EN 206:2013 is fit for purpose

In a recent article Alasdair N Beal[1] posed the question 'Concrete specification and testing – is EN 206 fit for purpose?' The answer, quite unequivocally, is yes. It is worth going through the various aspects raised concerning the concrete strength conformity requirements of EN 206[2] to demonstrate that this is the case. Chris Clear, chairman of the British Standards Committees for Concrete (B/517) and Concrete – production and testing (B/517/1) and MPA–BRMCA, reports.

CP 110[3] linked the required grade of concrete with the characteristic strength (f_{ck}) needed to provide the structure with adequate ultimate strength as long as go as 1972. Prior to that, Newman[4] reported that engineers were beginning to understand that the specified strength of a variable material such as concrete cannot be an absolute minimum since there is always a chance that a number of results will fall below the level specified. He cited the CEB[5] recommendation for a 5% failure rate, the same failure rate incorporated into EN 206 today. The concept of a characteristic strength is both well established and practical, and similar statistical concepts are used to define the performance classes of most other construction materials.

Characteristic strength is based on the assumption that the distribution of randomly variable materials is normal. So, where it is possible to sample, make and test sufficient specimens of a single concrete, the strength results will be normally distributed as shown by the bell-shaped curve in Figure 1. Where thousands of results have been studied from hundreds of construction sites as reported by Erntroy[6], the normal distribution is confirmed. In everyday projects the number of results available for a particular concrete or concrete family are very much lower and an example of what such results may look like are given by the columns in Figure 1 and the same results as a sequence in Figure 2. The mean strength of the 40 results shown is 44.4MPa, where the lowest result is 35MPa. The standard deviation of the sample results shown (s_n) is 3.9MPa but more importantly the established estimate of the standard deviation of the population (σ) is 4.1MPa.

Over the years a great deal of work has been carried out concerning the variation of concrete strength results and this is concisely summarised by BRE[7]. On the basis of 1970 data they observe that standard deviations less than 2.5MPa or more than 8.5MPa were rare, and that 60% of the time the value was between 4 and 6MPa. These observations were made before the widespread incorporation of statistically based factory production control systems for ready-mixed concrete and among British Ready-Mixed Concrete Association (BRMCA) members a typical value is close to 4MPa today.

On this basis, the examples represented by Figures 1 and 2 are typical and, with one of the 40 results less than the characteristic value for strength class C30/37, then it is worth considering what this means with respect to conformity according to EN 206.

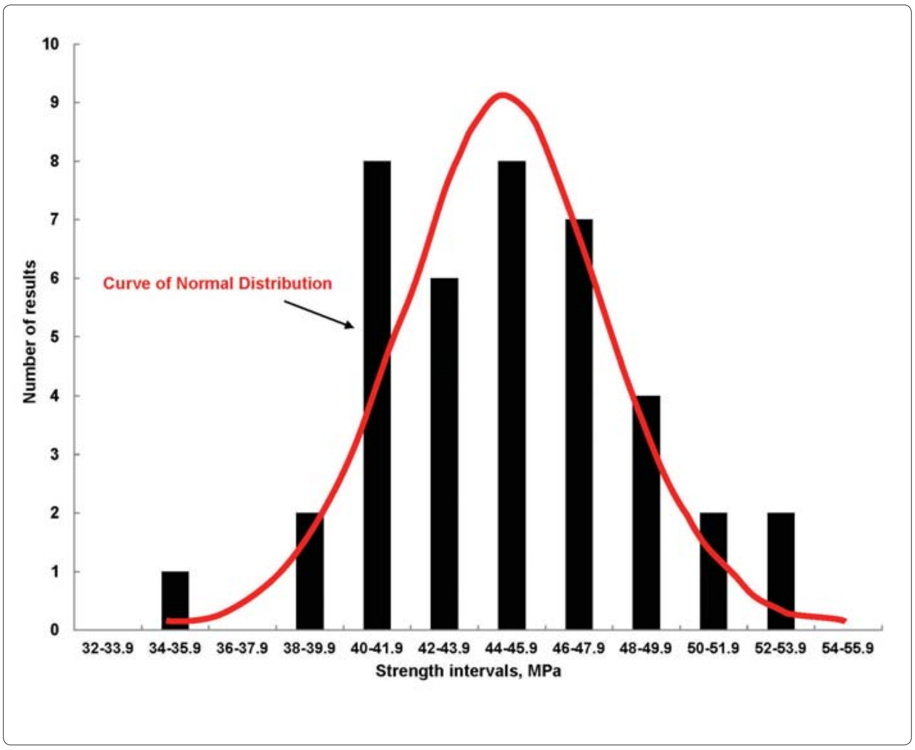
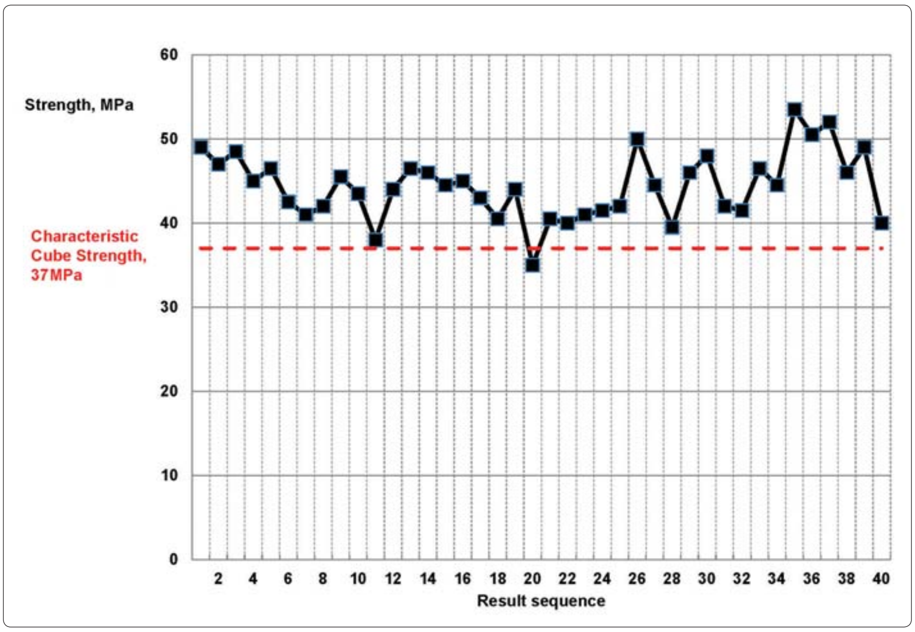


