ASSESSMENT OF CONCRETE COMPRESSIVE STRENGTH IN STRUCTURES

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Abstract

EN 13791: *Assessment of in-situ compressive strength in structures and precast concrete components* is being revised by CEN and will be probably released in 2016. The changes to this standard are significant and it now covers two main topics: the determination of the characteristic in-situ strength for structural assessment purposes using EN 1990, Annex D; and where there are issues over the quality of concrete supplied, whether the concrete conformed to its specified compressive strength class. A standard is not a textbook and consequently the 'rules' are not fully explained. This paper describes the background to a number of the key issues addressed in EN 13791. In particular the background to the procedures for combining core and indirect test data to determine the characteristic in-situ strength and the in-situ strength at specific locations. The reasoning behind the different approach used to assess whether the concrete conformed to its specification is also explained.

Keywords: In-situ strength, assessment, concrete, cores, rebound number, pulse velocity, conformity, statistics.

1. INTRODUCTION

EN 13791: *Assessment of in-situ compressive strength in structures and precast concrete components,* was published in 2006 and at its 5-year review it was decided to revise this standard. The 2006 version of the standard determined the EN 206-1 concrete compressive **strength class** based on in-situ testing, but for the new version of the standard, it was agreed that one main target would be to determine not a class, but the **characteristic in-situ compressive strength** in terms of cores with a 2:1 length to diameter ratio as this is the input needed for designing in accordance with EN 1990, Annex D [1]. The objectives of the standard are two: While to obtain data for structural analysis and re-design is one prime purpose of EN 13791, there is another equally important role which is to provide procedures and criteria to determine by in-situ testing whether the supplied concrete conformed to its specified compressive strength class. The Committee decided to keep the two objectives within a single standard.

The 2006 version of EN 13791 did not provide any detail on what are common assessment procedures and so the scope of the standard has been significantly increased. New topics include:

- smaller diameter cores;
- check if the concrete belongs to two different populations;
- test for outliers;
- characteristic in-situ compressive strength from core test data only;
- characteristic in-situ compressive strength from combined core and indirect test data;
- screening test using rebound number to determine if the concrete conformed to the specified compressive strength class;
- relative testing where conforming structural elements are compared with similar elements where the quality of the supplied concrete is under investigation;
- much more guidance on investigations.

The changes from the 2006 version of the standard are so significant, it is better to regard the revised standard as being a new standard as only Annex B of the 2006 version has been retained unchanged. All references to the revised EN 13791 refer to the February 2015 draft of the standard (draft 14).

The Task Group revising EN 13791 has requested CEN permission to produce a CEN Technical Report explaining the background to the revision and including worked examples to guide users. It is anticipated that this request will be approved.

2. SMALLER DIAMETER CORES

When coring a structure, it is best to avoid cutting rebar and this is not always possible with the 100mm diameter cores. While EN 13791:2006 permitted cores with diameter down to 50mm, it did not provide any guidance on cores other than 100mm diameter cores; this task was left to national provisions. Technically the strength of smaller diameter cores is more variable, particularly if they have a 2:1 length to diameter ratio.

Experience has shown that in practice either 2:1 or 1:1 cores are used. As design to the concrete Eurocode is in terms of 2:1 cylinder strength, it was agreed that the in-situ compressive strength would always be expressed in terms of a 2:1 core irrespective of the diameter and any 1:1 core would be transposed to the equivalent 2:1 core by using a constant factor of 0.82, which is the average of the ratio between cylinder and cube strength in the compressive strength classes in

EN 206. For practical reasons a small tolerance on the length after capping is permitted, but the target length of the capped specimens should be either twice or the same length as the diameter. The diameter is the diameter of the core and not the hole. There are limits on core diameter related to the maximum aggregate size.

While 2:1 cores require no conversion factor, 1:1 cores are often more practical. To deal with the issue of higher variability with smaller diameter cores, cores less than 80mm in diameter are required to have a 1:1 length to diameter ratio and a number of cores taken at one location are averaged to give a single test result. At 80mm diameter or more, both 2:1 and 1:1 cores are permitted and a test result may be based on a single core.

The current version of EN 13791 required a period of drying in laboratory air prior to testing and this will enhance the strength of the core. The consensus view of TG11 is the moisture content of cores should be that found in-situ, as it is the in-situ strength that is being determined, so after coring the surface is dried with a paper towel and then the core is labelled and placed in a close fitting sealed container, e.g. a polythene bag.

