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1. Which concrete products require CE marking?

✓ Not all concrete products require CE marking
✓ CE marking does not apply to ready-mixed concrete
✓ Reinforcing and prestressing steels are included in the CPR, but the harmonized standards are still a long way off.

There are exemptions to the products included on the list of the harmonized standards. These include:

• traditionally made products or in a manner appropriate to heritage construction
• those manufactured on the construction site
• bespoke products (i.e. those manufactured specifically for an identified construction project.)
1. Which concrete products require CE marking?

The summary of concrete related product groups that are included in the CPR and should have harmonised standards and therefore require CE marking are as follows:

precast concrete products; cladding; roof tiles; cement, building limes and other hydraulic binders; reinforcing and prestressing steel (and ancillaries); masonry and related products, masonry mortars and ancillaries; aggregates; road construction products; products related to concrete mortar and grout; screeds; fixings; structural metallic products and ancillaries; structural timber products and ancillaries.
2. Scope of EN 206

✓ There is **no consensus** on European level on the exact scope of EN 206.
✓ **There is consensus** that EN 206 covers concrete for structures designed in accordance with EN 1992-1-1 and structural precast concrete.
✓ **The lack of consensus** is on how far it covers the other extreme of the concrete market, i.e. that for non-structural concrete. It is unrealistic to think that EN 206 (or any other standard) will be used for minor housing works where the concrete is produced on site using a shovel or in a small free-fall mixer.
2. Scope of EN 206

The unclear ‘grey’ areas with respect to the scope of EN 206 are site-made concretes on small and medium-sized house building sites and non-structural precast products. Even the terms ‘structural’ and ‘non-structural’ are interpreted differently. Is a concrete masonry unit structural or non-structural? Some believe it is structural while others believe it is non-structural.
3. Terms and definitions

3.1.5.4 characteristic strength

value of strength below which 5% of the population of all possible strength determinations of the volume of concrete under consideration, are expected to fall below the specified strength.

This is a rather abstract definition: instead of real strength measurements it is based on expected values of possible strength determinations. In addition, no lower limits are placed on the strength of the 5% of tests that are allowed to fall below the specified strength.
3. Terms and definitions

3.1.5.4 characteristic strength (cont.)

For a structural engineer the phrase ‘the volume of concrete under consideration’ may be applied to all the concrete in their structure and to the concrete in a single element of that structure even if this comprises a single batch. For conformity to EN 206, the ‘volume under consideration’ is all the concrete in an assessment period.
3. Terms and definitions

3.1.5.4 characteristic strength (cont.)

Neither of these interpretations of this phrase is suitable for use in control systems as the process is continual. Caspeele and Taerwe have proposed that if the production achieves an \textit{average outgoing quality limit} (AOQL) of 5\%, the production can be accepted as having achieved the characteristic strength.
3. Terms and definitions

3.1.1.18 specifier

person or body establishing the **specification** for fresh and hardened concrete

3.1.5.1 average outgoing quality (AOQ)

percentage of the unknown distribution **below the required characteristic value** multiplied by the corresponding acceptance probability of that distribution when using the applied conformity assessment
3. Terms and definitions

3.1.5.6 conformity test

test performed by the **producer** to assess conformity of the concrete

3.1.5.7 evaluation of conformity

systematic examination of the extent to which a product fulfils specified requirements
3. Terms and definitions

3.1.5.8 identity test

*test to determine whether selected batches or loads come from a conforming population*

3.1.5.9 initial (testing)

*test or tests to check before the production starts how a new concrete or concrete family shall be composed in order to meet all the specified requirements in the fresh and hardened states*
3. Terms and definitions

A.2 Party responsible for initial tests

(1) Initial tests shall be the responsibility of the producer for designed concrete, the specifier for prescribed concrete and the standardization body for standardized prescribed concrete.

9. Production control

(1) All concrete shall be subject to production control under the responsibility of the producer.
4. Conformity control and conformity criteria

**General**

Conformity control comprises the combination of actions and decisions to be taken in accordance with conformity rules adopted in advance to check the conformity of the concrete with the specification of concrete.

The **goal of conformity analysis** is to provide estimation of whether specific concrete composition fulfils the conformity criterions and is considered conforming over the assessment period.
Algorithm of conformity assessment

Step 1 – looking for a proper previous period

If no proper previous period exists, the production is considered initial and valuated by the initial period criterions with a group of $n = 3$ results.

