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Elasticity Modulus For Low Strength Concrete

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Abstract: This study aims to experimentally determine the elasticity modulus of low strength concrete and propose new equations for the modulus of elasticity. Studies on elasticity modulus have been generally carried out for normal and high strength concrete samples. The elasticity modulus can be determined as static and dynamic elasticity modulus. 64 concrete test samples were prepared in this study. Samples with a total number of 38 were placed on the stress-strain frame and subjected to the compression test to determine static elasticity modulus. 40%, 45% and 50% of the characteristic concrete compressive strengths were used as a second point on the stress-strain curve to determine the static elasticity modulus of low strength concrete according to TS 500, ACI 318-11 and CEB 2004, respectively. Static elasticity modulus values were compared with three code equations and it was observed that three codes yield higher elasticity modulus values for low strength concrete. Dynamic elasticity modules of 26 concrete samples were determined using an ultrasonic test device. Dynamic elasticity modulus values were compared with Hermit function. It was observed that Hermit function also gives higher elasticity modulus values. Therefore, new equations for static and dynamic elasticity modulus of low strength concrete were proposed based on the experiment results using regression analysis.

Keywords: Low strength concrete, Static elasticity modulus, Dynamic elasticity modulus

Düşük Dayanımlı Betonların Elastisite Modülü

Öz: Bu çalışma, düşük mukavemetli betonun elastisite modülünü deneysel olarak belirlemeyi ve yeni elastisite modülü denklemlerini önermeyi amaçlamaktadır. Elastisite modülü ile ilgili çalışmalar genellikle normal ve yüksek dayanımlı beton numuneleri için gerçekleştirilmiştir. Elastisite modülü, statik ve dinamik elastisite modülü olarak belirlenebilir. Bu çalışmada 64 beton test örneği hazırlanmıştır. Gerilme birim şekil değiştirme çerçevesi üzerine 38 numune yerleştirilmiş ve statik elastisite modülünü belirlemek için basınç testine tabi tutulmuştur. Karakteristik beton basınç dayanımlarının %40, %45 ve %50'si TS-500, ACI 318-11 ve CEB 2004'e göre düşük mukavemetli betonun statik elastisite modülünü belirlemek için gerilme-birim şekil değiştirme eğrisinde ikinci bir nokta olarak kullanılmıştır. Statik elastisite modülü değerleri standart denklemleri ile karşılaştırılmış ve üç standardın düşük dayanımlı beton için daha yüksek elastisite modülü değerleri verdiği görülmüştür. 26 beton numunesinin dinamik elastisite modülleri ultrasonik test cihazı kullanılarak belirlenmiştir. Dinamik elastisite modülü değerleri Hermit fonksiyonu ile karşılaştırılmıştır. Hermit fonksiyonunun daha yüksek elastisite modülü değerleri verdiği gözlenmiştir. Bu nedenle, yapılan deney sonuçlarına göre düşük dayanımlı betonun statik ve dinamik elastisite modülü için regresyon analizi kullanılarak yeni denklemler, önerilmiştir.

Anahtar Kelimeler: Düşük dayanımlı beton, Statik elastisite modülü, Dinamik elastisite modülü

1. Introduction

Due to the increasing use of concrete in various fields, concrete quality has also remarkably increased with technological developments and concrete plants. 2018 Turkish Earthquake Code

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does not allow the use of concrete grade lower than C25 in any buildings. However, it was still observed that low strength concrete was used in existing constructions. Nowadays, the concrete strength used in a large portion of the building stocks in Turkey is lower than concrete grade C16. Elasticity modulus of concrete have utmost importance in the performance analysis and preparation of retrofitting projects for the existing building [1]. Elasticity modulus of the concrete has always been a popular research topic in the literature for many years and is determined using various methods. Many studies in the existing literature proposed several formulas for elasticity modulus of the concrete. These formulas are generally used to calculate elasticity modulus of concrete based on its compressive strength [2].

