times x^3}{3} + n \times A_{st} \times (d - x)^2 + n \times A_{sc} \times (x - d')^2 \text{ (m}^4\text{)} \tag{D.10}$$

D.4.4 Determination of stresses in reinforcement bars and concrete

The stress at any position (y) varying along the vertical cross section of the concrete structure can be expressed according to general Formula (D.11):

$$\sigma(y) = \frac{M}{I} \times y \tag{D.11}$$

For standard concrete structures, Formula (D.11) leads to following values in reinforcement bars and concrete :

- In tensile reinforcement bars $\sigma_{st} = n \times \frac{M}{I} \times (d - x)$ (N/m²) (D.12)

- In compressed reinforcement bars $\sigma_{sc} = n \times \frac{M}{I} \times (x - d')$ (N/m²) (D.13)

- In compressed concrete $\sigma_{sb} = \frac{M}{I} \times x$ (N/m²) (D.14)

The following tables indicate the bending moment to be produced within slabs and beams prepared with C25/30 strength class concrete and steel reinforcement bars which are ribbed and are of grade B500 (to EN 10080).

Table D.1 — Bending moment to apply on large dimensions concrete test slabs

Slab thickness	Bending moment corresponding to a tensile stress of 300 MPa in the reinforcement bars
120 mm	14 250 Nm/m width
130 mm	16 000 Nm/m width
140 mm	17 750 Nm/m width
150 mm	19 500 Nm/m width

Table D.2 — Bending moment to apply on small dimensions concrete test slabs

Slab thickness	Bending moment corresponding to a tensile stress of 300 MPa in the reinforcement bars
120 mm	9 500 Nm/m width
130 mm	10 500 Nm/m width
140 mm	11 500 Nm/m width
150 mm	12 500 width

Table D.3 — Bending moment to apply on concrete test beams

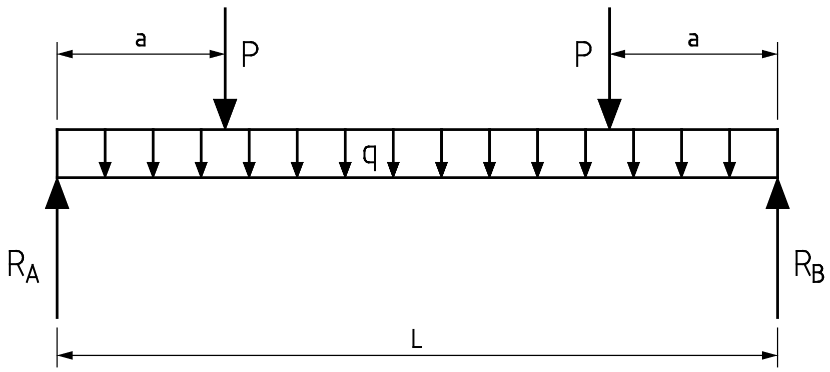
	Bending moment corresponding to a tensile stress of 300 MPa in the reinforcement bars		
	Width of concrete beam		
Height of concrete beam	140 mm	150 mm	160 mm
440 mm	28 000 Nm	28 000 Nm	28 250 Nm
450 mm	28 750 Nm	28 750 Nm	28 750 Nm
460 mm	29 500 Nm	29 500 Nm	29 250 Nm

The moment to apply on test structures designed with relevant dimensions between the values indicated in Tables D.1 to D.3 shall be linear interpolated.

Annex E
(informative)

Calculation of the load to apply on concrete member

E.1 Remind and scheme



Key

P is the applied load on each of the two points of the beam (N)

q is the dead weight per running meter of the beam (N/m)

R_A and R_B are reactive forces at the beam supports (N)

Here $R_A = R_B = R$

L is the span (distance between the supports) (m)

a is the distance between the support and the point of application of the force P (m)

Maximal bending moment (N.m): $Mo = P.a + q.\frac{L^2}{8}$

Figure E.1 — Localization of forces

E.2 Calculation of the force of the spring for a loaded beam

Maximal bending moment

$$Mo = P.a + q.\frac{L^2}{8}$$

where

The force P is applied at each of both loading points of the beam.

P = (Force of the spring + weight of the articulation piece + weight of the repartition beam) / 2.

The mass per running meter q shall take into account the dead weight of the beam, the dead weight of its cover in cellular concrete and the dead weight of the protective system.

$$q = \rho_{concrete}.h_{beam}.l_{beam}g + \rho_{aeratedconcrete}.e_{slab}.l_{slab}.g + \rho_{protection}.e_{protection}.c_{beam}g$$

where

- h height (m);
- l width (m);
- ρ density (kg/m^3);
- e thickness (m);
- g acceleration (9,81 m/s^2);
- c perimeter of the beam where the product is applied.

EXAMPLE When the standard requires to generate a bending moment of M=25kN.m, for a standard beam the result will be:

q= 2350 .0,45 .0,15 .9,81+650.0 ,125.0,6.9,81+~0

L= 4,9 m

a= 1,1 m

Mass of the articulation = 14 kg

Linear Mass of the repartition beam= 83,2 kg/ml

Length of the repartition beam = 3,1 m

Example of resulting force if the protection product mass is neglected (e.g. intumescent paint)

F= 31686 N

E.3 Calculation of the force of the spring for a loaded large slab

Maximal bending moment

$$Mo=P.a+q.\frac{L^2}{8}$$

where

The force P is applied at each of both loading of the beam.

P = (Force of the spring + weight of the articulation piece + weight of the repartition beam + 2 times the weight of the transverse beam) / 2.

The linear mass q shall take into account the dead weight of the slab and the dead weight of the protective system.

$$q = \rho_{concrete}.h_{slab}.l_{slab}g + \rho_{protection}.e_{protection}.l_{slab}g$$

where

h height (m);

l width (m);

ρ density (kg/m^3);

e thickness (m);

g acceleration (9,81 m/s^2).

EXAMPLE When the standard requires to generate a bending moment of M=14 kN.m/m of width

For 1 m width of a standard slab:

q= 2350 .0,14 .1 .9,81+ ~0

and

P = (Force of the spring + weight of the articulation piece + weight of the repartition beam + 2 times the weight of the transverse beam) / 6

L= 4,9 m

a= 1 m

Mass of the articulation = 14 kg

Linear Mass of the repartition beam= 83,2 kg/ml

Length of the repartition beam = 3,1 m

Linear Mass of one transverse beam = 26,7 kg/ml

Length of the transverse beam = 2,9 m

Example of resulting force if the protection product mass is neglected (e.g. intumescent paint)

F= 21695 N

Bibliography

EN 13381-1, *Test methods for determining the contribution to the fire resistance of structural members – Part 1: Horizontal protective membranes*

EN 13381-2, *Test methods for determining the contribution to the fire resistance of structural members – Part 2: Vertical protective membranes*

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