SLOVENSKI STANDARD
SIST CR 13901:2003

01-marec-2003

Uporaba koncepta družin betonov za kontrolo proizvodnje in skladnosti betona

The use of the concept of concrete families for the production and conformity control of concrete

Ta slovenski standard je istoveten z: CR 13901:2000

ICS:

91.100.30	Beton in betonski izdelki	Concrete and concrete products

SIST CR 13901:2003 **en**

CEN REPORT

RAPPORT CEN

CEN BERICHT

CR 13901

May 2000

ICS

English version

The use of the concept of concrete families for the production and conformity control of concrete

This CEN Report was approved by CEN on 10 April 2000. It has been drawn up by the Technical Committee CEN/TC 104.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

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

Central Secretariat: rue de Stassart, 36 B-1050 Brussels

Ref. No. CR 13901:2000 E

Members of the Task Group

Becker, A, Germany
Biasioli, F, ERMCO
Brown, B V, UK
Duarte, J, Portugal
Harrison, T A, Chairman
Souwerbren, C, Netherlands
La Plante, P, France
Larsen, F, Denmark
Lechuga, J A, Spain
Roberts, M, Secretary
Tveter, T, Norway
Zanco, P G, Italy

CONTENTS

1. INTRODUCTION

The use of concrete families for the production and conformity control of concrete is well established in many parts of Europe. In some CEN Member States it has been used for over a decade. The exact ways in which the concrete family systems are applied varies widely and they reflect local conditions and needs. The ready-mixed concrete industry have, in general, pioneered these developments, but the systems are equally applicable to site made concrete and concrete for use in precast elements.

1.1 Introduction to production control

In production control, samples are taken at random from the production and tested for the relevant properties to confirm that the control of constituent materials, plant, batching etc. is working as expected. These data are analysed for significant, real changes in properties. By combining these data into concrete families, changes in concrete quality can be detected more rapidly and consequently, appropriate action can be taken more rapidly.

The concrete family system when used for production control does not rely on any particular control system. It is applicable to the most basic systems e.g. strength/ date charts as well as to the most sophisticated computer based systems. Production control is solely the responsibility of the concrete producer and therefore the size and contents of any family used for production control should be the producers choice. However, the producer is warned that by attempting to include concretes with unreliable relationships to the Reference Concrete, production control will be much more difficult and the standard deviation will increase significantly.

1.2 Introduction to conformity control

The 28-day compressive strength and other test data used for production control may also be used for conformity control. All the test data obtained during an assessment period is checked for conformity to the conformity criteria given in the concrete standard e.g. EN 206-1: *Concrete - Part 1: Specification, performance, production and conformity* [1]. As the system of conformity control, which is operated by the producer, must have the full confidence of users and purchasers, the concrete family used for conformity control must be based on consensus.

The CEN Member States with the more complex and sophisticated concrete family systems arrived at these over time by developing confidence in smaller families. EN 206-1 has taken a pragmatic approach to families in that it sets the principles for family membership and then introduces a check to verify that all the individual concretes belong to the family.
It should be noted that the family system in EN 206-1 requires every single result to be checked against the individual criterion of $f_{ci} \geq f_{ck} - 4$ i.e. criterion 2 in **8.2.1.3** of EN 206-1.

An essential element in maintaining the confidence and credibility of the concrete family system is that the system, the relationships between members of the family and the functioning of the system are approved and regularly audited by a third party certification body that has expertise in concrete technology and production. For site made concrete where there is no third party involvement, the second party should take on this role using personnel with appropriate experience and expertise.

1.3 EN 206-1

The provisions for concrete families in EN 206-1: *Concrete - Part 1: Specification, performance, production and conformity* [1] were developed over a number of years. They are a consensus on what represents effective and practical conformity control for a family of concretes. EN 206-1 defines and delimits the concept of concrete families and permits their use for the production and conformity control of concrete. Concretes may be grouped into families and the relationships between members within a family have to be established by initial testing, existing production data and/or theory. Results of tests on samples taken at random within a family are pooled for production control purposes by converting them to equivalent values of the Reference Concrete. Control of the Reference Concrete is a strong indication that all members of the family are under control.