Turkel B.E. [2] produced 20 groups of concrete samples with different water-cement ratios, cement contents and additives to investigate the relationship between concrete compressive strength and elasticity modulus. They conducted experimental studies to determine the elasticity modulus, compressive strength, and ultrasound velocity on these concrete samples. The study reported a relationship with a high correlation between elasticity modulus and compressive strength. Emiroglu M. et al. [3] produced a concrete mixture using rubber wastes as fine and coarse aggregates. They determined the physical and mechanical properties of the concrete and measured mid-span deflection values of the beams using flexural tensile tests to determine elasticity modulus of the concrete. It was concluded that there was a high correlation between the formula recommended by American Concrete Institute (ACI) [4] and experimentally determined elasticity modulus. Pekgokgoz et al. [5] determined dynamic elasticity modulus of the masonry used in the minaret of Sanliurfa Mosque and indicated that the study using a direct method yielded more accurate results compared to the semi-direct method. Buyuktas K. et al. [6] conducted an experimental study to determine 28-day compressive strength and elasticity modulus of the concrete mixtures prepared by the cement types produced in Turkey. It was reported that elasticity modulus values of the mixtures converged to those specified in TS-500 standards [7] and that concretes with higher strength also had higher levels of elasticity modulus. Saman R. [8] analyzed compressive strength and elasticity modulus values of normal and self-consolidating concretes in different fiber volume ratios for 32 different samples. The findings of this study clearly demonstrated that static elasticity modulus could be determined using ultrasound device if it could not be determined using a core sample and the determined dynamic elasticity module could be used with an acceptable level of accuracy in structure analysis instead of static elasticity modulus. Abdullah V.S. [9] analyzed elasticity modulus of concrete using ultrasound device and an equation was proposed to estimate elasticity modulus of concrete based on ultrasound velocity value using regression analysis between the velocity obtained from ultrasound device and experimental elasticity modulus values. It was observed that the proposed models in these equations yielded better results compared to other models. Ozden V.A. [10] experimentally analyzed the relationship between compressive and tensile strength of concrete and elasticity modulus and indicated that elasticity modulus of concreate increased in proportion to its compressive strength. However, as the tensile strength of concrete increases, there is an increase in elasticity module up to concrete grade C20 and after that, it appears to remain approximately the same. Lee B.J. et al. [11] investigated the static and dynamic elasticity modules, and compressive strength of cylindirical samples. Two sets of concrete cylinders with the size of 150x300 mm and 100x200 mm were prepared from three different mixtures with compressive strength of 30, 35 and 40MPa. Static and dynamic elasticity modules tests were carried out on 4, 7, 14 and 28 days to evaluate the compressive strength and static and dynamic elasticity modules of the cylinders. For normal strength concrete (≤40MPa), it was observed that cylindir size didn't have any effect on the compressive strength and static and dynamic elasticity modules. The size effect became important in high strength concrete (>40 MPa). Watanabe S. et al. [12] investigated a method to estimate the compressive strength of concrete using the ultrasonic method. In an experiment with full-size reinforced concrete elements, it was observed that the proposed method has high accuracy. Duran B. et al. [13] discussed the usability of elasticity module formulas for low strength concrete. In the experimental study, axial compression tests were applied on 36 low strength concrete samples.

According to the experimental elasticity module values, a new formula was proposed and compared with the codes. In addition, the effects of the elasticity module values from different codes on the risk determination of an existing building were investigated according to the Principles Regarding the Determination of Risky Structures (RYTEIE). It has been determined that there is a 35% difference between the elasticity module values by ACI 318M-08 used in the risk assessment of the existing buildings and the values obtained by the experimental study. Sarıbas I., [14] investigated the usability of recycled aggregates in new concrete production. Within the scope of this study, a new stress-strain model is proposed depending on the rate of recycled aggregate used in the mixture for concrete with recycled aggregate. Stress-strain relations obtained from the proposed model were found to be compatible with the results obtained from experimental studies. The relationship between compressive strength and modulus of elasticity of concrete is studied by Sideris et al. [15] taking into account the cement hydration equation for normal concrete. Some researchers investigated this relationship for normal and high strength concrete, using the theory of fuzzy logic [16-18]. Ispir M. et. [19] preliminary work was carried out for determining the modulus of elasticity of low strength concrete. Based on the concrete cylinder experimental data conducted at Istanbul Technical University an empirical equation is proposed for making better estimations of modulus of elasticity as a function of the compressive strength of concrete. Ahmad S. et. [20] was presented the stress-strain results obtained from compression tests on cylindrical concrete specimens and was found new expressions for the modulus of elasticity, peak strain and failure strain.

In the present study, static and dynamic elasticity modulus of the low strength concrete will be determined experimentally by using 64 concrete samples. 38 out of 64 samples will be subjected to uniaxial compressive test to obtain a stress-strain curves. These stress-strain curves will be used to determine the static elasticity modulus of the low strength concrete according to Turkish, European and American Standards. The remaining 26 samples will be used to determine the dynamic elasticity modulus of the low strength concrete by using the ultrasound velocity measurement. Finally, equations for static and dynamic elasticity modulus will be proposed for low strength concrete based on the obtained the static and dynamic experimental values.

2. Materials and Methods

2.1. Materials

The objective of the present study is to determine elasticity modulus of concrete. Therefore, 64 cylindrical concrete samples were produced for the experimental studies. The largest aggregate sizused in the experiments was 32 mm. PC 42.5-CEM I R cement produced by KahramanmaraCement and Concrete Industry (KCS) was used to prepare concrete mixtures. No additives wereused in these concrete mixtures. The amount of aggregates, sand, crushed stone I, crushed stone IIand water for concrete mixtures were determined in accordance with TS 802 [21] standard.Depending on the water content, Graf formula in Equation 1 were used to calculate cement contentfor concrete with the characteristic strength of 5, 7, 9, 11 and 13 MPa. The proportions of the concrete mixtures were given in Table 1.

