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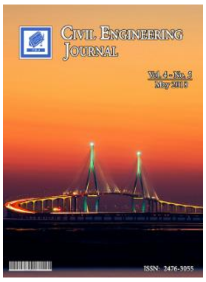

Redefining Existing Concrete Compressive Strength Acceptance Standard in Iran Concrete Code (ABA), by Experimental Data

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Abstract

In Iran Concrete Code (ABA), the criteria for calculation of standard deviation (s) are comprehensive and holistic. However, if it would be determined separately for each geographical area, significant changes could occur due to the use of concrete as one of the common materials. This paper analyses the criteria and redefines the acceptance standards for concrete compressive strength in ABA using experimental data available in Kohgiluyeh and Boyer-Ahmad and Fars provinces. The main hypothesis of the study is that using the statistical analysis of the test specimens for three categories C21, C30 and C35 in various projects located in Kohgiluyeh and Boyer-Ahmad and Fars provinces, extracting standard deviations, mean and the compressive strength of the specimens and their comparison with ABA proposed relationships and values, it is possible to propose new amendments for these areas in line with economic savings in national and international projects. In this study using the quantitative Strategy, library - Internet studies, field studies and in cooperation with the concrete labs, required information for 4878 concrete specimens was collected from the above-mentioned areas. By analysing the acceptance regulations for the specimens based on ABA and comparing the standard deviation of these data with the formulas of the regulations, significant results were obtained for the standard deviation factor correction and finally some formulas were suggested for the acceptance of the concrete specimens.

Keywords: Concrete Compressive Strength; Acceptance Standards; ABA; Iran Concrete Code.

1. Introduction

Given the importance of quality in terms of strength and reliability of concrete and reinforced concrete structures, the concrete quality control is one of the most important programs that is addressed in general quality control structures. Due to increasing demand for concrete and that it needs lesser cost than other materials as well as easy availability throughout the world; structural concrete have the great importance. By considering the importance and extent of studies required for the concrete, addressing such an issue is one of the most important operation in engineering branches .since concrete is a major material in constructions throughout the world, and huge monies are spent for design and implementation of concrete structures, safety is the most important aspect, particularly because concrete structures form a large part of essential infrastructure in many countries. Therefore, when constructing structures, sufficient control and care is needed in terms of durability and enough strength against malicious threats such as earthquakes, wind and other factors such as corrosion against chemicals. Strength assessment of existing concrete structures is often based on calculation models developed for design of new structures [1]. Large institutions perform experiments in form of designs and projects on concrete in terms of physical and chemical characteristics. The results of them are analyzed in terms of considering regulations, standards and constraints for the design, concrete mix and its acceptance. Concrete performance and flow, strength to environmental conditions and compatibility with the compressive strength test are effective in

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concrete mix ratios [2]. Usually the structures are designed based on the assumption of least strength for the concrete design but the real concrete strength is a quantitative variable value both in the workshop or laboratory [3]. In a concrete mix design, the purpose is to achieve an average strength which is higher than this minimum strength. On the other hand, it is not possible to determine any absolute minimum because from a statistical point of view, there is always a possibility that the test result is below a given minimum value (no matter how low it is). So reducing this amount of probability is not reasonable [4]. So usually the minimum strength is considered such that a certain percentage (usually between 95 to 99 percent) of all results is more than this amount. Therefore, by definition, the specific strength is the one that more than 95 percent of test specimens obtain it [5].

Study and research on concrete acceptance criteria is one of the key elements in the formulation of concrete codes for the most suitable concrete in terms of resistance and quality of implementation and control of economic costs. Calculating the standard deviation to determine the appropriate mixing plan based on environmental conditions and localizing the mixing patterns on the basis of the actual statistical information obtained from the laboratories will improve the conditions for obtaining more accurate results.