EN 206-1 defines a concrete family as a group of concrete compositions for which a reliable relationship between relevant properties is established and documented. Guidance on the selection of a family is given in Annex J. High strength concrete is excluded from the family concept for conformity control and high strength is defined as > C55/67 or > LC55/60. Lightweight concretes cannot be included into a family with normalweight concretes, but they may form their own family.

Clause **8** of EN 206-1 contains detailed provisions for the conformity of concrete families. The background to these provisions is given in section **4** of this report.

1.4 General

Examples of the application of concrete families to production and conformity control are given in Appendix A.

EN 206-1 defines how the concrete family system is to be applied for conformity assessment. This report provides details of the application of these requirements using a number of examples. Worked examples 1, 4 and 5 are based on concrete families currently in use. They use real production data obtained during the assessment period. For simplicity and consistency, conformity is assessed against the EN 206-1 conformity criteria, but it has to be recognised that the concrete data used in the examples were required to conform to other criteria which may have been less or more severe. Example 2 gives the principles of the concrete family system used for designed concrete product conformity in the Netherlands. Example 3 illustrates why a confirmation criterion has been introduced for family members. It shows the condition where a single family member is not in conformity and the evidence from production control has been ignored. This example uses simulated data to illustrate this situation.

The extent to which the concrete family system is of benefit will depend on the particular circumstances. Where large volumes of a few concretes are produced, the concrete family system is unlikely to be as effective as separate control systems for each concrete. However, as the number of concretes produced at a given plant increases, the concrete family system becomes a viable option and, where the number of different concretes produced is very high, some form of concrete family becomes essential.

Another factor is the cost of testing. Clause **8.1** of EN 206-1 permits sampling to be taken at the concrete plant provided the concrete properties and composition does not change significantly between the point of sampling and the place of delivery. Sampling and testing at a concrete plant makes it easier to obtain sufficient samples to make separate conformity control systems viable, whilst testing at the point of delivery (i.e. the site) makes it more difficult and expensive to obtain sufficient samples for separate control systems.

As a general guide, if sufficient test data can be obtained for each concrete within, say, 3 to 4 months, a separate conformity control system for each concrete is likely to be the more economic solution. In other circumstances, some form of concrete family is likely to be more cost effective.

In all cases, combining data into families in the production control system will reduce the time taken before a significant change in quality is detected.

Combinations of control systems for single concretes and concrete families are possible.

2. BACKGROUND

The concrete family system uses traditional concepts in the control of concrete. This section summarises some of these concepts.

2.1 Uncertainty

Concrete is designed to achieve specified requirements with a high level of probability. If data for design are scarce, a larger margin is applied to ensure conformity. As more data are generated the margin reduces. This concept is incorporated in Table 14 of EN 206-1 in that a different margin is required between initial and continuous production. Varying the margin is achieved in practice by varying the water/cement ratio.

The concrete family system extends this concept of increasing the margin to situations where the correlation between relationships may be less precise and to where data from a special concrete is scarce. This covers the practical situation where a producer is asked to supply an unusual concrete at short notice. He designs a concrete that errs on the side of safety, i.e. with an increased margin. These concretes are assessed individually for conformity.

Whilst test data from these concretes is used for conformity assessment, due to the uncertainty of the margin, including these data in the production control system may lead to false indications of changes in quality. It is therefore normal and prudent to exclude such data from the production control system.

2.2 Variability of test data

Test data will vary randomly and systematically due to

- inherent test variation;
- environmental conditions i.e. in controlling the initial concrete temperature;
- production and plant factors;
- materials quality variations.

Production control of concrete is concerned with distinguishing significant, real changes in concrete quality from differences due to random variability.

2.3 Systematic changes in concrete quality

Systematic changes in the quality of a constituent material will affect the quality of all concretes made with that material. In the concrete family system such changes are rapidly detected by changes to the Reference Concrete. Once a significant change is detected, all concretes in the family are adjusted using known or established relationships between members of the family and the Reference Concrete.

A systematic error in the operation of the plant will also be reflected by a change in the Reference Concrete. As a temporary measure, all the concretes in the family may be adjusted to protect the purchasers and users until the cause of the systematic error is identified and corrected.

2.4 Speed of response to changes in concrete quality

There is always a delay between the occurrence of a significant change in concrete strength and its detection by the production control system. To speed the response of their control systems, many producers estimate the 28-day strength from 7-day strength using continually updated relationships between 7 and 28-day strengths. Other systems use data obtained at earlier ages or from test specimens subject to accelerated curing. It should be noted that for conformity control only actual 28 day data are used and not predicted values.

