EUROPEAN ASSESSMENT DOCUMENT

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PRECAST BALCONY ELEMENTS MADE OF ULTRA HIGH PERFORMANCE FIBRE REINFORCED CONCRETE (UHPFRC)

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This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) No 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

Contents

1 Scope of the EAD

1.1 Description of the construction product

This EAD is applicable to precast balcony elements made from ultra-high performance fibre reinforced concrete (UHPFRC).

The product is not covered by a harmonised European standard (hEN).

This EAD covers the assessment of the precast UHPFRC balcony elements of variable size, shape, and design as basis for the structural design and production of the elements. The elements are cast in one operation and cured at the precast factory before they are transported to the building site and installed.

Common for all balcony types covered are:

- Constituent materials are generally according to EN 206 and especially the cement part is according to EN 197-1.
- They all consist of fibre reinforced concrete with a compressive strength above 110 MPa, which is outside the scope of EN 1992-1-1 (EC2).
- They are designed according to the principles of EC2, but with a few deviations based on UHPFRC material design. Examples of these deviations, made possible by the increased ductility of the UHPFRC compared to traditional concrete, are higher compressive design strength, lower rebar cover, shorter anchorage length and higher tensile strength. The specific composition of the concrete is deposited with the Technical Assessment Body handling the ETA application.

  Where the material properties/data differ from the scope of EC2, this is described in this EAD including the tests and the necessary performance and documentation requirements. Annex C comments on the background for selected performance requirements defined in this EAD.
- The precast UHPFRC balcony elements shall be reinforced with conventional reinforcement mesh typically placed in two layers. Reinforcement shall be class B500 as minimum and comply with EN 10080 as well as EC2.
- Furthermore, the balcony elements are reinforced with steel fibres. The steel fibres provide ductility, anchorage capacity and improved cracking performance to the material. The steel fibres do not constitute structural reinforcement.
- Steel fibres shall comply with EN 14889-1. They may be stainless or carbon steel with a minimum tensile strength of 1200 MPa, a maximum length of 30 mm and a fibre diameter up to 0.4 mm.
- The precast UHPFRC balcony elements may contain structural ribs and/or integrated beams with localised reinforcement.
- The sizes of the precast elements are normally governed by the lifting and transport capacity during installation. There is no limit to the size from a structural point of view.

All brackets, fastenings, bannisters etc. are designed, produced and installed according to relevant standards (e.g. steel, aluminium, glass. etc.) and are not covered by this EAD. Anchorage of the precast balcony unit into the building facade, is designed according to principles in EC2. The design for avoidance of thermal bridge between the precast element and the building is not covered by the EAD.

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary. The manufacturer is responsible for documenting how to handle and transport the product. This includes position of lifting hooks, support lines during transport, stacking height, stability during storage, etc.

As part of the product description the manufacturer provides information about the curing of the product after casting it. This includes information for protection against drying out, exposure to freezing temperatures and other detrimental weather exposures.

It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals. The manufacturer specifies that the placement and installation of the product shall be in accordance with EN 13670, clause 9.5. The manufacturer specifies as part of the product description the necessary minimum maturity prior to installation, to avoid problems with shrinkage and creep of the product as well as explosive spalling during fire exposure. Furthermore, any need for interim supports, will be specified by the manufacturer.

Relevant stipulations from the manufacturer, having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA.

Figs. 1-3 give examples of balcony types.

Figure 1: Cantilevered balcony elements ready for installation. The cantilevered flaps are cast monolithically as part of the element for attachment to the building floor.

Figure 2: Cantilevered balcony element placed on corbels in the bottom of the deck and with bolted connections transferring tensile forces into the façade from the top of the balcony upstands.

Fig. 3: a) Balcony elements partly supported by columns. b) The outer edge of the balcony element contains an integrated beam/rib.

The design of the product is based on the principles in EC2, but with a few deviations as mentioned earlier. The design loads and the safety factors are provided in Eurocodes 0 and 1.

The design of the fastenings between the product and the building façade are carried out according to the relevant Eurocodes, harmonized product standards, ETA´s, etc. This also applies for the support columns including foundations. These elements are not included in this EAD.

The deviations from EC2 design principles and those valid for precast UHPFRC balcony elements are specified in this EAD, clause 2.

Manufacturing of precast balcony elements are performed in accordance with EN 14650 and EN 13369 or similar standard – with the deviations specifically mentioned in this EAD.

1.2 Information on the intended use(s) of the construction product

1.2.1 Intended use(s)

The precast UHPFRC balcony element is used as outdoor balconies for houses subject to outdoor exposures. Environmental exposure classes given in EN 206 may be used to describe the exposure conditions. The assessment methods in this EAD are based on exposure class XC4 in EN 206.

The product is only intended to be used subjected to static or quasi-static load actions as cantilevered or simply supported exterior balconies. The product shall not be subjected to fatigue loading.

1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer’s request to take into account a working life of the UHPFRC balcony element for the intended use of 50 years when installed in the works (provided that the UHPFRC balcony elements are subject to appropriate installation (see 1.1). These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[1].

The indications given as to the working life of the construction product cannot be interpreted as a guarantee given by neither the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

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[1] The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subject, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than the assumed working life.

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2 Essential characteristics and relevant assessment methods and criteria

2.1 Essential characteristics of the product

Table 1 shows how the performance of the UHPFRC balcony element is assessed in relation to the essential characteristics.

Table 1 Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance *(level, class, description)*
Basic Works Requirement 1: Mechanical resistance and stability			
1	Compressive strength	2.2.1	Level
2	Compressive stress-strain curve	2.2.2	Description
3	E-modulus	2.2.3	Description and level
4	Tensile and bending strength (3-point bending curve)	2.2.4	Level
5	Uniaxial tensile strength	2.2.5	Level
6	Rebar anchorage length	2.2.6	Description and level
7	Creep and shrinkage behaviour	2.2.7	Level
8	Freeze/thaw resistance	2.2.8	Description and level
9	Chloride ingress (on cracked beams)	2.2.9	Description and level
10	Carbonation depth	2.2.10	Description and level
11	Fibre distribution	2.2.11	Level
Basic Works Requirement 2: Safety in case of fire			
12	Reaction to fire	2.2.12	Class
13	Resistance to fire	2.2.13	Description
14	Risk of explosive spalling	2.2.14	Description

2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

Characterisation of products to be assessed shall be done in accordance with available specifications, notably the assessed compressive strength of the UHPFRC, the mix composition of the UHPFRC, the type and dosage of steel fibres and the tensile performance of the UHPFRC measured on three-point bending test samples.

The basis for the assessment is the principles for calculation of concrete elements according to the principles of EC2. The methods in EC2 are modified to take into account the compressive strength of the UHPFRC and the ductility provided by the added steel fibres.

The calculation models are verified by means of full-scale tests, see annex E. This is done as part of the assessment of the product. The extent of full scale testing is described in the ETA and reflect the type of balcony elements and the structural behaviour of the elements covered by the ETA.

2.2.1 Compressive strength

The main property for product is the compressive strength of the UHPFRC. The minimum characteristic strength to be applied according to this EAD is 110 MPa.

The potential compressive strength is tested according to EN 12390-3 and determined in accordance with EN 13369.

For this purpose, cubic test specimens ø100x200 mm and ø150 mm cylinder are used. Testing is performed on 5 cubes and 5 cylinders according to EN12390-3. Samples must be water cured at 20ºC ± 2ºC until testing after 28 days.

The direct structural strength is determined in accordance with EN 13369 and stated in the ETA.

2.2.2 Compressive stress-strain curve

The assessment of the products shall include a determination of the complete uniaxial compressive stress-strain relationship (full stress-strain curve including the softening part after the peak load). Testing up to maximum load is performed in accordance with EN 12390-3, but using deformation control – measuring either the displacement of the test machine, the compression of the test specimen or the dilation of the mid-section of the test specimen. After maximum load the rate of deformation is maintained at the same level or slower.

The stress level at strains of 4 per mille is stated in the ETA as a % of the value of the compressive strength (f_{cm}), cf. annex C.

2.2.3 E-modulus

The secant E-modulus of the UHPFRC matrix shall be tested according to EN 12390-13 method A.

E-modulus shall be stated in the ETA.

2.2.4 Tensile and bending strength (3-point bending)

The tensile strength characteristics of the concrete used to manufacture the balcony elements is assessed by means of three-point bending on notched test beams are used to define the ductility of the UHPFRC and the performance of the steel fibres.

The deformation controlled three-point bending test shall be used to categorise the tensile ductility class according to the principles presented in fib Model Code 2010, section 5.6.3. Furthermore the manufacturer shall declare the fibre index ($V_f \times L_f / d_f$) to quantify the performance of the steel fibre. The minimum fibre index is 0.6.

Tensile strength is tested according to EN 14651.

The tensile ductility class for the UHPFRC material according to fib Model Code 2010, section 5.6.3 is stated in the ETA.

2.2.5 Uniaxial tensile strength

The LOP from the 3-point bending test described in 2.2.4 is used to model the uniaxial tensile strength based on equation 5.1-8 in the fib Model Code 2010. Alternatively, the uniaxial tensile strength can be assessed experimentally.

The uniaxial tensile strength in MPa is stated in the ETA.

2.2.6 Rebar anchorage length

The assessment of the rebar anchorage length is carried out as described in annex G.

The minimum anchorage length is given in the ETA as a function of the fibre content, transverse reinforcement, and the cover depth.