Given that assessment and acceptance of concrete in all parts of Iran is based on Iran Concrete Code (ABA) as the scientific reference and controller of the longevity and durability of concrete, it is expected that the reviews and field studies in different provinces and areas have results similar to the Code while the other factors may reveal different results. In order to assess these criteria, trough the statistical study of laboratory specimens of concrete for three categories C21, C30 and C35 in various projects located in Kohgiluyeh and Boyer-Ahmad and Fars provinces, their standard deviation and mean are studied and controlled and compared with the specific strength of the design, the permitted standard deviation and the criteria for the evaluation of the acceptance of the laboratory specimens.

2. Literature Review

2.1. Definitions and Statistical Variations in Concrete Strength

Concrete is a substance consisting of cement, water, aggregate and air and changes in the properties of these components and changes in issues such as transportation, placement and density of concrete lead to variations in the manufactures concrete strength [5]. As widely-known, pores, voids and other defects govern the most important mechanical properties of cement-based materials and especially in terms of strength and permeability [6–9]. On the other hand the difference in experimental conditions and devises cause significant differences in concrete strength. Despite the relevance and the potential impact on current practices for strength assessment of existing structures, the subject of compressive strength has received little attention in the literature [1, 10-17].

In The method of mix design, it is intended to make a concrete with maximum density and minimum of void space, leading to a concrete with very low permeability and high shrink. For this purpose, using the mathematical relations, the grain distribution (both aggregate and adhesive materials) are selected in such a manner that the aggregate material causes the mixture density to increase by filling the gap between the coarse aggregate; while in conventional methods curves are used that do not take into consideration the distribution of materials finer than 125 mm [18, 19].

Type specimens affect the compressive strength of concrete , so that the compressive strength of 28 day standard cylindrical samples with a diameter of 150 mm and height 300 mm , about 80 % of the compressive strength of the 28 day and 150 mm sample cube at 28 day compressive strength of about 82% after a 200 mm sample cube . However, for lightweight concrete compressive strength of cylindrical and cubic samples will be nearly identical. The main difference is due to the resistance of cylindrical and cubic samples should aspect ratio of the sample and the sample surface load induced shear stress between the steel plates due to the difference in elastic modulus and Poisson's ratio of steel and concrete sought [20].

It is hard to say that which kind of samples is better. But it seems that for research purposes, the trend is using the cylindrical samples. However, if the sample dimensions are larger than normal, common weaknesses in samples may be even and shall no longer decline in strength by increased dimensions [20]. Some studies have shown that the experimental results in comparison with the standard limit load equal 0/25 MPa/sec, 150×300 mm for cylindrical specimens; the loading rate is reduced to 3% (30 times less) for compressive strength of cylindrical only 12 percent decrease [20].

Apart from the above mentioned factors, other factors also affect the compressive strength of concrete, mainly considered as internal factors and return to the type and amount of progress in a concrete compound [20]. The regulation presents a statistical method to determine the required condition to ensure the attainment of compressive strength [2]. If a practical standard deviation (s) is obtained from the strength tests, it determines the specific strength which the mixing ratios should be determined for it. Otherwise, the mixing ratios should be chosen in such a way that a conservative and sufficient specific strength against variation is obtained in the test results.

A change in the type of concrete can increase the standard deviation with a dramatic increase in the amount of strength. Also, when the average strength is increased significantly, there may be an increase in the standard deviation;

however this increase might be less than the case that the standard deviation is directly proportional to the strength increases. Whenever the reliability of the standard deviation is reasonably doubted, the estimated standard deviation (which is used to calculate the necessary average strength) should be presented at the conservative side (greater necessary average strength). The standard deviation is done by the square root of the sum of squares divided by the number of tests minus 1 and showed by s [21]. The amount of $\overline{X}$ is calculated by the sum of the results of all tests divided by the number of summed up values [22]. The mathematical relationship to calculate s is as follows:

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})}{n-1}} \tag{1}$$

Where *s* is the standard deviation; *x* is the strength test results; $\overline{x}$ is the average of strength tests results of *n* successive specimens and *n* is the number of successive specimens [4].

According to Article 9-6-4-1 of the ninth topic of national building regulations of Iran and Article 6.4.1 of ABA, concrete specific strength is the strength that the maximum of 5% of all measured strengths for the concrete level are less than that [2]. Usually the structures are designed based on assumption of a minimum certain concrete strength but the actual produced concrete strength in workshop or in the laboratory is a variable quantity. Therefore in a concrete mix design the purpose is to achieve a moderate strength which is higher than this strength [2].