If at least 15 results exist in the assessment period and a proper previous period exists, the production is considered potentially continuous and a group of $n = 15$ results is considered as the evaluation group.
4. Conformity control and conformity criteria

**Step 2 – check of the standard deviation**

At the end of initial production, the standard deviation ($\sigma$) of the population shall be estimated from at least 35 consecutive test results taken over a period exceeding three months. When continuous production commences, this value of standard deviation shall be used to check the conformity over the first assessment period, by comparing this value with the value of the mean quadratic deviation ($s_{15}$) from the accumulated 15 or more results during the continuous production.
4. Conformity control and conformity criteria

Step 2 – check of the standard deviation (cont.)

At the end of the first and subsequent assessment periods, EN 206 provides two methods for verification the estimate of initial standard deviation ($\sigma$). The first method involves checking whether the standard deviation it has changed significantly using the limits given in Table 19. If it has not changed significantly, the current estimate of the standard deviation applies to the following assessment period. When there is a significant change in ($\sigma$), a new ($\sigma$) is calculated from the most recent 35 results. The second method involves a continuous control system and use of control charts, called CUSUM method.
4. Conformity control and conformity criteria

Step 2 – check of the standard deviation (cont.)

Table 19 — Values for verification of standard deviation

<table>
<thead>
<tr>
<th>Number of test results</th>
<th>Limits for $s_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 до 19</td>
<td>$0,63 \sigma \leq s_n \leq 1,37 \sigma$</td>
</tr>
<tr>
<td>20 до 24</td>
<td>$0,68 \sigma \leq s_n \leq 1,31 \sigma$</td>
</tr>
<tr>
<td>25 до 29</td>
<td>$0,72 \sigma \leq s_n \leq 1,28 \sigma$</td>
</tr>
<tr>
<td>30 до 34</td>
<td>$0,74 \sigma \leq s_n \leq 1,26 \sigma$</td>
</tr>
<tr>
<td>35$^a$</td>
<td>$0,76 \sigma \leq s_n \leq 1,24 \sigma$</td>
</tr>
</tbody>
</table>

In case of more than 35 test results Formula (4) applies.
4. Conformity control and conformity criteria

Step 2 – check of the standard deviation (cont.)

\[ \sqrt{\frac{\chi^2_{0.025;n-1}}{(n-1)}} \sigma \leq s_n \leq \sqrt{\frac{\chi^2_{0.975;n-1}}{(n-1)}} \sigma, \quad (4) \]

where \( \chi^2_{\alpha;\nu} \) the \( \alpha \) – fractile of a chi-square distribution with \( \nu = (n - 1) \) degrees of freedom
4. Conformity control and conformity criteria

**Step 3 – checks by use of conformity criteria**

**Conformity criteria for compressive strength**

<table>
<thead>
<tr>
<th>Production</th>
<th>Number n of results in the group</th>
<th>Criteria for individual test result</th>
<th>Criteria for mean results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>3</td>
<td>( \geq f_{ck} - 4 )</td>
<td>( \geq f_{ck} + 4 )</td>
</tr>
<tr>
<td>Continuous</td>
<td>( \geq 15 )</td>
<td>( \geq f_{ck} - 4 )</td>
<td>( \geq f_{ck} + 1,48\sigma )</td>
</tr>
</tbody>
</table>
4. Conformity control and conformity criteria

Step 3 – checks by use of conformity criteria (cont.)

A concrete strength below the characteristic strength is not a failure as statistically 5% of the results are expected and accepted as to fall below this value. However for structural safety reasons, a batch with a concrete strength significantly below the characteristic strength is excluded, even though it forms part of the expected population.

Consequently EN 206-1 specifies a minimum strength requirement for individual results \( (f_{ci}) \) of \( (f_{ci} - 4) \). Any batch below this strength is a non-conforming batch.
4. Conformity control and conformity criteria

**Method C: use of control charts**

Method C provides an alternative of assessment of conformity during the continuous production of concrete by the use of control charts.

The control charts indicate small changes in the normal variation of concrete characteristics in time of continuous production and provide the producer with a tool to apply insignificant corrections in concrete composition far before a non-conformity of mean strength appears.
Method C: use of control charts (cont.)

Annex H gives a method of application for SUSUM control charts and for Shewhart control charts with examples of conformity rules that achieve an average outgoing quality limit not exceeding 5,0 %. Guidance on values other than those given in Annex H are given in CEN/TR 16369.

Method C is based on the assumption, that the producer should undertake small changes in the concrete composition, in case, the production control system indicates the target mean strength is not being achieved during the assessment period.
4. Conformity control and conformity criteria

**Basics of statistical control**

When testing strength of concrete on “n” number of cube specimens, a statistical population of individual test results is obtained $f_{c1}, f_{c2}, \ldots, f_{ci}, \ldots, f_{cn}$.

