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Acceptance criteria of concrete strength: Being used in Bangladesh and suggestion for change

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ABSTRACT: Most of the infrastructure development work in Bangladesh is carried by four government department namely LGED, PWD, RHD and WDB. Other than RHD, the other departments have very limited understanding on the statistical behavior of concrete strength as random variable. The Bangladesh National Building Code has no practical reference on the subject. Only the RHD specification detailed the acceptance criteria of concrete produced for different bridge construction work which was developed during the end of last century and later updated in the year of 2011 with no change. This study tries to find the rationality of concrete production and acceptance criteria being used in different projects in Bangladesh. Furthermore this study suggests development to the understanding of the concept.

1 INTRODUCTION

Frequency distribution of concrete compressive strength (of any construction project) in ideal condition may take the form of symmetrical 'Bell Curve' as shown in Figure 1.

Here in Figure 1, we see that most of the strength values are concentrated in the central region while few low values are in the tail region and high values in the head region. For any concrete structure, this is true that some part of the structure is composed of lower concrete strength than desired.

How much lower value is accepted? It depends upon the Code/Standard being used. Most of the design code agrees that not more than five percent shall be accepted to be lower strength than the specified strength.

However, it is possible to get hundred percent of the values above or equal to the required specified strength. But this will result in very impractical and uneconomical solution and not required in any real life construction project. Exception may be Nuclear Power Station and/or very toxic Chemical Industry.

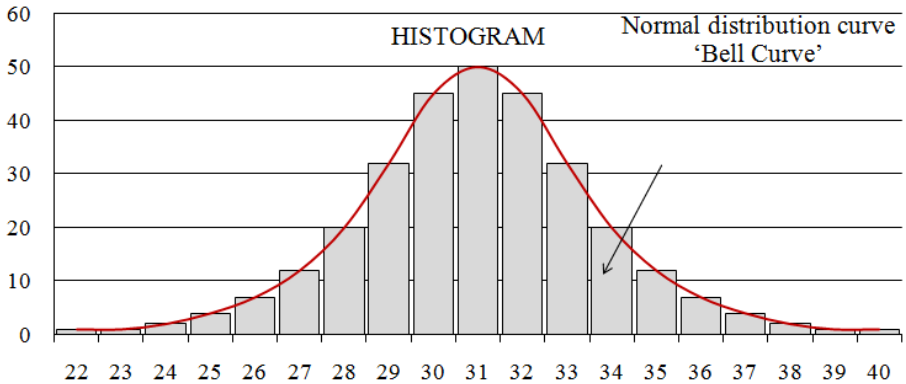

Figure 1. Typical frequency distribution curve.

2 PROBABILITY OF CONCRETE STRENGTH

Concrete's compressive strength is accepted as a normally distributed random variable. Its Probability Density Function (PDF) can be expressed as

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma} \right) 2 \right] \qquad (1)$$

where
x in the individual strength value of the samples;
μ is the Mean the data; and
σ is the Standard deviation of the data set.
A plot of the function *f(x)* takes the form similar as the frequency distribution bell curve as shown in Figure 2.

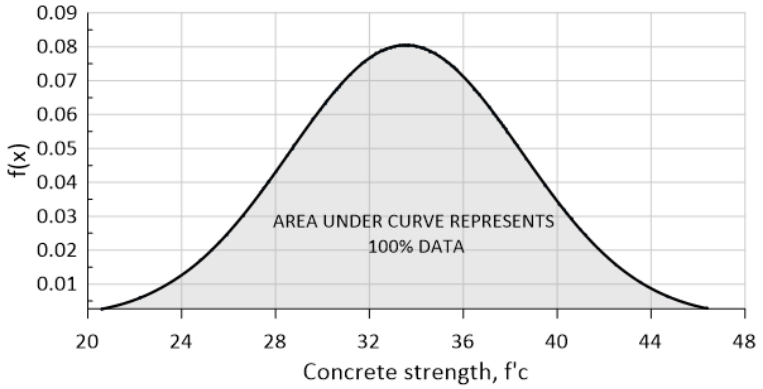

Figure 2. Typical plot of probability density function.

However, most of the cases, the PDF is normalized with what is called a 'z-value' in such a way that the Mean of the distribution is zero as shown in Figure 3. The area under the curve in Figure 3 represents 100% of the distribution. The Mean of the distribution at the centre is zero. If the distribution is symmetrical then Mean ±1σ represents 68.2% of the data, Mean ±2σ represents 95.4% and so on.