The design margin is set at a level so that normal random and systematic changes in concrete quality do not result in non-conformity. Exceptional changes in the performance of constituent materials cannot be accommodated in this way. In practice, producers have commercial agreements with their suppliers to inform them of changes in quality over agreed values. The concrete producer can then adjust the mix proportions immediately to prevent a non-conformity occurring.

For the same total number of tests, the relatively large number of data for the Reference Concrete means that the production control system will detect significant, real changes more rapidly than using separate concretes. For example, if two concretes were being tested daily and 20 results are needed to detect a significant, real change, combining these concretes into one family would indicate a change after 10 days whilst keeping them separate would require 20 days before the change was detected.

2.5 Variability in standard deviation

The relationships between members of the family are normally based on best-fit curves e.g. the relationship between strength and w/c ratio. Where this relationship is used to transpose data to the Reference Concrete some data should be slightly higher than the transposed value and others slightly less. These differences tend to even themselves out and have no significant effect on the mean value. However pooling data leads to higher standard deviations when the spread in the standard deviations of the members is not too large. As this is the normal case, the standard deviation of the Reference Concrete will normally be slightly higher than that calculated for single concretes. In addition to this, transposition is based on predetermined margins and not the actual difference between the mean strength achieved for the family member and the mean strength achieved directly for the Reference Concrete. The effect of this is to give the pooled data a wider spread and a higher standard deviation, see Figure 1 and Appendix B. The net result is an increase in the margin and an increased factor of safety. A decade of experience in the UK of using relatively large families indicates that the standard deviation of a family is typically 0,5 to 1 MPa higher than that calculated for individual concretes i.e. a typical family standard deviation would be in the range 4 to 5 MPa.

Some current systems require the family standard deviation to be checked against the standard deviation calculated from the last defined number of strength results e.g. the last 12 results, and if this differs significantly from the current family standard deviation, an adjustment to the family standard deviation has to be applied. Clause **8.2.1.3** of EN 206-1 has as one of the methods this type of requirement for conformity control. The alternative is a continual system and either method can be applied when the concrete family system is used.

The decision by the producer to use a family system or separate concretes for control and design will depend on the assessment of costs of increased margins against savings in cost of testing for the same or enhanced level of safety for the consumer.

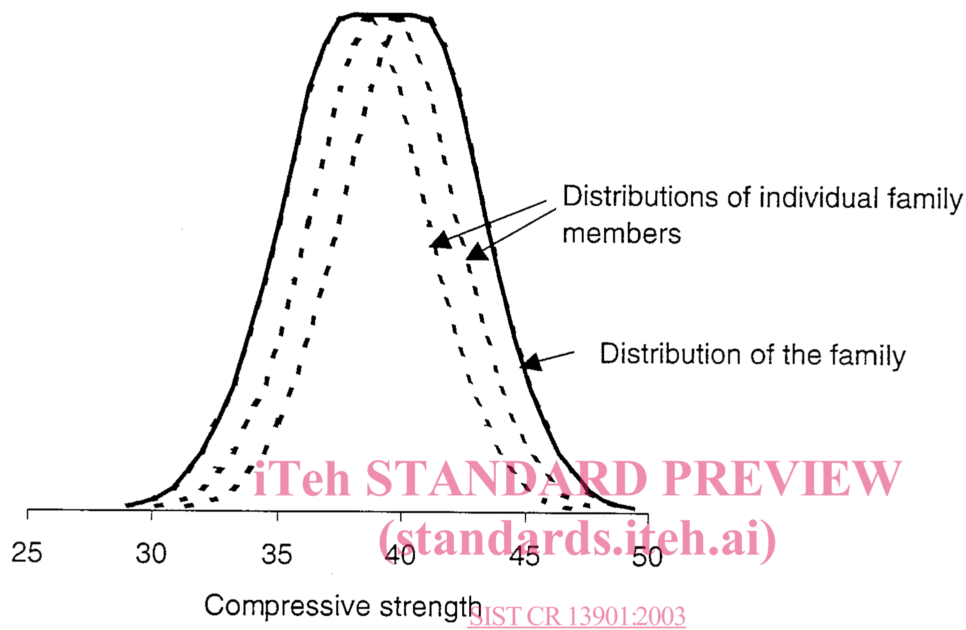

Figure 1: Illustration of the effect on the normal distribution of combining concretes.