If plot the individual results on a number axis, ordered by magnitude, the distribution of results is uniform over the whole range of the population. Highest frequency of the results is observed around their mean value and differing from the mean, the frequency of appearance of a individual test results decrease.
4. Conformity control and conformity criteria

**Basics of statistical control (cont.)**

Compressive strength test results tend to follow a normal distribution of “bell-shaped” distribution as illustrated in Figure 1.
4. Conformity control and conformity criteria

**Basics of statistical control (cont.)**

The simplest configuration of normal distribution, known as “Standard normal distribution”, can be expressed by the probability density function, with analytical expression as follow:

\[
\phi(\nu) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(f_{ci} - f_{cm})^2}{2\sigma^2}}, \quad \text{където} \quad \nu = (f_{ci} - f_{cm})
\]
A normal distribution is defined by two parameters, the mean value of the distribution ($f_{cm}$) and the standard deviation ($\sigma$), which is the measure of the spread of results around the mean value. A low standard deviation means that most strength results will be close to the mean value; a high standard deviation means that the strength of significant proportions of the results will be well below (and above) the mean value – figure 2.
4. Conformity control and conformity criteria

**Basics of statistical control (cont.)**

Figure 2
The mean compressive strength of concrete is obtained by:

\[ f_{cm} = \frac{1}{n} \sum_{i=1}^{n} f_c \]

The standard deviation \( \sigma \) is obtained from accumulated more than 35 test results by the equation:

\[ \sigma = \sqrt{\frac{\sum_{i=1}^{n} (f_c - f_{cm})^2}{n-1}} \]

where:
- \( f_c \) individual test result for compressive strength of concrete, MPa;
- \( f_{cm} \) mean compressive strength of concrete, MPa;
- \( n \) the number of test results.
4. Conformity control and conformity criteria

**Basics of statistical control (cont.)**

The area under the normal distribution between two values of \( f_{ci} \) represents the probability that a result will fall within this range of values. The area closed between the curve and the absciss is obtained by the integral:

\[
\int_{-\infty}^{+\infty} \phi(v).dv = \int_{-\infty}^{+\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(v)^2}{2\sigma^2}}.dv = 1
\]

It equals to 1.0, i.e. the probability of a concrete strength value between \(-\infty\) and \(+\infty\) is equal to 100%.
4. Conformity control and conformity criteria

Basics of statistical control (cont.)

It is generally agreed the compressive strength of concrete to be secured by 95% probability, where this probability strength is called characteristic strength – $f_{ck}$. Its position on a number scale is determined by solution of the integral:

$$
\int_{-q_n\sigma}^{+\infty} \phi(v) \cdot dv = \int_{-q_n\sigma}^{+\infty} \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{v^2}{2\sigma^2}} \cdot dv = 0.95
$$

The solution of the equation provide a value for $q_n = 1.64$. 
4. Conformity control and conformity criteria

Basics of statistical control (cont.)

Gibb, I. and T. Harrison, Use of control charts in the production of concrete, ERMCO, 2010
The choice of the value of $q_n$ of 1.48 is considered in Annex H of EN 206 for number of test results $15 \leq n \leq 35$, taking into account the average outgoing quality limit AOQL not exceeding 5.0%. The higher the value of $q_n$ the higher is the influence of the test results obtained by producers with lower variability of the production, and significantly higher is the limitation imposed on producers with higher variability of the production. In this way, EN 206 encourage in lower extent the achievement of lower variability of the results from the quality control of the production. Outside the reality, or more specifically, the theoretical percent “defective” results as a basis for the choice of $q_n$ value, there is one more, very important consideration. This is the precision of standard deviation estimation.
If we take a look at the tables 9.1, 9.2 и 9.3 together, one can mention that the error in the estimation of $\sigma$ at 3 results is about 5 times larger than at 30 results. Choice of a higher value for $q_n$ will be argumented, if the estimation of $\sigma$ is based on at least 30 results. Therefore in EN 206 a value of 1.48 is proposed, based mainly of the works of prof. Luc Taerwe.

