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Precast concrete products — Full-scale testing requirements in standards on precast concrete products

ICS 91.100.30

British Standards

National foreword

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- — monitor related international and European developments and promulgate them in the UK.

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English version

Precast concrete products - Full-scale testing requirements in standards on precast concrete products

Produits préfabriqués en béton - Exigences pour les essais en vraie grandeur dans les normes sur les produits préfabriqués en béton

Betonfertigteile - Anforderungen an Prüfungen an Bauteilen in Originalgröbe in den Normen für Betonfertigteile

This Technical Report was approved by CEN on 19 April 2004. It has been drawn up by the Technical Committee CEN/TC 229.

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Foreword

This document (CEN/TR 14862:2004) has been prepared by Technical Committee CEN/TC 229 "Precast concrete products", the secretariat of which is held by AFNOR.

Introduction

Any product standard will require a certain amount of testing as part of the evaluation of conformity. The tests may be part of initial type testing or part of production control. It may be tests on materials, dimensions etc. Or it may be tests on the finished product.

The following types of testing may be involved as a part of either initial type testing or production control, [1]:

a) tests to establish directly the ultimate resistance or serviceability properties of structural parts. Test results are treated as absolute values valid for the group from which the sample was taken;

b) tests to obtain specific material properties using specified testing procedures;

c) tests to reduce uncertainties in parameters in load or load effect models;

d) tests to reduce uncertainties in parameters used in resistance models. Test results are defined as the ratio between measured and calculated values and statistical rules are applied to the ratio;

e) control tests to check the identity or quality of delivered products or the consistency of the production characteristics;

f) tests carried out during execution in order to obtain information needed for part of the execution;

g) control tests to check the behaviour of an actual structure or of structural members after completion.

Testing of full-scale products may be involved in all types of test except type (b).

Testing methods may or may not leave the tested product fit for further use (non-destructive or destructive testing). However, apart from checks on geometrical properties, full-scale testing will usually damage the tested product so that it cannot be used in a structure.

Tests of type (a) do not take into account prior knowledge as easily as type (d) tests. It means that the most effective use of full-scale testing will be (effectively destructive) tests of type (d).

The aim of the report is to assist the standard writers in CEN/TC 229 regime in preparing requirements on full-scale testing in product standards. Initial type testing of a product requires the producer to establish relevant properties of the product. This is often done by means of calculation models given in a standard, but in some cases full-scale testing may be used effectively to reduce uncertainties in these calculation models, maintaining the intended reliability.

The main statistical rules to be followed in this process are given in Eurocode – Basis of structural design (prEN 1990). The report illustrates how these rules may be applied in a product standard.

A practical example concerning hollow core slabs is also given. The test results used in this example were made available from Spenncon AS Hønefoss, Norway.

1 Scope

This document gives guidelines on how full-scale tests may be incorporated in product standards as a tool to reduce incertainties in resistance models.

This document also gives guidelines to designers setting up a proper test programme as part of the initial design of a component.

2 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 1168, *Precast concrete products - Hollow core slabs for floors.*

EN 1990:2002, *Eurocode - Basis of structural design*.

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

EN 13369, *Common rules for precast concrete structures.*

ISO 12491:1997, *Statistical methods for quality control of building materials and components.*

RILEM TC40-TPC3:1985, *Flexural and shearing tests on prefabricated concrete elements, Materials and structures, Vol. 18, No 108.*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
accompanying test
test to determine a material property by direct or indirect methods

3.2
biased sampling
a selection of units, taken from a lot according to a selection plan

3.3
full-scale test
test performed on a finished product to determine directly the properties of the product. Properties may include behaviour, stiffness, strengths etc. of the product subjected to relevant actions

3.4
initial type testing
a procedure to demonstrate compliance of a product with the requirements applying to the product. The procedure may utilise calculation and standard materials testing and it may be assisted by full-scale tests on the product

3.5
random sampling
a selection of units, taken at random from a lot. Each unit of the lot has the same chance of being selected

3.6
resistance model
a formula used for calculation of a product property

3.7
prior knowledge
existing knowledge about the properties of a product and their dependence on geometry, materials, production process etc

3.8
product family
a type of product usually corresponding to one product standard, e.g. prestressed hollow core floor slabs

3.9
product group
a collection of products with such characteristics that all products can be attributed the same value of a chosen property. The grouping may depend on the property. Hollow core floor slabs with the same dimensions and concrete strength may be a group with respect to shear strength

3.10
production control
a production control system is a quality system to ensure that the product put on the market meets the requirements of the relevant standard and complies with the specified or declared values

4 The role of full-scale testing

4.1 Design using existing calculation models

Design of products according to Eurocode 2 (EN 1992-1-1), is normally based on resistance models giving the product properties as a function of the geometry and the properties of the material used in the product. The resistance model normally expresses the mean value of the property when the mean values of the parameters are inserted in the model. It is usually assumed that the same model express the characteristic value or the design value of the property if characteristic values or design values of the parameters are inserted in the model.

The design strength parameters for the materials are normally found by reducing the characteristic strength obtained from materials testing by a partial safety factor. In the initial type testing of a product, these design strength parameters are used together with nominal dimensions of the product in the resistance model to determine the design value of the property. The producer can then declare a design property less than or equal to the calculated design value.

It is noted that partial safety factors may change from country to country. The design value of a property for a specific product may therefore also be different from one country to the next.

Following initial type testing, the continuous production is monitored by production control to make sure that the declaration (and its assumptions) is fulfilled. The production control relies primarily on checking the process, including tests on materials etc. The finished product is checked for geometry, appearance etc. The resistance model used in initial type testing is usually taken for granted.

4.2 Design assisted by testing

The resistance models available in Eurocode 2 (EN 1992-1-1), may not be adequate for initial type testing of a number of products within the regime of CEN/TC 229. A model may intend to cover a large spectrum of products, and the model should be safe for the whole spectrum. The model may therefore become conservative for some of the products within that spectrum. In other cases the uncertainty on the model may in general be large.