2.2. Laboratory Specimens' Acceptance

ABA presents the following criteria for the acceptance of laboratory specimens. According to the ABA, concrete specifications are accordance with the intended category that one of the following conditions is met [2].

In testing three sequential specimens, none of the specimens' strength is less than the specified compressive strength.

$$X_{1,2,3} \geq f_c \tag{2}$$

According to the relations three and four the average strength of the specimens $\overline{x}$ is at least 1.5 MPa more than the specific strength and the maximum specimens' strength (x_{min}) is not lower than the final specific strength Minus 4 MPa.

$$X_{1,2,3} \geq f_c \tag{3}$$

$$X_{1,2,3} \geq f_c \tag{4}$$

According to ABA, if the Equation (4) does not apply or the average strength is less than the specific strength, the concrete characteristics are not acceptable [23].

3. Materials and Methods

In this research, the quality control of concrete is limited to the criteria for assessing the compressive strength of concrete in terms of adaptation with the desired category and the rules of the concrete mixing plan for its production (the required average compressive strength). These criteria has organized based on the results of the compressive tests of the samples taken at the workshop and stored in standard laboratory conditions, and finally judging the acceptance or non-acceptance of the quality of the concrete, which is common in most workshops Building.

By referring to the laboratories of soil and concrete in Kohgiluyeh and Boyer-Ahmad and Fars provinces and meetings with the management of the laboratories and then coordination with the relevant experts, the information of more than 30,000 specimens of concrete tests related to 180 projects was received. The required information was categorized in Microsoft Excel, which included serial number of samples, sampling date, characteristic resistance, compressive strength and the age (sample life).

Some of the projects that had valuable statistics and their compressive strength of the mixing plan were similar were categorized in three classes: C21, C30 and C35. Due to the more accurate statistics and information, other projects were eliminated. In this case, using the empirical formulas, all of the various sample life were transformed into 28 day strength. by re-examining the statistics, information, results and specially the existence of empirical formulas, all the statistics and information that were examined, modified, and used by empirical formulas, were Deleted and only the information of the actual 28 day strength samples of these projects were separated and other information (7,11,42 and 90 day strength) was eliminated. All laboratory samples were cubic and their side dimensions were 150 mm. By considering the determination of specified compressive strength in the design for most projects with a 28 day strength age and the more application of this age in the regulations and increasing accuracy, only 28 day olds samples have been investigated and have been converted to cylindrical specimens.

After further review the following steps are taken:

- Specimens with a 28 day life in the categories C21, C30 and C35 were 3147, 1578 and 153 cases and analyzed based on ABA criteria provided in Table 1.
- Specimens are analyzed by averaging three specimens and binary averaging three specimens (first and Second, second and third and first and third) based on ABA and the criteria for acceptance C21, C30 and C35 are discussed.

Table 1. Number and percentage of specimens acceptable by ABA

Concrete category	The total number of specimens	Number of acceptable specimens based on ABA	Percent of acceptable specimens based on ABA
C21	3147	2130	67
C30	1578	915	58
C35	153	81	58

4. Results

After calculating the standard deviation and the mean values, the charts of each category were drawn and presented as the Figures 1.4. It should be noted that the mean value and standard deviation of the specimens are calculated by the effect of Kilogram (kg) and in order to be converted into Newton (N) the amount 9.80665 ~10 should be considered.

- Average strength of the specimens accepted for Category C21 is 283.98 (Kg/cm^2) and the standard deviation of the accepted specimens in the same category is5.45. However, ABA acceptable standard deviation is 5.36 [23].