2.2.7 Creep and shrinkage behaviour

Creep deformations of the concrete used to manufacture the balcony elements are assessed as part of the assessment of the long term deformations of the balcony elements.

Creep shall be determined according to the standard test method described in ASTM C512. At the same time shrinkage shall be determined according to annex D.

Creep and shrinkage behaviour are given in the ETA.

2.2.8 Freeze/thaw resistance

The freeze-thaw resistance is tested according to CEN/TR 15177 and CEN/TS 12390-9.

The amount of scaling after 56 freeze-thaw cycles, m56, tested according to CEN/TS 12390-9:2006, in g/m^2 is stated in the ETA.

The residual relative dynamic modulus of elasticity (RDM) by using ultrasonic pulse transmit time or fundamental transverse frequency after 56 freeze-thaw cycles in % of the reference value is stated in the ETA.

2.2.9 Chloride ingress

The purpose of the characteristic is to assess that the chloride ingress is independent of the loading level in the test, and concerns the durability of the balcony element.

Resistance to chloride ingress shall be tested using a special test rig mounted with a pre-cracked specimen subject to chloride solution. The test method is described in Annex A of this document.

The maximum rate of chloride ingress after pre-cracked testing shows the effective chloride transport coefficients. The coefficient is stated in the ETA in m^2/s.

The manufacturer stipulates that the chloride ingress is independent of the loading level in the test.

2.2.10 Carbonation depth

Carbonation resistance shall be determined according to CEN/TS 12390-10 or equivalent. The carbonation depth after 2 years of exposure is stated in the ETA and is below 1.0 mm as it relates to the expected working life of 50 years.

2.2.11 Fibre distribution

The fibres are not used as structural reinforcement in the balcony elements, but are necessary in order to provide ductility and a minimum tensile capacity to the matrix. Assessment of fibre distribution and orientation is carried out according to the method described in Annex F.

The uniaxial tensile strength of the matrix in the weakest part of the element is stated in the ETA.

2.2.12 Reaction to fire

The precast UHPFRC balcony element is considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire in accordance with the Decision 1996/603/EC (as amended) without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, the performance of the product is A1.

2.2.13 Resistance to fire

The part of the works or assembled system in which the precast UHPFRC balcony element is intended to be incorporated, installed or applied shall be tested, using the test method relevant for the corresponding fire resistance class, in order to be classified according to the appropriate part of EN 13501.

If – after the initial full scale fire tests - calculations are used to demonstrate the required fire resistance, the heat capacity and heat transport can be determined experimentally, or alternatively the temperature curves can be determined from tests, where thermocouples are installed at various depths in concrete elements, which are then exposed to a standard fire (according to EN 13501). Standard values cannot be used without testing.

The part of the works or assembled system in which the precast UHPFRC balcony element is intended to be incorporated, installed or applied shall be classified according to the appropriate part of EN 13501-2.

2.2.14 Risk of explosive spalling

Risk of spalling shall be determined according to the method described in annex B.

UHPFRC must reach a certain maturity prior to installation in order to eliminate the risk of explosive spalling as a consequence of fire impact. The necessary maturity (alternatively moisture content) is determined through a test program, where test specimens are exposed to high temperatures according to annex B at different maturities.

A description of the risk of explosive spalling is given in the ETA.

3 Assessment and verification of constancy of performance

3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is: Decision 1999/94/EC

The system is: **2+**

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the precast UHPFRC balcony element in the procedure of assessment and verification of constancy of performance are laid down in Table 2. In addition to this, a factory control according to EN 14650 and EN 13369 will be carried out.

Table 2 Control plan for the manufacturer; cornerstones

No	Subject/type of control *(product, raw/constituent material, component - indicating characteristic concerned)*	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) including testing of samples taken at the factory in accordance with a prescribed test plan					
1	Compressive strength	2.2.1	Minimum 110 MPa	2	1/15m^3
2	Tensile and bending strength (3-point bending curve)	2.2.4	Minimum class 5b	3	2/year

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of verification of constancy of performance for precast UHPFRC balcony elements are laid down in Table 3.

Table 3 Control plan for the notified body; cornerstones

Subject/type of control *(product, raw/constituent material, component - indicating characteristic concerned)*	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control				
Initial inspection of the manufacturing plant and of factory production control carried out by the manufacturer	As defined in the control plan	As defined in the control plan	As defined in the control plan	As defined in the control plan
Continuous surveillance, assessment and evaluation of factory production control				
Continuous surveillance, assessment and evaluation of the factory production control carried out by the manufacturer	As defined in the control plan	As defined in the control plan	As defined in the control plan	As defined in the control plan

4 Reference documents

As far as no edition date is given in the list of standards thereafter, the standard in its current version at the time of issuing the European Technical Assessment, is of relevance.

EN 197-1 Cement - Part 1: Composition, specifications and conformity criteria for common cements

EN 206 Concrete - Specification, performance, production and conformity

EN 1992-1-1 + AC:2008 Eurocode 2: Design of concrete structures – Part 1-1 General rules and rules for buildings

EN 12390-3 + AC:2012 Testing hardened concrete - Part 3: Compressive strength of test specimens

CEN/TS 12390-9 Testing hardened concrete - Part 9: Freeze-thaw resistance – Scaling

CEN/TS 12390-10 Testing hardened concrete - Part 10: Determination of the relative carbonation resistance of concrete

EN 12390-13 Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression

EN 13369 Common rules for precast concrete products

EN 13501-2 + A1:2009 Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services

EN 13670 Execution of concrete structures

EN 14650 Precast concrete products – General rules for factory production control of metallic fibered concrete

EN 14651 + A1:2007 Test method for metallic fibre concrete, Measuring the flexural tensile strength (limit of proportionality (LOP), residual)

EN 14889-1 Fibres for concrete - Part 1: Steel fibres - definitions, specifications and conformity

CEN/TR 15177 Testing the freeze-thaw resistance of concrete - Internal structural damage

Fib Model Code 2010, Federation International du Beton, Lausanne, Switzerland, 2012

ASTM C512 - Standard Test Method for Creep of Concrete in Compression

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

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Annex A Test method for chloride ingress resistance

For very slender elements that will be highly stressed under service loads it is not sufficient to determine chloride ingress based on NT BUILD 443. The proposed test method differs in type of exposure, while interpretation of the results is carried out according to Fick’s Law similarly to NT BUILD 443.

The test method is based on ponding/exposure with a NaCl solution after pre-cracking the test specimen in order to accelerate the chloride ingress and in order to assess the sensitivity of the material durability towards cracks.

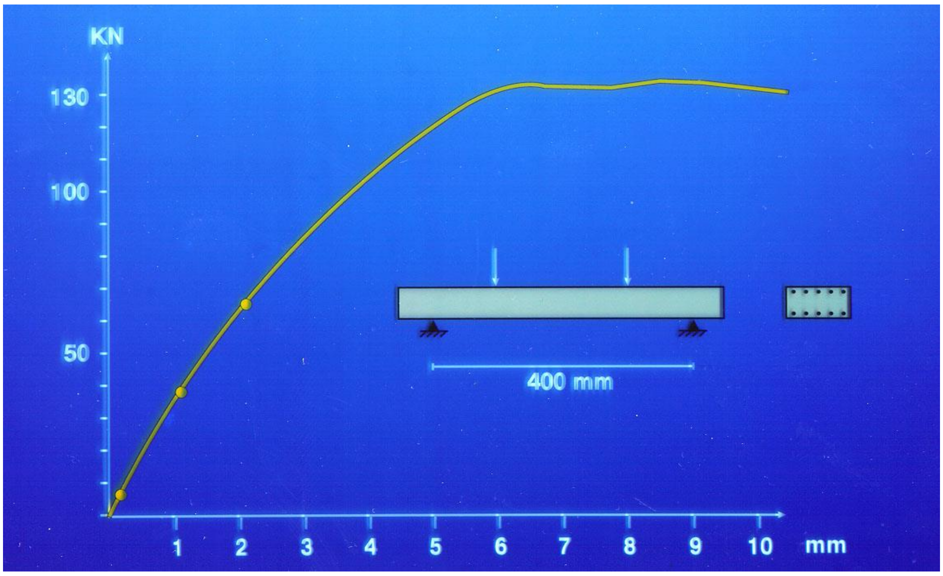

Figure A.1: Example of load-deflection curve for test beams.

Test specimens

A number of small test beams are cast including reinforcement. An example of beam size could be approximately 500 mm long beams with a width of 100 mm and a height of 50 mm and reinforced with 4 ø8 mm bars in top and bottom, having cover thickness of 10 mm (at least 4 ø8 bars should be present in the tensile face). The beams are subjected to four-point loading in a test frame. The two load points shall be applied with a 200 mm distance (Fig. A.2).

A schematic of the beams is shown in fig. A.1 along with a load-deflection curve. Based on the load-deflection curve from at least two reference tests up to the failure load, it is determined which load levels should be applied to the beams during chloride ingress testing. At least 2 load levels should be chosen:

- low load level corresponding to a situation with only a few micro cracks (corresponding to about 10 % of the failure load),
- high load level corresponding to 40 - 60 % of the failure load. At this level extensive micro cracking is expected to take place.

Pre-cracking of the test beams according to the above is carried out in a test rig as shown in fig. A.2, where a constant deflection is imposed according to the two above-mentioned load levels. After pre-cracking the beams are exposed to a chloride solution of 3,5 % NaCl by weight for a period of at least 6 months.

