Structural Assessment According to EN 13791: Assessment of *in situ* Compressive Strength in Structures and Precast Concrete

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1.0 INTRODUCTION

In some cases, we need to determine the quality of the existing concrete structure. This was carried out in accordance with BS 6089 [1]. This standard has been partially superseded by BS EN 13791 [2]. There are two basic questions that need to be addressed:

i) Are the test results reliable?
ii) Do the test results truly represent the actual site conditions?

In this article, we will discuss the basic procedure of the concrete structure assessment in accordance with EN 13791 and put forward the interpretation to some field test results as a demonstration on the interpretation to EN 13791.

2.0 SCOPE OF EN 13791

The scope of EN 13791 includes the following:

i) Gives the methods and procedures for the assessment of the *in situ* compressive strength of concrete in structures and precast concrete components;
ii) Provides the principles and guidance for establishing the relationship between the test results from indirect test methods and the *in situ* core strength;
iii) Provides guidance for the assessment of the in-site concrete strength in structures or precast concrete components by indirect or combined methods.

However, it specifically excluded the following cases:

i) where indirect methods are used without correlation to core strength;
ii) assessment based on sample cores less than 50mm in diameter;
iii) assessment based on less than three sample cores used for testing;
iv) use of microcores.

In the National Annex to BS EN 13791: 2007, it included Clause 4 (General guidance on planning an investigation) and Clause 5 (general guidance on core test method) of BS 6089 as a supplement to EN 13791.

3.0 WHY TEST?

Both BS 6089 and EN 13791 give similar reasons for the need to test. These includes the following:

i) when an existing structure is to be modified or redesigned;
ii) to assess structural adequacy when doubt arises about the compressive strength in the structure due to defective workmanship, deterioration of concrete due to fire or other causes;
iii) when an assessment of the *in situ* concrete strength is needed during the construction stage;
iv) to assess structural adequacy in the case of non-conformity of the compressive strength obtained from standard test specimens;
v) to assess conformity of the *in situ* concrete compressive strength when specified in a specification or product standard.

In general, the purpose of the test is to obtain the characteristic compressive strength of the existing concrete. Basically, the testing plan constitutes part of hypothesis testing where accepting the null hypothesis means that the concrete complied with the specification while rejecting the null hypothesis means that the concrete may not comply with the specification:

Null hypothesis: $H_o : \mu = f_{cu} + 1.64\,\sigma$

Alternative hypothesis: $H_1 : \mu < f_{cu} + 1.64\,\sigma$

However, this may not be possible due to the fact that the standard deviation (σ) may not be part of the parameter in the specification. Hence, the problem becomes more complicated as standard deviation has to be estimated based on the test plan. Furthermore, to accept or reject the null hypothesis depends on the level of significance. Hence, EN 13791 gives specific rules on the acceptance of the null hypothesis (*i.e.* the concrete complied with the specification).

4.0 RELIABILITY OF THE TEST

In general, reliability of the test depends on the following factors:

i) Planning of the test – Test shall be planned carefully including the purpose of the test, determination of the test location, test methods and characteristics of the sample whether it is random or not.

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ii) Execution of the test;
iii) Number of tests.
iv) Interpretation of the results.

Various statistical methods can be used to assist in the interpretation of the test results. Furthermore, engineering judgement shall be applied carefully to determine the reasons for the non-conforming of the test results.

In order to achieve the level of reliability of the test, all tests shall be carried out according to the proper procedure. A common question is the representative of the single core. EN 13791 specifies that three cores is the minimum number for the core test. Similar recommendations are given for the requirement on the number of samples for indirect tests.

In Malaysia, it is rather common that a single-core or two-core samples are used to determine the quality of the *in situ* concrete.

5.0 CHARACTERISTIC CUBE COMPRESSIVE STRENGTH

Characteristic value is defined as the value for which 5% of all possible value is expected to fall below. However, there are many factors affecting the exact value of the characteristic strength of the material. These include the population distribution and sampling techniques. Normally, it is assumed that the material behaves normally and random sampling is used.

BS 5328 [3] recommends moving an average of four samples and minimum sample result for the checking of compliance. Similarly, EN206-1 [4] recommends an average of up to 15 samples (either overlapping, i.e. moving average or non-overlapping) for the checking of compliance.

BS 6089 recommends the following formula for determining the characteristic strength of *in situ* concrete:

$$f_{cu} = \mu - 1.64\,\sigma \qquad \text{Eq. (1)}$$

where μ is the mean concrete strength and σ is the standard deviation of the samples.

