

Precast concrete products — Hollow core slabs

ICS 91.060.30; 91.100.30

National foreword

This British Standard is the UK implementation of EN 1168:2005+A3:2011. It supersedes BS EN 1168:2005+A2:2009, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN amendment. For example, text altered by CEN amendment A1 is indicated by **A1** **A1**.

EN 1168 is a candidate “harmonized” European standard and fully takes into account the requirements of the European Commission mandate M/100, Precast concrete products, given under the EU Construction Products Directive (89/106/EEC), and is intended to lead to CE marking. The date of applicability of EN 1168 as a harmonized European Standard, i.e. the date after which this standard may be used for CE marking purposes, is subject to an announcement in the *Official Journal of the European Communities*.

The Commission in consultation with Member States has agreed a transition period for the co-existence of harmonized European Standards and their corresponding national standard(s). It is intended that this period will comprise a period, usually nine months, after the date of availability of the European Standard, during which any required changes to national regulations are to be made, followed by a further period, usually of 12 months, for the implementation of CE marking. At the end of this co-existence period, the national standard(s) will be withdrawn. In the UK, there are no corresponding national standards.

The UK participation in its preparation was entrusted to Technical Committee B/524, Precast concrete products.

In the opinion of the UK national committee, this product standard does not provide a satisfactory link between product design and building/project design. The design of the bearing support details is likely to include horizontal forces at the support from restraint effects (shrinkage, temperature, creep, etc.) and these forces need to be considered in the plank design. Reference should be made to *Design of Hybrid Concrete Buildings* published by The Concrete Centre (2009).

Subclause 4.3.3.2.2.1 of this Product Standard provides an alternate method of design of Hollowcore Units for shear to that given in EN 1992-1-1:2004, subclause 6.2.2, in regions uncracked in bending. Therefore, use of this method could result in a design that does not conform to the Eurocode EN 1992-1-1:2004.

Practice in the UK has been for the engineer responsible for the overall stability of the structure to ensure the compatibility of the design and details of parts and components, even when some or all of the design and details of those parts are not made by this engineer.

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

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

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

Amendments/corrigenda issued since publication

Date	Comments
28 February 2011	Implementation of CEN consolidated amendments A1:2008 and A2:2009
30 November 2011	Implementation of CEN consolidated amendment A3:2011

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 9 August 2005

© BSI 2011

ISBN 978 0 580 73137 2

English Version

Precast concrete products - Hollow core slabs

Produits préfabriqués en béton - Dalles alvéolées

Betonfertigteile - Hohlplatten

This European Standard was approved by CEN on 1 July 2004 and includes Amendment 1 approved by CEN on 14 January 2008, Amendment 2 approved by CEN on 4 January 2009 and Amendment 3 approved by CEN on 11 August 2011.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Contents

The numbering of clauses is strictly related to EN 13369: Common rules for precast concrete products, at least for the first three digits. When a clause of EN 13369 is not relevant or included in a more general reference of this standard, its number is omitted and this may result in a gap on numbering.

Foreword	4
Introduction	6
1 Scope	7
2 Normative references	7
3 Terms and definitions	8
3.1 Definitions	8
4 Requirements	9
4.1 Material requirements	9
4.1.1 Prestressing steel	10
4.2 Production requirements	10
4.2.1 Structural reinforcement	10
4.3 Finished product requirements	11
4.3.1 Geometrical properties	11
4.3.2 Surface characteristics	14
4.3.3 Mechanical resistance	14
4.3.4 Resistance and reaction to fire	23
4.3.5 Acoustic properties	23
4.3.6 Thermal properties	23
4.3.7 Durability	24
4.3.8 Other requirements	24
5 Test methods	24
5.1 Tests on concrete	24
5.2 Ⓐ₃ Tests on pre-stressing steel Ⓐ₃	24
5.3 Measuring of dimensions and surface characteristics	24
5.3.1 Element dimensions	24
5.4 Weight of the products	25
6 Evaluation of conformity	25
6.1 Ⓐ₂ General	25
6.2 Type testing	25
6.2.1 General	25
6.2.2 Initial type testing	26
6.2.3 Further type testing	26
6.3 Factory production control Ⓐ₃	26
7 Marking	27
7.1 General	27
8 Technical documentation	27
Annex A (normative) Inspection schemes	28
Annex B (informative) Typical shapes of joints	31
Annex C (informative) Transverse load distribution	33
Annex D (informative) Diaphragm action	42
Annex E (informative) Unintended restraining effects and negative moments	43
Annex F (informative) Mechanical resistance in case of verification by calculation: shear capacity of composite members	46

Annex G (informative) Resistance to fire	49
Annex H (informative) Design of connections	57
Annex J (normative) Full scale test	59
Annex K (normative) Thermal prestressing	65
Annex ZA (informative) Clauses of this European Standard addressing essential requirements or other provisions of EU Directives	67
Bibliography	81

Foreword

This document (EN 1168:2005+A3:2011) has been prepared by Technical Committee CEN/TC 229 “Precast concrete products”, the secretariat of which is held by AFNOR ^{A2} and was examined by and agreed with a joint working party appointed by the Liaison Group CEN/TC 229 – CEN/TC 250, particularly for its compatibility with structural Eurocodes ^{A2}.

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 April 2012, and conflicting national standards shall be withdrawn at the latest by July 2013.

^{A1} This European Standard was examined by and agreed with a joint working party appointed by the Liaison Group CEN/TC 229 – TC 250, particularly for its compatibility with structural Eurocodes. ^{A1}

This document includes Amendment 1 approved by CEN on 2008-01-14, Amendment 2 approved by CEN on 2009-01-04 and Amendment 3 approved by CEN on 2011-08-11.

This document supersedes ^{A3} EN 1168:2005+A2:2009 ^{A3}.

The start and finish of text introduced or altered by amendment is indicated in the text by tags ^{A1} ^{A1}, ^{A2} ^{A2} and ^{A3} ^{A3}.

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 has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of Construction Products Directives (89/106/EEC) of the European Union (EU).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

This standard is one of a series of product standards for precast concrete products.

For common aspects reference is made to EN 13369: *Common rules for precast products*, from which also the relevant requirements of the EN 206-1: *Concrete – Part 1: Specification, performances, production and conformity* are taken.