3. THE USE OF CONCRETE FAMILIES IN PRODUCTION CONTROL

3.1 The basic concept

Concretes that can be related to each other are grouped together in families. Each family contains a Reference Concrete. When a member of the family is tested, the test result is transposed into an equivalent value of the Reference Concrete. These equivalent values of the Reference Concrete are used in the production control system [2] and also as part of conformity assessment.

3.2 Principles applicable to all systems

The main principles are:

a) A single Reference Concrete is selected for assessment by the control system.

This Reference Concrete contains the predominantly used cement and aggregates and it is selected as a concrete that is in the mid-range of the family or the concrete that is produced most frequently.

b) Relationships are established by initial testing, production data and/or theory to enable results obtained from one concrete in the family to be transposed to the Reference Concrete. Transposition factors are routinely monitored and reviewed. Where the concretes in the family are of one strength class and from one exposure class, transposition is not necessary.

c) The sampling rate for compressive strength testing applies to the family. The samples should attempt to cover the whole range of the family, but, obviously, can only be selected from the concretes being produced at that time.

Where the sophistication of the family includes members that are not within the production control system, see **3.5**, the sampling rate for production control should be based on those members within the production control system and then additional samples should be taken from the other concretes for conformity control purposes only. As it is likely that there will be few test data for these special concretes, conformity should be based on the criteria 2 and 3 given in EN 206-1.

d) Where applicable, the test data are transposed to equivalent values of the Reference Concrete.

There are various methods for transposing data based on strength, w/c ratio or cement content. The actual method is not critical as they give similar end results provided the cement content and w/c ratio are controlled by the structural strength and not minimum cement content or maximum w/c ratio requirements. The examples illustrate various methods that are in current use.

e) The Reference Concrete is used in the plant's production control system. Any production control system can be used.

f) When the production control system detects a change in quality of the Reference Concrete, all concretes in the family are adjusted using the established relationships or transposition factors. This is to protect the users.

The producer then attempts to establish the cause of the change in quality and when this has been established, he may modify his adjustments accordingly. For example, if the cause of the change were due to a change in the admixture, only concretes containing the admixture would be adjusted.

g) Prior to making a change to batch quantities, any requirements for maximum water/cement ratio and minimum cement content must be checked to ensure that they are still satisfied.

h) Both the original test data and the transposed data are used in the conformity assessment.

3.3 Selecting the family

When selecting the family for production control, the producer must be able to achieve control over all the family members. Where there is little experience of using the concrete family system, the following is recommended as a suitable starting point for a basic family:

cement of one type, strength class and source;
demonstrably similar aggregates and type 1 additions;
concretes with or without a water reducing/ plasticizing admixture;
full range of consistence classes;
concretes of a few strength classes.

Concretes containing a Type II addition i.e. a pozzolanic or latent hydraulic addition, should be put into a separate family.

Concretes containing high range water reducing/superplasticizing, retarding or air entraining admixture should be treated as individual concretes or separate families.

To be demonstrably similar, aggregates should be from the same geological origin, be of the same type e.g. crushed, and have a similar performance in concrete. Whether this is characterised by having a similar loose bulk density and strength, by its grading or by some other method can be left to local traditions.

Before using the family concept or extending the basic families given above, it is useful to test the relationships on previous production data to prove that they give adequate and effective production control.

3.4 Satisfying the specification

EN 206-1 recommends that, for durability purposes, a maximum water/cement ratio, a minimum cement content and an optional minimum strength class be specified. These requirements may result in a strength in excess of that specified for structural purposes. Most requirements for the composition of the concrete e.g. a minimum cement content, can be transposed to a strength requirement.

The strength for the production control of the concrete will be the higher of those needed to satisfy the specified requirements for strength and durability:

strength (structural or required for durability);
maximum water/cement ratio;
minimum cement content.

3.5 Coping with specials

Frequently a concrete producer is required to supply a variation of the concretes that are within a family and the production control system. To design this concrete he uses pre-established transposition factors related to the Reference Concrete, which includes a higher margin to reflect uncertainty, see **2.1**. It is advantageous to link such concretes to the Reference Concrete, as the actual batch quantities at the time of production will reflect the latest information on the performance of the constituent materials and the plant.