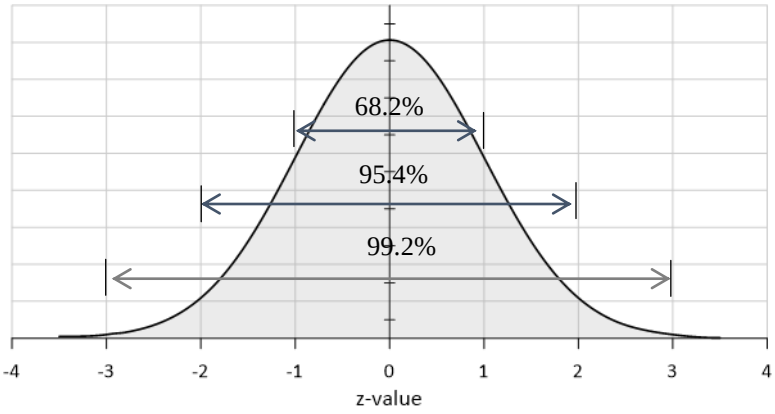

Figure 3. Normalized probability density function.

The desired 'confidence level' for the concrete strength is 95%. It means that we want 95% of the area of the curve must be to the right side of the specified strength, $f_c^{'}$ as shown in Figure 4.

For 95% confidence level, the value of z (the multiplier to the standard deviation) can be found from statistics is equal to 1.64. If we know the Mean value of the concrete strength, then the specified strength of the concrete for 95% confidence level shall be,

$$\text{Specifiend strength} = \text{Mean strength} - 1.64 \times \sigma \qquad (2)$$

Specified strength of concrete, $f_c^{'}$ is a known variable. So, to get 95% confidence level, concrete shall be designed for a

$$\text{Target Mean strength} = \text{Specified strength}, f_c^{'} + 1.64 \times \sigma \qquad (3)$$

[This relation is based on the assumption that the distribution is symmetrical about the Mean value. However, for a distribution with positive skew the multiplier to the standard deviation shall be less than 1.64 and with negative skew the multiplier shall be more than 1.64.]

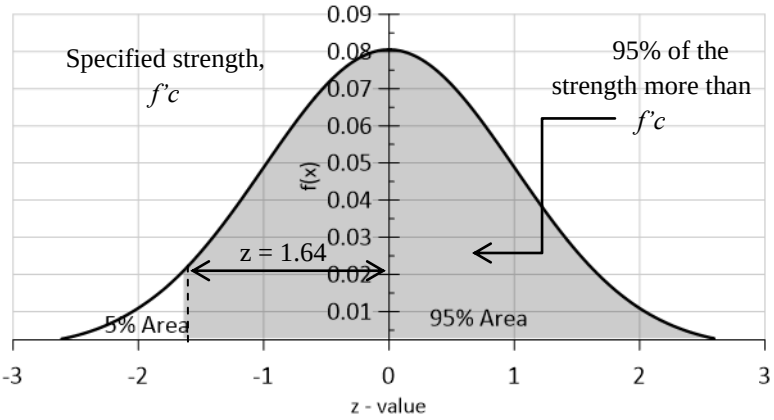

Figure 4. 95% confidence level of concrete strength.

3 ACCEPTANCE CRITERIA OF CONCRETE STRENGTH IN BANGLADESH

Bangladesh National Building Code and different engineering department has different understanding of statistically behaviour of concrete strength and its acceptance criteria. None is truly based on scientifically approved procedure.

3.1 *Bangladesh National Building Code (BNBC) 2006*

Bangladesh National Building Code (2006) defines some provision concrete strength and acceptance criteria in Part 6, Chapter 5.6 Concrete Mix Proportion, and Chapter 5.12 Evaluation and Acceptance of Concrete. The Provisions of BNBC is almost impossible to understand. Extractions from BNBC are:

- 28 days cylinder strength shall be evaluated (Art. 5.12.1.2);
- Two samples shall be tested (Art. 5.12.2.4) and the average shall be equal to 'required average compressive strength';
- When no data of standard deviation is available, average compressive strength shall be as per Table 6.5.5 of BNBC.
- When data are available to establish a standard deviation, required average compressive strength shall be maximum of the following two equations.

  $f_{cr}^{'} = f_{c}^{'} + 1.34\sigma$

- This equation represents 91% confidence level

  $f_{cr}^{'} = f_{c}^{'} + 2.33\sigma - 3.5$

- No confidence level can be established from this equation but if the minus part is omitted, the equation represents 99.1% confidence level.

If someone checks the equations carefully, the two equations shall yield equal value for σ = 3.5353 …. and the first equation shall only governs for σ = < 3.5353… So, for all practical cases, the second equation shall govern.