The references to EN 13369 by CEN/TC 229 product standards are intended to make them homogeneous and to avoid repetitions of similar requirements.

^{A3} Eurocodes are taken as a common reference for design aspects. The installation of some structural precast concrete products is dealt with by EN 13670. In all countries it can be accompanied by alternatives for national application. ^{A3}

The programme of standards for structural precast concrete products comprises the following standards, in some cases consisting of several parts:

- ^{A1} EN 1168:2005+A1 ^{A1}, *Precast concrete products – Hollow core slabs*
- ^{A1} EN 12794:2005+A1 ^{A1}, *Precast concrete products – Foundation piles*
- EN 12843, *Precast concrete products – Masts and poles*
- ^{A1} EN 13224:2004+A1 ^{A1}, *Precast concrete products – Ribbed floor elements*
- EN 13225, *Precast concrete products – Linear structural elements*

- EN 13693, *Precast concrete products – Special roof elements*
-  EN 13747 , *Precast concrete products – Floor plates for floor systems*
-  EN 13978-1, *Precast concrete products - Precast concrete garages - Part 1: Requirements for reinforced garages monolithic or consisting of single sections with room dimensions* 
-  EN 14843 , *Precast concrete products - Stairs*
-  EN 14844 , *Precast concrete products – Box culverts*
-  EN 14991 , *Precast concrete products – Foundation elements*
-  EN 14992, *Precast concrete products – Wall elements* 
-  EN 15037-1, *Precast concrete products – Beam-and-block floor systems – Part 1: Beams*
- EN 15037-2, *Precast concrete products – Beam-and-block floor systems – Part 2: Concrete blocks*
- EN 15037-3, *Precast concrete products – Beam-and-block floor systems – Part 3: Clay blocks*
- prEN 15037-4, *Precast concrete products – Beam-and-block floor systems – Part 4: Polystyrene blocks*
- prEN 15037-5, *Precast concrete products – Beam-and-block floor systems – Part 5: Lightweight blocks* 
-  EN 15258 , *Precast concrete products – Retaining wall elements*
-  EN 15050 , *Precast concrete products – Bridge elements*

This standard defines in Annex ZA the application methods of CE marking to products designed using the relevant EN Eurocodes (EN 1992-1-1 and EN 1992-1-2). Where, in default of applicability conditions of EN Eurocodes to the works of destination, design Provisions other than EN Eurocodes are used for mechanical strength and/or fire resistance, the conditions to affix CE marking to the product are described in ZA.3.4.

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, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

The evaluation of conformity given in this standard refers to the completed precast elements which are supplied to the market and covers all the production operations carried out in the factory.

For design rules reference is made to EN 1992-1-1. Additional complementary rules are provided where necessary.

The verification of the mechanical resistance of hollow core slabs is, at this stage of standardisation, only fully accepted by calculation; ^{A2} however, concrete properties adopted as input for calculation of shear resistance depend on the proper functioning of the production machine; therefore a full scale test method to confirm both the shear resistance obtained by calculation and the proper functioning of the production machine, is given in Annex J (normative). ^{A2}

Special rules for structures with hollow core elements are presented in annexes about load distribution (Annex C), diaphragm action (Annex D), negative moments (Annex E), shear capacity of composite members (Annex F) and design of connections (Annex H).

^{A3} Special rules for pre-stressing by means of thermal pre-stressing are given in Annex K. ^{A3}

Because of some specialities of the product, e.g. the absence of transverse reinforcement, some complementary design rules to EN 1992-1-1 are necessary. Furthermore, research on hollow core slabs has resulted in special, widely used, design rules which are not incorporated in the design rules of EN 1992-1-1. According to subclause 1.2 of EN 1992-1-1:2004 the complementary rules, given in informative annexes in this standard, comply with the relevant principles given in EN 1992-1-1.

Because of the fact that the experimental evidence is mainly based on elements with limited depth and width, this standard is applicable to elements with these limited dimensions. This limitation is not intended to prohibit the application of elements with larger sizes, but the experience is not yet wide enough to draw up standardised design rules.

1 Scope

This European Standard deals with the requirements and the basic performance criteria and specifies minimum values where appropriate for precast hollow core slabs made of prestressed or reinforced normal weight concrete according to EN 1992-1-1:2004.

This European Standard covers terminology, performance criteria, tolerances, relevant physical properties, special test methods, and special aspects of transport and erection.

Hollow core elements are used in floors, roofs, walls and similar applications. In this European Standard the material properties and other requirements for floors and roofs are dealt with; for special use in walls and other applications, see the relevant product standards for possible additional requirements.

Ⓐ The elements have lateral edges with a grooved profile in order to make a shear key to transfer shear through joints contiguous elements. Ⓐ For diaphragm action the joints have to function as horizontal shear joints.

Ⓐ To improve this action vertical grooves may be provided. Ⓐ

The elements are manufactured in factories by extrusion, slipforming or mouldcasting. Ⓐ Fitting slabs (narrowed slab elements) and recesses to the hollow core slabs can be made during production or afterwards. Hollow core slabs can have provisions for thermal activation, heating, cooling, sound insulation, etc. Due to these provisions, the concrete temperature remains in its natural range. Ⓐ

Ⓐ This European Standard also deals with solid slab elements used in conjunction with hollow core slabs and manufactured by extrusion, slipforming or mouldcasting, equivalent to the manufacturing of hollow core slabs. These solid slabs have the same overall cross-section as hollow core slabs, however without hollow cores. Ⓐ

Ⓐ The application of the standard is limited for prestressed elements to a maximum depth of 500 mm and for reinforced elements to a maximum depth of 300 mm.

For both types, the maximum width without transverse reinforcement is limited to 1 200 mm and with transverse reinforcement to 2 400 mm. Ⓐ

The elements may be used in composite action with an in situ structural topping cast on site.

The applications considered are floors and roofs of buildings, including areas for vehicles in the category F and G of Ⓐ EN 1991-1-1 Ⓐ which are not subjected to fatigue loading. For building in seismic zones additional provisions are given in EN 1998-1.

This European Standard does not deal with complementary matters. E.g. the slabs should not be used in roofs without additional protection against water penetration.