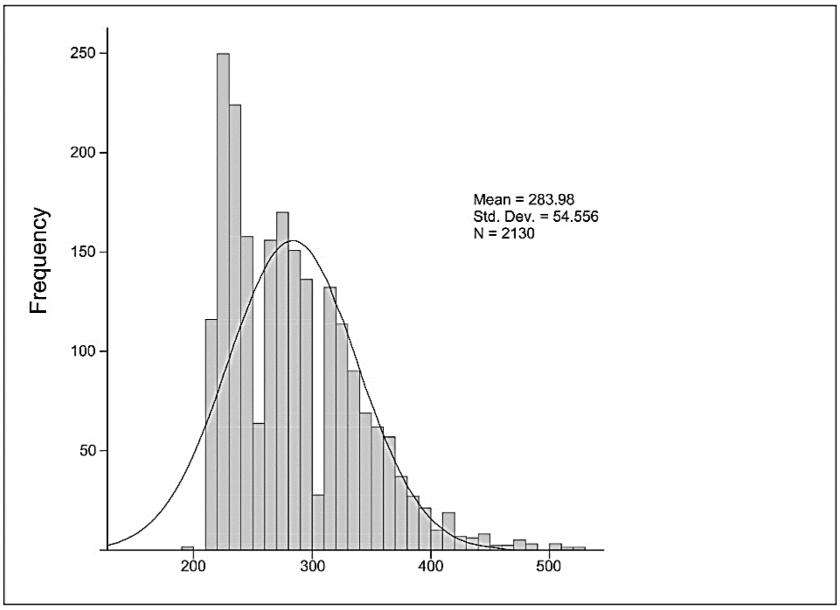

Figure 1. Mean specific strength and the standard deviation for ABA acceptable specimens C21

- The mean specific strength of 915 accepted specimens for the concrete category C30 is 360.03 (Kg/cm^2) and this amount is equal with ABA. The standard deviation of accepted specimens in this category is 3.5997 while ABA accepted standard deviation is 6.71 [23].

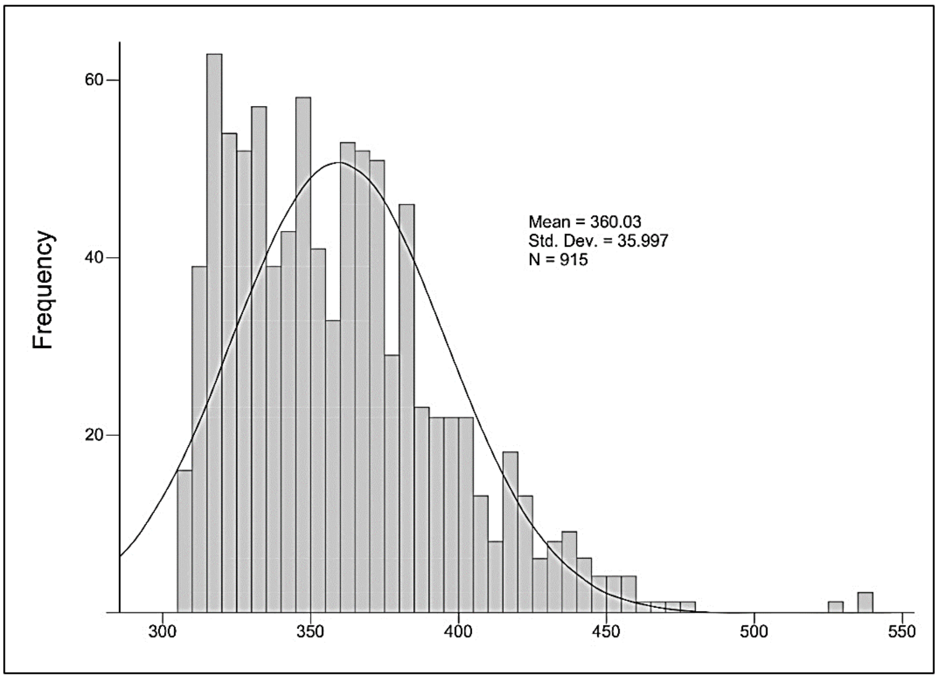

Figure 2. Mean specific strength and the standard deviation for ABA acceptable specimens C30

- The mean specific strength of 81 accepted specimens for the concrete category C35 is 388.04 (Kg/cm^2) and this amount is equal with ABA. The standard deviation of accepted specimens in this category is 3.9062 while ABA accepted standard deviation is 6.71 [23].