3. CHECK IF THE CONCRETE BELONGS TO TWO POPULATIONS

While careful selection of test regions will minimise the risk of including two strength classes in a single population, it does not entirely exclude the possibility that the test region contains more than one compressive strength class. There is a requirement to check that this is not the case. Exactly how this is to be undertaken is not specified as it is often based on an inspection of the data from different elements. If the data looks as if it came from two populations, the data should be split and a statistical test applied to determine if this is true. An example of how this is done will be given in the Guide to EN 13791.

4. CHECK FOR OUTLIERS

The revised EN 13791 includes the use of a test to check for statistical outliers. Outliers are results that are about 3 standard deviations from the mean value and values that in a Gaussian distribution have a one in a thousand chance of occuring. The test may be applied twice to a set of data provided certain conditions are satisfied. If more than two test results are outliers, this may be an indication that the concrete comprises two populations. Guidance is provided on handling outliers and there is no presumption that they should be excluded from the data analysis. In all cases an outlier needs special consideration of its cause and how it should be handled. For example, if it represents a weak area of concrete that will be removed, it should not be included in the determination of characteristic in-situ strength. On the other hand a high outlier i.e. a too high strength, in air-entrained concrete may be an indication of insufficient entrained air. The standard simply provides the tool to determine outliers and the organisation or person appointed to review the data decides what to do about them.

5. CHARACTERISTIC IN-SITU COMPRESSIVE STRENGTH FROM CORE TEST DATA

Where using core test data only to determine the characteristic in-situ strength, the core locations are selected to represent the average quality of the in-situ concrete. Guidance is provided on selecting core locations.

The approach to determining the characteristic in-situ strength has been changed to align with that in EN 1990:Annex D: *Design assisted by testing*, except that the revised EN 13791 does not use the log-normal version of the equation. The equation is now based on the t-statistic at 95% probability and is:

$$f_{c,is,ck} = f_{c,m(n)is} - t_{0.05}s_n \sqrt{(1 + (1/n))}$$

As the number of core test data is often low, there is a risk that the sample will yield an unrealistically low standard deviation (s_n) and so a minimum value of it, 3.0 N/mm^2 , is specified and this is independent of the mean strength.

6. CHARACTERISTIC COMPRESSIVE STRENGTH BASED ON COMBINED CORE AND INDIRECT TEST DATA

The revision of EN 13791 includes three procedures for using a combination of indirect tests and core tests depending upon the number of pairs of data. A pair of data is where there is both an indirect test measurement, e.g. ultra-sonic pulse velocity, and a core test result from the same location. For 12 or more pairs of data a correlation between the 2 sets of results is determined, for 11 to 6 pairs of data the mean values are used to shift a standard curve given in EN 13791and for five to three pairs of data a non-statistical procedure is used. EN 13791:2006 provided some standard curves but these have been revised based on comprehensive test data supplied by a Swiss testing materials equipment company.

While EN 13791:2006 provided means for converting indirect test data, e.g. ultra-sonic pulse velocity and rebound number, into in-situ compressive strength, there was no guidance on how to convert the estimated in-situ strength values into an in-situ characteristic strength. Handling such data is not as simple as it may first appear. This is best illustrated with an example from practice. A structure was surveyed using a rebound hammer and then selected cores were taken to determine the correlation between the rebound number and the in-situ strength. The characteristic in-situ strength determined using the core test data only was 14.0 N/mm^2 but when determined using both the core data and the in-situ strengths estimated from rebound tests at locations where there was no core test data it was 18.9 N/mm^2. Neither of these values give the correct characteristic in-situ strength for the following reasons.

When determining the correlation, there is a requirement to take cores over the whole range of indirect test values, if safe to do so. This is to ensure the best correlation between the results from the two procedures, and there is a limit of 5 N/mm^2 on extrapolation of the correlation. Figure 1 shows a typical set of data. Unsurprisingly, more cores have been taken where the indirect test indicated low strengths. There are data over the whole range, but the core data set does not represent the population of results (it is under-representative of the average concrete quality) and this data set gives a higher standard deviation than the population as a whole. When combined with the $\sqrt{(1 + (1/n))}$ term, this results in an unrealistically low characteristic in-situ strength.