2 Normative references

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

EN 206-1:2000, *Concrete — Part 1: Specification, performance, production and conformity*

EN 1992-1-1:2004, *Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings*

EN 1992-1-2:2004, *Eurocode 2: Design of concrete structures — Part 1-2: General rules – Structural fire design*

EN 12390-2, *Testing hardened concrete — Part 2: Making and curing specimens for strength tests*

EN 12390-3, *Testing hardened concrete — Part 3: Compressive strength of test specimens*

EN 12390-4:2000, *Testing hardened concrete — Part 4: Compressive strength — Specification for testing machines*

EN 12390-6, *Testing hardened concrete — Part 6: Tensile splitting strength of test specimens*

EN 12504-1, *Testing concrete in structures — Part 1: Cored specimens — Testing, examining and testing in compression*

EN 13369:2004, *Common rules for precast concrete products*

Ⓐ₁ EN 13791, *Assessment of in-situ compressive strength in structures and precast concrete components* Ⓐ₁

Ⓐ₃ EN ISO 15630-3, *Steel for the reinforcement and prestressing of concrete — Test methods — Part 3: Prestressing steel (ISO 15630-3:2010)* Ⓐ₃

3 Terms and definitions

For the purposes of this European Standard, the following terms and definitions apply. For general terms EN 13369:2004 shall apply.

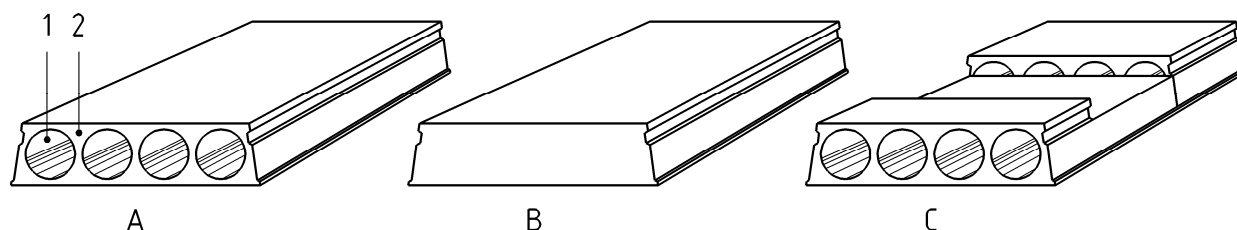
3.1 Definitions

3.1.1

hollow core slab

monolithic prestressed or reinforced element with a constant overall depth divided into an upper and a lower flange, linked by vertical webs, so constituting cores as longitudinal voids the cross section of which is constant and presents one vertical symmetrical axis (see Figure 1)

Ⓐ₃



Key

- A hollow core slab
- B solid slab
- C combined slab
- 1 core
- 2 web

Figure 1 — Types of hollow core slabs (examples) Ⓐ₃

Ⓐ₃ 3.1.2

solid slab

slab with the same overall cross-section as a hollow core slab where, during manufacturing no voids are made (Figure 1 B). This slab is manufactured in the same manner (machine, bed, ...) as hollow core slabs with voids

NOTE Hollow core slabs where the voids are filled with concrete after manufacturing of the hollow core element can not be considered as a solid slab.

3.1.3

combined slab

hollow core slab that has partially a solid cross section (Figure 1 C). The depth of the cross section may vary over the length of the element

3.1.4

fitting slab

slab sawn from a standard slab with a width ≥ 250 mm with at least two webs A_3

A_3 3.1.5 A_3

core

longitudinal void produced by specific industrial manufacturing techniques, located with a regular pattern and the shape of which is such that the vertical loading applied on the slab is transmitted to the webs

A_3 3.1.6 A_3

web

vertical concrete part between two adjacent cores (intermediate webs) or on the lateral edges of the slab (outermost webs)

A_3 3.1.7 A_3

lateral joint

lateral profile on the longitudinal edges of a hollow core slab shaped so to allow grouting between two adjacent slabs

A_3 3.1.8 A_3

topping

cast in situ concrete on the hollow core slab floor intended to increase its bearing capacity and so constituting a composite hollow core slab floor

A_3 3.1.9 A_3

screed

cast in situ concrete or mortar layer used to level the upper face of the finished floor

A_3 3.1.10 A_3

hollow core slab floor

floor made of hollow core slabs after the grouting of the joints

A_3 3.1.11 A_3

composite hollow core slab floor

hollow core slab floor complemented by a cast-in-situ topping

A_3 3.1.12

solid slab floor

floor made of solid core slabs after the grouting of the joints A_3

A_3 3.1.13

composite solid slab floor

solid slab floor complemented by a cast in situ topping A_3

4 Requirements

4.1 Material requirements

Complementary to 4.1 of EN 13369:2004 the following subclauses shall apply. In particular the ultimate tensile and tensile yield strength of steel shall be considered.

4.1.1 Prestressing steel

4.1.1.1 Maximum diameter of prestressing steel

Ⓐ₃ The diameter of pre-stressing steel is limited to:

- Class 1: Elements with pre-stressing steel with a maximum of 11 mm for wires and 16 mm for strands;
- Class 2: Elements with thermal pre-stressed bars with a maximum of 16 mm.

The use of pre-stressing bars is only allowed in accordance with Annex K. Ⓐ₃

4.2 Production requirements

Ⓐ₂ 4.2 of EN 13369:2004 shall apply.

Proper placing and compacting of concrete by the production machine shall be verified by initial type testing according to 6.2.2.

Complementary to 4.2.3 of EN 13369:2004 4.2.1 shall apply for structural reinforcement. Ⓐ₂

4.2.1 Structural reinforcement

4.2.1.1 Processing of reinforcing steel

4.2.1.1.1 Longitudinal bars

For the distribution of the longitudinal bars the following requirements shall be fulfilled:

- a) the bars shall be distributed uniformly across the width of the elements;
- b) the maximum centre to centre distance between two bars shall not exceed 300 mm;

Ⓐ₃

- c) in the outermost webs there shall be at least one bar, for solid slabs, the equivalent position shall be considered; Ⓐ₃

- d) the clear spacing between bars shall be at least:

- horizontally : $\geq (d_g + 5 \text{ mm}), \geq 20 \text{ mm}$ and $\geq \emptyset$;
- vertically : $\geq d_g, \geq 10 \text{ mm}$ and $\geq \emptyset$.