The age of the test beams at the time of pre-cracking shall be at least 4 weeks.

For each load level at least three test beams shall be exposed to chloride exposure.

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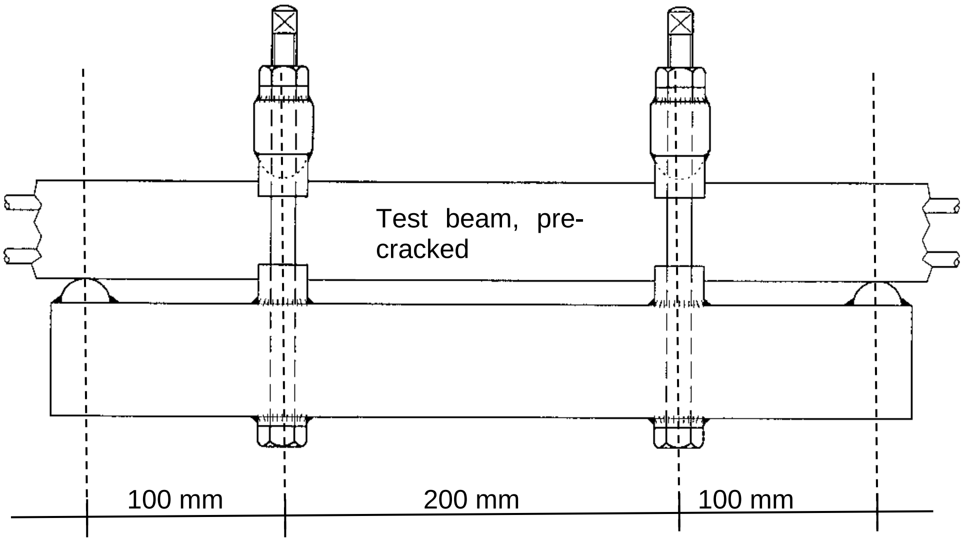

Figure A.2: Example of test frame layout for loading beams. The deflection of the mid-point section of the test beam is used to quantify the loading.

Exposure conditions

Exposure to chlorides could either be by ponding or by submerging the whole test rig (including test beam) into a NaCl solution. If the whole beam is submerged, exposure should be in a wetting/drying cycle, so that the beams are submerged for 3 days, dried in air for 4 days, submerged for 3 days, etc.

Only the pre-cracked face of the test beam shall be subject to the chloride solution. In case of submerged test the three other faces of the test beams shall be sealed effectively against chloride ingress by a suitable material.

In all cases the NaCl concentration is maintained at 3.5 % throughout the entire exposure period. The temperature of the NaCl solution and the temperature of the surroundings of the test shall be kept constantly at 23°C ± 2°C.

Exposure should be for at least 6 months before the first test results are determined.

Test results

The determination of the effective chloride transport coefficient follows the procedure in NT BUILD 443. Cores are taken from the test beam after the exposure period and the chloride content is determined according to NT BUILD 443. Grinding for determination of chloride levels should be carried out in steps not larger than 0.5 mm. At least 10 grinding depths shall be used. The content of the test report shall include the same information as described in NT BUILD 443.

The maximum rate of chloride ingress after pre-cracked testing are effective chloride transport coefficients and these are stated in the ETA. Coefficients less than $5 \cdot 10^{-14}$ m^2/s for the low load level can be considered as confirmation of the estimated working life according to section 1.2.2. In addition to this the chloride ingress must be relatively independent of the pre-cracking (load) level, meaning that the value at the high load level should not be more than 20% higher compared with that of the low load level in order to take into account the estimated working life.

Annex B Proposed test method for explosive spalling during fire exposure

Concrete cylinders (ø100x200 mm) are heated in a furnace to 700 °C and the residual strength is determined (after 1 week in laboratory conditions at approximately 20 °C). The concrete specimens should be intact after the heating cycle and at time of testing (no spalling/disintegration is allowed, but surface cracks and minor surface damage are acceptable).

At least 5 test specimens shall be tested as described above. Furthermore, 3 samples must be used to determine the reference compressive strength without prior exposure to the heat cycle.

Heating cycle

Heating shall be carried out in a furnace up to the maximum temperature of 700 °C at a rate of 20 ± 5 °C/minute. The maximum temperature is then maintained constantly (± 20 °C) for 4 hours duration before the furnace is turned off and left to cool down at its natural rate.

Prior to the heat cycle the test specimens should be prepared and cured similarly to how the precast UHPFRC balcony slabs are cured.

Test results

Immediately after the conclusion of the heat cycle, the cylinders are inspected visually and no signs of explosive spalling or disintegration of the samples must be present. However, minor degradation of the cylinder surfaces as well as cracking is allowable. Photos of all the test specimens are taken to register the amount of damage before they are subjected to the compressive strength test.

The compressive residual strength of the cylinders is measured together with the reference compressive strength. The storage/curing of the reference cylinders and the samples exposed to the heat cycle must be identical up to the time of compressive testing. The residual strength of the samples should be above 20 MPa.

The test report shall contain the following:

- identification of the test samples, number of samples, casting date, laboratory, etc.
- description of the storage conditions up to the heat cycle
- temperature curve from the furnace covering the full heat cycle
- visual registrations of the samples after the heat cycle including photos that document the findings
- individual compressive strengths as well as the mean value and the standard deviation both for the reference tests and the residual strength tests

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Annex C Comments for selected properties and tests

Compressive stress-strain curve

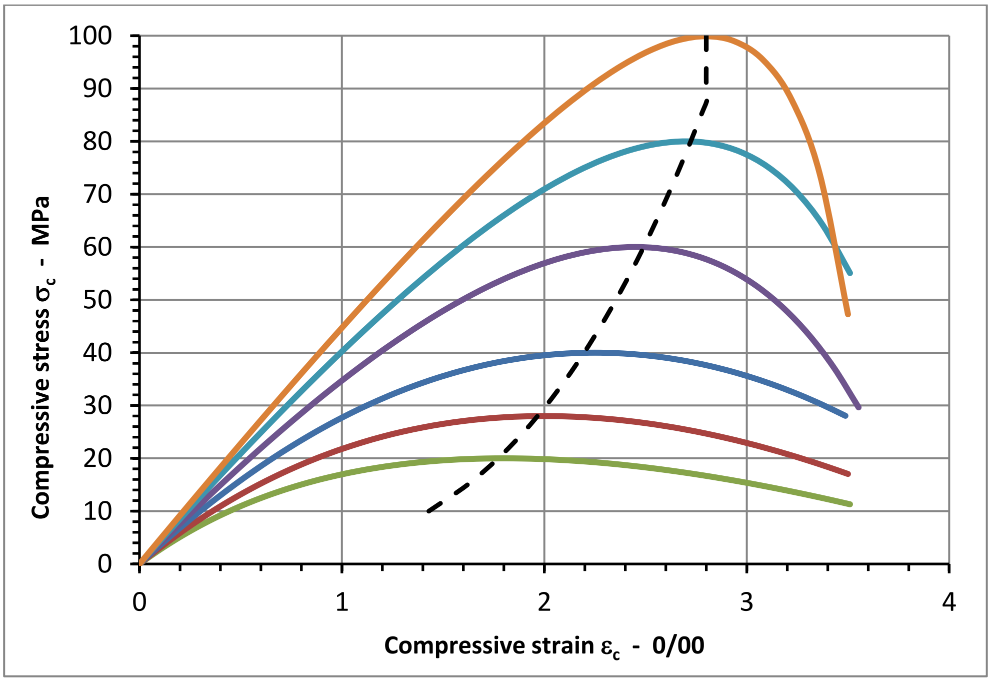


***Figure C.1** Compressive stress-strain relationship for concrete at different strength classes according to material model in EN 1992-1-1. The dashed line corresponds to the compressive strain at peak load according to the Eurocode model.*

As shown in the diagram above (which is based on the Eurocode 2 material model) it is generally considered that brittleness increases with higher strength – or at least that the descending branch of the stress-strain curve in compression becomes more steep with higher strength, resulting in the reduction factor η described in section 3.1.7 of EN 1992-1-1. In order to avoid using this factor – and to demonstrate that design with this type of UHPFRC can be done similarly to the design approach in the Eurocode – initial testing must include determination of the full stress-strain curves in compression – at least up to a strain of 4 ‰.

At 4 ‰ compression the load on the test specimen should correspond to at least 80% of the peak load. Deformation control and/or a closed-loop testing set-up should be used and up till at least 80% of the expected maximum load the rate of load application should be in the same range as that used in EN 12390-3 + AC:2012.

Secant E-modulus
The secant E-modulus is established according to EN 12390-13:2013.

Tensile and bending strength (3-point bending curve)
The class (minimum 5b according to fib Model Code 2010) is established based on mean values rather than characteristic values according to EN 14651. While the tensile strength of the matrix is not used directly in design, it is necessary that the matrix has a certain level of ductility, as well as a minimum tensile capacity necessary for controlling cracks, ensuring adequate bond etc.

Uniaxial tensile strength
Preferably, the uniaxial tensile strength is established experimentally (a number of suitable test methods are available), as this property relates to first cracking in balcony elements and thus to calculation of short and long term deformations. Alternatively, the uniaxial tensile strength can be assessed from the LOP value according to EN 14651 using equation 5.1-8 in Model Code 2010.