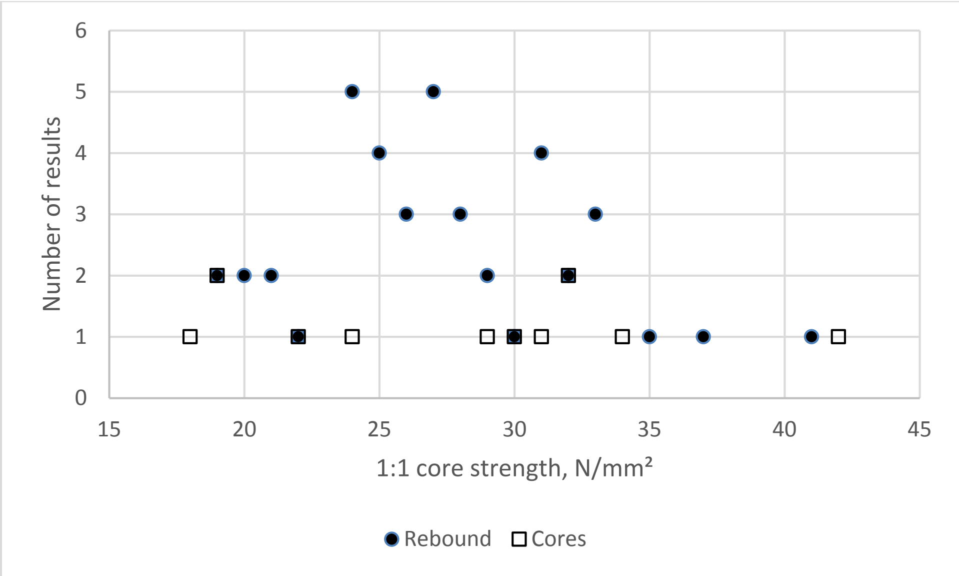

Figure 1: Distribution of strength in an element under investigation

On the other hand, simply using the correlation curve to detremine the in-situ strength at locations where there is no core result and calculating the mean and stanadrd deviation of these values leads to an unrealistically high characteristic in-situ strength for the following reason. Figure 2 shows that the actual pairs of results are spread around the correlation. For every location where there is only an indirect test value, this test value is converted to an estimated in-situ strength using the correlation curve equation and these values will lie exactly on the correlation curve. In reality these results would be spread around the correlation curve and consequently by using the correlation curve the spread of results is under-estimated and the characteristic in-situ compressive strength is over-estimated.

The equations provided in the revised EN 13791 take account of this under-estimation of the variability in the transposed indirect test results when calculating the in-situ characteristic compressive strength. When this is done the characteristic strength falls between these two values given earlier and for the same example is a value of 16.5 N/mm^2 (greater than 14.0 N/mm^2 but less than 18.9 N/mm^2).

The correlation between the indirect test value and the in-situ compressive strength is a mean to mean relationship meaning there is a 50% probability that the actual strength is lower than the estimated strength. Therefore the use of such an estimated value of in-situ strength is not safe when assessing the performance of the structure at a specific location. With correlations based on relatively low numbers of pairs of results the use of the 90% confidence limit is not sufficiently safe [2] and so EN 13791 requires the use of what is known by statisticians as the prediction limit to determine the in-situ strength at a specific location, see Figure 2.

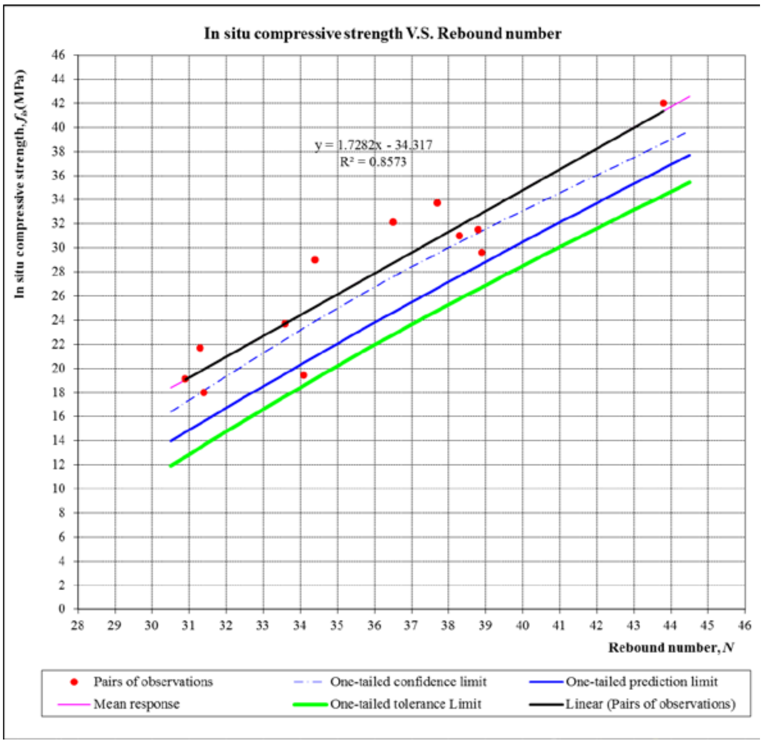

Figure 2: Illustration showing why the 90% confidence limit is not safe
(Figure by courtesy of INEC)