For the reasons given in **2.1**, test data from these concretes would only be used for conformity control and not in production control.

4. THE USE OF CONCRETE FAMILIES IN CONFORMITY CONTROL

4.1 Procedure for conformity

The use of the concrete family in conformity control will require in the European Union conformity to EN 206-1. The conformity criteria in this standard are based on non-overlapping results, but the standard permits the producer to use either non-overlapping or overlapping results using the same criteria. As the use of the family concept will ensure sufficient test data, it is recommended that the assessment of conformity be based on non-overlapping consecutive compressive strength results.

Prior to the use of the family system, the producer has to develop and document the relationships between family members (**8.2.1.1** and Annex A of EN 206-1). Where there is the involvement of a third party certification body, these relationships have to be approved (**C.2.1** of EN 206-1). These relationships have to be reviewed on the basis of original compressive strength data every assessment period and where there are appreciable changes in production conditions (**8.2.1.1** of EN 206-1). Where there is the involvement of a third party certification body, this review will be periodically examined (**C.2.2.1** of EN 206-1).

The procedure for determining conformity is given in Figure 2.

The conformity criteria for strength are given in **8.2.1.3** of EN 206-1 and they require:

a) Each original compressive strength test result to conform to criterion 2 in Table 14 of EN 206-1 for the specified strength class. This is identical to the equivalent requirement for conformity of individual concretes.

b) Each member i.e. each concrete composition, is confirmed as belonging to the family using criterion 3 in table 15 of EN 206-1. The test is applied to the original test data and it confirms that the data belong to the specified population (strength class). If these data are transposed into values of the Reference Concrete, they would have been a non-conforming set, see Figure 3, but because they comprise so few data may not have led to non-conformity of the Reference Concrete. Any family member that fails the confirmation criterion is removed from the family and assessed individually for conformity.

c) Where more than one strength class is in the family, each compressive strength test result within a family is to be transposed to an equivalent strength value of the Reference Concrete and the standard deviation is calculated from the transposed results.