Table 1. Concrete Mixture

Concrete Grade	Cement (kg)	Water (kg)	Crushed stone I (kg)	Crushed stone II (kg)	Sand (kg)	Water/cement ratio
C5	9.05	13.2	24.4	24.4	75.7	1.459
C7	10.71	13.2	24.12	24.12	74.85	1.232
C9	12.15	13.2	23.88	23.88	74.11	1.086
C11	13.43	13.2	23.67	23.67	73.45	0.983
C13	14.6	13.2	23.47	23.47	72.84	0.904

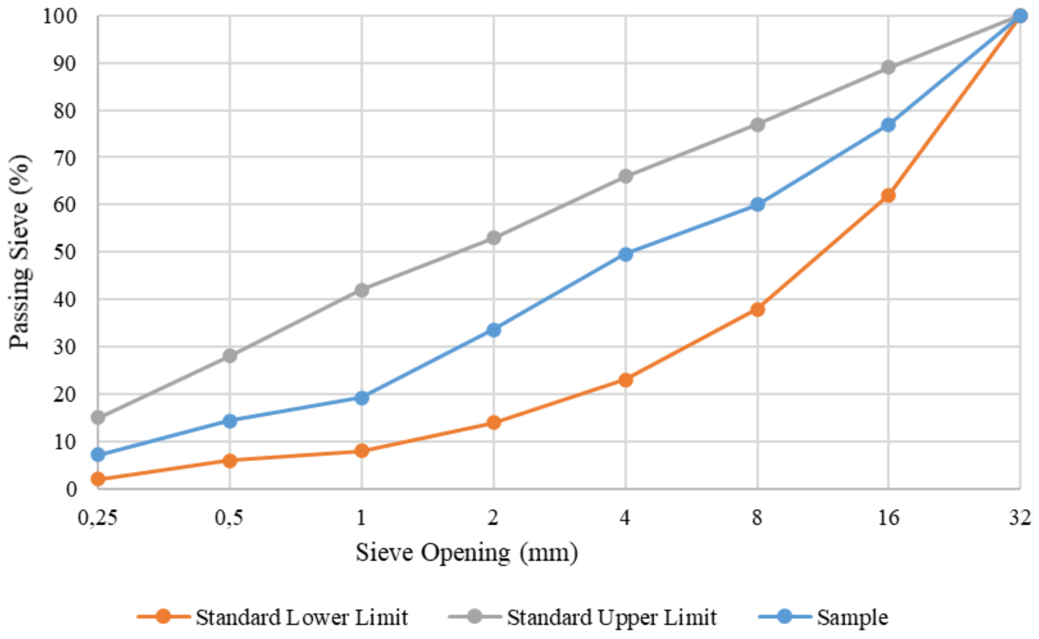

Figure 1. Sieve Analysis (Granulometry Curve)

As shown in Figure 1, aggregate granulometry remainconstant for all concrete samples. Concrete samples were kept in cure tanks for 4 days based on the method specified in TS EN 12390-2 [22] in order to reach to low concrete strength. After the curing, in accordance with TS EN 12390-3 [23], a sulfur graphite capping process was applied to eliminate measurement errors caused by surface roughness.

$$f_c = \frac{f_{cc}}{K_g}\left(\frac{c}{s}\right)^2 \tag{1}$$

where f_{cc} is the norm N/mm^2 strength of concrete, c is cement content, s is water content, K_g value varies between 4 and 10, which is an independent coefficient [24].

2.2. Elasticity Modulus of Concrete

The relationship between elasticity modulus of concrete and compressive strength is approximately known. However, because different methods are used in the calculation of elasticity modulus, heterogeneous structure of concrete materials may lead to variations in elasticity modulus [2].

Various methods have been so far proposed in the existing literature for the determination of elasticity modulus [25]. In the present study, static elasticity modulus was calculated using secant modulus based on stress-strain curve obtained from the compressive strength experiment and dynamic elasticity modulus was calculated using ultrasound test method.

2.2.1. Static Elasticity Modulus

Initial tangent modulus is defined by the slope of a tangent drawn on the starting point of stress strain curve. On the other hand, secant modulus is defined by the slope of a line drawn from the starting point of stress-strain curve to a specified stress on the curve. Specified stress value is selected as a certain ratio of the compressive strength of the concrete. In general, secant modulus is calculated based on a point corresponding to stress values of 0.4, 0.45 and 0.5f_c [10]. Tangent modulus is the slope of a tangent drawn on a given point of stress-strain and it is equivalent to elasticity modulus of elastic region on a stress-strain curve. Initial modulus, secant modulus and tangent modulus are shown in Figure 2.

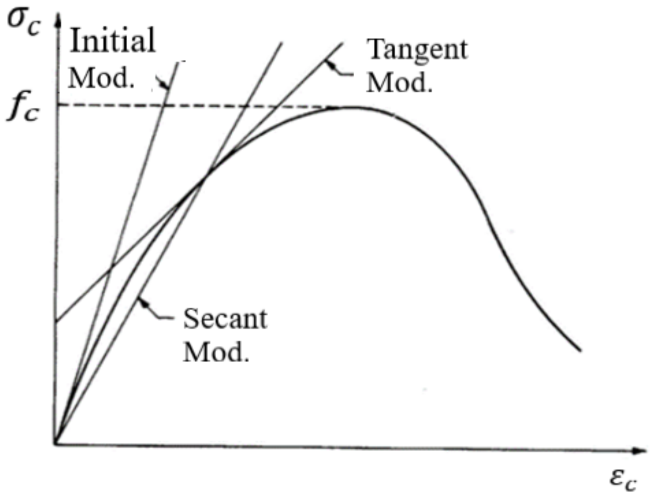

Figure 2. Different Modulus on Stress-Strain Deformation Graph [26]

Standard cylindrical concrete samples with a total number of 38 were prepared in accordance with TS 12390-2 [22] standard. These fresh samples were placed in cylindrical molds and removed from the molds on the following day after concrete setting had been completed. Later, concrete samples were placed in compression testing press as specified by TS EN 12390-3 [23], and longitudinal strain changes were recorded using a transducer. Compression test was continued to determine the compressive strength until the concrete samples were broken.