EN 13791 gives two approaches to determine the characteristic strength based on cores test. Based on approach A (for at least 15 samples), the characteristic compressive strength of the *in situ* concrete shall be the lower value of $(\mu - k_2\sigma)$ or $(f_{min} + 4)$, where f_{min} is the lowest result of the sample and k_2 shall be given in the National Annex or use a value of 1.48. Based on approach B (for three to 14 samples) the characteristic compressive strength of the in situ concrete shall be the lower value of $(\mu - k)$ or $(f_{min} + 4)$, where k is given by Table 2 of EN 13791. National Annex NA to BS EN 13791 suggested t distribution shall be used in place of approaches A and B.

EN 13791 suggests that the concrete tested in accordance with EN 206-1 and that of *in situ* testing are of different population. A ratio of 0.85 is suggested for the ratio of the *in situ* characteristic strength to the characteristic strength of a standard specimen. BS 6089 suggested that the partial safety factor for concrete can be reduced up to 1.2 subject to the decision of the design engineer, and normally consent should not be unreasonably withheld.

6.0 CORE TEST FOR APPLICATION

It is generally agreed that core test is the most reliable method for determining the quality of concrete in terms of compressive strength. Core test shall be carried out in accordance with BS 1881: Part 120: 1983 [5] or BS EN 12504-1:2000 [6]. However, it was also recognised that core tests have to be planned and carried out properly to ensure reliable results are being obtained so that correct interpretation can be reliably given. Further guidance can be obtained from CSTR 11 [7] and the Manual for Ready Mixed Concrete [8]. There are many factors affecting the strength of the core. These include age, location, curing history, moisture content, voidage and imperfection of the concrete, diameter of the core, length to diameter ratio, flatness of the end surface, capping of the end surfaces, effect of drilling and reinforcement. A notable difference between EN 13791 and BS 6089 is the correction for the direction of drilling. BS 6089 gives two different formulae for the horizontal and vertical direction of drilling. BS EN 13791 proposed the following correction factor for the conversion of the tested core strength to the equivalent in situ cube, for both horizontal and vertical drilling (*i.e.* independent of the direction of drilling):

$$K_{is,\,cube} = \frac{2.5}{1.5 + \frac{1}{\lambda}} \qquad \text{Eq. (2)}$$

where λ is the length/diameter ratio.

7.0 INDIRECT METHODS

Indirect methods stated in EN 13791 include rebound hammer tests, Ultrasonic pulse velocity measurements and pull out tests. However, EN 13791 only recognised an indirect test with correlation to the core tests. Indirect tests carried out without correlation to the core tests is actually beyond the scope of EN 13791.

In fact, as pointed out by BS 6089, rebound hammer tests, if carried out properly, may estimate the strength of the concrete near the surface to an accuracy of ±20%. This is a rather high percentage of inaccuracy and hence it shall be used with care.

8.0 COMPARISON OF THE INTERPRETATION OF CORE TESTS RESULT BASED ON BS 6089 AND EN 13791.

In this section, we will compare the interpretation of two actual test programs based on BS 6089, EN 13791 as well as the general procedure of hypothesis testing.

Case I (Core test for apartment):

This was a core test carried out in 2005 with a total of 22 samples. The concrete was C30. The results are shown in Table 1.

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Table 1 (part 1): Core test results (Core 1 to 12)

Sample identification	1	2	3	4	5	6	7	8	9	10	11	12
Location	BA - wall	BA - wall	BA - wall	BA - wall	BA - slab	BA - slab	BA - slab	BA - slab	BB - alab	BB - alab	BB - wall	BB - wall
Direction of drilling	Hor	Hor	Hor	Hor	Ver	Ver	Ver	Ver	Ver	Ver	Hor	Hor
Diameter of core	69	69	69	69	69	69	69	69	69	69	69	69
L/D	1.11	1.10	1.10	1.12	1.11	1.11	1.12	1.12	1.10	1.10	1.10	1.10
Correction of reinforcement	1.05	1.00	1.00	1.06	1.00	1.00	1.00	1.06	1.00	1.00	1.13	1.16
Measured strength	32.0	31.0	34.0	33.0	35.5	33.5	31.0	34.0	31.5	35.0	34.0	26.5
Correction of L/D ratio (BS 6089)	1.041	1.038	1.038	1.045	0.958	0.958	0.961	0.961	0.955	0.955	1.038	1.038
Estimated *in situ* strength (BS 6089)	35.0	32.2	35.3	36.5	34.0	32.1	29.8	34.6	30.1	33.4	39.9	31.9
Mean and Standard deviation	34.1, 2.8											
Estimated *in situ* characteristic strength	34.1 , 2.8											
Correction of L/D ratio (BS EN 13791)	1.041	1.038	1.038	1.045	1.041	1.041	1.045	1.045	1.038	1.038	1.038	1.038
Estimated *in situ* strength (EN 13791)	35.0	32.2	35.3	36.5	37.0	34.9	32.4	37.7	32.7	36.3	39.9	31.9
Mean and Standard deviation	35.5, 2.6											
Estimated *in situ* characteristic strength	31.7											