4.2.1.1.2 Transversal bars

Transverse reinforcement is not required in slabs up to 1 200 mm wide. Slabs having a width greater than 1 200 mm must have transverse reinforcement designed to suit the loading requirements. The minimum transverse reinforcement shall be 5 mm diameter bars at 500 mm centres.

4.2.1.2 Tensioning and prestressing

4.2.1.2.1 Common requirements for the distribution of prestressing tendons

The following requirements shall be fulfilled:

- a) the tendons shall be distributed uniformly across the width of the elements;
- b) in every width of 1,20 m at least four tendons shall be applied;
- c) in every element of a width greater than 0,60 m and less than 1,20 m, at least three tendons shall be applied;
- d) in every element with a width of 0,60 m or less at least two tendons shall be applied;
- e) the minimum clear spacing between tendons shall be:
 - horizontally : $\geq (d_g + 5 \text{ mm}), \geq 20 \text{ mm}$ and $\geq \varnothing$;
 - vertically : $\geq d_g, \geq 10 \text{ mm}$ and $\geq \varnothing$.

4.2.1.2.2 Transfer of prestress

Clause 8.10.2.2 of EN 1992-1-1:2004 shall apply:

NOTE “Good” bond conditions are obtained for extruded and slip-formed elements. For the description of “good” and “poor” bond conditions, see Figure 8.2 of EN 1992-1-1:2004.

4.3 Finished product requirements

4.3.1 Geometrical properties

4.3.1.1 Production tolerances

4.3.1.1.1 Dimensional tolerances related to structural safety

The maximum deviations, measured in accordance with 5.2, on the specified nominal dimensions shall satisfy the following requirements:

- a) slab depth:
 - $h \leq 150 \text{ mm}$: $- 5 \text{ mm}, + 10 \text{ mm}$;
 - $h \geq 250$: $\pm 15 \text{ mm}$;
 - $150 \text{ mm} < h < 250 \text{ mm}$: linear interpolation may be applied;
- b) nominal minimum web thickness:
 - individual web (b_w): $- 10 \text{ mm}$;
 - total per slab (Σb_w): $- 20 \text{ mm}$;
- c) nominal minimum flange thickness (above and underneath cores):
 - individual flange: $- 10 \text{ mm}, + 15 \text{ mm}$;

d) vertical position of reinforcement at tensile side:

- individual bar, strand or wire: $h \leq 200 \text{ mm} \pm 10 \text{ mm};$
 $h \geq 250 : \pm 15 \text{ mm};$
 $200 \text{ mm} < h < 250 \text{ mm}$: linear interpolation may be applied;
- mean value per slab: $\pm 7 \text{ mm};$
- the requirement in this paragraph shall not conflict with subclause 4.3.1.2.3 of this standard.

4.3.1.1.2 Tolerances for construction purposes

The maximum deviations, unless declared otherwise by the manufacturer, shall satisfy the following:

a) slab length: $\pm 25 \text{ mm};$

A3

b) slab width:

- general $\pm 5 \text{ mm};$
- in case of fitting slabs $\pm 25 \text{ mm};$ **A3**

c) slab width for longitudinally sawn slabs : $\pm 25 \text{ mm};$

A3

d) length of protruding strands.

The minus deviation from the measured length of the protruding part of the protruding strand in regard to the nominal (design) value:

- 10 mm.

This value may be increased with half of the actual deviation (positive) of the measured slab length (a)). **A3**

4.3.1.1.3 Tolerances for concrete cover

A1 The maximum deviation for concrete cover shall be $\Delta c = -10 \text{ mm}$. A more stringent tolerance may be declared by the manufacturer. **A1**

4.3.1.2 Minimum dimensions

Complementary to 4.3.1.2 of EN 13369:2004 next subclauses shall apply.

4.3.1.2.1 Thickness of webs and flanges

The nominal thickness specified on the drawings shall be at least the minimum thickness increased by the maximum deviation (minus tolerance) declared by the manufacturer.

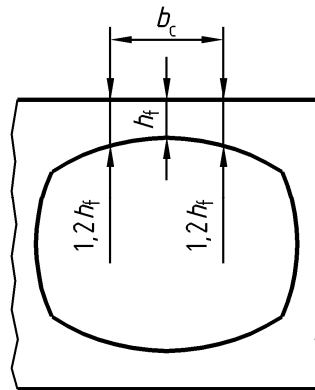
The minimum thickness shall be:

- for any web, not less than the largest of $h/10$, 20 mm and $(d_g + 5 \text{ mm})$, where d_g and h are in millimetres;

- for any flange, not less than the largest value of $\sqrt{2h}$, 17 mm and $(d_g + 5 \text{ mm})$, where d_g and h are in millimetres; however for the upper flange, not less than $0,25 b_c$, where b_c is the width of that part of the flange in which the greatest thickness is not greater than 1,2 times the smallest thickness (see Figure 2).

Thickness of webs and flanges shall be measured in accordance with 5.2.1.1.

Ⓐ₂



Ⓐ₂

Figure 2 — Minimum thickness of upper flange

4.3.1.2.2 Minimum concrete cover and axis distances of prestressing steel

For indented wires or smooth and indented strands, the minimum concrete cover $c_{\min}$ to the nearest concrete surface and to the nearest edge of a core shall be at least:

- only with respect to the exposed face, the one determined in accordance with 4.4.1.2 of EN 1992-1-1:2004 shall apply;
- for preventing longitudinal cracking due to bursting and splitting and in the absence of specific calculations and/or tests:

- Ⓐ₁ a) when the nominal centre to centre distance of the strands is $\geq 3 \varnothing$: $c_{\min} = 1,5 \varnothing$;
- b) when the nominal centre to centre distance of the strands is $< 2,5 \varnothing$: $c_{\min} = 2,5 \varnothing$;

where $\varnothing$ is the strand or wire diameter, in millimetres (in the case of different diameters, the average value shall be used for $\varnothing$).

For intermediate centre to centre distance, $c_{\min}$ may be derived by linear interpolation between the values defined in a) and b).