When there are insufficient pairs of data to determine a reliable relationship, the given standard curves may be used. For the pairs of data, the mean in-situ strength and the mean indirect test value is determined. The standard curve is then shifted vertically to pass through this point. This shifted curve is then used to determine the in-situ strength for all the test locations where there is only an indirect measurement. The way in which the data are used to determine the characteristic in-situ strength is the same as for a correlation.

Where the strength at a specific location is required, the prediction limit is needed but there are not sufficient data to determine reliably the prediction limit. Consequently the strength at a specific location is based on empirical rules given in EN 13791.

When there are five to three pairs of data, a simple non-statistical approach is applied. After the indirect test survey, the average quality areas are identified and cored. The mean of the core values, provided the spread is not more than 15%, is taken as the characteristic in-situ strength. This rule does not apply where there are issues over the quality of concrete supplied. When detremining the characteristic in-situ strength or the compressive strength at a specific location within the structure, there is no assumption about the value and the procedures lead to safe design values. When checking whether the concrete conformed to its specified compressive strength class the assumption is that it conformed and for a small volume of concrete, e.g. concrete where only a few cores are taken, if its mean strength is within the accepted tail of the strength distribution, the concrete is accepted as conforming to its specified strength class.

7. ISSUES OVER THE QUALITY OF CONCRETE SUPPLIED

Clause 9 of EN 13791 is for the situation where there are issues over the quality of concrete supplied. If the concrete producer has declared non-conformity, clause 9 does not apply and the procedures given in clause 8 to determine the characteristic in-situ compressive strength and, if necessary, the in-situ compressive strength at specific locations may be used as input for a structural assessment of the impact of the non-conformity. Where there are differences, for example, between the producer's conformity control and identity testing, the null hypothesis is that the concrete conformed to the specification, and the tests are used to determine whether this hypothesis is correct. The null hypothesis is the hypothesis that there is no significant difference between specified populations, any observed difference being due to sampling or experimental error.

The concrete under investigation is treated as a 'lot' and the average quality of the 'lot' may be determined using core testing or combined indirect and core testing to determine the mean strength of the lot. Multiplying the average strength by a factor 1.18 (=1/0.85) to convert the in-situ strength to the equivalent strength of test specimens, this value is compared with the limit for the specified compressive strength class. The factor of 0.85 is the part of the partial safety factor for concrete that is attributed to differences between the strength of test specimens and the in-situ compressive strength. For small volumes, e.g. 25m^3, and for compressive strength classes ≥C20/25, the strength of the lot is compared with the lowest acceptable strength, i.e.:

$$1{,}18\, f_{c,m(n)is} \geq (f_{ck,spec} - 4)$$

Where the compressive strength class is less than C20/25, the margin of 4 is reduced. This criterion is accepting concrete that is in the tail of acceptable strengths. For large volumes of concrete, it is reasonable to expect that at least the characteristic strength is achieved and thus the criterion becomes:

$$1{,}18\, f_{c,m(n)is} \geq f_{ck,spec}$$

8. ALTERNATIVE APPROACHES

While cores give the most reliable measure of in-situ strength, it is often more convenient, quicker and less expensive to use one of the other procedures provided in EN 13791. EN 13791 provides two options that do not involve core testing: a) a screening test using the rebound hammer and b) relative testing.

9. SCREENING TEST USING THE REBOUND NUMBER

EN 13791 has adopted a screening test using the rebound number that has been widely used in Germany. The screening test is a safe relationship between rebound numbers taken in-situ and the compressive strength class of the supplied concrete. If the concrete in the structure satisfies the given criteria, it may be assumed that the concrete conformed to its specified compressive strength class; however, failure to meet these criteria is insufficient proof that the concrete was not conforming and one of the other assessment procedures has to be used. The basis for these criteria are given in Figure 3.

