Assessment of in-situ Compressive Strength Clarified

by Ir. Tu Yong Eng

The paper entitled "Structural assessment according to EN 13791: Assessment of in-situ compressive strength in structures and precast concrete" published in the pages 26-30 of the April 2010 issue of the Bulletin (Paper series on Structural Eurocodes) by Ir. Tu Yong Eng and Mr. Yap Seow Keong has received comments from Ir. Yeoh Sik Ching (on 21 April 2010 and 13 May 2010) and Dr Tam CT (10 May 2010). The authors would like to take this opportunity to thank both engineers for their valuable comments. The following tables show the comments and replies from the authors.

Comments from Ir. Yeoh Sik Ching

Firstly, I would like to thank the authors for the article. I read the article with great interest as I am also in the construction industry. I would like to highlight to the authors the possible error in tabulating the "Mean in-situ Characteristic Strength".

1) Table 1, row, BS6089, Estimated insitu characteristic strength work out to be 29.51
2) Table 2, row, BS6089, Estimated insitu characteristic strength work out to be 29.6 instead of 35.9
   row, BS EN 13791, Estimated insitu characteristic strength work out to be 31.15 instead of 33.2

Authors' reply

In BS 6089:1989, it was recommended that 95% of the confidence level lies within $\pm\frac{12\%}{\sqrt{n}}$ *and based on the Manual of Ready-Mixed Concrete, the estimated characteristic strength of the core tests shall be* $(1-\frac{0.12}{\sqrt{n}})\,\bar{x}$, *where* $\bar{x}$ *is the mean of the group of the core and n is the number of the cores. Hence, standard deviation is not used in the computation of the estimation of the characteristic strength.*

Query 1 from Dr Tam

BS 6089: 1981 (prepared in relation to CP 110, before BS 8110) provides guidelines but without specific details on the number of cores and the interpretation of such results compared to EN 13791. It is clearly stated in EN 13791 that characteristic in-situ strength forms the basis of the assessment. However, the mean strength is often considered when the in-situ strength is considered. Hence, the statement under Section 5.0 (page 28) that "BS 6089 recommends the following formula for determining the characteristic strength of in-situ concrete, $f_{cu} = \mu - 1.64\sigma$ Equation, (1)" is the interpretation by the authors. Personally, I always favour this approach, but this is seldom (or rarely) adopted by most engineers. The authors reported that "it is rather common that a single-core or two-core samples are used" for which, at best, the mean of two values is available. Even with such limited information, the minimum value of 1.2 times the characteristic strength often form the basis of acceptance. The approaches in EN 13791, in all cases, tend to provide a much more conservative (and in the view of the writer, more appropriate) assessment.

Authors' reply

Clause 6.5 of BS 6089: 1981 give the formula

f_{cu} = *mean concrete cube strength – 1.64 x standard deviation*

for a large number of the standard cube test result which is the same with Equation (1) of our paper. We agree with Dr Tam that EN 13791 gives a better approach to the assessment of the core test.

Query 2 from Dr Tam

Under Section 3.0, the authors have selected for the Null hypothesis and the Alternate hypothesis, the mean value, $\mu = f_{cu} + 1.64\sigma$. It would appear that the requirement to reach the target mean strength in the design of concrete mix for production is extremely demanding. It is expected that the in-situ concrete strength is lower than the standard cube strength of the same batch of concrete.

Authors' reply

We believe that hypothesis testing is a better approach in assessing the concrete strength. As pointed out by Dr Tam, the in-situ strength is normally expected to be lower. In this paper, it only gives preliminary suggestion on the procedure for hypothesis testing. The actual null hypothesis shall be subjected to an agreement between the industry players to ensure fairness to all parties.

Query 3 from Dr Tam

In Section 6.0, both core test standards BS 1881: Part 120 and BS EN 12504-1 are stated. However, it is to be noted that Clause 7.1 of EN 13791 states that "Except for where it is not feasible, cores shall be exposed to a laboratory atmosphere for at least three days prior to testing", *i.e.* in air-dried condition, compared to the requirement of soaking (to saturated condition) in the BS 1881: Part 120 and "when required" in EN 12504-1. The saturated case is expected to indicate a lower strength.

Authors' reply

This is an important observation. Tests based on BS EN 12504–1 is in fact closer to the actual site condition. Hence, it is important to carry out the assessment based on a set of harmonised codes.

Query 4 from Dr Tam

In Section 8.0, half of the 22 cores is drilled "Hor" and the other half "Ver". Since the direction of coring is considered in BS 6089 but not in EN 13791, the separation into the two cases will lead to different comparison with BS 6089.

Authors' reply

This was done on purpose to show the difference between BS 6089 and EN 13791. We fully agree with Dr Tam that a separation into two different sets may show a more remarkable difference.

Query 5 from Dr Tam

In Section 8.0 i) BS 6089, it is not shown how the value for the characteristic strength of 33.2 N/mm^2 is derived from the mean value of 34.1 N/mm^2.

Authors' reply

In 6089, the means are expected to be within $\pm \frac{12\%}{\sqrt{n}}$ *and based on CSTR [1] and the Manual of Ready-Mixed Concrete [2], characteristic strength can be estimated from the mean by* $(1 - \frac{0.12}{\sqrt{n}})\,\bar{x}$.

Query 6 from Dr Tam

In Section 8.0 ii) EN 13791, the characteristic in-situ cube compressive strength = 31.7 N/mm^2. Based on Table 1 of EN 13791, the corresponding compressive strength class in EN 206-1 is slightly above C 30/37.

Authors' reply

We agree with Dr Tam. Based on EN 13791, the result complies with C 30/37.

Query 7 from Dr Tam

In Case II i) BS 6089, similar to Query 5, it is not shown how the characteristic strength is derived from the mean strength.

Authors' reply

Refer to the response in Query 5.

Query 8 from Dr Tam

In Case II ii) EN 13791, based on a mean of 39.2 and standard deviation of 5.4, Sample 1 with a value of 30.9 is more than 1.5 times the standard deviation (the criteria adopted by the authors for detecting outliers).

Authors' reply

There are two schools of thought on the outliers. One school of thought believes that we should respect our testing, unless it is proven that it is an outlier based on sufficient information (for core test, a core with initial defect or samples from a different mix or supplier shall be considered as outlier), it should be included in the interpretation. The other school of thought believes that whenever results move away from the majorities, it shall be considered as the outlier.

Query 9 from Dr Tam

In Case II iii) Statistical testing, it is not clear for the standard deviation to be taken as 3 N/mm^2. Since the eight cores may not be from the same population, it is doubtful if they should be considered statistically as a group.

Authors' reply

This was from an actual test carried out by others, thus we have no prior knowledge on the original population. Hence, it is advisable for a proper understanding of the testing object prior to the actual planning of the strength investigation.

Query 10 from Dr Tam

BS 6089 has been revised as a complimentary standard to EN 13791, the use of *t*-distribution is expected to be provided with more guidance. The final review for the national guidance clauses may be delayed until this is available for consideration.

Authors' reply

We are in fact in favour of hypothesis testing using t-test (if the underlying distribution is normal) compared to the recommendation of BS 6089: 2010.

REFERENCES:

[1] Concrete Core Testing for Strength. Second edition, including addendum, Technical Report No. 11, Concrete Society, London 1987.

[2] Dewar, J.D., Anderson R., Manual of Ready-Mixed Concrete, Blackie Academic and professional, Second edition, 1992.