For ribbed wires, the concrete cover shall be increased by $1 \varnothing$. Ⓐ₁

4.3.1.2.3 Minimum concrete cover of reinforcing steel

Clause 4.4.1.2 of EN 1992-1-1:2004 shall apply.

4.3.1.2.4 Longitudinal joint shape

The longitudinal joint width shall be:

- at least 30 mm at the top of the joint;
- greater than the larger value of 5 mm or d_g at the lower part of the joint, where d_g is the maximum aggregate size in the joint grout.

If tie bars, with a diameter of $\varnothing$, are to be placed and anchored in the longitudinal joint, the width of the joint at the tie bar level shall be at least equal to the larger of $(\varnothing + 20 \text{ mm})$ or $(\varnothing + 2 d_g)$, where d_g and $\varnothing$ are in millimetres.

When the longitudinal joint has to resist vertical shear, the joint face shall be provided with at least one groove.

The size of the groove shall be appropriate with regard to the resistance of the grout against vertical shear.

The height of the groove shall be at least 35 mm, and its depth at least 8 mm. The distance between the top of the groove and the top of the element shall be at least 30 mm. The distance between the bottom of the groove and the bottom of the element shall be at least 30 mm.

Typical shapes of longitudinal joints are given in Annex B.

4.3.1.2.5 Vertical grooves shape

The shape of possible vertical grooves used to improve the diaphragm action shall be appropriate with regard to the resistance of the grout against horizontal shear. A typical shape of vertical grooves is given in Annex B.

In any case vertical grooves shall not be compulsory for diaphragm action, but only an additional provision. 

4.3.2 Surface characteristics

Requirements given in 6.2.5 of EN 1992-1-1:2004 shall apply for hollow core slabs intended to be used with an in situ topping.

4.3.3 Mechanical resistance

4.3.3.1 General

Complementary to 4.3.3 of EN 13369:2004 the following subparagraphs shall apply.

Where relevant, consideration should be given in the design to the effects of dynamic actions (e.g. impulse) during transient situations. In the absence of a more rigorous analysis this may be allowed for by multiplying the relevant static effects by an appropriate factor. For the effects of seismic actions, appropriate design methods should be used.

Special rules for structures with hollow core elements are presented in annexes about load distribution (Annex C), diaphragm action (Annex D), negative moments (Annex E), shear capacity of composite members (Annex F) and design of connections (Annex H).

 The test method for confirmation of the shear resistance is given in Annex J. 

4.3.3.2 Verification by calculation

4.3.3.2.1 Resistance to spalling for prestressed hollow core slabs

Visible horizontal  spalling  cracks in the webs are not allowed.

Applying one of the requirements in a) or b) hereafter prevents  spalling  cracks:

- a) for the web in which the highest σ_{sp} spalling σ_{ct} stress will be generated, or, for the whole section if the strands or wires are essentially well distributed over the width of the element, the σ_{sp} spalling σ_{ct} stress σ_{sp} shall satisfy the following condition:

$$\sigma_{sp} \leq f_{ct}$$

$$\text{with } \sigma_{sp} = \frac{P_o}{b_w e_o} \times \frac{15 \alpha_e^{2,3} + 0,07}{1 + \left(\frac{\ell_{pt1}}{e_o} \right)^{1,5} \left(1,3 \alpha_e + 0,1 \right)}$$

$$\text{and } \alpha_e = \frac{(e_o - k)}{h} \geq 0$$

where

f_{ct} is the value of the tensile strength of the concrete deduced at the time that the prestress is released on the basis of tests;

P_o

is the initial prestressing force just after release in the considered web or the total prestressing force of the slab in case of solid slabs;

b_w is the thickness of the individual web or the total width b of the slab in case of a solid slab;

e_o is the eccentricity of the prestressing steel;

ℓ_{pt1}

is the lower design value of the transmission length;

k is the core radius taken equal to the ratio of the section modulus of the bottom fibre and the net area of the cross section (W_b/A_c);

- b) a fracture-mechanics design shall prove that cracks will not develop.

4.3.3.2.2 Shear and torsion capacity

4.3.3.2.2.1 General verification procedure

Shear failure of hollow-core slabs without shear reinforcement may occur in regions cracked by bending or in regions uncracked by bending. If a flexural crack arises within the anchorage length of the reinforcement, an anchorage failure can also occur. All the three failure modes shall be considered.

- 1) Shear resistance in cracked regions shall be calculated using EN 1992-1-1:2004, Expressions (6.2.a) and (6.2.b).
- 2) Shear resistance in uncracked regions shall be calculated using EN 1992-1-1:2004, Expression (6.4), taking into account, when relevant, the additional shear stresses due to the transmission of the prestressing force and referring to the most unfavourable position in the cross section. A procedure to apply this calculation is given in 4.3.3.2.2.2 and 4.3.3.2.2.3.

NOTE A guidance on the calculation of the additional shear stresses in the anchorage zones of prestressing tendons can also be found in CEB-FIP Model Code 90, clause 6.9.12.

- 3) Resistance against anchorage failure shall be calculated following EN 1992-1-1:2004, 9.2.1.4.

In case of flexible supports, the reducing effect of transversal shear stresses on the shear resistance shall be taken into account.

For hollow-core slabs deeper than 450 mm the shear strength, both for regions cracked and uncracked by bending, shall be reduced by 10 % with respect to the equations and procedures quoted above.

4.3.3.2.2 Shear resistance in uncracked regions

Regions uncracked by bending are defined by a flexural tensile stress smaller than $f_{ctk0,05}/\gamma_c$. Here, the shear resistance shall be calculated with the following equation:

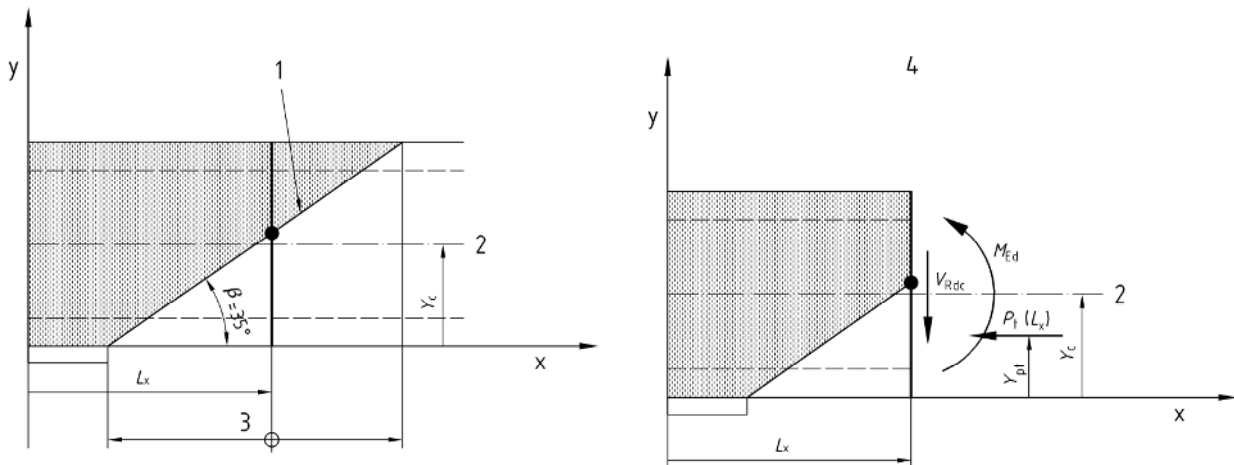
$$V_{Rdc} = \frac{I b_w(y)}{S_c(y)} \left(\sqrt{(f_{ctd})^2 + \sigma_{cp}(y) f_{ctd}} - \tau_{cp}(y) \right)$$

where

$$\sigma_{cp}(y) = \sum_{i=1}^n \left\{ \left[\frac{1}{A} + \frac{(Y_c - y)(Y_c - Y_{pt})}{I} \right] \times P_t(l_x) \right\} - \frac{M_{Ed}}{I} \times (Y_c - y) \quad (\text{positive if compressive})$$

$$\tau_{cp}(y) = \frac{1}{b_w(y)} \times \sum_{i=1}^n \left\{ \left[\frac{A_c(y)}{A} - \frac{S_c(y) \times (Y_c - Y_{pt})}{I} + C p_t(y) \right] \times \frac{dP_t(l_x)}{dx} \right\}$$

This equation shall be applied with reference to the critical points of a straight line of failure rising from the edge of the support with an angle $\beta = 35^\circ$ with respect to the horizontal axis. The critical point is the point on the quoted line where the result of the expression of V_{Rdc} is the lowest.



Key

- 1 line of failure
- 2 height of centroidal axis
- 3 considered cross-section
- 4 forces in considered cross-section

Figure 3 a) Line of failure

Figure 3 b) Forces and moments in considered cross-section

Figure 3 — Shear structure in uncracked regions

The definition of symbols is given here below.

I	is the second moment of area of the cross section
$b_w(y)$	is the web width at the height y
Y_c	is the height of the centroidal axis
$S_c(y)$	is the first moment of the area above height y and about the centroidal axis
y	is the height of the critical point on the line of failure
l_x	is the distance of the considered point on the line of failure from the starting point of the transmission length (= x)
$\sigma_{cp}(y)$	is the concrete compressive stress at the height y and distance l_x
n	is the number of tendon layers
A	is the fictive cross section surface
$P_t(l_x)$	is the prestressing force in the considered tendon layer at distance l_x . The transfer of prestress shall be taken into account according to EN 1992-1-1:2004, 8.10.2.2
M_{Ed}	is the bending moment due to the vertical load
$\tau_{cp}(y)$	is the concrete shear stress due to transmission of prestress at height y and distance l_x
$A_c(y)$	is the area above height y
$C_{pt}(y)$	is a factor taking into account the position of the considered tendon layer $C_{pt} = -1$ when $y \leq Y_{pt}$ $C_{pt} = 0$ when $y > Y_{pt}$
Y_{pt}	is the height of the position of considered tendon layer

4.3.3.2.2.3 Simplified expression

As an alternative to the above equation, the following simplified equation may be applied

$$V_{Rdc} = \phi \frac{I b_w}{S} \sqrt{(f_{ctd})^2 + \beta \alpha_\ell \sigma_{cp} f_{ctd}}$$

where

- I is the second moment of area;
- S is the first moment of area above and about the centroidal axis
- b_w is the width of the cross-section at the centroidal axis,
- $\alpha_\ell = l_x / l_{pt2}$ is the degree of prestressing transmission ($\alpha_\ell \leq 1,0$);
- l_x is the distance of the considered section from the starting point of transmission length;
- l_{pt2} upper value of transmission length (see EN 1992-1-1:2004, Expression (8.18));
- $\sigma_{cp} = N_{Ed}/A$ is the full concrete compressive stress at the centroidal axis,

$f_{ctd} = f_{ctk0,05}/\gamma_c$ is the design value of tensile strength of concrete;

$\varphi = 0,8$ reducing factor;

$\beta = 0,9$ reducing factor referred to transmission length.

Sections between the edge of the support and the section at a distance $0,5h$ from this edge (where h is the depth of the section), need not to be checked. A3

4.3.3.2.2.4 A3 Shear capacity of elements subjected to torsion

If a section is subjected simultaneously to shear and torsion, the shear capacity V_{Rdn} shall be calculated in the absence of particular justifications as follows:

$$V_{Rdn} = V_{Rd,c} - V_{Ed}$$

in which V_{Ed} is

$$V_{Ed} = \frac{T_{Ed}}{2b_w} \times \frac{\sum b_w}{(b - b_w)} \quad \text{for hollow-core elements}$$

or

$$V_{Ed} = T_{Ed} \times \frac{(3 + 1,8 \times b/h)}{b} \quad \text{for solid elements}$$

where

V_{Rdn} is the net value of the shear resistance, in newtons;

$V_{Rd,c}$ is the design value of shear resistance according to 6.2.2 of EN 1992-1-1:2004, in newtons;

V_{Ed} is the design value of acting shear force taking into account the torsional moment, in newtons;

T_{Ed} is the design value of the torsional moment in the considered section, in newtons millimetres;

b_w is the width of the outermost web at the level of the centroidal axis (see Figure 4), in millimeters;

$\sum b_w$ is the sum of width of the webs at the level of the centroidal axis, in millimeters.