Full-scale testing may in such cases support the initial type testing in two different ways:

— tests (of type (a)) may be used to determine directly the property of a specific product ("single property determination"), e.g. the shear strength of a hollow core floor slab with specified dimensions and materials. The tests may yield a number [kN/m] for the mean value and a number for the characteristic value. These properties will be different for different variants of a product family. Although the approach may sometimes be useful, it often becomes economically unfeasible because the product family may contain so many variants, that the cost of testing is prohibitive. Furthermore, the design value of the property depends on a partial safety factor that is not known, unless the property depends on the strength of only one material. Declaration of a design value for the property may therefore not be easy;

— tests (of type (d)) may be used to improve inadequate resistance models ("determination of resistance model"). The result is a revised resistance model to determine the mean values of the property for a product family. For example, an improved formula to determine the mean value of the shear strength of hollow core floor slabs as a function of the actual dimensions and actual material strengths of the test specimens.

When a revised resistance model is found, initial type testing continues in the same way as if the resistance model was taken from Eurocode 2. It means that design properties are calculated by the revised formula (using nominal values for dimensions and design values for material strengths). The producer can declare properties less than the calculated design values. Different declarations will appear due to variations in the partial safety factors.

The production control procedures will contain the same items as if calculation by Eurocode 2 was used in initial type testing. New items may have to be added, if the revised resistance model is sensitive to parameters that are not monitored as part of the normal production control.

5 Specification of full-scale testing requirements.

A product standard may include requirements on full-scale testing and such requirements should be specified with the same degree of stringency as is normally used when calculations are specified. It means that the following three subjects shall be dealt with:

— **why** are full-scale testing to be considered (Objectives and planning);

— **how** can a relevant full-scale test be performed (Test method);

— **what** are the consequences of the results of the test (Interpretation).

These subjects are interrelated. A test method is relevant only if it produces information about the objectives. The planning shall foresee the interpretation phase and the interpretation of course is linked to the objectives.

The **why** and **what** issues are natural parts of the product standard itself, while the **how** issue may be treated either in a separate standard or in the product standard itself.

Clauses 6, 7 and 8 in the present document outline the considerations to be dealt with by the standardisation body with respect to objectives, planning and interpretation. The outline is supported on two annexes:

— Annex A containing a brief summary of the statistically based procedure described in EN 1990:2002 to determine a resistance model. The procedure is illustrated by an example dealing with shear strength of hollow core floor slabs;

— Annex B contains a list of items to be covered in the specification of a full-scale test in a CEN/TC 229 product standard. Text that can be used independently of the product is given to the extent possible.

6 Objectives

If a standardisation body decides to introduce provisions on full-scale testing, the body shall specify directly those subjects that full-scale testing is supposed to clarify. The need for full-scale testing will often be associated with initial type testing, where resistance models are needed. The existing models, however, may be too conservative or otherwise insufficient for calculation of product properties. A possible reason for such conservatism could be that the model is intended to be safe within a larger range of parameters than needed for the specific product.

6.1 Option or requirement in initial type testing

The first decision to be made by the standardisation body is whether full-scale testing is an option or a requirement:

— if given as an option the product properties may be declared based on either a resistance model, referred to or given by the standard, or on a resistance model verified by test results. The option should allow a benefit from testing;

— if given as a requirement the declared property must be based on a resistance model verified by the test results.

If available resistance models are considered sufficient there is no need for full-scale testing. If so there is no reason that a standard should require such testing, also considering that the cost of full-scale testing is generally rather high. Full-scale testing should therefore preferably be used as an option leaving the producer to decide whether money should be spent on testing or on more conservative declarations of properties.

6.2 Part of production control

In principle, the use of full-scale testing as part of production control is possible, but it may not necessarily be warranted.

Testing included in the production control process should be considered as a basis for acceptance or not acceptance of a part of the total production. This also applies to full-scale tests if they are made as part of the production control. The available number of full-scale tests, however, is likely to be small for economical reasons. An acceptance procedure based on a small number of tests becomes very unreliable. If initial type testing has been performed, it is much more relevant to consider such tests during production as further type testing.

6.3 Further type testing

If full-scale testing has been part of the initial type testing there may be good reasons to require further type testing at certain intervals. According to EN 13369, further type testing is required when major changes take place (new raw materials, new production process etc.). In practice smaller changes are made from time to time - intentionally or not intentionally. Especially changes in the production process may occur without being recognised as a change requiring new initial type testing. The standardisation body may therefore consider a maximum time limit for the validity of the initial type testing.

The further type testing may (or may not) lead to a revision of the declared properties or a new design for future production, while the result is of no consequence for the past production. It should also be noted, that validation of an earlier initial type testing may only require a few additional tests.

6.4 Technical questions to be clarified

The technical questions to be solved by testing may depend heavily on the product. Typically, strength properties for the product may be questioned.

In the normal design process, some failure modes for the product are favoured, while other modes are considered less acceptable or even unacceptable. For a beam, e.g., a bending failure is favoured, a shear failure may usually not be accepted and a spalling failure in the anchorage zone may be considered unacceptable. The protection against shear failure is often specifically designed for each individual component to obtain a bending failure at a lower load level than a shear failure, but economy may call for a small margin between the two load levels. Protection against spalling is often obtained by a more conservative approach leaving no significant doubt that this type of failure mode is unlikely.

A design process assisted by testing may therefore include a determination of the critical strength properties (e.g. the shear capacity) and a check, that failure modes considered in the actual case to be unlikely are in fact unlikely (e.g. a spalling failure). This last objective may not require a precise determination of the failure load. It may be sufficient to establish that the capacity is higher than some threshold value, which is likely to be the upper value of the action effect.

7 Planning

7.1 Groups in the product family

A product standard shall normally cover all products within a range of variations (geometry, raw materials, etc.) and resistance models given in the standard for the relevant properties shall therefore cover that range. In most cases such resistance models are available based on prior knowledge about the properties of a product family, although the models may be more or less accurate. If the model is known to be very accurate, the need for testing is non-existent. Less accurate models may also be used in the standard – most likely with a built-in margin reflecting the uncertainty. The larger uncertainty, the more the testing option is needed.

Although a model may be associated with a large uncertainty, it usually identifies the most important parameters. The model can therefore be used to separate a family of products into groups within the family that can be assumed to have (almost) the same property.