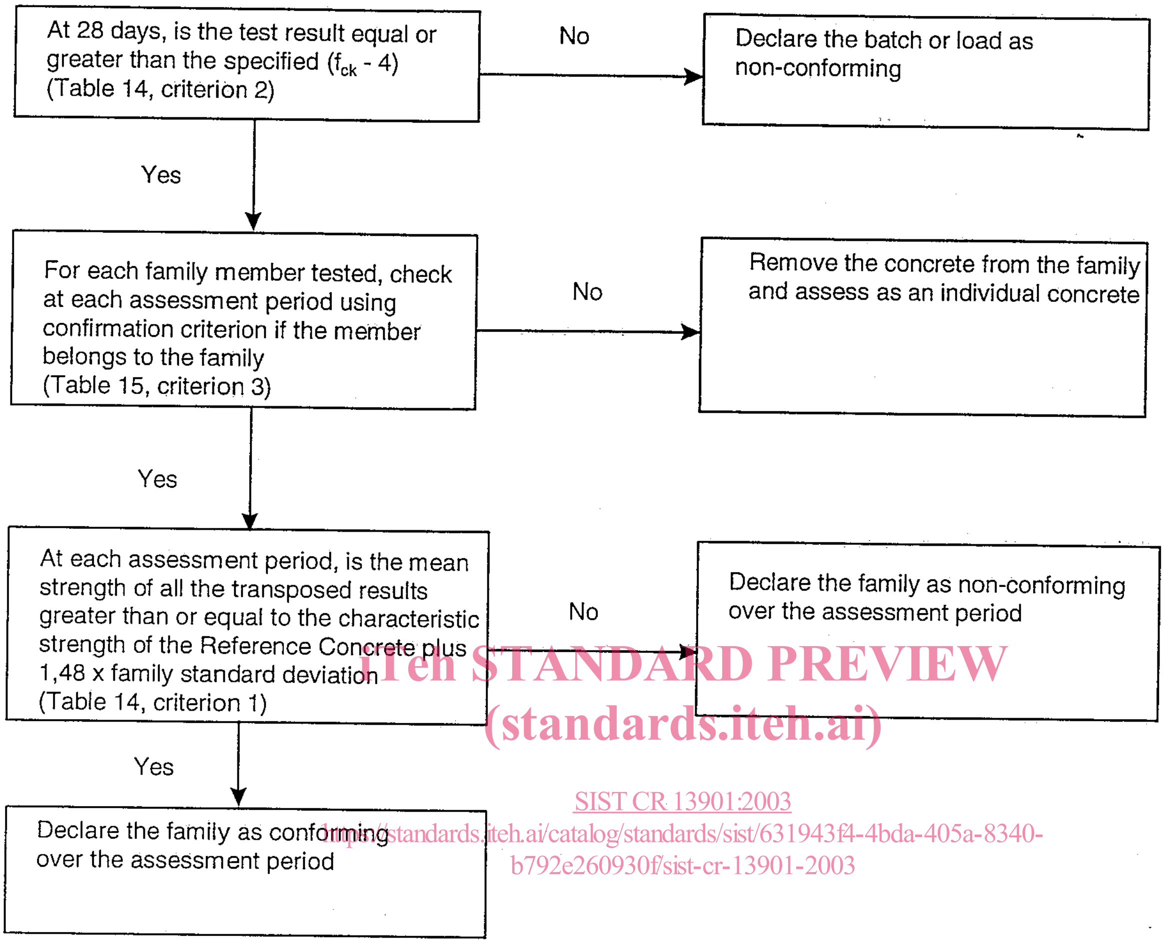

Figure 2: EN 206-1 procedure for conformity of a concrete family

d) The transposed results for the Reference Concrete shall conform to criterion 1 in Table 14 of EN 206-1. If sufficient data are available for specific concretes within the family, the producer may wish to assess these on an individual basis. In this case they are taken out of the family assessment.

e) The distinction between initial and continuous production given in Table 13 of EN 206-1 to be based on the number of transposed results.

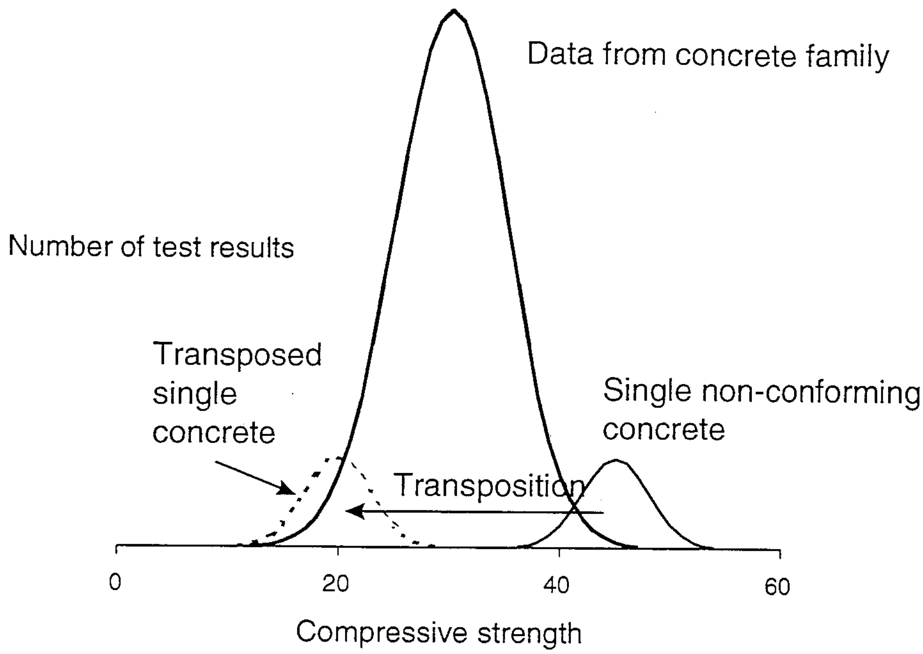

Figure 3: Illustration of the purpose of the confirmation criterion

4.2 Assessment of relationships

In addition to the conformity assessment, at each assessment period, the original results of each family member shall be inspected to verify that the relationship with the Reference Concrete and the design margins is still valid. One way of doing this is to calculate, for each family member, the mean strength for all the original test data taken during the assessment period and check that it is $\geq f_{ck} + 1,48\sigma$. If it satisfies this criterion, no further action is needed. If it fails this criterion, a more detailed investigation of the relationship is needed. This should involve the consideration of data from previous assessment periods and what was happening to the general production when this concrete was produced. This test is not part of the determination of conformity.