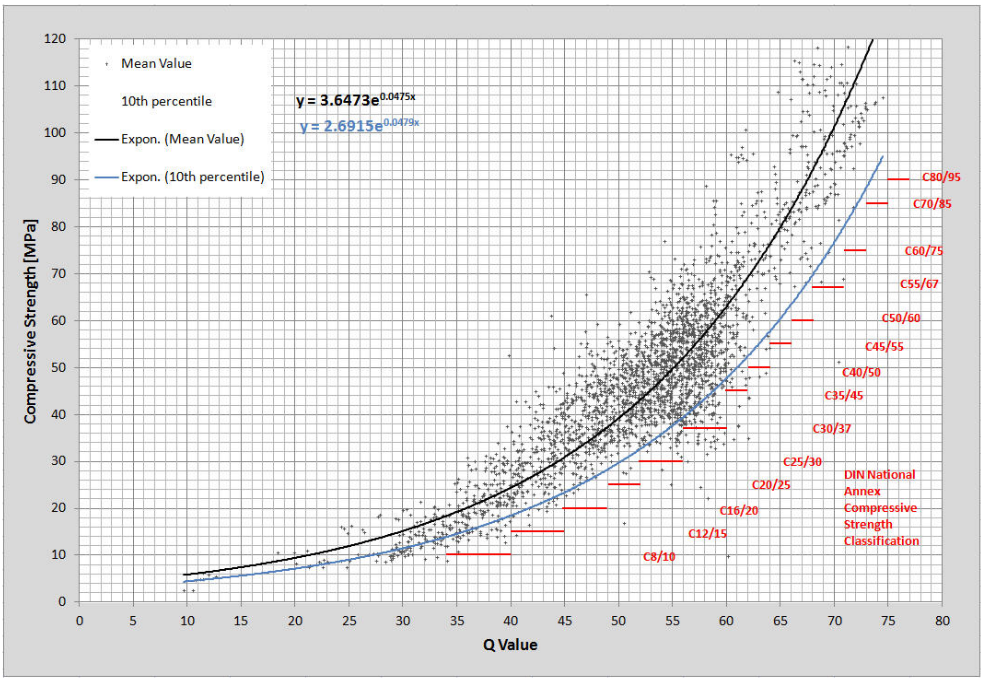

Figure 3: Relationship between cube strength and rebound number (Type Q)
(Figure by courtesy of Proceq)

10. RELATIVE TESTING

A procedure that has been used successfully and now adopted within EN 13791 is the use of relative testing. This is where the element under investigation is compared with a similar element of accepted quality. The use of the rebound number or pulse-velocity are ideal for use in this procedure.

As the null hypothesis is that the two elements have the same concrete quality, the fewer the data the less is the chance of proving a difference. Consequently EN 13791 recommends that at least 20 pairs of data are obtained. The criteria for a comparison of twenty pairs of data are provided in the standard but any (higher) number may be compared using standard statistical tests for difference in mean value.

11. MORE GUIDANCE

Whilst drafting the revision of EN 13791, a need for more guidance was identified. A clear difference between the procedures necessary to obtain a test result, characteristic in-situ strength, strength at a specific location or to identify an outlier (the normative text) and guidance on what to do with these data (in informative annexes) is made in EN 13791.

One of the new annexes describes the differences between test specimens and the concrete in the structure. We are hoping that CEN TC250/SC2, the European Concrete Design Committee will confirm what is included in the partial safety factor for concrete, as the factors in the concrete Eurocode were based on calibration with existing design methods and not on a fundamental analysis of the factors involved. This is more than an academic issue as there is a rare possibility that the concrete in a structure may be assessed as conforming to its specification, but from a structural analysis viewpoint prove to be inadequate. By working

together on these issues we may be able to find a solution, we should be able to produce better standards with a clear understanding of what is included in each of the factors.
The Task Group that prepared the draft of EN 13791 have plans to produce a CEN Technical Report setting out the background to the revision and examples of the calculations.

12. CONCLUSIONS

The revised draft of EN 13791 if positively voted upon will provide a more comprehensive and useful standard for the assessment of concrete compressive strength in structures and precast concrete components.

REFERENCES

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[2] DE GRYZE S, LANGHANS I and VANDEBROEK M, *Using the correct intervals for prediction: A tutorial on tolerance intervals for ordinary least-square regression,* Science Direct, Chemometrics and intelligent laboratory systems, 87 (2007) p147-154.