Concrete specification and testing – is BS EN 206 fit for purpose?

A new edition of BS EN 206, the Standard for concrete specification and testing, was published in December 2013[1]. Does it address previous criticisms[2,3]? Is the new edition now 'fit for purpose'? Alasdair N Beal of Thomasons reports.

BS EN 206:2013 covers concrete from strength class C8/10 to C100/115 (characteristic cube strengths 10–115MPa).

Cl. 3.1.5.4 defines concrete 'characteristic strength' as the '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'. This is a strangely 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, so if a customer specifies 30MPa concrete and receives 20 batches with strengths of 30–45MPa and one batch of 20MPa, the supplier could claim that this complies with a specification.

'Volume of concrete under consideration' and test criteria

Most of the recommendations in BS EN 206 concern statistically based control criteria for concrete producers. According to Cl. 8.2.1.2, concrete in continuous production by a producer with product control certification shall be sampled at a rate of at least one per 400m^3, or per five production days or per month (whichever is greatest). Test results can be based on one test cube/cylinder per sample. The acceptance criteria are:

- individual tests ($f_{ci} \geq (f_{ck} - 4)$ MPa)
- tests are also assessed either in groups of three (mean $f_{cm} \geq f_{ck} + 4$) MPa) or groups of at least 15 (mean $f_{cm} \geq f_{ck} + 1.48\sigma$) MPa, where σ is the standard deviation).

Annex B covers 'identity testing', in which clause B.1 states, 'indicates whether the defined volume of concrete under review belongs to the same population as that verified as conforming via conformity assessment by the producer'. A translation of this clause into plain UK English would be helpful – one assumes it means 'testing to establish whether concrete supplied to site complies with the specification'.

According to Cl. B.2, the 'volume of concrete under review' for 'identity testing' may be anything from a single batch to 400m^3 of concrete. Very little is said about sampling rates. According to Cl. B.3.1, if there is product control certification, one to six test results may be used for conformity assessment:

- individual tests $f_{ci} \geq (f_{ck} - 4)$ MPa
- for a group of two to four tests $f_{cm} \geq (f_{ck} + 1)$ MPa, or group of five to six tests $f_{cm} \geq (f_{ck} + 2)$ MPa).

Although concrete producers checking concrete are permitted by Section 8 to only test one cube/cylinder from each concrete sample, if a customer wants to check the concrete Annex B would require him to carry out twice as many tests – two cube/cylinder tests from every concrete sample. No explanation is given as to why the requirement for customer tests is different from producer tests.

Where the concrete has no product control certification, Cl. B.3.2 imposes more stringent requirements for assessing conformity: at least three test results are required and the strength requirements are:

- individual tests $f_{ci} \geq (f_{ck} - 4)$ MPa
- group of three to six tests $f_{cm} \geq (f_{ck} + 4)$ MPa.

Thus at least six cubes/cylinders must be tested, even if only a single batch of concrete is being considered.

Analysis

The compliance rules in BS EN 206 have some odd features:

- As can be seen, the criteria for 'identity testing' are more lenient than those for production control. They are also lenient compared with past UK practice; although the definition of 'characteristic strength' is similar to that in the old BS 5328[4], the allowable limits on test results in BS EN 206 are generally 1MPa lower. The Note to Table B.1 states that the probability of conforming concrete being rejected is only 1%; no figure is given for the probability of the customer having to accept non-conforming concrete. Annex J states that more stringent criteria may be applied in Spain because of its legal requirement that the risk to customers of defective concrete being accepted should not exceed 50%. Therefore presumably under the standard BS EN 206 rules the risk to the customer of having to accept defective concrete is more than 50%.
- If one test per sample is acceptable for producers, then it should also be acceptable for customers. Requiring customers to carry out twice as many tests simply increases costs and discourages testing.
- On a small project with concrete from a non-certified supplier, the requirement for a minimum of six tests regardless of volume involved is simply absurd.
- The BS EN 206 compliance rules appear to be based on analysis from 'large number' probability theory, where a small number of random samples is used to estimate the characteristics of random variations in a quasi-infinite population. However, concrete is delivered to construction sites in batches, so its strength variations are 'quantised' and although large variations are possible between batches, the variations within a batch of properly-mixed concrete are usually small. 'Large number' probability theory does not apply in this situation unless the sampling rate is very low (1/10 or less)[5].
- The compliance rules ignore the effect of sampling rate on customer and producer risk. If the entire concrete for a project is assessed on the basis of a single test result, or the combined results of a single group of test results, this creates a high risk for both the producer and the customer. However, these risks can be reduced by increasing the sampling rate. If every batch of concrete is sampled and tested, so that only good batches are accepted and bad batches rejected, the risk for both producer and customer falls to 0%.