The statistical basis of the criterion for mean value in EN 206 is achieving average outgoing quality limit (AOQL) of 5%. Not satisfying the criterion for the mean value shows that AOQL exceeds 5% limit, but not that the concrete is inappropriate for the untended use. However, this indicates that the producer must undertake action to reach AOQL $\leq$ 5%.
4. Conformity control and conformity criteria

### Table 9.1 Percentage of results outside statistical limits

<table>
<thead>
<tr>
<th>A (%)</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>3.09</td>
</tr>
<tr>
<td>1.0</td>
<td>2.33</td>
</tr>
<tr>
<td>2.5</td>
<td>1.96</td>
</tr>
<tr>
<td>5.0</td>
<td>1.65</td>
</tr>
<tr>
<td>10</td>
<td>1.28</td>
</tr>
</tbody>
</table>

### Table 9.2 Error in mean for various values of standard deviation

<table>
<thead>
<tr>
<th>Standard deviation (SD) values</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of results</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.30</td>
<td>4.95</td>
<td>6.60</td>
</tr>
<tr>
<td>2</td>
<td>2.33</td>
<td>3.49</td>
<td>4.65</td>
</tr>
<tr>
<td>3</td>
<td>1.91</td>
<td>2.86</td>
<td>3.81</td>
</tr>
<tr>
<td>5</td>
<td>1.47</td>
<td>2.21</td>
<td>2.95</td>
</tr>
<tr>
<td>10</td>
<td>1.04</td>
<td>1.56</td>
<td>2.08</td>
</tr>
<tr>
<td>20</td>
<td>0.73</td>
<td>1.10</td>
<td>1.46</td>
</tr>
<tr>
<td>30</td>
<td>0.60</td>
<td>0.90</td>
<td>1.20</td>
</tr>
</tbody>
</table>

### Table 9.3 Error in standard deviation for various values of true standard deviation

<table>
<thead>
<tr>
<th>Standard deviation values</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of results</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.65</td>
<td>2.48</td>
<td>3.30</td>
</tr>
<tr>
<td>5</td>
<td>1.05</td>
<td>1.58</td>
<td>2.09</td>
</tr>
<tr>
<td>10</td>
<td>0.74</td>
<td>1.11</td>
<td>1.48</td>
</tr>
<tr>
<td>30</td>
<td>0.42</td>
<td>0.63</td>
<td>0.85</td>
</tr>
</tbody>
</table>
5. Identity testing

The conformity rules in EN 206 were formulated on the basis that only the producer exercises conformity control. Any change to this approach will require a fundamental re-appraisal of the conformity rules. In recognition that some specifiers (in some countries, also the contractor) may wish to sample and test the delivered concrete, EN 206 provides rules for identity testing. Annex B provides additional criteria for identity testing. This type of tests are done by the specifier or the user/contractor to verify that the delivered concrete on site belongs to conforming population.
5. Identity testing

For instance, identity criteria for the consistency are identical as those for continuous production, but with new tolerances. The class limits in Table 21 are unchanged, but there are changes to the permitted deviations on the class limits. The upper limits for the slump classes have been reduced. Previously only 15% of the results could be outside the class limits. The net result is that some of the tolerances on target values are smaller than the precision obtainable with the test procedure!
5. Identity testing

Table 1: Limits on consistence classes based on testing a spot sample taken from the initial discharge

<table>
<thead>
<tr>
<th>Consistence class A)</th>
<th>Conformity criteria based on testing the initial discharge (former EN 206-1:2000 limits shown in brackets)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower limit</td>
</tr>
<tr>
<td>Slump classes tested in accordance with EN 12350-2</td>
<td></td>
</tr>
<tr>
<td>Slump class S1</td>
<td>0 mm (0)</td>
</tr>
<tr>
<td>Slump class S2</td>
<td>30 mm (30)</td>
</tr>
<tr>
<td>Slump class S3</td>
<td>80 mm (80)</td>
</tr>
<tr>
<td>Slump class S4</td>
<td>140 mm (140)</td>
</tr>
</tbody>
</table>

* A) ERMCO Guide to EN206:2013
5. Identity testing

Reality of concrete production
• The main reason for the actual strength not being the same as the target strength value of concrete is changes in constituent materials, particularly changes in cement strength
• The concrete produced on a single day is not very likely to have the same statistical characteristics as the population of the results gathered during the period of assessment of the conformity
• Identity testing rules assume it does
6. Provisions valid in the place of use

‘Provisions valid in the place of use’ have been defined in EN 206 as ‘national provisions given in a National Foreword or National Annex to this Standard or in a complementary standard to EN 206 applicable in the place of use of the concrete. The National Foreword does not have to provide the provisions, it simply has to identify where they are to be found.

Annex M of EN 206, Guidance on provisions valid in the place of use lists all these provisions/permissions.
6. Provisions valid in the place of use

In some cases it is essential to provide national provisions, e.g. for resistance against damaging ASR. National departures to the standard, other than where stated in Annex M, are not permitted. Aspects not covered by EN 206 may be covered by national provisions, e.g. transport times to site; resistance to alkali-carbonate reaction, provisions for sulfate resistance with mobile ground water.
Thank you for your attention!