2.2.2. Dynamic Elasticity Modulus

In the present study, elasticity modulus of 26 standard cylindrical concrete samples were determined using ultrasound measurement method. In this method, the time elapsed during the transmission of vibrations from one end of the cylinder to the other end at a certain frequency is measured. The velocity of vibrations transmitted through concrete samples is calculated to determine elasticity modulus using Equation 2 [7]. The relationship between ultrasound velocity, V, and the dynamic elasticity module, Ed, is given by Equation 3 [2]. Elasticity modulus is calculated in kgf/cm².

$$V = \frac{L}{t} \tag{2}$$

$$E_d = \frac{k * 10^5 * V^2 * \Delta}{g} \tag{3}$$

where V denotes ultrasound velocity (km/s), Δ denotes specific weight in kg/dm³, L represents sample length (m), and t is the time elapsed (sec), k is taken as 1 for cylindrical samples and as 1.37 for cubic samples.

The relationship between the dynamic elasticity modulus and compressive strength is given by Hermit function shown in Equation 4. The relationship between the ultrasound velocity measured using ultrasound method and concrete compressive strength is obtained by substituting Equation 3 in Equation 4 and given in Equation 5 [2].

$$E_d = K \times \sqrt{R} \quad (4)$$

$$\frac{k \times 10^5 \times V^2 \times \Delta}{g} = K \times \sqrt{R} \quad (5)$$

where K is a number between 18000 and 23000, and R is the compressive strength of a standard cylindrical concrete sample.

3. Experimental Study

The stress-strain curve obtained from the compressive strength test was used for the calculation of static elasticity modulus. In addition, ultrasound method was used for the calculation of dynamic elasticity modulus.

3.1. Concrete Compression Test

Concrete samples reserved for concrete compression test were placed in a deformation frame with an upper and lower perimeter of 250 mm in order to measure the longitudinal deformations. As shown in Figure 3, the longitudinal deformations of the concrete samples loaded at a fixed velocity of 10.60 m/sec were recorded using a transducer with an accuracy of 0.001 mm.

Figure 3. Static Elasticity Modulus Experiment

Table 2. Compressive Strength Values of Concrete Samples

Sample No	Compressive Strength (MPa)
1	5.7
2	5.9
3	6.1
4	6.8
5	8.1
6	8.5
7	8.7
8	9.8
9	10.3
10	11.1
11	13.1
12	14.2