As an example, a producer of hollow core floor slabs may consider a resistance model from Eurocode 2 to give conservative shear capacity results for the range of products in his own production. The producer wants to improve the resistance model based on full-scale tests. The existing model suggests that the shear strength of a hollow core floor slab is sensitive to the slab thickness, the thickness of the webs and the concrete strength, and less sensitive to the amount of reinforcement and prestress. The producer may therefore choose to consider all slabs with the same concrete dimensions and concrete strength as one group. A test program to improve the model should consequently contain specimens from those groups that are contained in the producers production program.

A product standard, which requires or allows design assisted by testing should preferably identify the best possible resistance model, or it should identify, alternatively, the rules and limitations that shall be applied with respect to grouping. Members of the standardisation body are likely to have expert knowledge about these items and the body is therefore suited to give such guidance. Otherwise, rules of this kind are effectively decided by the producer or by a third party.

7.2 Sampling techniques

Random sampling is not necessarily a requirement. First of all random sampling is not likely to be possible in a type testing process, because a continuous production is not yet started. Secondly, the use of prior knowledge in a resistance model is likely to call for sampling of specimens with parameters that are to some degree predetermined. Any kind of grouping will require, that the sample of a group covers all relevant parameters included in the group or that the sample is deliberately biased to contain the unfavourable parameters.

If the grouping of hollow core floor slabs mentioned above is chosen, the possible positive effect of a high prestress is neglected. The test program should therefore use random sampling within the group (no bias) or deliberately choose specimens with a low degree of prestress (safe bias).

7.3 Accompanying tests.

In principle, design assisted by testing compares the property measured on a test specimen with the property obtained from the resistance model using dimensions and material properties from the actual test specimen. Tests on the properties of the materials actually used in the test specimens shall therefore be part of the program in order to make a relevant comparison between the measured and calculated properties.

If the material properties in the finished product are likely to depend on variations in the production process the standard material testing procedures (e.g. concrete compressive strength of cylinders) may have to be supplemented by a measure of the properties in the finished product.

For example, the production process for hollow core floors often utilises a rather dry concrete mix. The compaction of the concrete provided by the extrusion process is important for the concrete strength obtained in the webs. Variations in the compaction of the slab are not reflected in a standard material testing of the concrete strength. The test program shall therefore include either a direct measure of the concrete strength in the web or an indirect measure of a property that reflects the concrete strength in the web including the effects of variations in the compaction. The preferred method should also be suitable for use in the production control procedures since that method should be included as an inspection point on the production process (compaction).

The standardisation body may want to leave the choice of method to the producer. The standard should specify, however, the need for such accompanying tests in initial type testing as well as in production control.

8 Interpretation based on prior knowledge

Any test result is by nature a statistical variable and should be evaluated by normal statistical rules. These rules are reasonably simple to apply when no prior knowledge is available. On the other hand, a useful test program in that situation is likely to be very expensive. The crucial point is therefore how prior knowledge can be utilised in a test program.

Prior knowledge may essentially have two useful forms:

— known coefficient of variation. he results of a sample from a lot are used to determine an expected value, valid for the whole lot. A mean value for the lot may be determined with fairly high reliability on even a small sample. The coefficient of variation (and thus the characteristic value) requires a much bigger sample to yield a reliable result. Therefore prior knowledge on the true coefficient of variation can be translated into a higher characteristic value based on the same sample;

— resistance model. Any idea about relations between parameters and resulting properties may be used in the planning process as earlier described. The effect in statistical terms is primarily, that results at a required level of confidence can be obtained based on a smaller number of tests in combination with a resistance model. The better known the resistance model is, the fewer tests are required. Annex A describes the practical procedure based on EN 1990:2002.

Prior knowledge on the resistance model is to a large extent producer independent. The standardisation body is likely to have expert opinions on the model and is therefore suited to give guidance on the content of the model and its use.

Use of prior knowledge from a resistance model entails that random sampling is not necessarily required. It may even be a good idea to use biased sampling, so that the properties attributed to a group of products within a family is determined from specimens likely to be in the lower range of the group. Prior knowledge on the shear capacity of hollow core slabs may for example be expressed in a formula neglecting the effects of reinforcement and prestress. A sampling plan containing deliberately test specimens with low values of prestress would be biased, but it would on the other hand produce results that are likely to be on the safe side.

The possible acceptance of biased test programs may, however, invite misuse. The standardisation body should be aware of this possibility and specify limitations where needed.

Annex A
(informative)

Statistic determination of resistance model

A.1 Statistical background

A.1.1 Introduction

Initial type testing of a precast concrete product may include "design assisted by testing". The testing may be used either to determine a single property or to determine or revise a resistance model. Guidelines for the planning and evaluation of experiments to be used for both types of "design assisted by testing" may be found in reference EN 1990:2002.

The statistical evaluation is based on Bayesian procedures with vague prior distributions and it is assumed that the property has a normal or a log normal distribution. It is stated that the procedures lead to almost the same result as classical statistics with confidence levels equal to 0,75.

A.1.2 Procedure for initial type testing

The procedure contains the following steps:

— the starting point for “design assisted by testing” is the best possible resistance model to express a product property, e.g. the shear strength of hollow core slabs. The model may from the beginning be incomplete. The test program is used to modify or calibrate the model, so that the calibrated model can be used with confidence to determine the property for all members of the product family;

— tests are performed on a sample representing the whole product family. Random sampling is not necessarily possible (continuous production has not yet been started). Specimens representative for the range of parameters should be stressed;

— for each specimen in the sample the test yields the measured value of the property, R_{ei}, and the resistance model yields a calculated value, R_{ti}. This calculated value must be based on measured values of all the parameters entering the resistance model and, consequently, the ratio between the measured and the calculated values would be 1,0 if 1) the resistance model is perfect and 2) the scatter is zero. Systematic deviations from the value 1,0 should be investigated and – if possible – removed by a revision of the model;