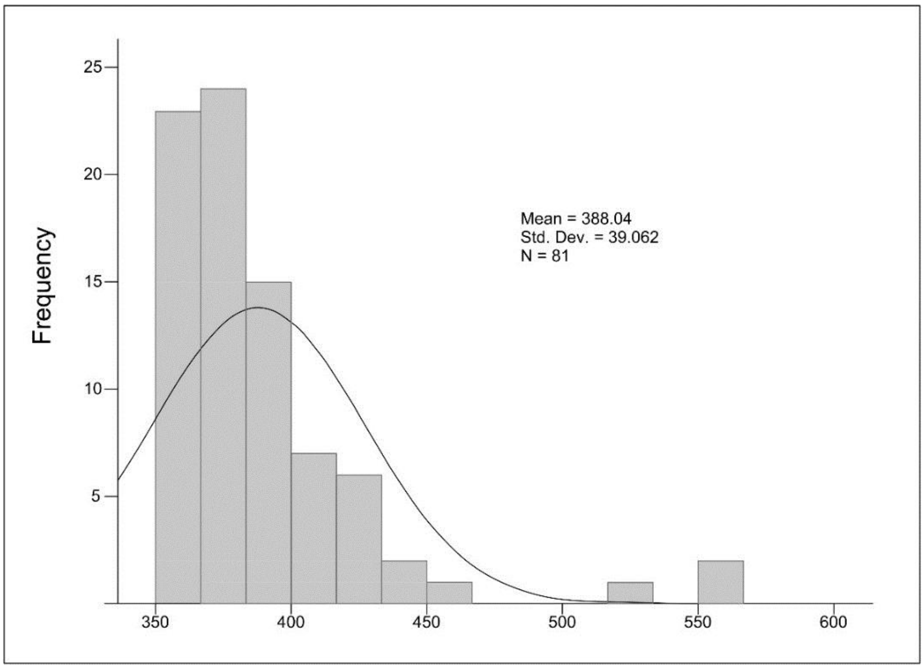

Figure 3. Mean specific strength and the standard deviation for ABA acceptable specimens C35

5. Discussions

According to the proposed relations of Article 9-6-4-4 of the ninth topic of national building regulations, the necessary mean compressive strength is calculated by the maximum value of the following equations [2]:

$$f_{cm} = f_c + 1.34s + 1.5 \quad (5)$$

$$f_{cm} = f_c + 2.33s - 4 \quad (6)$$

Also the necessary compressive strength when the results for determining the standard deviation are not available is presented for different categories in Table 2. Equalizing the two sides of the equation presented above $(f_{cm} - f_c)$ and the amount written in the third column of Table 2 give the allowed standard deviation values by the code presented in Table 3.

Table 2. The necessary compressive strength when the results for determining the standard deviation are not available [2]

Concrete category	The necessary compressive strength	$f_{cm} - f_c$
C21	$f_{cm} - f_c = 8.5$	$f_{cm} - f_c = 8.5$
C30,C35	$f_{cm} - f_c = 10.5$	$f_{cm} - f_c = 10.5$

Table 3. Allowed standard deviation values of Iran Concrete Code (ABA)

Concrete category	The standard deviation obtained by both equations	The acceptable (allowed) standard deviation
C21	$1.34s + 1.5 = 8.5 \Rightarrow s = 5.22$ $2.33s - 4 = 8.5 \Rightarrow s = 5.36$	$s = 5.36$
C30	$1.34s + 1.5 = 10.5 \Rightarrow s = 6.71$ $2.33s - 4 = 10.5 \Rightarrow s = 6.23$	$s = 6.71$
C35	$1.34s + 1.5 = 10.5 \Rightarrow s = 6.71$ $2.33s - 4 = 10.5 \Rightarrow s = 6.23$	$s = 6.71$

5.1. A Comparison between the Standard Deviation of ABA Acceptable Specimens and the Allowed Standard Deviation of ABA

For the category C21 the allowed standard deviation is 5.36 MPa [23]. On the other hand, as shown in Table 4 for acceptable laboratory specimens the standard deviation is 5.40 MPa. By comparing these two values it can be concluded that the allowable standard deviation of ABA is almost equal with the standard deviation of laboratory specimens and there is no need to provide new equation. For concrete category C30 the ABA allowed standard deviation is 6.71 MPa. On the other hand, as shown in Table 4 for acceptable laboratory specimens the standard deviation is 3.60 MPa. By comparing these two values it is concluded that the ABA allowed standard deviation is higher than the laboratory specimens' standard deviation. So a new value can be provided for ABA equation.