Figure 1: Example of 40 normally distributed concrete strength results.

Figure 2: Example of concrete strength results in sequence.



Conformity of mean strength

For established production the conformity criterion for mean strength (f_{cm}) during an assessment period is:

$$f_{cm} \geq (f_{ck} + 1.48\,\sigma)\text{MPa} \qquad \text{(Equation 1)}$$

Taking the 40 results shown as those for an assessment period then the requirement is for the mean strength of 44.4MPa to be greater than the result of the calculation 37 + 1.48 × 4.1, that is 43.1MPa. So during this assessment period the concrete is conforming as the mean strength is 1.3MPa greater than the required level.

As Beal[1] points out, EN 206 Annex J contains a deviation to accommodate a notified Spanish Regulation, where Spain requires the flexibility to use higher values of particular coefficients for conformity assessment. A justification for this deviation was that in Spain the majority of concrete suppliers do not hold product conformity certification and that by setting a higher requirement for mean strength they think they will reduce the risk of inadequate concrete being supplied. All other CEN member states disagreed with the Spanish approach, as demonstrated by their acceptance of EN 206 conformity rules without National deviations.

Absolute minimum

In addition to checking the mean strength there is also a requirement for each sample test result to exceed an absolute minimum, and as far as the author is aware this was agreed by discussion and agreement between producers and specifiers, both at national and then European level. Hence the rule that any individual result (f_{ci}) shall satisfy:

$$f_{ci} \geq (f_{ck} - 4)\text{MPa} \qquad \text{(Equation 2)}$$

In the UK f_{ck} is taken as the characteristic compressive strength of cube results ($f_{ck,\,cube}$), whereas other countries may apply exactly the same equation to the compressive strength of cylinders, demonstrating the somewhat arbitrary nature of the rule.

For the example the lowest result is 35MPa and so this meets the limit set by Equation 2. If there is any logic to this rule it is that 4MPa represents around one standard deviation below the characteristic for a strength class of C20/25 or more. This takes the probability of a fail from 5% to less than 1% and unlikely to cause any problems in practical situations.

As Beal notes, the criteria for individual results do not work for low-strength concrete. Below a strength class of C20/25 the standard deviation reduces with mean strength, as reported by Erntroy[6] and BRE[7]. In practice there is very little demand to check conformity of strength class of C20/25 and below, so there is no need to put a complicated rule in EN 206 that will hardly ever be used.

Results from individual or multiple specimens

According to EN 206, a test result shall be that obtained from an individual specimen, or two or more specimens made from the same sample and tested at the same age. Most ready-mixed and precast concrete companies will use one test specimen for 28-day strength assessment. Comparison between sets of results from double specimens and sets of results from single specimens show that where sampling, cube making and curing is under controlled conditions and with appropriately trained staff, there is no statistical benefit from using double or multiple specimens. However, it is accepted that there is always a risk of mistakes and hence a check that the range of multiple test values from the same sample is no more than 15% of the mean is useful. When a producer opts to use single test specimen per result, it is a balance between the resources to produce the specimens and the perceived risk of a lower than otherwise result. For the producer the penalty is increased variability and the consequent increased cement content across the family of concretes under assessment. Experience has shown that site-made cubes are more likely to be subject to poor sampling, cube preparation or curing and hence the EN 206 identity testing requirement for two or more test specimens to facilitate a validity check. Where the range is greater than 15% the result shall be disregarded unless there is an acceptable reason to justify disregarding an individual value and accepting the mean of the remaining values as the result.