— a mean value correction factor, 1k, is estimated using "least squares" best-fit to the slope, given by:

$$k_1 = \frac{\sum R_e R_t}{\sum R_t^2}$$

— the characteristic value of the property, R_k, is then determined as a fraction, k_2, of the mean value, R_m. The fraction depends on the coefficient of variation, V_r, which can be determined as a function of a model variation, V_δ, and a parameter variation, V_{rt}:

$$V_r^2 = V_{rt}^2 + V_\delta^2$$

The model variation is determined from the following set of formulae:

$$\bar{\Delta} = \frac{1}{n}\sum_{i=1}^{n}\ln(\frac{R_{\text{ei}}}{bR_{\text{ti}}}) \text{ and } \Delta_{\text{i}} = \ln(\frac{R_{\text{ei}}}{bR_{\text{ti}}})$$

$$S_{\Delta}^{2} = \frac{1}{n-1}\sum_{i=1}^{n}\left(\Delta_{\text{i}} - \Delta^{-2}\right)$$

$$V_{\delta} = \sqrt{\exp(s_{\Delta}^{2}) - 1}$$

The parameter variation is determined from the following:

$$V_{\text{rt}}^{2} = \sum_{i=1}^{j} V_{\text{Xi}}^{2}$$

where

V_{Xi} is the variation on each of the independent parameters entering the calculation model.

Finally, the reduction factor, k_2, to determine the characteristic strength, R_{k}, can be determined by

$$K_2 = R_{\text{k}}/R_{\text{m}} = k_1 \exp\left[-k_{\infty}\, \alpha_{\text{rt}}\, Q_{\text{rt}} - k_{\text{n}}\, \alpha_{\delta}\, Q_{\delta} - 0{,}5\, Q^2\right]$$

where

$$Q_{\text{rt}} = \sqrt{\ln(V_{\text{rt}}^{2} + 1)} \qquad Q_{\delta} = \sqrt{\ln(V_{\delta}^{2} + 1)} \qquad Q = \sqrt{\ln(V_{\text{r}}^{2} + 1)}$$

$$\alpha_{\text{rt}} = \frac{Q_{\text{rt}}}{Q} \qquad \alpha_{\delta} = \frac{Q_{\delta}}{Q}$$

A.1.3 Observed principal result of the procedure

Figure A.1 shows the ratio between the characteristic value and the mean value as a function of the total coefficient of variation assuming a test program of 20 tests. Figure A.2 illustrates the effect on the same ratio from the number of tests for certain values of total variation.

From these Figures it may be observed that:

— the characteristic value depends heavily on the total coefficient of variation (Figures A.1 and A.2);

— the characteristic value is insensitive to changes in the distribution between model variation and parameter variation as long as the total variation is kept constant;

— a number of tests smaller than about 10 reduce the characteristic values significantly - even for the same coefficient of variation;

— the characteristic value is approximately 77 % of the mean value for a total coefficient of variation of 15 %.

A small number of tests will often lead to a conservative estimate of the coefficient of variation. A larger test program may therefore be required to obtain a reasonable estimate of the coefficient of variation.

A.1.4 Procedure for additional testing during production

Repeated initial type testing may utilise, that the resistance model and the coefficient of variation are known already from the tests performed in the first initial type-testing program. EN 1990:2002 specifies that if this prior knowledge exists a new characteristic value may be determined from the results of 1-3 additional tests, provided that the individual, additional test result is within +/- 10% of the mean value of the additional tests.

The following rules may be used:

$$R_k = \frac{\eta_k}{n} \sum R_i$$

where

$$\eta_k = 0{,}9 \exp \left[-2{,}31 V_r - 0{,}5 V_r^2 \right] \text{ for n = 1}$$

and

$$\eta_k = \exp \left[-2{,}0\, V_r - 0{,}5\, V_r^2 \right] \text{ for n = 2 or n = 3}$$

and

V_r is the total variation known from the initial testing.

The value of η_k for 2 or more tests is illustrated in Figure A.1 together with the reduction factor found from the initial testing. If a reasonable initial testing program has been performed earlier, it is possible to verify with a limited effort that the earlier results are still valid. Figure A.1 shows that the reduction factor to be used on the additional few tests may be of the order of 5 % smaller than the one found in the initial program.