In BNBC, acceptance criteria is right but provision for establishing the average strength requirement is faulty and does not represent any definite confidence level.

3.2 *PWD Specification (PWD 2016)*

PWD Specification has very limited information on concrete's strength evaluation and no guideline for acceptance criteria.

Table 1. Information on concrete strength in PWD technical specification.

28 days cylinder strength, f'_c	Current margin	Target mean strength, f_{cr}	Standard deviation, □
22.00	5.00	27.00	3.05
25.00	5.00	30.00	3.05
32.00	8.00	40.00	4.88
40.00	9.00	49.00	5.49

There is no provision on how to evaluate the concrete's strength and accept and/or reject. The standard deviation for different concrete strength may be noted here. Such small standard deviation indicates very good quality concrete production with strict quality control procedure. This is very contradictory to practical scenario as exists in the country.

3.3 *RHD Specification (RHD 2011)*

Other than Roads and Highway Department (RHD) other engineering department works in infrastructure development where concrete is concern, namely Local Government Engineering Department (LGED) has no understanding of the statistical behaviour of concrete strength and has no practical acceptance criteria for their work. RHD Standard Technical Specification was prepared in 1999 through IDC project by a group of British Consultants and later it was updated in 2011. Section 7 – Chapter 5 of the Technical Specification details the requirements of Concrete. As per RHD Technical Specification, it asked for 4 (four) cylinder per batch of concrete for strength checking (Article 5.1.2.4). Most of the design codes suggest to take minimum three (3) samples. It is not clear why it has suggest for four(4) samples while this never actually followed in any of the project done following this specification. Initial Target Mean Strength considered as 2/3rd of the Characteristicstrength. As per this criteria, the concrete has different standard deviations based on the strength (see Table 2). This is not really practical and may be prepared with a very poor understanding about the country. If a batching plant has a standard deviation of 16.26 (for 40 MPa concrete), it should not be allowed to operate. The testing plan and acceptance criteria.

1. The average strength determined from any group of four consecutive test cylinders exceeds the specified Characteristic strength by not less than 0.5 times the current margin, and
2. Each individual test result is greater than 85% of the specified Characteristic strength.

Table 2. Initial standard deviation as per RHD technical specification.

28 days cylinder strength, $f_c^{'}$	Current margin $= \frac{2}{3} f_c^{'}$	Target mean strength	Standard deviation, σ	Acceptance criteria	
				Individual Minimum = $0.85 f_c^{'}$	Minimum average = $\frac{2}{3} f_c^{'} + 0.5 \times current\ margin$
1	2 = (2/3rd) x 1	3=1+2	4=2/1.64	5 = 0.85 x1	6 = 1+0.5x2
20.00	13.33	33.33	8.13	17.00	26.67
25.00	16.67	41.67	10.16	21.25	33.33
30.00	20.00	50.00	12.20	25.50	40.00
35.00	23.33	58.33	14.23	29.75	46.67
40.00	26.67	66.67	16.26	34.00	53.33
45.00	30.00	75.00	18.29	38.25	60.00
50.00	33.33	83.33	20.33	42.50	66.67

As per RHD acceptance criteria, for 25 MPa concrete the average of the samples shall be greater than or equal to 33.33 MPa. One can see in Table 2, the target mean strength for the corresponding strength is 41.67 MPa. It is very much clear that, this acceptance criteria cannot meet the desired confidence level for the specified design strength (25mPa in this case) with 8.34mPa less in average is accepted than target mean strength.

4 EVALUATION OF CONFIDENCE LEVEL

A random data set is prepared to exactly fit RHD concrete test compliance criteria for 25 MPa concrete to check the confidence level. Basic statistics of the data is shown in Table 3 it can be seen that to satisfy the 95% confidence level, the standard deviation needs to 4.94 instead of 10.16 as proposed.

Table 3. Descriptive statistics of the data.

Count	100
Mean	33.55
Standard Deviation	4.94
Sample Variance	24.36
Minimum	21.25
Maximum	46.40

Well, it may be assumed that the batching plant can produce concrete with standard deviation 4.94. (It is really possible and being done in many projects.) In such case, for 25 MPa concrete,

Target Mean Strength = 25+1.64 x 4.94 = 33.10 MPa

Again, the acceptance criteria accepts the minimum average of samples = 25 + 0.5 x (1.64 x 4.94) = 29 MPa. This cannot meet the 95% confidence level.