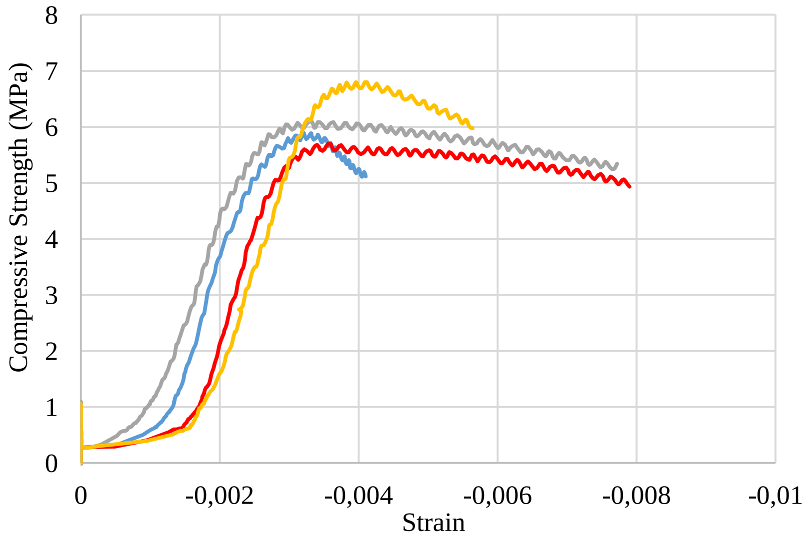

Figure 4. Stress-Strain Curves of C4-C8 Concrete Samples

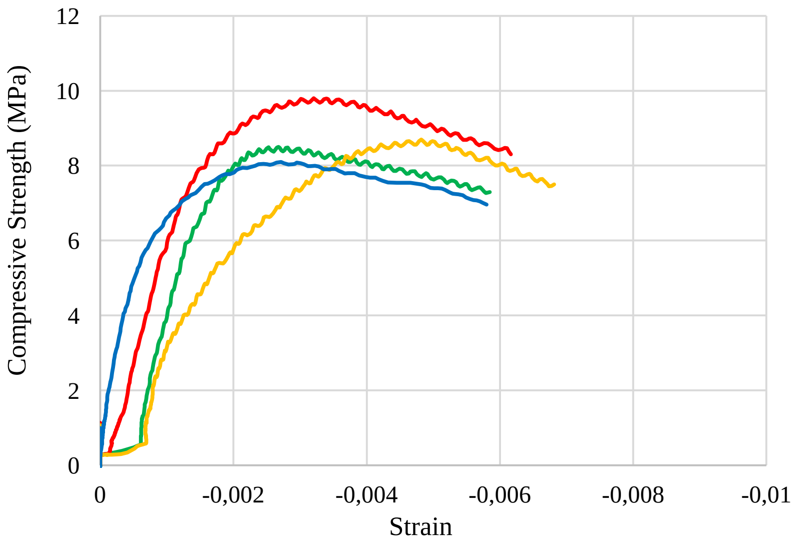

Figure 5. Stress-Strain Curves of C8-C10 Concrete Samples

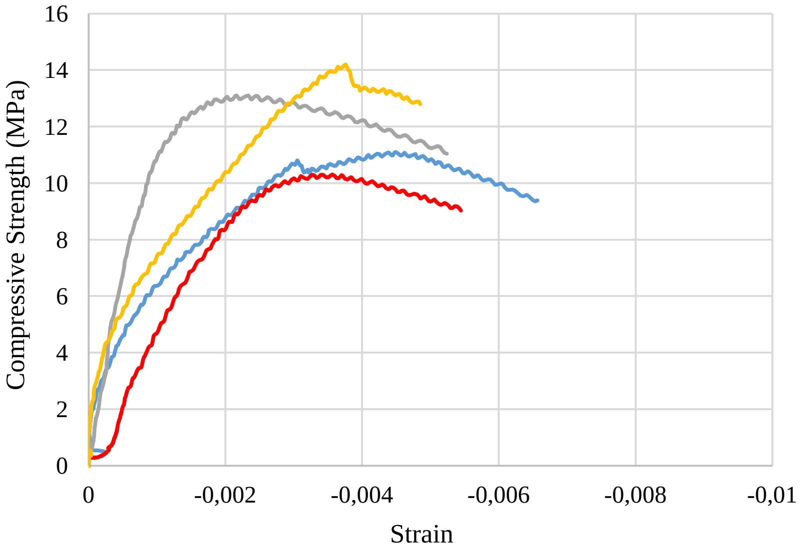

Figure 6. Stress-Strain Curves of C10-C14 Concrete Samples

The compressive strength of concrete samples was shown in Table 2. 12 concrete samples out of 38 were used to evaluate the elasticity modulus due to experimental errors resulting from measurement devices. Stress-strain curves were drawn based on the obtained data as shown in Figures 4-6.

3.2. Ultrasound Measurement Method

A concrete compression test was applied to 26 concrete samples for ultrasound measurement. The lengths of all 26 concrete samples were measured as 29.5 cm in the ultrasound velocity measurement. A suitable gel was painted on ends of the concrete samples which were placed between the transmitting and receiving probes in order to calculate ultrasound velocity as shown in Figure 7.

Figure 7. Ultrasound Management

4. Experiment Results and Proposed Equations

4.1. Static Elasticity Modulus

Elasticity modulus is defined as a function of the concrete compressive strength in various codes. Elasticity modulus equations used by ACI 318 [4], European Committee for Concrete (CEB) [27] and Turkish Standards Institute (TS 500) [7] are given in Equations 6, 7 and 8, respectively.

$$E = 4700 \times \sqrt{f_{ck}} \quad (MPa) \tag{6}$$

$$E = 22000 \times \left(\frac{f_{ck}}{10}\right)^{0.3} \quad (MPa) \tag{7}$$

$$E = 3250 \times \sqrt{f_{ck}} + 14000 \quad (MPa) \tag{8}$$

where f_{ck} represents the characteristic concrete compressive strength.

In this study, the static elasticity modulus was calculated using secant modulus. In the determination of secant modulus of elasticity, 40%, 45% and 50% of the characteristic concrete compressive strengths in were used as a second point on the stress-strain curve according to TS 500, ACI 318-11 and CEB 2004, respectively. The elasticity modulus values obtained from concrete samples based on three secant modulus values were given in Table 3. Two types of regression analysis were performed to obtain the elasticity modulus formula. In the first type, linear regression analysis was applied to have an equation in the form of $E_c = a\sqrt{f_{ck}} + b$ similar to the equation used in TS500. In the second type, linear regression analysis was applied to have an equation in the form of $E_c = a\sqrt{f_{ck}}$ similar to the equation used in ACI 318-11. These two types of equation for elasticity modulus were calculated for 40%, 45% and 50% of the characteristic concrete compressive strengths of the concrete samples and shown with the correlation coefficient in Figure 8-10, respectively. The elasticity modulus equation in the form of $E_c = a\sqrt{f_{ck}} + b$ has higher correlation coefficient compared to the equation in the form of $E_c = a\sqrt{f_{ck}}$ for each case, as shown in Figure 8.