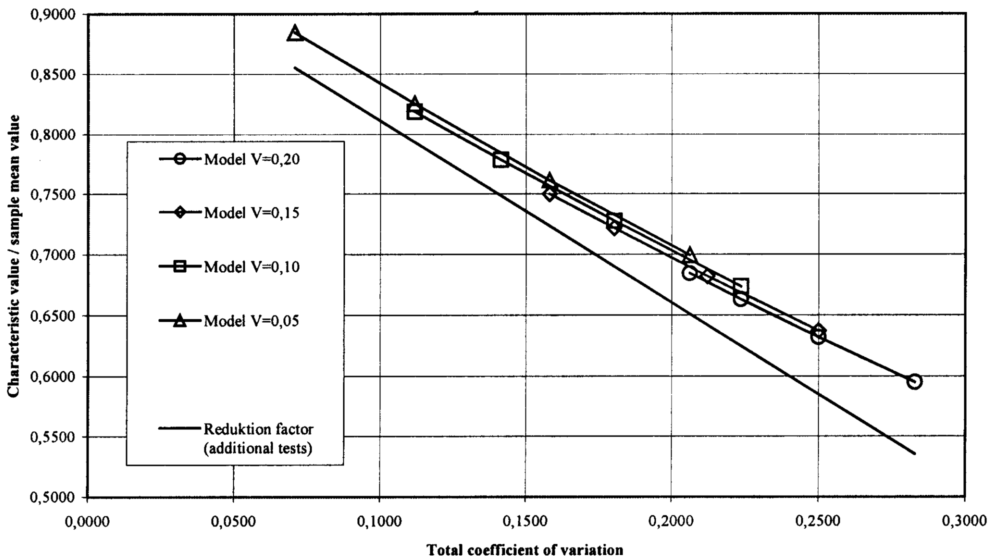

Figure A.1 — Characteristic value based on 20 tests

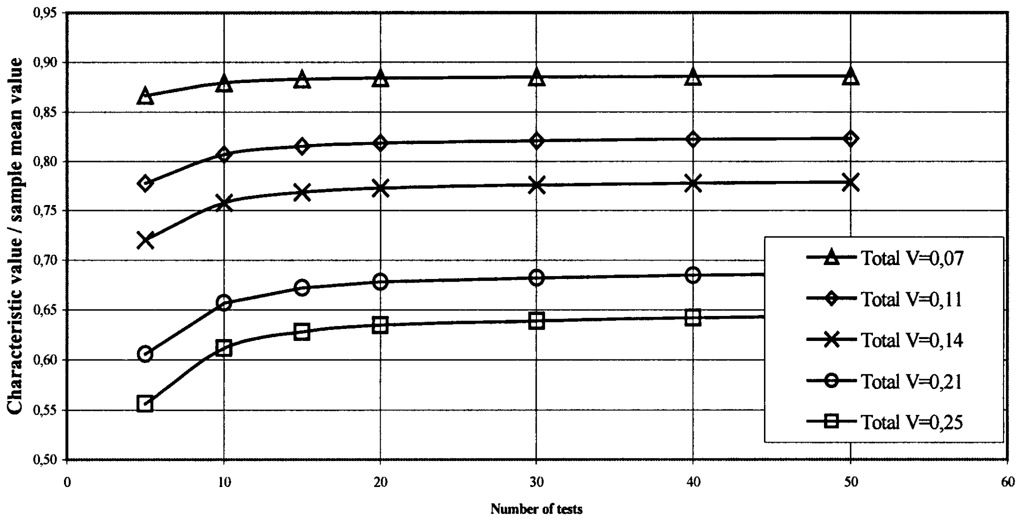

Figure A.2 — Characteristic value for different numbers of test and low parameter variation

A.2 Case study of "design assisted by testing"

A.2.1 Test data

A Norwegian producer of hollow core floor slabs has provided results of full-scale tests performed as a part of the production control over a period of 2 years. The tests were performed to verify the shear strength of the slabs according to the test method given in EN 1168.

Although the test program was planned on a different basis, the tests are here treated as if they were performed as part of an initial type testing, replacing an existing resistance model by a revised model. Subclause A.2.5 indicate changes that would have made the test program more efficient from the point of view of initial type testing.

A total of 64 shear tests on 32 slab elements were reported. Detail measurements were missing from 24 of these tests (primarily actual dimensions of the cross section). The remaining 40 test results were used to verify the shear strength of the slabs in two different ways. Firstly, a revised resistance model was verified according to EN 1990:2002 (D.8). Secondly, the shear strength was determined as a "single property" according to EN 1990:2002 (D.7).

Mean values, characteristic values and design values are calculated (where possible) using the existing as well as the revised resistance model and compared to the values found from "single property" testing.

A.2.2 Resistance models

As a first step, the shear strength for each individual test specimen was calculated according to the existing model 1 from EN 1992-1-1, using the measured values of h, b_{w} and f_{c} from the actual specimen:

$$R = \frac{I b_{\mathrm{w}} f_{\mathrm{ct}}}{S} \sqrt{(1+\alpha\sigma_{\mathrm{cpm}})} \approx 0{,}5 h b_{\mathrm{w}} f_{\mathrm{ct}}$$ (double symmetric section)

where

$$f_{\mathrm{ct}} = 2{,}12 \ln(1+0{,}1 f_{\mathrm{c}})$$ (high strength concrete)

A comparison between measured shear strength values and values calculated from Model 1 are shown in Figure A.3.

Figure A.3 suggests that model 1 underestimates the strength of 265 mm slabs and overestimates the strength for the other dimensions. Without going into possible physical explanations for this tendency, it was recognised that the cores constitute different parts of the section for different slabs. A revised calculation model (model 2) was formulated as:

$$R = 0{,}5\, h b_w f_{\text{ct}} \frac{0{,}50}{\psi}$$

where

ψ is the core portion of the section.

A new comparison between measured and calculated values is shown in Figure A.4. Model 2 may be argued to underestimate the strength of slabs with large height. On the other hand such a conclusion would be supported on a rather limited number of tests on slabs with large height.

It was decided that systematic deviations from model 2 were sufficiently small to be acceptable. The final step in developing the revised resistance model was the determination of the correction factor that would give a ratio of 1,0 between measured and calculated mean values. This correction factor, k_1, was found (Figures A.3 and A.4) to be 1,35 and 1,29 respectively. The total coefficient of variation was determined to be 16,5 and 14,5 %. This gives a ratio, k_2, between characteristic values and mean values of 0,747 and 0,775 (Figure A.1).

Finally, half the test results were discarded by random selection to see the effect of the number of tests on the conclusions that may be drawn from the test program. This turned out to give almost the same result as if all 40 tests were included.