For concrete category C35 the ABA allowed standard deviation is 6.71 MPa. On the other hand, as shown in Table 4 for acceptable laboratory specimens the standard deviation is 3.90 MPa. By comparing these two values it is concluded that the ABA allowed standard deviation is higher than the laboratory specimens' standard deviation. So a new value can be provided for ABA equation as well.

Table 4. The mean values and standard deviations of the specimens

Concrete category	f_{cm}	s
C21	28.4	5.4
C30	36.0	3.6
C35	38.8	3.9

5.2. Providing the New Ultimate Equations

By analyzing the standard deviation values obtained from acceptable laboratory specimens by the Code and calculating the related coefficients the following relations are presented.

A. Providing new equations when the minimum of 15 specimens are available. In this case it is possible to obtain a new relation by linear interpolation in two categories C21 and C30 of the specimens acceptable in ABA.

$$f_{cm} - f_c = a \times s + b \tag{7}$$

$$28.4 - 21 = a \times 5.46 + b \Rightarrow 7.4 = 5.46a + b \tag{8}$$

$$36 - 30 = a \times 3.6 + b \Rightarrow 6 = 3.6a + b \tag{9}$$

B. With regard to the equations eight and nine, the a value is equal with 0.75 and b is equal with 3.3 and by placing them in equation 7:

$$f_{cm} = f_c + 0.75s + 3.3 \tag{10}$$

Where $f_{cm}$is the mean strength of laboratory specimens; $f_c$is specific strength of the design and s is the standard deviation of the laboratory specimens.

C. Providing new equations when the number of specimens is less than 15. In this case by placing the standard deviation obtained from the specimens in Table 5, it is possible to obtain a new equation for different concrete categories.

Table 5. New equations in the absence of at least 15 specimens

Category	standard deviation	New equations	Code equations
C21	5.456	$f_{cm} = f_c + 7.4$	$\mathbf{f_{cm} = f_c + 8.6}$
C30	3.6	$f_{cm} = f_c + 6$	$\mathbf{f_{cm} = f_c + 9.5}$
C35	3.9	$f_{cm} = f_c + 6.2$	$\mathbf{f_{cm} = f_c + 10.5}$

6. Conclusion

The present study analyzed equations proposed by ABA for the standard deviation and necessary average compressive strength in Kohgiluyeh and Boyer-Ahmad and Fars provinces. Given that in all parts of Iran the assessment and acceptance of concrete is performed based on ABA which is the scientific reference and controller of the longevity and durability of concrete in Iran, it is expected that the reviews and field studies in different provinces and areas of the country have results similar to the Code. But few test and retest have been conducted on these relations in different locations to evaluate their performance and this is the gap that the present study attempts to cover. Studies and surveys conducted in this paper make it clear that ABA proposed equations except the relations related to concrete category C21 are overestimated and lead to high costs at the macro level economically. Therefore, with respect to the values obtained for categories C30 and C35, it can be understood that ABA equations can be subject to revision and correction to determine the mix design of these two categories and the proposed equations are presented as follows.

A. Providing new equations when the minimum of 15 specimens are available (Equation 10).

B. Providing new equations when the number of specimens is less than 15, by placing the specimen standard deviation in the proposed equation in the paragraph A it is as follows:

Table 6. New equations in the absence of at least 15 specimens

Category	New equations
C21	$\mathbf{f_{cm} = f_c + 7.4}$
C30	$\mathbf{f_{cm} = f_c + 6}$
C35	$\mathbf{f_{cm} = f_c + 6.2}$

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