Rebar anchorage length
In general, the concrete covered by this EAD exhibit superior bond properties so that lap splice lengths

can potentially be reduced considerably. However, this behavior is very dependent on the type of fibres and the type of concrete used, so if an applicant wants to deviate from EC2 design provisions, relevant design parameters must be established (effect of cover, rebar diameter, transverse reinforcement, distance between bars etc.) through a comprehensive testing program. The testing program includes pull-out tests and bending of beams with lapped splices. An example of a suitable testing program is shown in annex G.

Creep and shrinkage behavior
The creep-curve for the specific UHPFRC used is determined according to ASTM C512 in order to correctly calculate long term deformations. It is not necessarily conservative to use standard creep curves for conventional concrete for a UHPFRC (where binder content is typically quite high and the maximum aggregate size is small), so testing is necessary.

At the same time the autogenous and drying shrinkage behaviour should be established, as this is of importance for rebar configurations, moulds, dimensions of elements, storage of elements etc. Typically autogenous shrinkage for UHPFRC will be larger than for conventional concrete. A method for measurement of shrinkage is described in annex D.

Freeze/thaw resistance
Freeze/thaw resistance is determined according to CEN/TR 15177:2006. In principle there should be no deterioration, as the pore structure of the UHPFRC ensures that there is no freezable water present at temperatures above -50 °C.

Resistance to fire
The thermal conductivity of UHPFRC is likely to be higher than for conventional concrete, so this value should be determined experimentally rather than be based on values determined for conventional concrete.

If tests have shown there is no risk of explosive spalling, mechanical properties can be expected to be similar to conventional concrete (which should be on the safe side), or flexural and tensile properties for the matrix can be determined experimentally (hot as well as residual).

Annex D Description of shrinkage testing

The equipment shown in fig. 1 measures the linear deformation of specimens and was developed at Aalborg University by Per Freiesleben Hansen and Ole Mejlhede Jensen. It was developed specifically for measurement of paste, but has also been used for mortars. With this type of system measurements can start before setting and thus autogenous shrinkage can be included in the measurements. This is possible because the mortar is cast in corrugated tubes of plastic, where there is little resistance to shrinkage – also at an early age. The sealing prevents exchange of material and moisture with the surroundings. For measurement of drying shrinkage the corrugated tubes are removed from the mortar samples.

Measurements should start as early as possible after mixing of the mortar and no later than1 hour in order to include as much of the autogenous shrinkage as possible. Measurements are to be carried out for a minimum of 180 days.

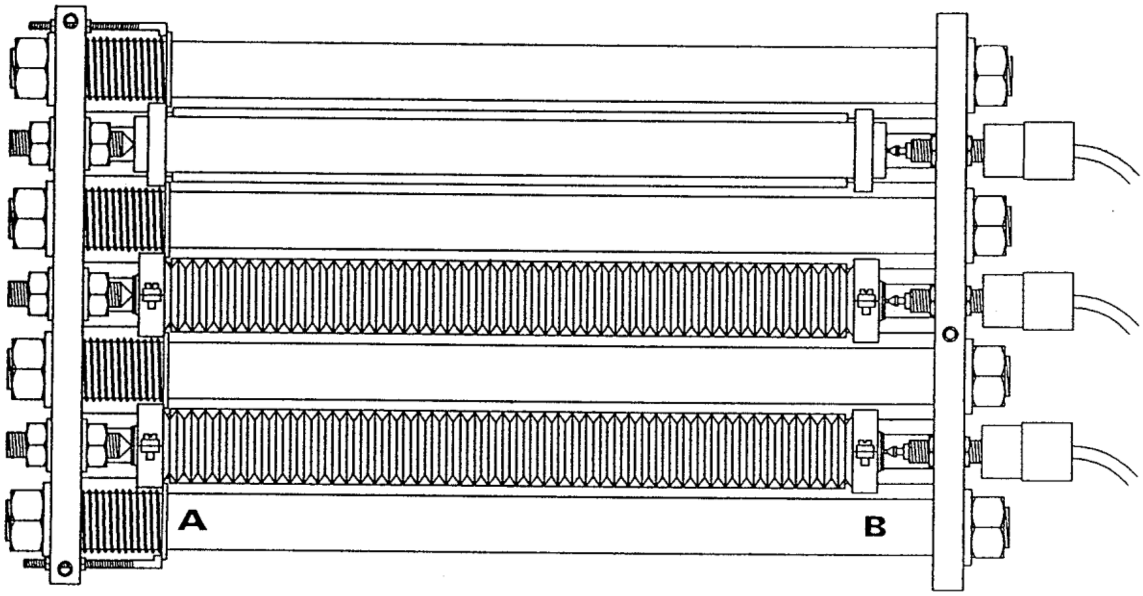


Figure 1: Dilatometer with two test specimens and one reference rod (in top slot). The specimens are fixed at A with spiral springs and the changes in length are registered by displacement transducers at B. The length of the samples is approximately 400 mm and diameter is 30 mm.

Simultaneous measurements are made on two test specimens and a reference rod. The measurement of the reference rod is used to check the operation of the electronic measurements (or the accuracy of manual measurements). Initially the test specimens should be measured every 30 minutes, but after 10 hours the measurements can be carried out at longer intervals. Measurements can be made electronically with connection to a data-logger or they can be made with a micrometer gauge as shown in fig. 2.

Measurements and storage of the specimens is at 20° C +/- 0.5° C.

For measurements of drying shrinkage a similar set of specimens are taken out of their moulds 24 hours after setting, and are placed in controlled environments at a relative humidity in the range of 30 to 60% RH. Measurements as described above are to be carried out for a minimum of 180 days.

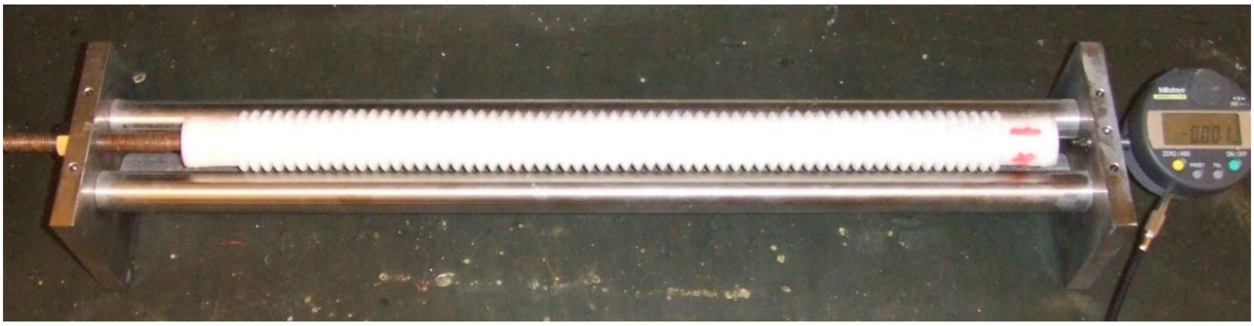


Figure 2: Experimental set-up for measurement of autogenous shrinkage using micrometer gauge.

Annex E Full scale testing

As described in section 2.2, calculations are generally based on EC2, but with a few exceptions and it is important to verify that these exceptions do not reduce the safety level in design. This is the reason for the requirements listed in the following:

Calculations can be validated by model tests as well as full scale tests. This is done as part of the initial type testing. The full scale tests should be performed on elements intended for actual applications and up to loads that exceed the calculated ultimate loads. It is important that the complexity of the test element reflects the type of balcony elements used by the producer, and the element should be more advanced than a simply supported slab, in order to demonstrate that the calculation models are able to predict the behavior of also more complicated elements. An example of full scale testing is given in the following.

A cantilevered balcony slab – as shown in fig. 1 – is suitable for the full scale test. The balcony slab should have a sufficient maturity at the time of testing – one to three months.

The part of the balcony that is normally attached to a building – section A-A in fig. 1 (snit A-A) **-** is attached to an angle beam with 13 Ø20 bolts and washers as shown in fig. 2. Fig. 2 also shows deflection measuring points at the beam. Other measuring points are shown in figs. 3 and 4. Loading is shown in fig. 5. Loading is introduced through four evenly spaced fibre boards placed at the front edge of the balcony, to simulate a line load. Load is applied with a hydraulic loading jack. Loading rate is in the range of 5 kN/min and load is applied in 10 steps from zero loading and up to the expected failure load (based on characteristic values).

After testing a diagram is drawn, with corresponding values of load and measured deformation for the 10 loading steps. This graph is compared to another graph – with calculated deformation values for each of the 10 loading steps. For prediction of deformations, the mean value of material properties should be used rather than the characteristic values.

In order to demonstrate compliance between the calculation models that are used and the test results the following should be demonstrated:

- Calculated values should be conservative compared to the measured deflections (meaning that the calculated deflection values should be larger than the measured deflection values for each load step)
- Measured deflections should be less than the allowable limits for EC2 design, and
- The measured failure load should exceed the calculated ultimate load (including material safety factors).