Assessment period

For all but the lowest production ready-mixed concrete plants the assessment period for conformity is three months for EN 206 Method B: 'continuous production', or less depending on the sampling rate. As non-conformity means that the producer shall notify all specifiers and users in order to avoid consequential damage, it acts as a very powerful incentive to check results and take action to ensure there is no possibility of producing non-conforming concrete. For this reason most ready-mixed concrete suppliers currently use control charts to assess results on a result-by-result basis as part of their factory production control. In effect the use of control charts means the Method B assessment is a formality. EN 206 now includes an alternate method of assessing conformity for strength, namely Method C: 'Use of control charts option for assessing conformity'. Method C will be adopted by most, if not all, members of the BRMCA. Guidance on the use of control charts in the production of concrete is set out as a CEN/TR[8]. Where control charts are used for conformity assessment then in effect the assessment is carried out for every new result from each production day and early action limits mean that the risk of producing non-conforming concrete for compressive strength is non-existent.

Quality-assured ready-mixed concrete

A quality-assured ready-mixed concrete supplier, ie, a supplier that has either Quality Scheme for Ready-Mixed Concrete (QSRMC) or BSI Kitemark Scheme for Ready-Mixed Concrete certification, has a considerable history of continual or initial use for the materials used for any concrete supplied and the product conformity certification has the following minimum requirements:

- approval of a concrete producer's quality management system to BS EN ISO 9001[9]
- product testing by or calibrated against a laboratory accredited for the tests undertaken
- surveillance, which includes checking the validity of the producer's declarations of conformity, by a certification body accredited to ISO 17021[10] and EN 45011[11] by UKAS or an equivalent accreditation body. A UKAS equivalent accreditation body is recognised by UKAS through the European co-operation for Accreditation (EA) for the relevant areas of product conformity certification.

This means that when concrete is supplied to any one or more construction sites, on any day, then the supplier is confident that the concrete conforms to the specified requirements in accordance with EN 206. The testing carried out by the supplier is only part of the product conformity certification, and although the rate of testing may look small compared to what a major site may carry out in accordance with some project specifications it does not need to be extensive because it is just to check for gradual changes in raw materials, or combinations of raw materials. Provided that concrete is ordered from a ready-mixed concrete supplier with the right level of product conformity certification then there should be no need for identity testing.

Identity testing

On a statistical basis, taking a single sample and making either single or multiple specimens to produce a strength result is unlikely to confirm fail or pass with any level of confidence, regardless of whether the result is above or below the specified characteristic strength. There are occasions when a site may wish to carry out identity testing of concrete delivered to site, these include:

- The site has placed a concrete order with a supplier who does not have an adequate standard of product conformity certification and needs to confirm that the concrete delivered is as specified, in which case the specifier should set an identity testing rate commensurate with the potential costs of non-compliance.

- There is concern that the strength of a particular batch or batches of concrete is not of the required quality, eg, the consistence is higher than expected possibly because site personal have instructed additional water to be added prior to discharge, or just that the concrete looks different and there has been a batching error.
- The project specification requires identity, eg, projects covered by the *Specification for Highways Works*[12].

Beal sets out a number of examples where a concrete is supplied with product conformity certification. In one hypothetical example, five loads of a C25/30 are sampled and tested that give five separate results of 30, 34, 31, 32 and 33MPa, where the author appears surprised that the concrete is deemed non-conforming. To a concrete technologist with a rudimentary understanding of statistics, the hypothetical results are so consistently close to the characteristic strength that there is a clear indication of a problem that warrants further investigation.

Beal also sets out three examples of identity testing for C25/30 concrete supplied without any product conformity certification:

1. One load, sampled and tested to generate three separate results of 33, 34 and 34MPa. In accordance with EN 206 this is a fail, and quite rightly so as the concrete supplied is of a consistently low strength that means it is unlikely to be C25/30.
2. Fifty loads, where three loads sampled and tested to generate three separate results of 26, 36 and 40MPa. In accordance with EN 206 this may be considered a pass. Unless the user had carried out an audit of the producer's facilities, systems and staff prior to delivery, the author would question the user's judgement in accepting 50 deliveries of ready-mixed concrete from a supplier that does not have product conformity certification and only sampling and testing three loads.
3. Five loads where each was tested to generate five separate results of 30, 34, 40, 32 and 33MPa. Beal records this as a fail but the mean strength of five results at 33.8MPa but with a mean value more than 2MPa above the characteristic and the lowest individual result above $f_{ck} - 4$ (26MPa) they satisfy all the EN 206 Table B.1 criteria and so the concrete is conforming. Where a producer does not have product conformity certification then identity testing every load of concrete supplied may well be considered appropriate.

Concluding remarks

Beal is to be congratulated in that the concrete industry needs engineers to question the requirements and suitability of both British and European Standards, and in this respect his contribution is gratefully received. If nothing else it prompted this consideration of the EN 206 conformity requirements, but having done this the conclusion is that concrete specification and testing to EN 206 is fit for purpose. ●

● **Author's note:**
There is an open invitation for Alasdair Beal, or any other interested engineers, to participate in BSI committee work, particularly as we are currently revising BS 8500 *Concrete. Complementary British Standard to EN 206-1.*

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