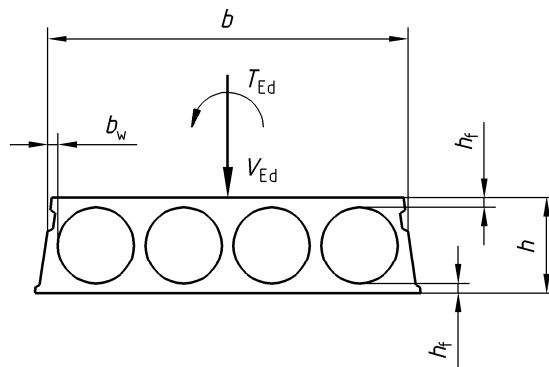


Figure 4 — Eccentric shear force $\langle A_3 \rangle$

4.3.3.2.3 Shear capacity of the longitudinal joints

Load distribution from an element to the adjacent element will cause vertical shear forces in the joint and the elements at both sides of the joint.

The shear capacity in this case depends on the properties of the joint and of the elements.

This shear capacity v_{Rdj} , expressed as resisting linear load, is the smaller value of the flange resistance v'_{Rdj} or the joint resistance v_{Rdj} :

$$v'_{Rdj} = 0,25 f_{ctd} \Sigma h_f$$

and

$$v''_{Rdj} = 0,15 (f_{ctdj} h_j + f_{ctdt} h_t)$$

where

f_{ctd} is the design value of the tensile strength of the concrete in the elements;

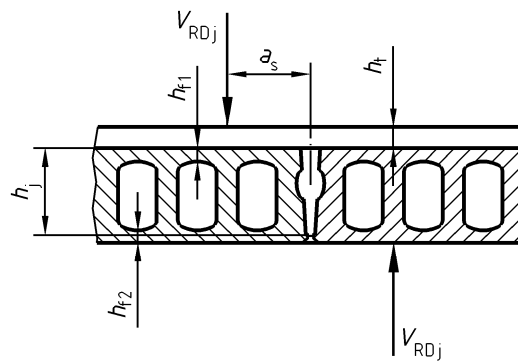
f_{ctdj} is the design value of the tensile strength of the concrete in the joints;

f_{ctdt} is the design value of the tensile strength of the concrete of the topping;

Σh_f is the sum of the smallest thicknesses of the upper and lower flange and the scaled thickness of the topping (see [A3] Figure 5 [A3]); [A1] where this scaled thickness is the nominal thickness of the topping multiplied by the ratio between the tensile strength of the topping and the tensile strength of the slabs; [A1]

h_j is the net height of the joint (see [A3] Figure 5 [A3]);

h_t is the thickness of the topping (see [A3] Figure 5 [A3]).



[A3] Figure 5 [A3] — Shear force in joints

The shear capacity V_{Rdj} expressed as resisting concentrated load, shall be calculated as follows:

$$V_{Rdj} = v_{Rdj} (a + h_j + h_t + 2 a_s)$$

where

v_{Rdj} is the smaller value of v'_{Rdj} or v_{Rdj} ;

a is the length of the load parallel to the joint ;

a_s is the distance between the centre of the load and the centre of the joint.

4.3.3.2.4 Punching shear capacity

In the absence of particular justifications, the punching shear capacity of slabs without topping V_{Rd} , in newtons, expressed as resisting point load, shall be calculated as follows:

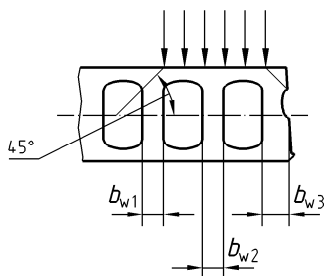
$$V_{Rd} = b_{ef} h f_{ctd} \left(1 + 0,3 \alpha \frac{\sigma_{cp}}{f_{ctd}} \right)$$

with $\alpha = \frac{\ell_x}{\ell_{bpd}} \leq 1$ according to 6.2.2 of EN 1992-1-1:2004

where

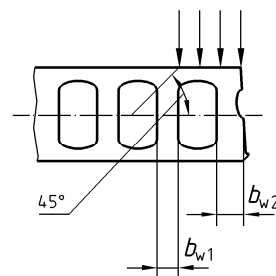
b_{eff} is the effective width of the webs according to **Figure 6**;

σ_{cp} is the concrete compressive stress at the centroidal axis due to prestressing.



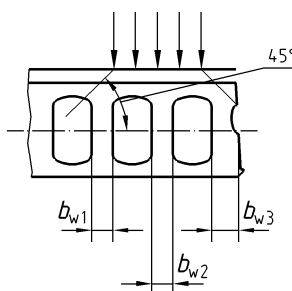
$$b_{\text{eff}} = b_{w1} + b_{w2} + b_{w3}$$

a) General situation



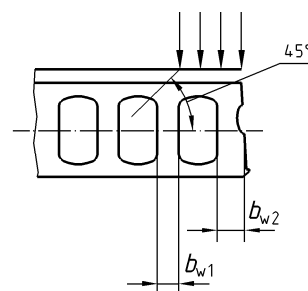
$$b_{\text{eff}} = b_{w1} + b_{w3}$$

b) Free edge of floor-bay



$$b_{\text{eff}} = b_{w1} + b_{w2} + b_{w3}$$

c) General situation with structural topping



$$b_{\text{eff}} = b_{w1} + b_{w3}$$

d) Free edge of floor-bay with structural topping

Figure 6 — Effective width

For concentrated loads of which more than 50 % is acting on outermost web (b_{w2} in **Figures 6 b) and 6 d)** of a free edge of a floor bay, the resistance resulting from the equation is applicable only if at least one strand or wire in the outermost web and a transverse reinforcement are present. If one of these or both conditions are not satisfied, the resistance shall be divided by a factor of 2.

The transverse reinforcement shall be strips or bars at the top of the element or in the structural topping, with a length of at least 1,20 m and fully anchored, and shall be designed for a tensile force equal to the total concentrated load.

If a load above a core has a smaller width than half of the width of the core, a second resistance shall be calculated with the same equation, but in which h shall be replaced by the smallest thickness of the upper flange and b_{eff} by the width of the loading pad. The lowest value of the calculated resistances shall be applied.

If a structural topping is used, the thickness of the topping may be taken into account for calculation of punching shear capacity.