Therefore with a high sampling rate, the risk for both producer and customer is low. Reducing the sampling rate cuts testing costs but for the producer it increases the volume of concrete at risk on a single decision and for the customer it increases the risk of defective concrete being accepted.

- For the producer, a criterion based on the mean of a group of test results leads to a large volume of concrete being put at risk on a single decision. It can also lead to good batches of concrete with perfectly satisfactory test results being rejected because a bad batch has been included in their group. However, group criteria also mean that customers may be expected to accept bad batches of concrete if they are assessed alongside other better batches.

Table 1 shows the results from the BS EN 206 'identity testing' assessment rules in various situations. As can be seen, strict application of the BS EN 206 rules would lead to some very peculiar decisions.

- Where there is only a single batch of concrete (i, vi), the results are bizarre: if the producer is certified, individual test results 4MPa below the specified strength are accepted. Therefore, although Cl.3.1.5.4 only permits 5% defective concrete, under the BS EN 206 assessment rules concrete may be judged 'acceptable' even when 100% of it is below the specified strength. If the specified strength is 10MPa, the strength of the concrete that is accepted might be only 60% of what was specified.
- Some 400m^3 of concrete in a structure could be accepted on the basis of a single test result 4MPa lower than the specified strength (ii, vii).
- When there is more than one test result, the rules mean that the entire concrete on a project may be rejected even if all the test results exceed the specified strength (iii), (v), (viii), (x). On the other hand, on another project concrete could be accepted even when the results show that 10% or more was below the specified characteristic strength (eg, iv, ix).
- The rules for concrete from non-certified suppliers give even stranger results: if there is only a single batch of concrete, this would be rejected unless the test results exceeded the specified strength by 4MPa (x). On a larger project, concrete could be rejected when the tests clearly show that all of the concrete supplied exceeds the specified characteristic strength (xii). On the other hand, on another project concrete might be accepted even though the tests show that more than 5% fell below the specified characteristic strength (xi).

Concluding remarks

The concrete strength rules in BS EN 206 are unsatisfactory.

The definition of 'characteristic strength' is abstract and impractical. The assessment rules in later parts of the code are not consistent with the definition and can lead to concrete that complies with the definition being rejected and concrete that does not comply being accepted.

The risk to the customer of substandard concrete being deemed 'acceptable' is too high. This is recognised in Annex J, which permits more stringent acceptance rules to be used in Spain.

It is unreasonable to require customers to test two cubes/cylinders from each sample when producers are allowed to use single tests. The statistical analysis of acceptance rules should be revised to take into account:

- the difference between within-batch and between-batch strength variations
- the effect of different sampling rates on risks to both customers and producers.

The lower limit for individual test results of 4MPa below characteristic strength is too low, particularly for lower-strength concretes.

Assessment based on the average of a group of test results puts an excessive volume of concrete at risk on a single decision.

Assessment based on the average of a group of test results also creates a risk that good concrete may be rejected because a low-strength batch has been included in the group, or substandard concrete may be accepted because it has been assessed in a group that contains better batches. ●

References

1. BRITISH STANDARDS INSTITUTION, BS EN 206. *Concrete. Specification, performance, production and conformity*, BSI, London, 2013.
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3. BEAL, A.N. Viewpoint: Concrete strength testing – are the code writers getting it right? *The Structural Engineer*, Vol.87, No.10, 19 May 2009, pp.12–13.
4. BRITISH STANDARDS INSTITUTION, BS 5328. *Concrete. Guide to specifying concrete*. BSI, London, 1997, superseded.
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Table 1 – Results from BS EN 206 'identity testing' assessment rules

	Certified production	Non-certified production	Specified strength (MPa)	No. of batches	No. of tests	Results (MPa)	Pass/fail?
(i)	/		10	1	1	6	Pass
(ii)	/			50	1	6	Pass
(iii)	/			2	2	11, 10	Fail
(iv)	/			50	2	7, 15	Pass
(v)	/			5	5	10, 13, 11, 12, 13	Fail
(vi)	/		30	1	1	26	Pass
(vii)	/			50	1	26	Pass
(viii)	/			2	2	30, 31	Fail
(ix)	/			50	2	26, 36	Pass
(x)	/			5	5	30, 34, 31, 32, 33	Fail
(xi)		/	30	1	3	33, 34, 34	Fail
(xii)		/		50	3	26, 36, 40	Pass
(xiii)		/		5	5	30, 34, 40, 32, 33	Fail