Table 1 (part 2): Core test result (Core 13 to 22)

Sample identification	13	14	15	16	17	18	19	20	21	22
Location	BC - slab	BC - slab	BC - wall	BC - wall	BD - wall	BD - wall	BD - wall	BD - slab	BD - slab	BD - slab
Direction of drilling	Ver	Ver	Hor	Hor	Hor	Hor	Hor	Ver	Ver	Ver
Diameter of core	69	69	69	69	69	69	69	69	69	69
L/D	1.12	1.12	1.10	1.10	1.10	1.13	1.10	1.10	1.10	1.11
Correction of reinforcement	1.00	1.05	1.00	1.05	1.00	1.00	1.03	1.14	1.05	1.11
Measured strength	35.0	30.0	35.5	30.0	35.5	35.0	33.0	31.0	30.0	36.0
Correction of L/D ratio (BS 6089)	0.961	0.961	1.038	1.038	1.038	1.048	1.038	0.955	0.955	0.958
Estimated *in situ* strength (BS 6089)	33.6	30.3	36.8	32.7	36.8	36.7	35.3	33.7	30.1	38.3
Mean and Standard deviation	34.1, 2.8									
Estimated *in situ* characteristic strength	33.2									
Correction of L/D ratio (BS EN 13791)	1.045	1.045	1.038	1.038	1.038	1.048	1.038	1.038	1.038	1.041
Estimated *in situ* strength (EN 13791)	36.6	32.9	35.3	32.7	36.8	36.7	35.3	36.7	32.7	41.6
Mean and Standard deviation	35.5, 2.6									
Estimated *in situ* characteristic strength	31.7									

i) BS 6089

Mean value was 34.1 N/mm^2 with a standard deviation of 2.79 N/mm^2. Based on BS 6089, the characteristic strength of the concrete is estimated to be 33.2 N/mm^2. Hence, the concrete is deemed to comply with the concrete specification.

ii) EN 13791

Mean value was 35.5 N/mm^2 with a standard deviation of 2.56 N/mm^2. Based on EN 13791, the characteristic strength of the concrete is estimated to be 31.7 N/mm^2. Hence, the concrete is deemed to comply with the concrete specification.

Case II (core test for reinforced concrete piles)

This was a core test carried out in 2005 with a total of eight samples. The concrete was C40. The results are shown in Table 2, 2a and 2b. In order to have a better understanding of the quality of the *in situ* concrete, outlier detection and zoning were carried out to detect the presence of any extreme value. There was no outlier detected since all values lie within ±1.5 standard deviation. However, there was a clear zoning. Hence, it was concluded that these eight samples may be taken from two different populations (*i.e.* different test regions). Hence, it may be interpreted differently for these two test regions.

i) BS 6089

Overall mean was 37.5 N/mm^2 with a standard deviation of 4.80 N/mm^2. Based on BS 6089, the characteristic strength of the concrete is estimated to be 36.9. If the design engineer permitted to lower down the safety factor to 1.2, then the concrete is deemed to comply with the concrete specification.

Mean value for zone 1 was 40.8 N/mm^2 with a standard deviation of 1.94 N/mm^2. The characteristic strength of the in situ concrete was 38.6 N/mm^2. For zone 2, the mean was 32 with a standard deviation of 0.97 N/mm^2 and the characteristic strength of the in situ concrete was 29.8 N/mm^2.

ii) EN 13791

Based on EN 13791, the characteristic strength of the concrete is estimated to be 33.2 N/mm^2. Even by applying the ratio of 0.85 for the *in situ* characteristic strength to the characteristic strength of a standard specimen of *in situ* concrete, the concrete is still deemed to be not complying with the concrete specification.

The characteristic strength of the *in situ* concrete for zone 1 was 35.9 N/mm^2 and with the ratio of 0.85, it is equivalent to the characteristic strength of the standard specimen of 42.2 N/mm^2 and, hence, complied with the specification. The characteristic strength of the *in situ* concrete for zone 2 was 26.0 N/mm^2.

iii) Statistical testing

Based on the statistics, since mean and standard deviation has to be estimated, this is a t-distribution. The results are shown in Table 3a (for data based on BS 6089) and Table 3b (data based on EN 13791). Based on the hypothesis testing, the overall result of the core test did not comply with the specification at the significance level of 0.01.