Table 3. Elasticity Modulus of Concrete Samples based on different ratios of f_c

Sample No	f_{ck}(MPa)	$E_c 0.4f_c$ (MPa)	E_c $0.45f_c$ (MPa)	$E_c 0.5f_c$ (MPa)
1	11.1	8377	8086	7025
2	14.2	10717	9397	8068
3	10.3	6754	6349	6058
4	8.5	7906	7649	6967
5	6.1	3753	3760	3719
6	9.8	6533	6485	6621
7	6.8	3830	3923	4096
8	5.9	4627	4499	4682
9	5.7	3304	3246	3352
10	8.7	4971	4605	4182
11	8.1	8308	8284	8100
12	13.1	12476	12031	11909

Moreover, the highest correlation coefficient was observed when 40% of the characteristic concrete compressive strengths of the concrete samples were used to calculate the elasticity modulus values in the form of $Ec = a\sqrt{fck} + b$

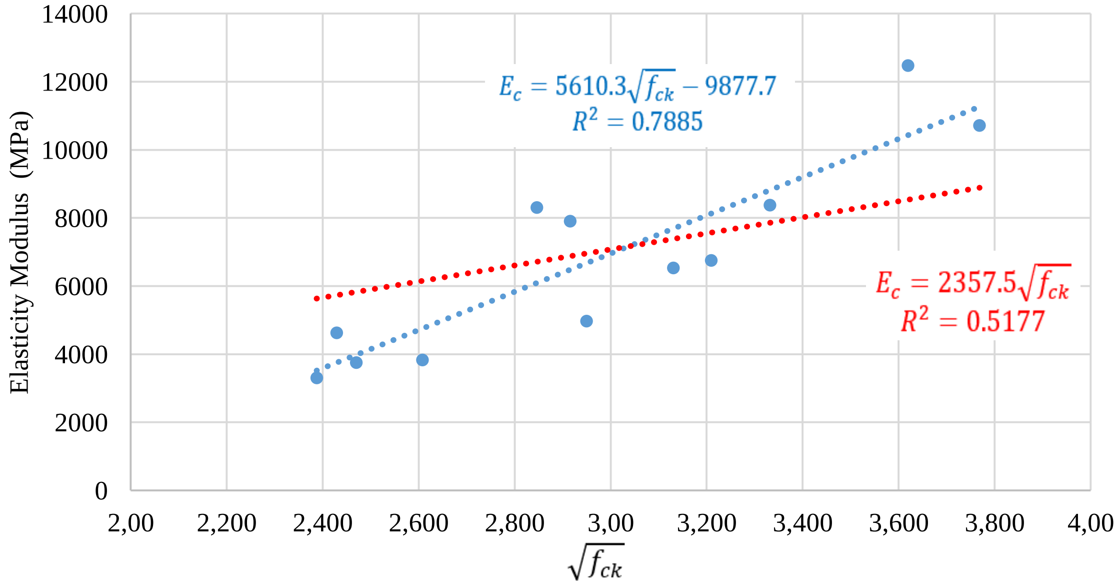

Figure 8. Secant modulus of elasticity with 0.40 f_c

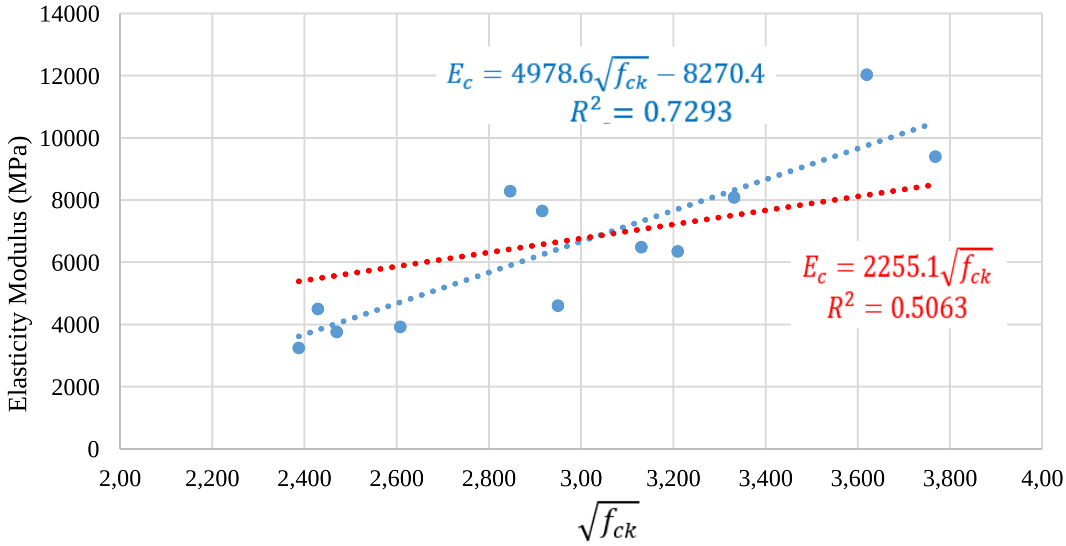

Figure 9. Secant modulus of elasticity with 0.40 f_c

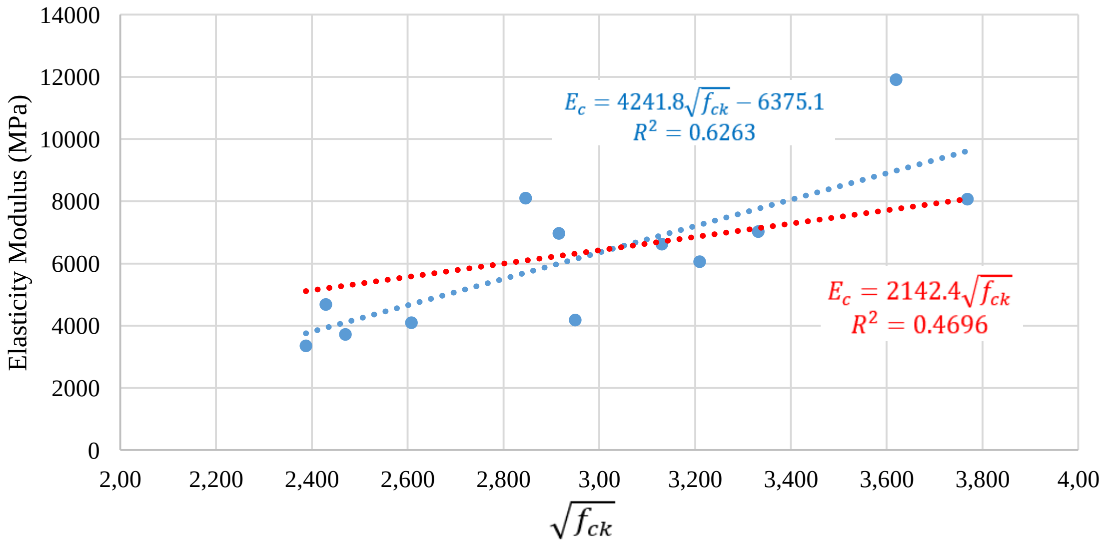

Figure 10. Secant modulus of elasticity with 0.40 f_c

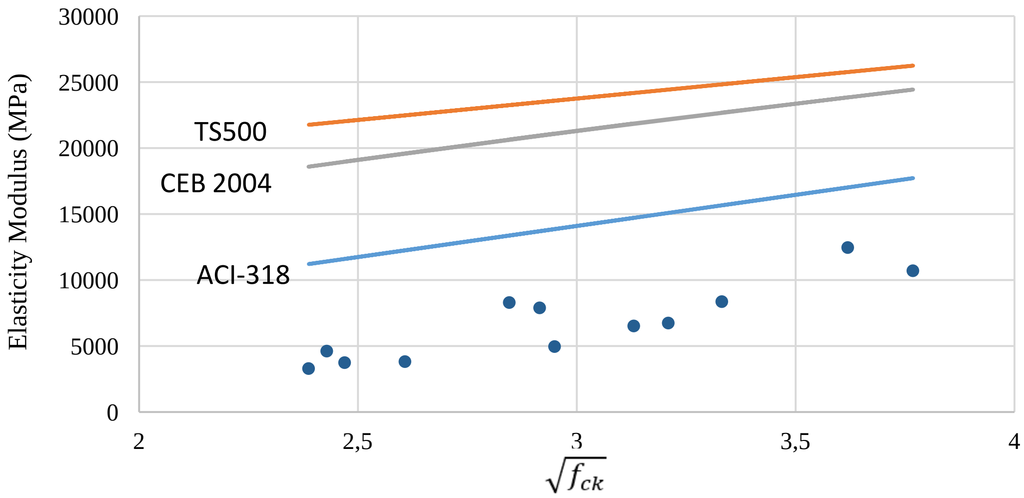

Figure 11. The Comparison of the Obtained Elasticity Modulus Values with Regulations

So, in case of highest correlation coefficient, the coefficients a and b in the form of $Ec = a\sqrt{fck} + b$ were determined as 5610.3 and 9877.7, and the coefficient a in the form of $Ec = a\sqrt{fck}$ was determined as 2357.5. Then, these coefficients were further modified to make them easy to use for practicing engineers. So, the final form of the proposed equations for static elasticity modulus for low strength concrete becomes $Ec = 5600\sqrt{fck} - 9900$ and $Ec = 2360\sqrt{fck}$, for two forms of the equation.