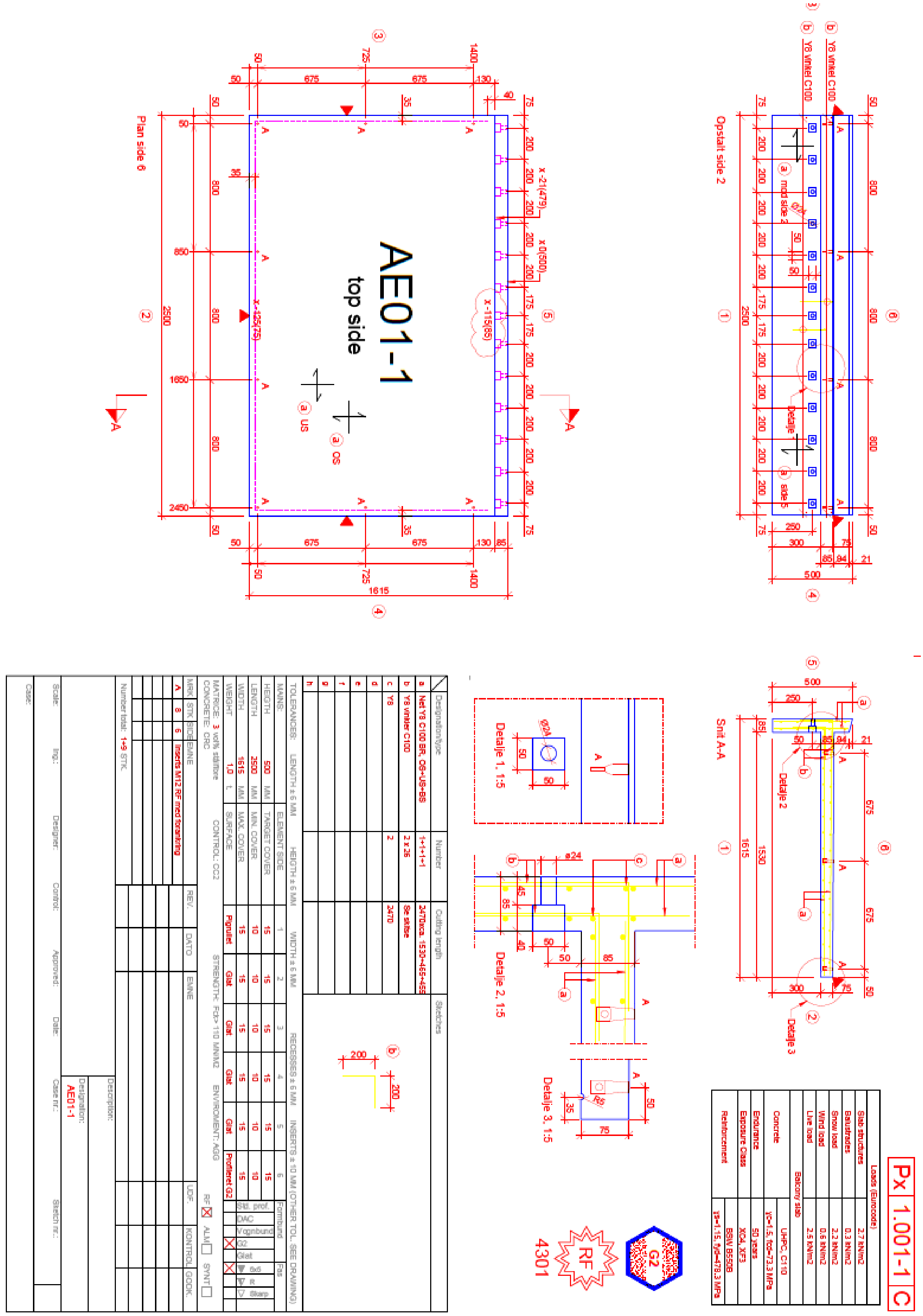


Figure 1: Design drawings for cantilevered balcony slab.

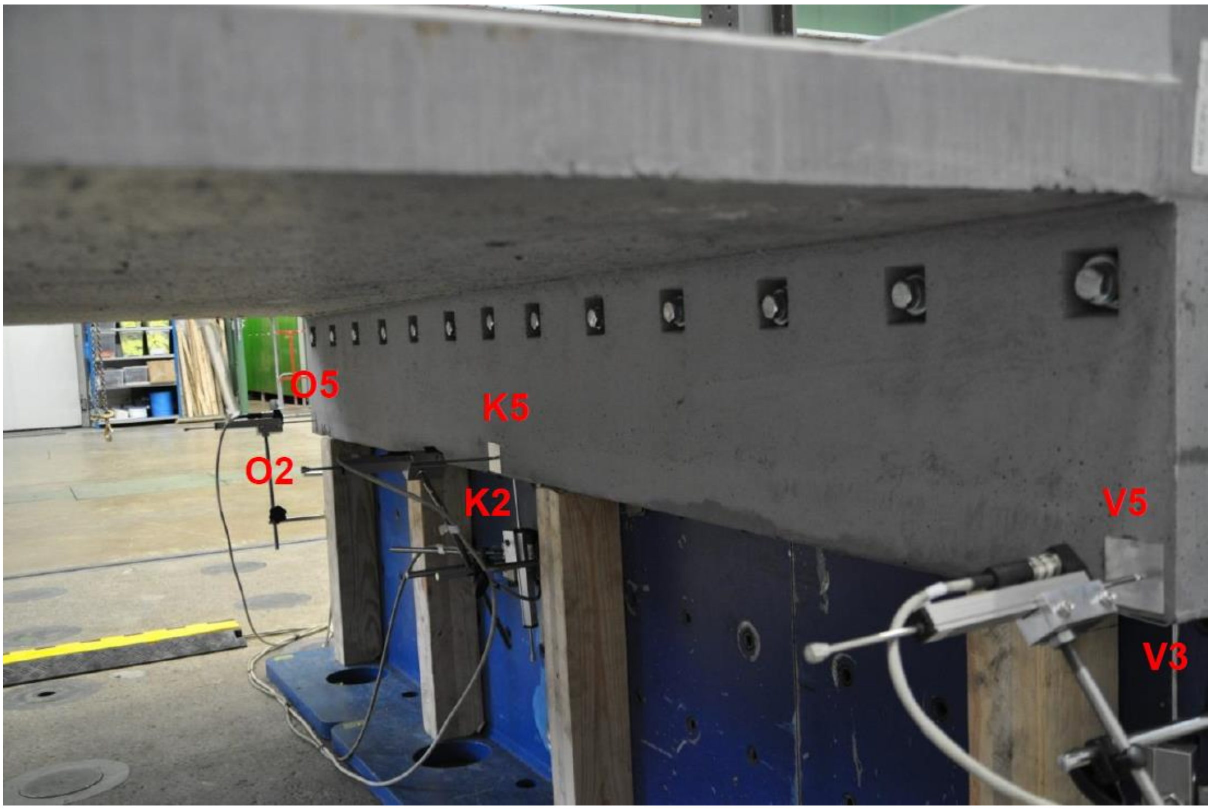


Figure 2: Fastening of balcony with bolts. Measurement of deformations at support.

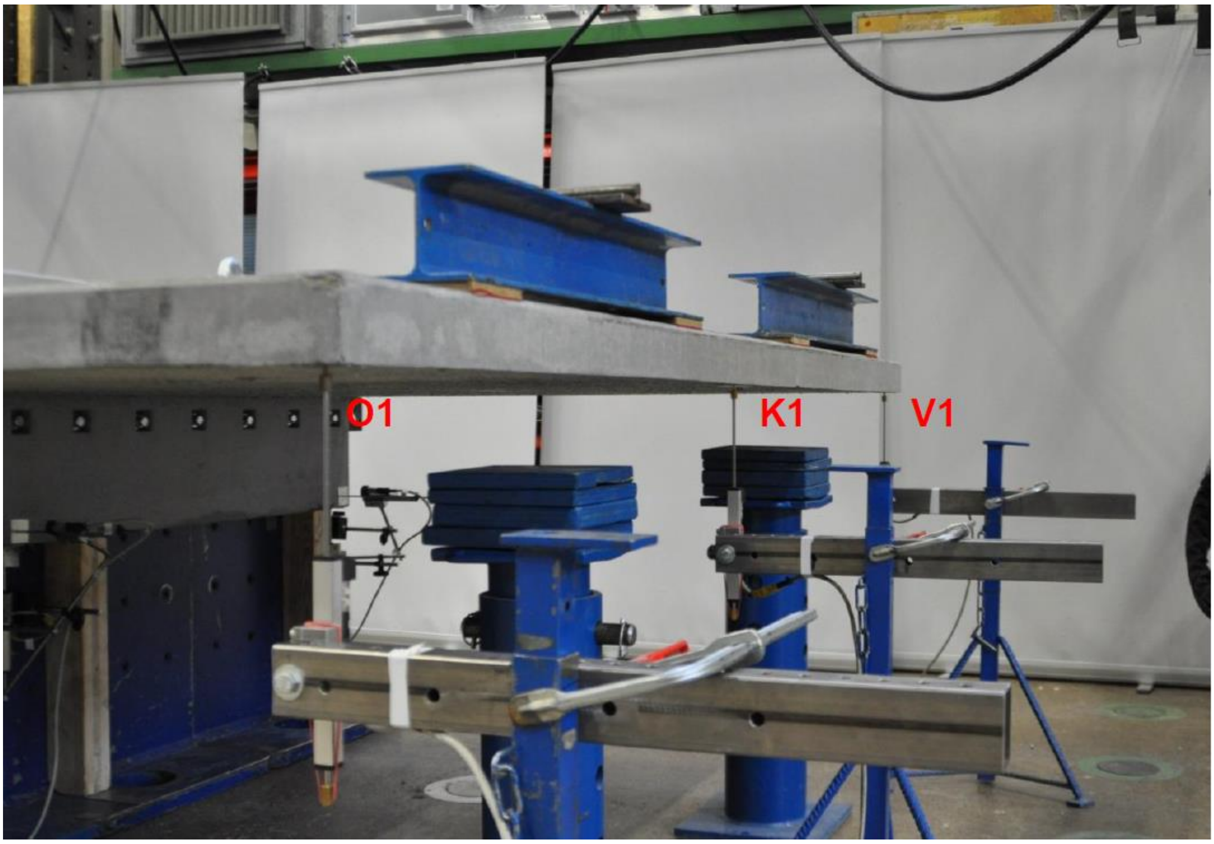


Figure 3: Measurement points at front edge of slab.