Table 2: Overall core test results (Case 2)

Sample identification	1	2	3	4	5	6	7	8
Direction of drilling	Hor	Hor	Hor	Hor	Ver	Ver	Ver	Ver
Density	2320	2320	2360	2380	2330	2350	2370	2390
Diameter of core	100	100	100	100	100	100	100	100
L/D	1.08	1.07	1.07	1.08	1.08	1.08	1.08	1.07
Correction of reinforcement	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Measured strength	30.0	39.5	40.5	43.5	34.5	31.5	42.5	42.5
Correction of L/D ratio (BS 6089)	1.031	1.027	0.945	0.948	0.948	1.031	0.948	1.027
Estimated *in situ* strength (BS 6089)	30.9	40.6	38.3	41.2	32.7	32.5	40.3	43.6
Mean Standard deviation	37.5 4.80							
Estimated *in situ* characteristic strength	35.9							
Correction of L/D ratio (BS EN 13791)	1.031	1.027	1.027	1.031	1.031	1.031	1.031	1.027
Estimated *in situ* strength (EN 13791)	30.9	40.6	41.6	44.8	35.6	32.5	43.8	43.6
Minimum *in situ* strength	30.9 39.2							
Mean and Standard deviation	5.44							
Estimated *in situ* characteristic strength	33.2							

Table 2a: Zone 1 core test results

Sample identification	2	3	4	6	7
Direction of drilling	Hor	Hor	Hor	Ver	Ver
Density	2320	2360	2380	2370	2390
Diameter of core	100	100	100	100	100
L/D	1.07	1.07	1.08	1.08	1.07
Correction of reinforcement	1.00	1.00	1.00	1.00	1.00
Measured strength	39.5	40.5	43.5	42.5	42.5
Correction of L/D ratio (BS 6089)	1.027	0.945	0.948	0.948	1.027
Estimated *in situ* strength (BS 6089)	40.6	38.3	41.2	40.3	43.6
Mean Standard deviation			40.8 1.94		
Estimated *in situ* characteristic strength			38.6		
Correction of L/D ratio (BS EN 13791)	1.027	1.027	1.031	1.031	1.027
Estimated *in situ* strength (EN 13791)	40.6	41.6	44.8	43.8	43.6
Minimum *in situ* strength Mean			40.6 42.9		
Standard deviation			1.75		
Estimated *in situ* characteristic strength			35.9		

Table 2b: Core test results for zone 2

Sample identification	1	5	6
Direction of drilling	Hor	Ver	Hor
Density	2320	2330	2350
Diameter of core	100	100	100
L/D	1.08	1.08	1.08
Correction of reinforcement	1.00	1.00	1.00
Measured strength	30.0	34.5	31.5
Correction of L/D ratio (BS 6089)	1.031	0.948	1.031
Estimated *in situ* strength (BS 6089)	30.9	32.7	32.5
Mean Standard deviation		32.0 0.97	
Estimated *in situ* characteristic strength		29.8	
Correction of L/D ratio (BS EN 13791)	1.031	1.031	1.031
Estimated *in situ* strength (EN 13791)	30.9	35.6	32.5
Minimum *in situ* strength Mean		30.9 33.0	
Standard deviation		2.36	
Estimated *in situ* characteristic strength		26.0	

Table 3a: Hypothesis testing based on BS 6089

Item	Description	Value
1	Characteristic strength	40
2	Standard deviation	3
3	Targeted mean strength	44.9
4	Degree of freedom	7
5	t – score	-4.37
6	Critical value for level of significant of 0.01	-2.988

Table 3b: Hypothesis testing based on EN 13791

Item	Description	Value
1	Characteristic strength	40
2	Standard deviation	3
3	Targeted mean strength	44.9
4	Degree of freedom	7
5	t – score	-2.988
6	Critical value for level of significant of 0.01	-2.988

9.0 CONCLUSION

Assessment of the compressive strength of the *in situ* concrete shall be carried out in accordance with the standard specification and great care shall be taken in the interpretation. Various techniques shall be applied to enhance the interpretation of the test results. It was noted that BS EN 13791 gives higher result for vertical drilling compare to BS 6089 due to the fact that same factor be used for both horizontal and vertical drilling in BS EN 13791. Further guides shall be written for Malaysia scenario in the form of the national annex to EN 13791. ■

REFERENCES

[1] BS 6089: 1981, Guide to assessment of concrete strength in existing structures

[2] BS EN 13791:2007, Assessment of in-situ compressive strength in structures and precast concrete

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[4] BS EN 206-1: 2001: Part 1: Specification, performance, production and conformity.

[5] BS 1881: Part 120: 1983, Part 120. Method for determination of the compressive strength of concrete core.

[6] BS EN 12504-1:2000 Testing concrete in structures – Part 1: core specimens – taking, examining and testing in compression

[7] CSTR 11: 1987, Concrete core testing for strength Concrete Society Technical Report No. 11.

[8] Dewar, J.D., Anderson, R., Manual of Ready Mixed Concrete, Blackie Academic & Professional