The experimental elasticity modulus values were compared with TS 500, ACI 318-11 and CEB 2004 codes as shown in Figure 11. TS 500, ACI 318-11 and CEB 2004 code equations yields higher elasticity modulus values compared to those obtained by experimental study. TS500 standard yields highest elasticity modulus values. So, use of these code equations, especially TS500 and CEB 2004, will be unsafe in engineering analyses. ACI 318-11 code equation yields elasticity modulus values close the experimental elasticity modulus values compared to TS500 and CEB 2004.

4.2.Dynamic Elasticity Modulus

The values related to the calculation of dynamic elasticity modulus are presented in Table 4. The transmission of the ultrasound through the concrete samples was calculated in microseconds. As shown in Figure 12, following a regression analysis, an equation is proposed to calculate the dynamic elasticity modulus. Similar to the calculation of the static elasticity modulus, two types of regression analysis were performed to obtain the dynamic elasticity modulus formula. These two types of equation for dynamic elasticity modulus were calculated and shown with the correlation coefficients in Figure 12.

The elasticity modulus equation in the form of $Ec = a\sqrt{fck} + b$ and the equation in the form of $Ec = a\sqrt{fck}$ has almost the same correlation coefficient. Since the equation in the form of $Ec = a\sqrt{fck}$ is similar to Hermite function and easy to use, it is proposed to be used for the dynamic elasticity modulus of the low strength concrete. So, the coefficient a in $Ec = a\sqrt{fck}$ was determined as 11887. Then, this coefficient was further modified to make it easy to use for practicing engineers. So, the final form of the proposed equation for dynamic elasticity modulus for low strength concrete becomes $Ec = 12000\sqrt{fck}$.