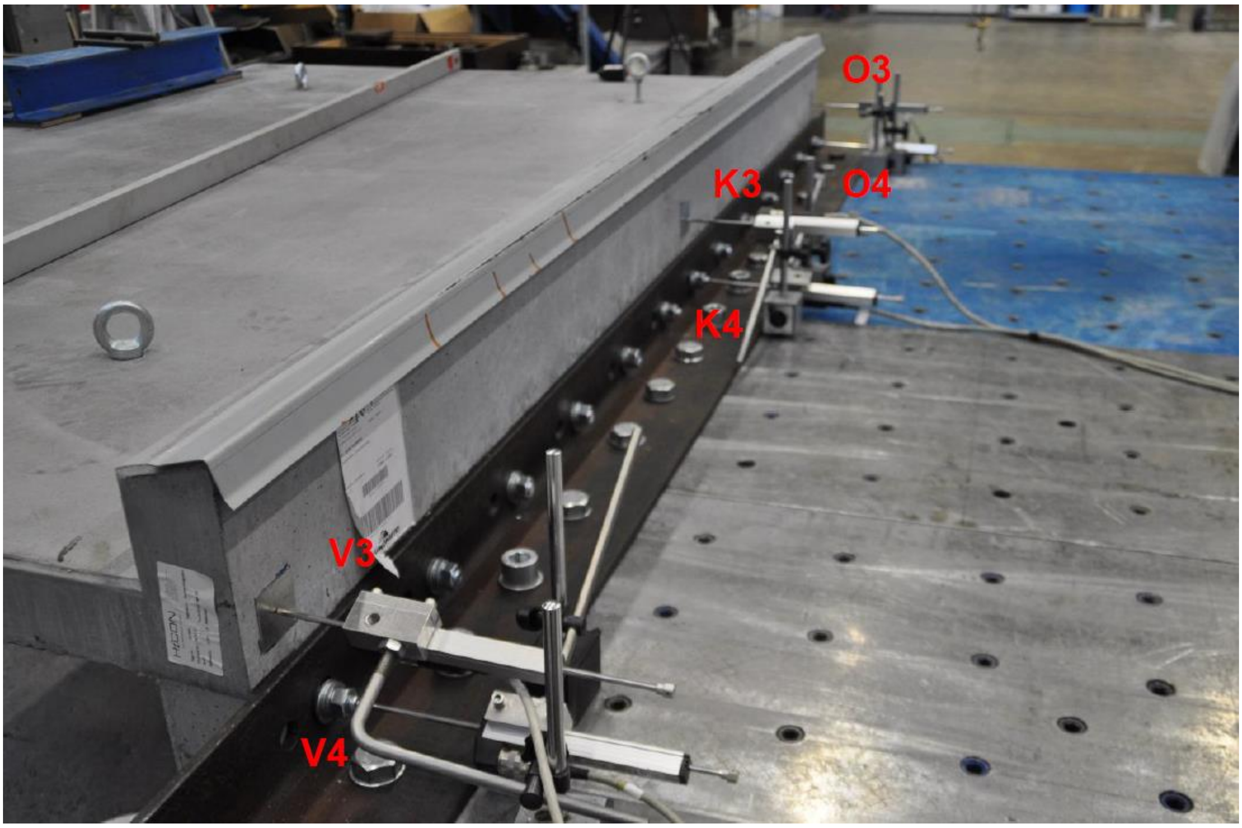


Figure 4: Measuring points for deflection at top of support.

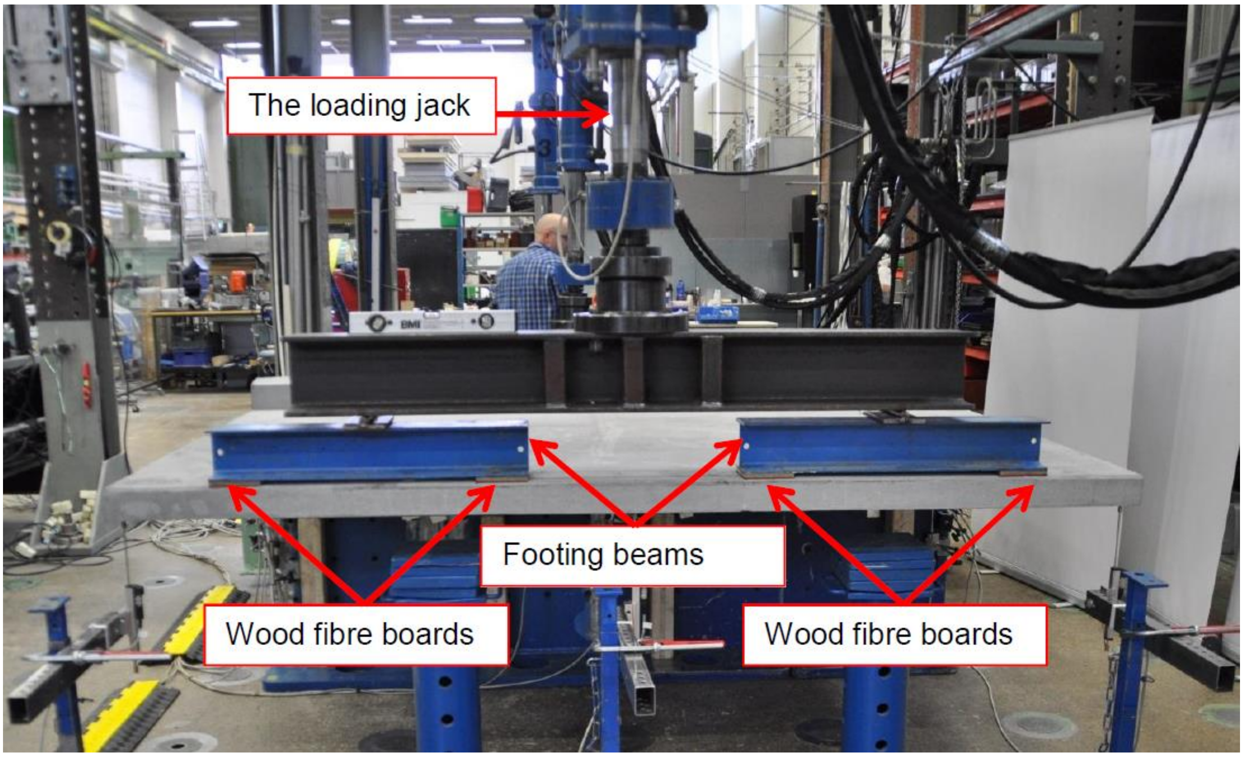


Figure 5: Loading at front edge of the balcony slab.

Annex F Effect of fibre distribution and fibre orientation

As mentioned in section 2.2 of the EAD, the fibers in the matrix are used to provide ductility and a minimum of tensile strength, while rebars are used to provide the structural reinforcement – in accordance with the EC2 principles of design. But as the fibers are of importance for the performance of the balcony, it is important to be able to assess whether a minimum effect of fibers is present in each cross section of the element. One method for doing this is described in EN 14650 – for fresh and hardened concrete, but this method is not necessarily practical for a UHPFRC, where the number of fibers per m^3 can be as high as 10-15,000,000. Additionally, the method proposed in EN 14650 would not reveal anything about the orientation of the fibers, which can be equally important with regard to performance of the matrix. Instead an alternative method for assessment of fibre distribution and fibre orientation is proposed in section 2.2.11 - and described in the following.

According to this method a number of beams are cut from a test specimen. The beams are subsequently tested in bending and compared to the results achieved from reference beams, and the results can then be used to assess fiber distribution and fibre orientation. This gives an indication of the homogeneity of the matrix as well as a result for the minimum effect of the fibres that can be expected.

Investigations of this type are well-described in the literature, including in the French guidelines for UHPFRC design issued by AFGC in 2013 (2nd edition). The method has been modified to be particularly suitable for slabs such as those used in balconies.

Fig. 1 shows a mould for a 1020x1020 mm test slab. The mould is placed at a 45 degree angle and concrete is introduced from the top. Compaction is carried out similar to the typical compaction method of the balcony slabs – if the concrete is self compacting no vibration is used, but if vibration is typically used in the production, then vibration should also be used for the test.