In the examples in Appendix A, the check on relationships is combined with the conformity assessment and it has been used as a filter for the application of the confirmation criterion. If a concrete passes the assessment of relationships (a more severe test) then it is deemed to have satisfied the confirmation test (criterion 3). Only where the data for a particular concrete fails this assessment of relationships is the confirmation check applied.

Where an inspection or certification body is involved, it is required to check the results of the conformity assessment by the producer. For site made concrete where there is no third party involvement, the second party should take on this role.

4.3 Derivation of the confirmation criterion

The basis of the criterion is whether the tested volume of each family member belongs to a population that fulfils the 5%-fractile requirement.

This is achieved by comparing the mean value of the results of any single concrete $\bar{x}$ with the mean value $\mu = f_{ck} + 1,645\sigma$ of such a population at a 99 % significance level. In this case the hypothesis $\bar{x} \approx \mu$ will be accepted if:

$$|\eta_{test}| = \left|\frac{\bar{x} - \mu}{\sigma}\sqrt{n}\right| \leq \eta_{0.99} = 2,576$$

This leads to:

$$-\frac{\bar{x}-\mu}{\sigma}\sqrt{n} \leq 2{,}576\,;$$

Where $\bar{x} < \mu$ (If $\bar{x} \geq \mu$, conformity is achieved without further analysis.)

$$\bar{x} \geq \mu - \frac{2{,}576}{\sqrt{n}}\sigma = f_{ck} + 1{,}645\sigma - \frac{2{,}576}{\sqrt{n}}\sigma$$

$$\bar{x} \geq f_{ck} + \left(1{,}645 - \frac{2{,}576}{\sqrt{n}}\right)\sigma = f_{ck} + \Delta_n$$

With an assumed standard deviation of σ = 5 MPa, this formula leads to the confirmation criterion in Table 1. When the actual standard deviation is less than 5 MPa, the confirmation criterion in Table 1 is more severe than that indicated by the hypothesis. The converse is true when the standard deviation is greater than 5 MPa.

Table 1: Confirmation criterion

Number. of test results, n	**Confirmation criterion** Mean $\geq f_{ck} + \Delta_n$, **MPa**
1	$\geq f_{ck}$ - 4,0
2	$\geq f_{ck}$ - 1,0
3	$\geq f_{ck}$ + 1,0
4	$\geq f_{ck}$ + 2,0
5	$\geq f_{ck}$ + 2,5
6	$\geq f_{ck}$ + 3,0

EN 206-1 does not give requirements for the confirmation criterion when there are more than 6 test results for the family member. In this situation, the following is recommended. When the number of test results is ≥ 15, apply the criterion:

Mean of the family member $\geq f_{ck} + 1{,}48\sigma$

When the number of test results is in the range 7 to 14, apply linear interpolation between the requirement for 6 test results and ($f_{ck} + 1{,}48\sigma$).

5. DISCUSSION

Where the concrete production is to be controlled using the concept of the concrete family, the necessary size of the family will depend upon:

the number of types of concrete produced;
the production;
the point of sampling;
the rate of sampling and testing;
the size of any additional margin;
the relative costs of these factors.

What is the most economical solution to one producer may not be the same for another. Permitting flexibility in the application of the principles of concrete families is important in achieving cost-effective production. Appendix A contains a number of examples of how the concrete family system is currently in operation.

6. CONCLUSIONS

The concrete family system provides an effective means of controlling a large number of different concretes. Large families normally have a higher margin due to an increase in the standard deviation. Special concretes can also be designed and controlled within a family provided there are appropriate increases in the margin to cope with uncertainty.

7. REFERENCES

1. prEN 206-1 *Concrete - Part 1: Specification, performance, production and conformity* has been submitted to the CEN members for formal vote. The latest official version available is prEN 206:1997 *Concrete – Performance, production and conformity.*

2. DEWAR, J D and ANDERSON, R *Manual of ready-mixed concrete.* Blackie Academic & Professional, 2nd edition, ISBN 0 7514 0079 3 0 442 30866 3