4.3.3.2.5 Capacity for concentrated loads

Concentrated loads will cause transverse bending moments. Since the elements have no transverse reinforcement the tensile stresses due to this bending moments shall be limited.

The limiting value depends on the basic design assumptions concerning load distribution.

If the elements are designed assuming no load distribution, which means that all loads acting on an element should be resisted by that element, the limiting value of the tensile stress is $f_{ctk\,0,05}$ in the serviceability limit state. In this case for elements without topping, in the serviceability limit state, the capacities for concentrated loads q_k and F_k are calculated in the absence of particular justifications as follows:

— for a linear load not on an edge of a floor area: $q_k = \frac{20W_{\ell b} f_{ctk\,0,05}}{\ell + 2b}$

— for a linear load on an edge of a floor area: $q_k = \frac{10W_{\ell t} f_{ctk\,0,05}}{\ell + 2b}$

— for a point load anywhere on a floor area: $F_k = 3 W_{\ell} f_{ctk\,0,05}$

where

$W_{\ell b}$ is the minimum section modulus in transverse direction per unit length related to the bottom fibre of the elements;

$W_{\ell t}$ is the minimum section modulus in transverse direction per unit length related to the top fibre;

W_{ℓ} is the smaller of $W_{\ell b}$ or $W_{\ell t}$.

If the elements are designed by assuming load distribution according to the elastic theory, which means that a part of the loads acting on one element are distributed to adjacent elements, the limiting value of the tensile stress is f_{ctd} in the ultimate limit state.

The capacities for concentrated loads in this case, in the ultimate limit state, may be derived from the same equation, but in which q_k , F_k and $f_{ctk\,0,05}$ shall be replaced by q_d , F_d and f_{ctd} .

4.3.3.2.6 Load capacity of elements supported on three edges

Distributed imposed loads on an element of the floor with one supported longitudinal edge will cause torsional moments. The resulting support reaction due to this torsion shall be ignored in the design in the ultimate limit state.

The shear stresses due to these torsional moments shall be limited to $f_{ctk\,0,05}/1,5$ in the serviceability limit state.

A3 The load capacity q_k , in newtons per millimeter, for imposed load per unit area which is the total load minus the load due to the self weight of the elements, shall be calculated, in the serviceability limit state, as follows:

$$q_k = \frac{f_{ctk\,0,05} W_t}{0,06\ell^2}$$

in which W_t is the lower value of

$$W_t = 2t(h - h_f)(b - b_w)$$

and

$$W_t = \frac{b^2 h}{(3 + 1,8b/h)},$$

where

W_t is the torsional section modulus of an element according to the elastic theory, in cubic millimetres;

t is the smallest of the values of h_f and b_w , in millimetres;

h_f is the smallest value of the upper or lower thickness of the flange;

b_w is the thickness of the outermost web, in millimeters;

L is the length of the element. $\langle A_3 \rangle$

4.3.3.3 $\langle A_2 \rangle$ Verification by calculation aided by physical testing

The shear resistance obtained by calculation shall be confirmed by physical full scale testing according to Annex J. $\langle A_2 \rangle$

4.3.4 Resistance and reaction to fire

4.3.4.1 Resistance to fire

$\langle A_3 \rangle$ Complementary to EN 13369:2004, 4.3.4.1 to 4.3.4.3 the calculation method and tabulated data is given in Annex G. In absence of national rules concerning shear capacity under fire conditions, additional rules can be found in the Annex G. $\langle A_3 \rangle$

$\langle A_3 \rangle$ NOTE The fire resistance given for a hollow core element (load bearing function) is valid when installed in a floor structure with necessary tying system according to EN 1992-1-1:2004, unless additional measures are taken. For separating function of hollow core slab floors, insulation (for minimum thickness see Annex G) and integrity (for joints see EN 1992-1-2:2004, 4.6) are additionally required. The topping or screed cast directly on the precast unit may be taken into account in the fire resistance of the floor for the separating function. $\langle A_3 \rangle$

4.3.4.2 Reaction to fire

For reaction to fire, 4.3.4.4 of EN 13369:2004 shall apply.

4.3.5 Acoustic properties

Clause 4.3.5 of EN 13369:2004 shall apply.

NOTE The impact sound insulation of a building is influenced by the total floor structure, including floor-covering, support conditions, joint details and walls.

4.3.6 Thermal properties

Complementary to 4.3.6 of EN 13369:2004 the following rules may apply.

A rough approximation of the thermal resistance of hollow core slabs (height > 0,2 m) may be estimated as follows:

$$R_c = 0,35 (h + 0,25)$$

where

R_c is the thermal resistance of the slabs (exclusive $\boxed{A_1}$ surface $\boxed{A_1}$ resistance), in square metres Kelvins per Watt;

h is the total height of the elements, in metres.

4.3.7 Durability

Clause 4.3.7 of EN 13369:2004 shall apply.

4.3.8 Other requirements

Clause 4.3.8 of EN 13369:2004 shall apply.

5 Test methods

5.1 Tests on concrete

Clause 5.1 of EN 13369:2004 shall apply.

5.2 $\boxed{A_3}$ Tests on pre-stressing steel

In case of thermal pre-stressing, all additional tests described in Annex K shall apply. $\boxed{A_3}$

5.3 Measuring of dimensions and surface characteristics

Complementary to 5.2 of EN 13369:2004 the following subclauses shall apply.

5.3.1 Element dimensions

5.3.1.1 Procedure

For the dimensions hereafter, the indicated procedures shall be applied:

a) slab depth h :

Take six measurements at one end of the slab (three at core and three at web centre lines): two near the middle, two near each edge of the slab. The result is the mean of these six measurements. Compare the result with the permissible values according to 4.3.1.1.1 a).

For elements not wider than 0,6 m, the number of measurements may be decreased to three.

b) web thickness b_w :

Take measurements of the minimum thickness of each web at one end of the slab.

Sum up the measurements.

Compare each individual value b_w and the total sum Σb_w with the permissible values according to 4.3.1.1.1 b).

c) flange thickness h_f :

Take six measurements at one end of the slab (three at lower flange, three at upper flange): two near the middle, two near each edge of the slab.

Calculate the mean value for lower flange and for upper flange values separately.