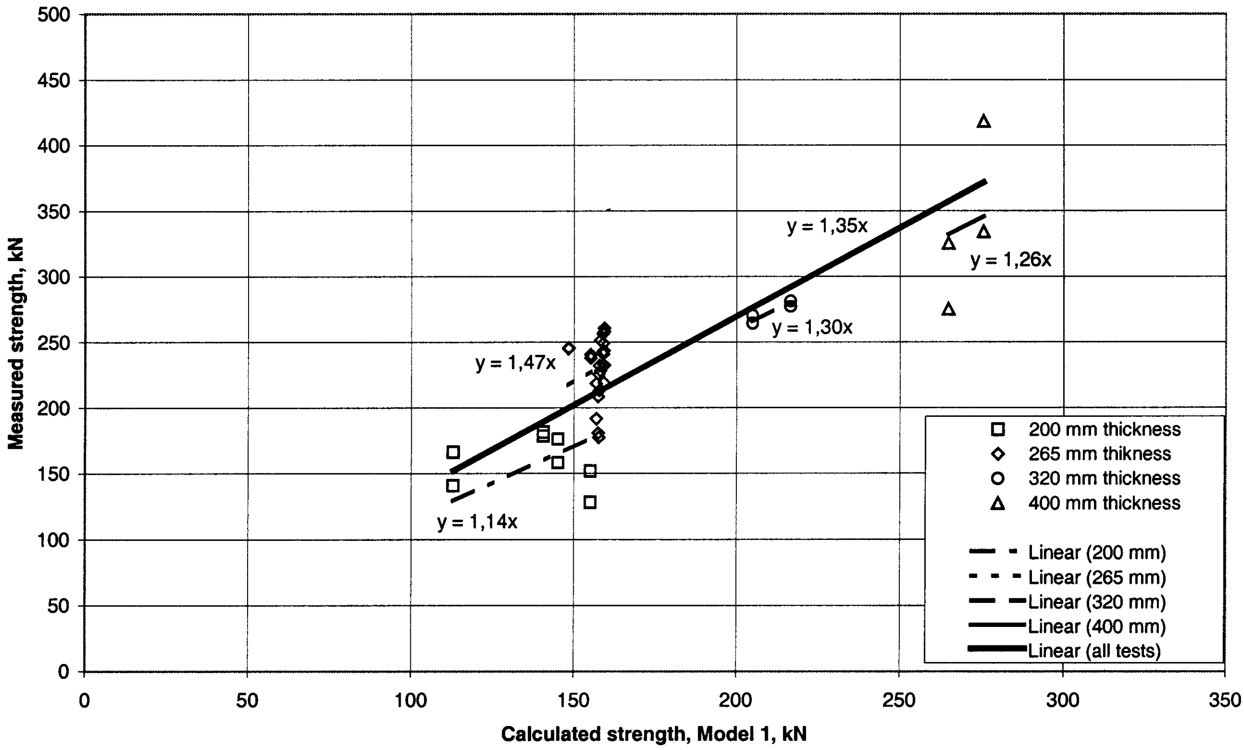

Figure A.3 — Calculated versus measured strength, Model 1

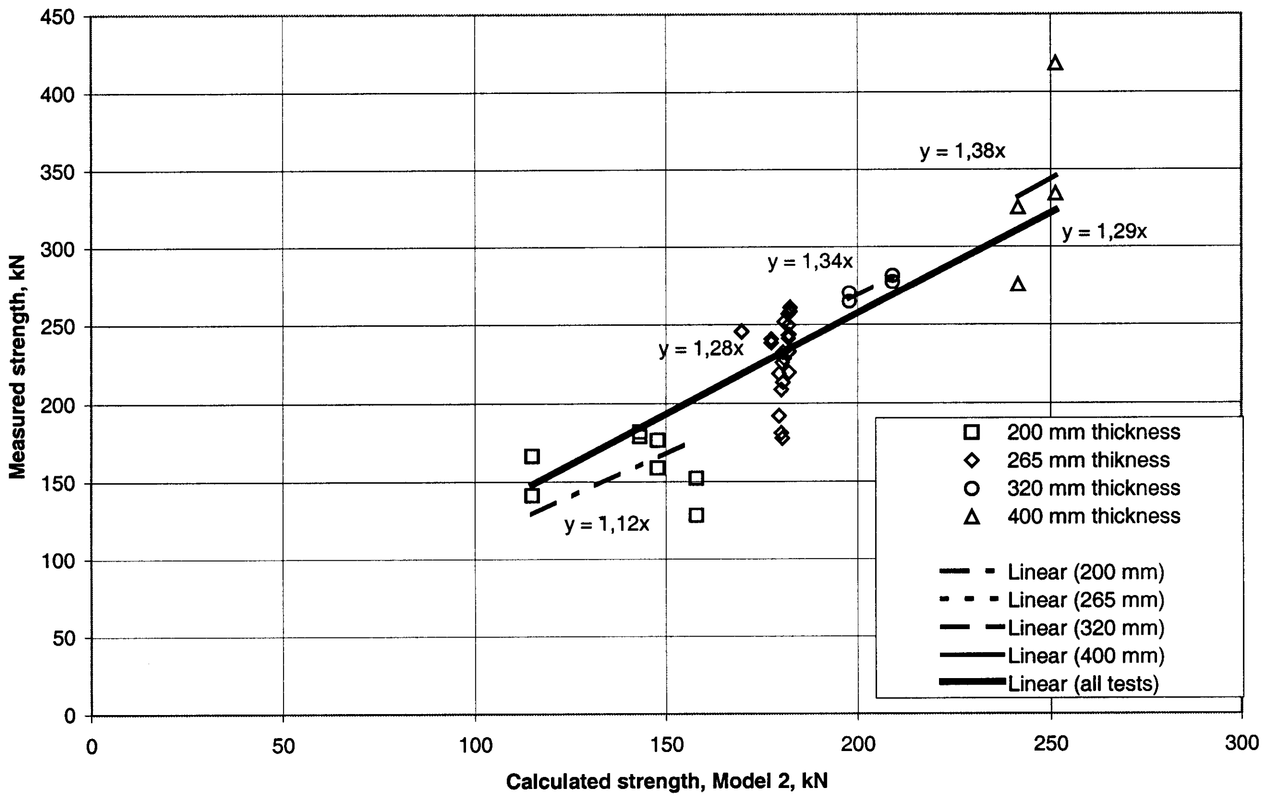

Figure A.4 — Calculated versus measured strength, Model 2

A.2.3 Determination of characteristic values and design values

Table A.1 summarises the outcome of this part of the analysis. The mean value and characteristic value of the shear strength is determined in 4 different ways:

— calculation using Eurocode 2, EN 1992-1-1 directly. A mean concrete compressive strength of 76 Mpa has been assumed, corresponding to the mean strength measured in the 40 tests. The corresponding tensile strength (mean and characteristic) is found from Table 3.1 in EN 1992-1-1. Dimensions are taken as the actual average dimensions in the test program;

— calculation based on model 1 verified by the test program of 40 tests according to the procedure in A.1.2. This implies that the original eurocode formula is modified by a correction factor, k_1=1,35, determined as the slope of the linear regression line in Figure A.3. The shear strength mean value is found from the modified resistance model using the actual average values for dimensions and concrete strength. The procedure from A.1.2 is also used to determine the total coefficient of variation and the reduction factor used to transform the mean value to a characteristic value. The variation on the model is dominant compared to the variation on dimensions and concrete strength. The design strength is found by inserting the design strengths of the materials entering in the model (based on Eurocode 2, safety factor). In this case only the concrete tensile strength enters the model;

— calculation based on model 2 using the same procedure as described for model 1;

— determination of the shear strength as a “single property” according to EN 1990:2002 (D.7). The number of tests is so small for two groups that the determination of characteristic strength for these groups is debatable. It should also be noted that D.7 introduces a conversion factor, η_d, in the calculation of the design value from the characteristic value. The conversion factor depends on the type of test and the type of material. Values, however, are not given. A relevant partial safety factor in this particular case could be the factor used on concrete strength. But in general terms a single property is found without utilising prior knowledge and the choice of safety factor may not always be so clear.