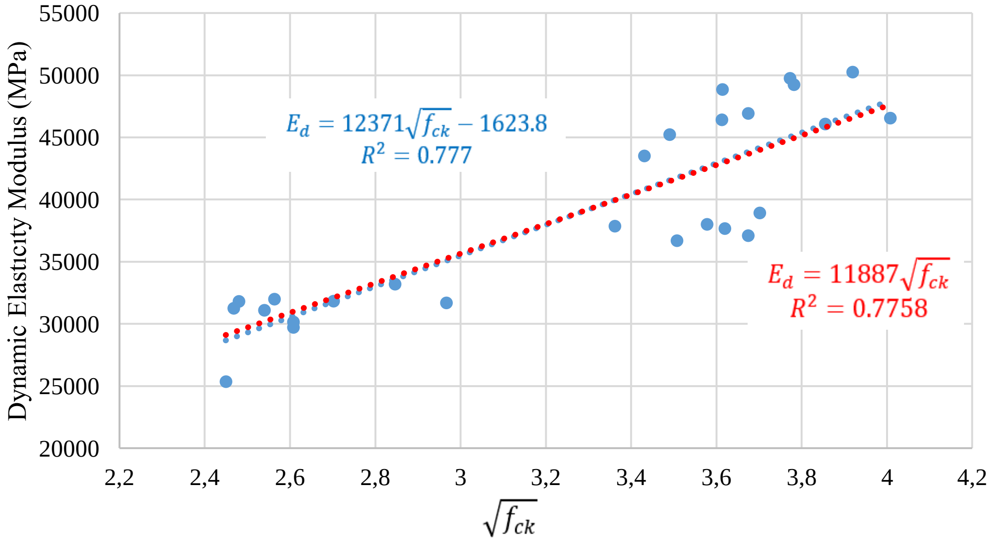

Figure 12. Ultrasound Measurement Regression Analysis

Table 4. Dynamic Elasticity Modulus Values based on Ultrasound Measurement

Weight (g)	f_c (MPa)	V (km/sec)	Δ (kg/dm^3)	E_d
11455	6.00	3.42	2.1679	25358
11479	6.09	3.79	2.1725	31258
11615	6.15	3.80	2.1982	31812
11487	6.45	3.78	2.1740	31098
11663	6.57	3.81	2.2073	31993
11595	6.80	3.68	2.1945	29721
11577	6.80	3.71	2.1911	30160
11526	7.30	3.82	2.1813	31833
11591	8.10	3.89	2.1938	33199
11535	8.80	3.81	2.1831	31692
11728	11.30	4.13	2.2197	37863
11810	11.77	4.41	2.2351	43512
11879	12.18	4.49	2.2482	45226
11820	12.30	4.05	2.2371	36697
11888	12.80	4.11	2.2500	38010
11888	13.05	4.54	2.2499	46418
12088	13.06	4.62	2.2878	48855
11840	13.10	4.10	2.2409	37671
11718	13.50	4.09	2.2177	37100
11935	13.50	4.56	2.2588	46931
11999	13.70	4.14	2.2710	38926
12043	14.23	4.67	2.2792	49754
11919	14.30	4.67	2.2558	49241
11885	14.86	4.53	2.2493	46080
11938	15.36	4.72	2.2594	50253

5. Discussion and Conclusions

It was observed that elasticity modulus formulas in different codes around the world were used for normal and high strength concrete and these formulas give higher values for low strength concrete.

Therefore, it is evident that a new formula for low strength concrete is needed for the use in engineering applications. The following findings were obtained in the present study.

- The stress-strain curves of concrete samples shown in Figures 4-6 were used to determine the elasticity modulus using secant modulus. The second point corresponding to 40%, 45% and 50% of the characteristic concrete compressive strengths on stress-strain curves were used as a basis for the determination of secant modulus in accordance with TS500, ACI 31811 and CEB 2004, respectively. The regression analysis demonstrated that 40% of the characteristic concrete compressive strength yielded the highest correlation coefficient value.
- According to the static elasticity modulus values, TS500, ACI 318-11 and CEB 2004Standards yields higher values compared to the those obtained experimentally. TS500standard yields the highest elasticity modulus values. So, use of these code equations, especially TS500 and CEB 2004, will be unsafe in engineering analyses.
- The elasticity modulus equation $3250 \times \sqrt{fck} + 14000$ used in TS500 yields 14000 MPa when fc equals to 0. Therefore, it is needed to set a maximum and minimum limit for concrete compressive strength to be used with this equation. In the present study, when the elasticity modulus equation does not pass through the origin as in TS500, the use of $5600 \times \sqrt{fck} - 9900$ equation is recommended. Secondly, if the elasticity modulus equation passes through the origin as recommended by ACI 318-11 and CEB 2004 equations, the use of $2360 \times \sqrt{fck}$ equation is recommended.
- Although Hermite equation used for the dynamic elasticity modulus yields accurate results for normal strength concrete, it cannot be safely used for low strength concrete as it yields higher results for low strength concrete. So, as demonstrated by the regression analysis, the new K coefficient for Hermite equation is recommended as 12000 to estimate the dynamic elasticity modulus of low strength concrete.
- All the proposed equations are valid to estimate the elasticity modulus for the low strength concrete with characteristic strength between 6-14 MPa.

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