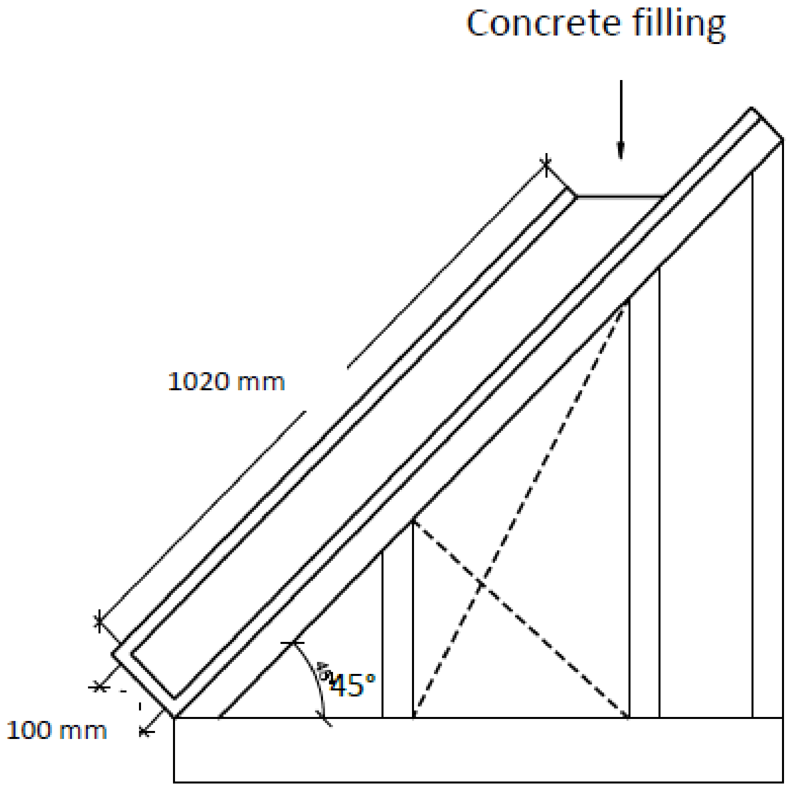


Figure 1: Mould for test slab with indication of casting direction.

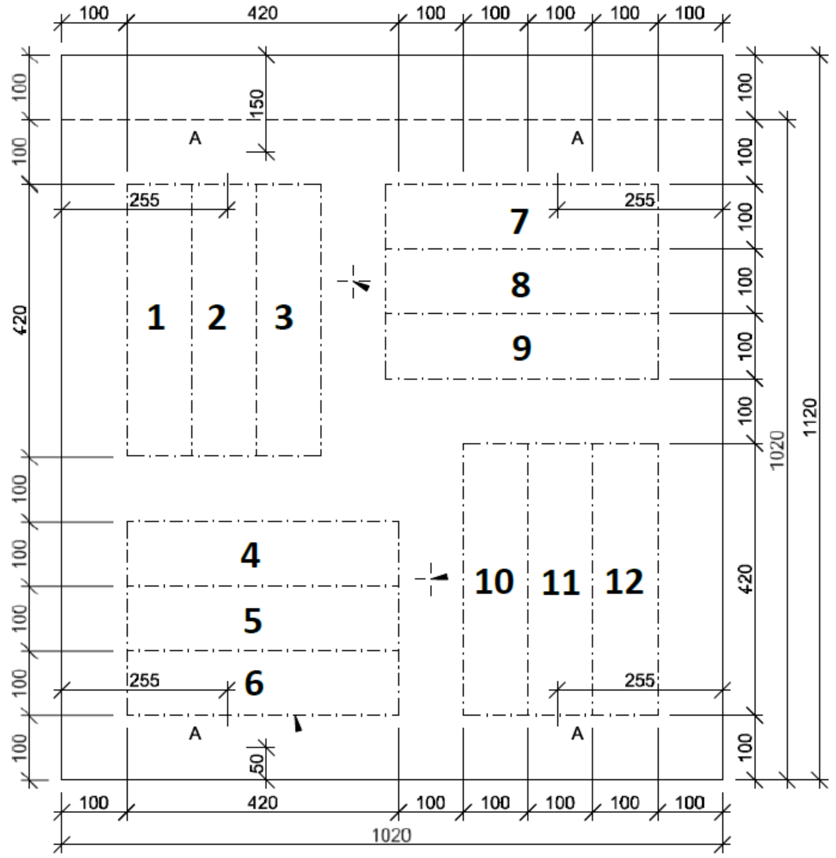


Figure 2: Sketch showing how beams are to be cut from the test slab. Filling is from the top.

After one day the beams and the slab are de-moulded and the slab is cut up into a number of 100x100x420 mm beams according to fig. 2. All specimens are treated according to EN 12390-2.

After 28 days all beams are tested in 3-point bending – in principle according to EN 14651, but with the reduced dimensions of the beams and with a span of 300 mm. Before testing a notch with a depth of approximately 10 mm is sawn into one of the sides of the beams that have been cast against a mould. The maximum width of the notch should be 2 mm. After the beams are tested, they are sawn in half at the cross section where the notch is placed, and the fibre distribution is assessed visually, to check for differences in fibre content and fibre orientation.

While tests of this type are used to assess the level of homogeneity – or to modify design parameters based on variation of fiber orientation and fiber distribution – these benefits are more incidental in this case – the main control parameter of interest is to determine uniaxial tensile strength in the weakest section of the element. This value is determined as LOP – Limit of Proportionality - according to EN 14651 and then – using formula 5.1-8 from Model Code 2010 – converted into a uniaxial tensile strength. The mean value of 3 beams taken from one section (beams 1-3, 4-6, 7-9 or 10-12) should be above 5 MPa.

Annex G Testing of anchorage length and lap length

If design of bond and anchorage is done according to the formulas in EC2, this will be conservative provided the requirements of section 2.2.2, 2.2.4 and 2.2.11 are met and there is no need to carry out the additional testing described in this annex. If, however, a designer wants to utilize the added ductility of UHPFRC by using other calculation methods for anchorage and lap length of rebars, a large number of tests are necessary. An example of how these tests could be carried out is shown in the following.

As the number of variables that should be investigated is quite large, it will be necessary to test well over 500 specimens before other values for lap length are used, than those that can be used based on EC2.

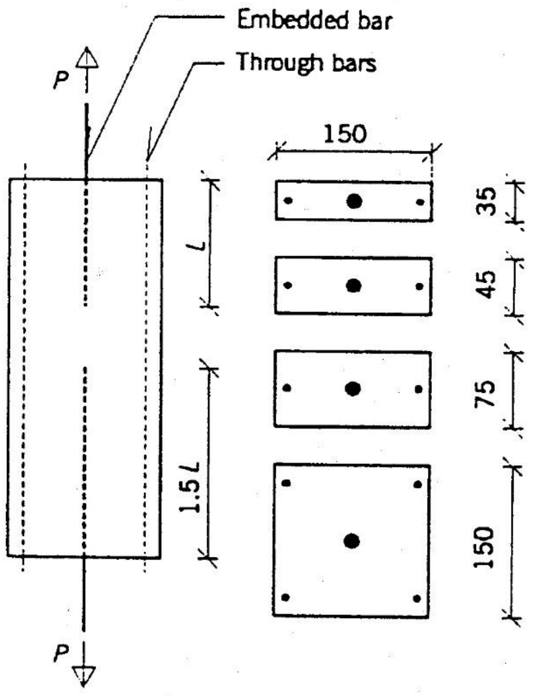


Figure 1: Example of design of pull-out specimens.

An example of a test specimen for pull-out testing is shown in fig. 1. With this type of test specimen it is possible to vary the following parameters:

- **Size of pull-out bar.**
  Different rebar sizes - ø5 mm bars up to ø25 mm bars - can be tested.
- **Embedment length.**
  The embedment length of rebars can be varied from embedment corresponding to a few bar diameters up to full anchorage.
- **Cover to rebar.**
  With the different thicknesses available, it is possible to vary the rebar covers.
- **Strength of concrete.**
  By testing the specimens at different maturities, it is possible to vary the strength of the concrete at the time of testing (typically from 70 MPa and up to 150 MPa).
- **Effect of transverse reinforcement**
  The number of transverse bars and their dimension can be varied as shown also in figs. 2 and 3.

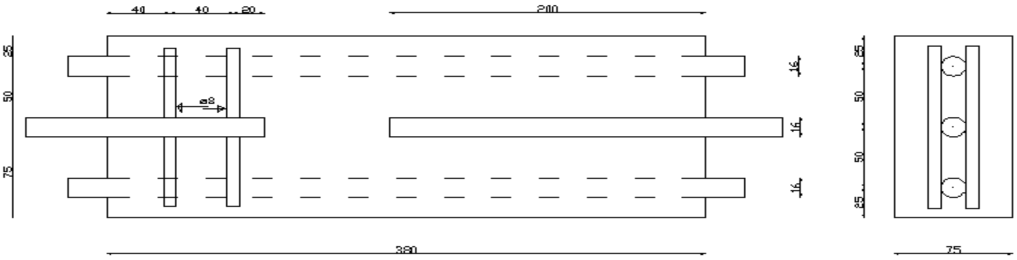


Figure 2: Example of pull-out specimen with transverse reinforcement.