A.2.4 Determination of declared values.

The calculated shear strength values in Table A.1 are determined on the basis of actual average values of dimensions and concrete strength measured on the specimens in the test program to be comparable with the strength values found as a “single property”. The statistical procedure used to determine these values imply a confidence level of approximately 75 % (EN 1990:2002) In other words the client has a 25 % risk that the statistically determined values are smaller than the correct value. This is the normal confidence level built into the safety systems of Eurocode 2.

Declared values should of course take into account that values in a continuous production may well be smaller than the average values in the test program. This is no different from other design situations, where the designer will use values for dimensions and for characteristic strengths that are not afterwards likely to be violated in the production.

In principle, the decision about the declared value in relation to the characteristic value is a producer decision. The producer would like to limit the risk of having a satisfactory product rejected. This can be obtained by declaring a value smaller than the value found in Table A.1. In principle, the producer risk becomes smaller and smaller as the number of tests in the sample is increased and as the declared value is reduced compared to the value determined from procedures in A.1.2.

On the other hand, the producer risk also depends on the requirements given in the product standard on production control. Any loophole in these requirements will make it easier to run a production without discovering that the real properties do not comply with the declared values. The standardisation body may therefore have a legitimate reason to include rules in the standard about the relation between declared values and values determined by the procedures in A.1.2.

Table A.1 — Statistical analysis leading to characteristic values

Nominal dimensions mm			**Shear strength Determined by**	**Calculation by**			**Single property**
Slab height	**Sum of wall thickness**	**Core portion of slab %**		**EC 2**	**Model 1**	**Model 2**	**40 tests**
			Model correction factor, k_1	1,00	1,35	1,29	
			Total variation %		16,5	14,5	
			Reduction factor, k_2	0,700	0,747	0,775	
			Partial safety factor	1,50	1,50	1,50	
200	268	49,1	Mean value	122,3	165,0	160,2	160,4
			Number of tests				8,0
			Variation %				11,9
			Reduction factor, k_2				0,761
			Characteristic value	86	123	124	122
			Design value	57	82	83	
265	272	43,7	Mean value	164,4	221,9	242,1	230,7
			Number of tests				24,0
			Variation %				9,9
			Reduction factor, k_2				0,826
			Characteristic value	115	166	188	191
			Design value	77	111	125	
320	287	51,8	Mean value	209,5	282,7	260,2	273,4
			Number of tests				4,0
			Variation %				2,7
			Reduction factor, k_2				0,928
			Characteristic value	147	211	202	254
			Design value	98	141	134	
400	327	54,8	Mean value	298,3	402,7	350,3	338,5
			Number of tests				4,0
			Variation %				17,5
			Reduction factor, k_2				0,539
			Characteristic value	209	301	272	182
			Design value	139	201	181	

A.2.5 Comments on the test plan and the data interpretation.

A.2.5.1 Test number

As mentioned earlier, the test data consist of 40 results from 20 specimens – each end of the slabs were tested. It may be argued that the results should rather be treated as 20 results – each result being an average of the two ends.

If that argument is accepted, the values calculated above would of course to some extent be changed (unchanged mean value, variation maybe a little smaller, reduction factor a little smaller). In the context of the present paper, however, the argument illustrates that the standardisation body may have to specify further the sampling of test specimens. Is it acceptable, for example that a sample contains more than one specimen from the same casting operation?

A.2.5.2 Random versus biased sampling

It may also be noted that the 40 tests are unevenly distributed over the 4 groups of slabs. This happens to be the result of random sampling from an actual production with 265 mm slabs as the predominant variant. The distribution is clearly not ideal for verification of a model. Considering, however, the uneven distribution of the actual production, the producer might also deliberately choose the uneven sampling, because he is prepared to declare relatively smaller values for other variants than the 265 mm slab. The sampling plan is biased but combined with the choice of model 2 it is likely that the “error” would be correct values for the 265 mm slabs and underestimated values for the large slab dimensions, which means a safe bias. If model 1 is used the result is likely to underestimate values for 265 mm slabs and to overestimate values for the other slab dimensions, possibly resulting in an unsafe bias.

A.2.5.3 Concrete strength

A last comment deals with the parameter concrete strength. The shear strength according to both models depends on the tensile strength and in the relevant compressive strength classes the tensile strength calculated from the compressive strength is almost constant. Thus, the calculated shear strengths are insensitive to the concrete compressive strength, measured on cylinders.

The measured shear strength results do not disagree with this observation but two comments are called for:

— the test programme contains one strength class only (because only one strength class is used in the factory). Therefore the results do not prove that model 1 or model 2 can be used for other strength classes than used in the tests;

— in some productions of hollow core slabs the casting process includes heavy compaction of the concrete in the slab. The properties of the concrete in the webs of the slabs depend on the concrete mix and the compaction. More water in the mix will improve compaction, but will decrease the strength of the concrete in the cylinders. This might lead to a potential sensitivity to variations in the compaction that is not necessarily revealed by testing the concrete cylinders. The test program as described in this report does not handle this possible effect. Auxiliary tests to link the strength of the cylinders to a measure of the strength in the webs should have been added.

This type of problem may apply for properties of several other products, and it underlines the need for standards to specify relevant auxiliary tests as part of the initial testing program as well as the production control.

Annex B
(informative)

Provisions for full-scale testing in CEN/TC 229 product standards

B.1 General

The present annex contains a list of items, which should be dealt with in a CEN/TC 229 standard in case the standard calls for full-scale testing of products. The items may be covered partly in a separate test standard and partly in the product standard itself. The list is therefore not intended as a template but as a guidance note to task groups writing product standards.

The text in B.2 written in normal style letters is intended to be product independent and may be used directly in a standard. Text in italic letters indicates the product specific details that should be defined in the individual product/test standard.

B.2 Provisions

B.2.1 Objectives

This testing method is intended to provide the basis for initial type testing of *product* with respect to:

List of objectives mentioned in the main text of the standard as part of design and type testing, e.g.:

- verification of behaviour;
- determination of characteristic values;
- establish correlation between full-scale test results and results from alternative test methods.