Basic limitations of the RHD acceptance criteria are:
- the initial strength requirement is higher and not rational; and
- the acceptance criteria for limited sampling (4 test samples for a batch of concrete) to fit the strength demand is faulty and cannot meet the required confidence level.

4.1 *Practical Case Study*

Bhulta Flyover at Rupgonj, Narayangong is being constructed under RHD. This is a government funded project and being done following RHD specification. Only change was made in the selection of current margin. Instead of 2/3rd, concrete's initial current margin was set to 1/3rd of the specified strength. So, for a 25 MPa concrete,

$$\text{Target Mean Strength} = 25 + \frac{1}{3} \times 25 \approx 33\text{MPa}$$

112 nos. of 28 days cylinder strength test result was available to check and study (100x200mm cylinder cast and tested during 05 April, 2016 to 29 May, 2016). Descriptive statistics of the population is given in Table 4.

Table 4. Descriptive statistics of concrete strength for Bhulta flyover.

Mean	39.185
Standard Deviation	3.635
Sample Variance	13.215
Skewness	0.0192
Minimum	30.38
Maximum	49.31

The Mean is 39.185 > 33 and individual minimum value is 30.38 > 0.85 x 25 = 21.25. All data individually and wholly satisfies the acceptance requirements of RHD.

If we see the PDF that plotted in Figure 5, no calculation is required to show that the specified concrete strength, $f_c' = 25$ MPameets 100% confidence level. 25 MPa concrete as designed in Bhulta Flyover could comfortably be used as $(25 + 1.64 \times 4.04 \cong)32.0 <$ MPa concrete which in turn would economized the design or the trail mix design could be done with less cement (for less target mean strength). Any of the options are results in economy and optimum used of material quantity and strength. The positive skew of the distribution can be noted in Table 4. This is true for almost all concrete producer/Contractor. To avoid rejection of concrete slightly higher value concrete than required is always produced. This in-turn results in lower z-value (< 1.64) for 95% confidence level.

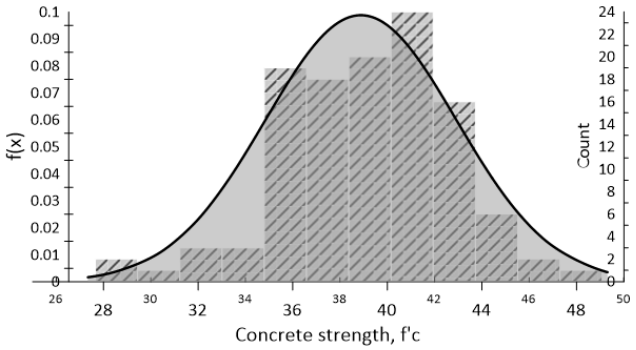

Figure 5. PDF Plot of Bhulta Flyover concrete strength.

5 RECOMMENDATIONS

Based on the study and observation, it is being recommended to make following changes in the Technical Specification for Sampling/Testing/Accepting concrete for its strength:

A. Confidence level
Confidence level of specified strength of concrete, $f_c^{'}$ shall be 95%

B. Sampling

– 28 days concrete strength shall be evaluated in general. However, 56 days concrete strength may be evaluated for concrete made with composite cement or High Performance Concrete(HPC).
– Minimum 3(Three) samples in cylinder shall be taken for each lot/batch of concrete. Volume of a lot/batch of concrete shall be as per specific requirement detailed in the Technical Specification.

C. Trail mix

– At the initial stage, if statistical data are not available, the current margin shall be taken as 10 MPa (standard deviation, $\sigma \approx 6$ MPa)to establish the target mean strength irrespective to concrete class;
– Current margin may be adjusted based on calculated standard deviation after 45 individual cylinder test results cast and tested in three(3) months of continuous period of production;

D. Acceptance criteria

– Average of 3(three) cylinder shall be at least equal to or greater target mean strength;
– No individual test result shall fall 4.0 MPa below the specified strength;
– If acceptance criteria 2 as above does not meet for a specific batch of concrete, the Engineer shall take decision based on location of concrete used, structural requirement and practical judgement. But in no case such under value of individual test cylinder shall be accepted for more than three times.
– If acceptance criteria 1 as above does not meet for specific batch of concrete, the Engineer shall take decision based on location of concrete used, structural requirement and practical judgement. But in no cases such under value of average shall be accepted for more than three times.

E. Samples in Cube
For sample taken in Cubes (150mm x 150mm), initial current margin shall be 12.5 MPa and individual test result of a batch of sample shall not fall 5.0 MPa below the specified strength. All other criteria shall be same as for Cylinder sample.

REFERENCES

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