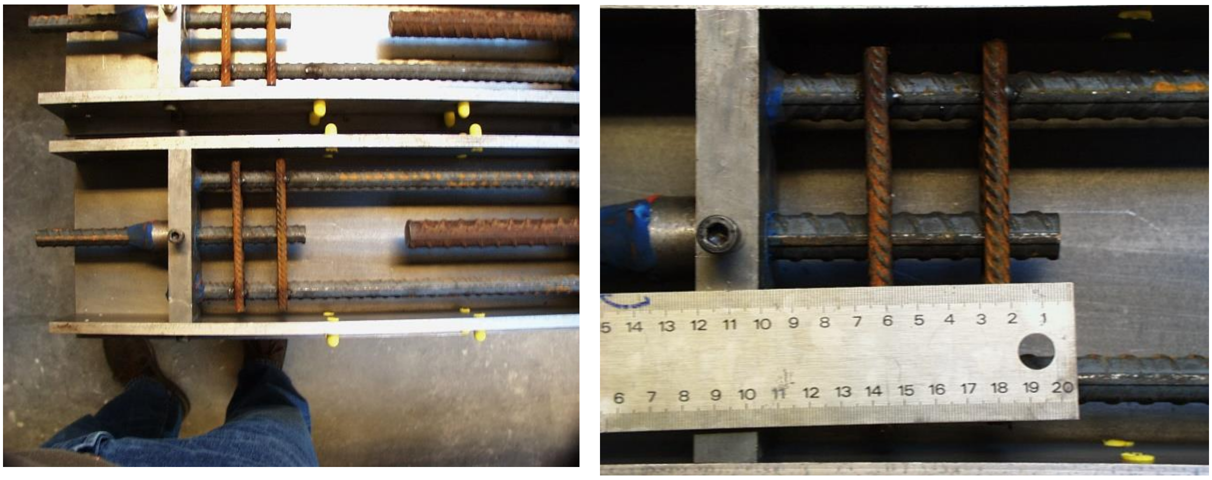


Figure 3: Preparation of test specimen with 100 mm embedment length of ø16 bar and 2 transverse bars.

In order to ascertain that failure occurs in the pull-out bar, the embedment length of the opposite bar is at least 50% larger than the embedment length of the pull-out bar, but in addition a larger diameter can be used for this opposite bar. The pull-out bar and the opposite bar have a sufficient length outside the test specimen, that the bar ends can be gripped by a hydraulic jaw of a tensile testing machine.

Figs. 4 and 5 show an example of pull-out testing. One case shows pull-out failure, while the other test show full anchorage of the rebar. The rebar has to fail outside the test specimen to be considered full anchorage – not merely achieve yielding.

After a sufficient number of tests have been carried out, it is possible to modify existing models for anchorage in order to allow for the effect of the fibres and the higher strength of the UHPFRC. This modification is then tested against the different results to ensure that the calculated results are conservative compared to the test results. It should also be noted where the modified model is expected to be valid – the range of rebar sizes, rebar covers etc. If the largest rebar size tested is ø20 mm it should be noted that the anchorage model is not valid for rebar sizes larger than ø20 mm. However, a few tests should be carried out outside the valid range of the model – e.g. with larger bar sizes - to check the robustness of the modified model.

After a modified model has been developed based on pull-out tests, a series of validation tests should then be carried out on different types of specimens such as beams, columns and slabs, where the model is applied to lap length of bars.

Figure 4: Pull-out of specimen with 100 mm embedment length of ø16 bar tested at 3 days.

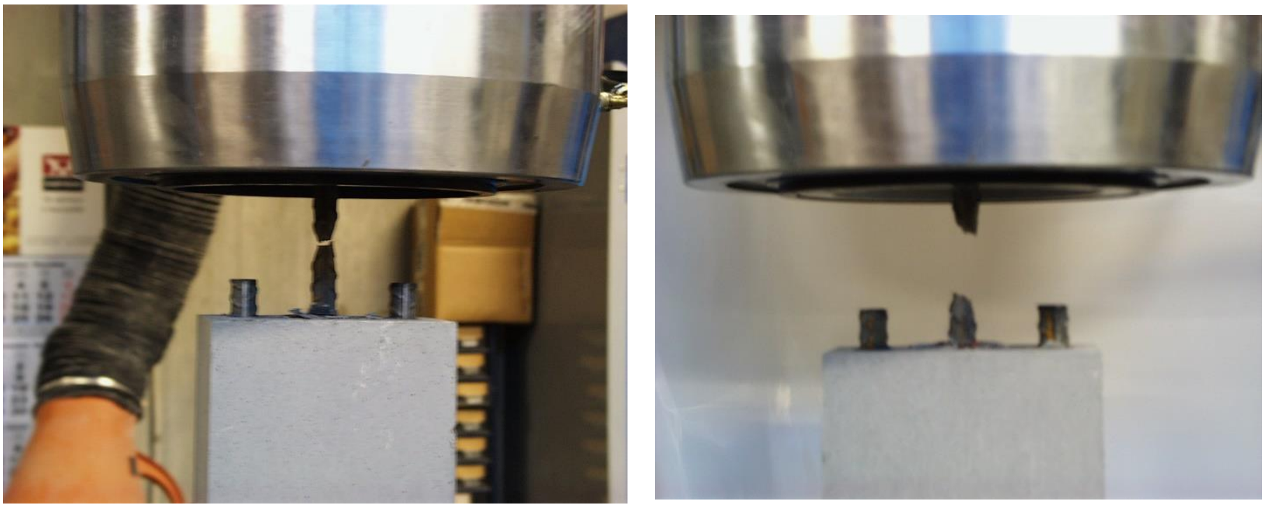
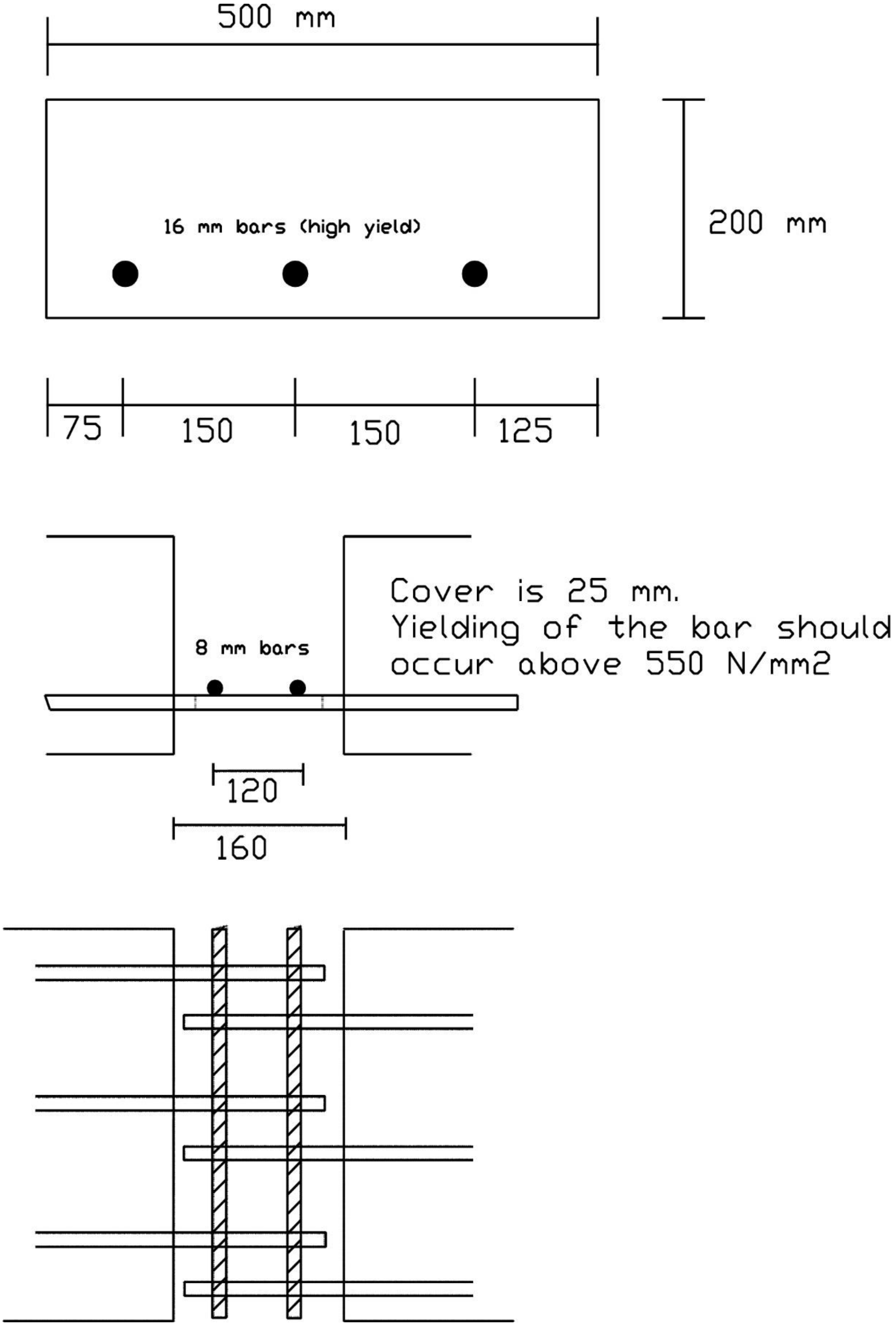


Figure 5: Full anchorage of specimen with 140 mm embedment length of ø16 bar tested at 3 days.

An example of a specimen for a bending test is shown in fig. 6. In this case parameters such as rebar size, lap length, proximity of bars and amount of transverse reinforcement can be varied. Fig. 7 shows a beam specimen of this type – in this case with ø12 mm bars, a joint width of 100 mm and a lap length of 80 mm – before the joint is cast. Fig. 8 shows testing of the beam in 3-point bending at the point where the rebars have started to yield.

As for the pull-out tests, it is important that a wide enough range of the different parameters are tested in bending to validate the modified model. As a conservative estimate it is suggested that the estimated anchorage length is also used as lap length.



Cover is 25 mm.
Yielding of the bar should
occur above 550 N/mm2

Figure 6: Example of test specimen for bending test with lapped bars.

Figure 7: Beam specimen with lapped ø12 mm bars before casting.

Figure 8: Beam specimen from fig. 7 in 3-point bending.

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