B.2.2 Specification and selection of specimens

B.2.2.1 Identification of product family

The producer shall identify groups of elements within the product family, which he will treat as having the same product properties. For each group a specific set of product properties shall be defined as representative for the group. The grouping need not be the same with respect to all properties. The producer shall record the reasoning behind the identification.

The standardisation body may give requirements/recommendations with respect to this grouping.

B.2.2.2 Design of test specimens

The specimens shall be designed to facilitate the objectives in B.2.1. The main layout of the test specimens should be defined by the standard.

The producer shall prepare and record a test plan containing appropriate drawings and documents describing the test specimens and their relations to the groups defined in B.2.2.1.

The standard committee may include further details as warranted for the actual product.

B.2.2.3 Selection of specimens

Specimens are produced for the specific purpose of testing according to the test plan.

or

Specimens shall be taken from the continuous production in accordance with the rules for random sampling.

The standardisation body may give guidelines with respect to the effect of grouping. Possible rules for sampling to avoid unsafe bias should be considered.

B.2.2.4 Accompanying tests

The test plan shall contain relevant tests on material properties for the specimens to be tested.

It should be considered if standard material testing is a reliable measure of the properties of the material in the product. If not, accompanying tests are required to:

- determine directly the material strength in the product; or
- determine an indirect measure of the strength of the material or the strength of the product. Both types of accompanying tests may be specified further if needed.

B.2.2.5 Age at testing

The specimens should preferably be at least 28 days old, when cured under natural conditions, or 14 days old when thermally cured. Testing of elements less than 7 days old is not recommended. In all cases, the precise history of the specimen shall be known (age, production and curing methods, storage etc.).

B.2.2.6 Pre examination

Before the test, the main dimensions of the element shall be recorded and a visual examination made. Information on conditions that might affect the test shall be recorded and may include:

Specific risks for the product should be mentioned (e.g. unsatisfactory surface appearance, curvature, warping, cracking).

B.2.3 Loading conditions

B.2.3.1 Climatic conditions for the test specimen

The test should be made in a space maintained in stable environmental conditions. During the loading the ambient temperature should be kept constant with a ± 5 °C tolerance. The minimum temperature, however, should be at least 5 °C. Specimens should be climatically stabilised for at least 24 h under these ambient conditions.

If this cannot be achieved for the specific product, it should be stated how temperature variation is taken into account when planning the test and assessing the test results.

B.2.3.2 Type of loading

The loading on the test specimen shall be specified to reflect the objectives of the test. It means:

- distribution of load effects in the specimen shall be representative for actual conditions in a structure;

or

— loads shall be chosen to highlight the problem embedded in the objective.

B.2.3.3 Support conditions

The element to be tested shall be supported and loaded in such a manner, that it is statically determinate (roller supports, rotation allowed at simple supports, load and reaction directions to be maintained under deflection, no bridging effect in dead weight loading etc.).

Irregularities on the bearing surfaces shall be corrected (e.g. using mortar or bearing pad) unless the effects of the irregularities are part of the objectives).

B.2.3.4 Frame stiffness

When behaviour and/or other results at the ultimate load level is part of the objectives the stiffness of the testing rig should be specified (dead weight = soft rig, stiff rig unload specimen when non-elastic deformations take place).

B.2.3.5 Loading history

The load shall be applied to the specimen according to the following rules:

— speed of loading shall not exceed 10 % of expected ultimate load pr minute. The time includes actual time used to increase the load from one level to the next and the time spent at each load level to record displacements and to make other observations;

— the loading history should start with one loading-unloading step to a small load value ([x] % of expected ultimate load to settle the set-up);

— the loading history shall contain [x] loading-unloading sequences to service load level each sequence consisting of [x] load steps (if the stiffness or permanent deflections are part of the objectives).

The final loading sequence to failure load shall contain at least *[x]* load steps and/or deflection steps

B.2.4 Measurements

B.2.4.1 Force measurements

The loads transferred to the specimen shall be measured with a tolerance better than […]

B.2.4.2 Deformation measurements

Deformations of the test specimen shall be recorded as follows:

— where and what to measure;

— tolerance on deflection and strain measurements either in absolute terms (± [x] mm) or in relative terms ([x] % of expected value);

— possibly extra rules for measurements of permanent deformations.

B.2.4.3 Registration of observations

Failure mode shall always be recorded if ultimate load conditions are part of the objectives.

Specify if cracking shall be recorded (reference to objectives) and how.

B.2.5 Test frequency

B.2.5.1 Initial type testing

The minimum number of tests for each of the identified groups in the product family (see B.2.2.1) shall be at least [x].

B.2.5.2 Further type testing

Initial type testing shall be repeated when a change takes place either in the design, in the materials used or in the production process.

Initial type testing shall be confirmed by further type tests at least every [x] months.

B.2.5.3 Production control

Accompanying tests or indirect tests that have been identified during initial type testing to monitor the production process should be part of the production control. Full-scale testing is not likely to be relevant as part of production control.

B.2.6 Statistical evaluation

The statistical evaluation shall follow the Guidelines of:

- EN 1990:2002, Annex D;
- ISO 12491:1997.

B.2.7 Test report

The test report is composed of:

- purpose of test;
- type, number, designation and origin of the elements;
- specification of elements belonging to the same lot (group, production period etc.);
- sampling of specimens;
- characteristics of the elements;
- date of test and age of the element at testing;
- description of test:
  - testing conditions, temperature, method of loading;
  - class of testing machine ;

  - apparatus and method of measurement;
  - names of responsible persons;
- main results:
  - dimensions, cracks, deformations;
  - maximum load, failure characteristics;
  - results of accompanying tests;
- observations relating to behaviour under load etc.;
- any product specific addition.

B.2.8 Consequences

B.2.8.1 Non-compliant products

Irrelevant for initial type testing.

B.2.8.2 Corrective actions

Initial type testing may yield non-compliant results with respect to some of the objectives listed in B.2.1 (e.g. unacceptable behaviour). In that case the design or production process shall be changed.

With respect to other objectives in B.2.1, the initial type testing may lead to either the determination of declared values for the tested design or a change of the design or the production process in order to obtain more appropriate results.

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