Dicle University
Journal of Engineering
https://dergipark.org.tr/tr/pub/dumf
duje.dicle.edu.tr

Research Article

Variation of Dynamic Elasticity Modulus with Experimentally Determined Concrete Compressive Strength

Esra TUĞRUL TUNÇ[1*]

[1] Fırat University, Engineering Faculty, Civil Engineering Department, esratugrul@firat.edu.tr, Orcid No: 0000-0001-9071-774X

ARTICLE INFO

Article history:

Received 24 September 2023
Received in revised form 09 October 2023
Accepted 15 December 2023
Available online 31 December 2023

Keywords:

concrete specimens, compressive strength, dynamic elasticity modulus, concrete quality

Doi: 10.24012/dumf.1365518

* Corresponding author

ABSTRACT

In reinforced concrete structures, one of the most important factors for structural safety is the quality of concrete. The first thing that comes to mind for concrete quality is the compressive strength of concrete. However, properties such as elasticity modulus are also among the properties that determine concrete quality. Since concrete is a brittle material, different methods are used to determine dynamic elasticity modulus. In practice, dynamic elasticity modulus of concrete can be identified by utilizing concrete compressive strength value. In this context; compressive strength tests were performed on a series of concretes accordingly relevant standards. Since it is difficult to determine elasticity modulus from the stress and strain relationship, the dynamic elasticity modulus values in this study was calculated using empirical formulas according to TS 500-2000, ACI 318-95 and CEB-FIP 1978 on the basis of experimental data in this study. The relationship between the calculated dynamic elasticity modulus values and concrete compressive strength was analyzed. From the study, it is concluded that as concrete compressive strength increases, dynamic elasticity modulus increases for the concrete specimens.

Introduction

In classical terms, concrete is a building material obtained by mixing sand, aggregate, cement, water and additives when necessary. When the aforementioned materials are mixed in a certain proportion, a plastic material that can take the desired shape in molds is obtained. One of most important characteristics of concrete that makes it superior to other building materials is its plastic consistency that allows it to be given the desired shape [1].

It can be said that cement and aggregate are the most important materials that constitute concrete [2]. Cement binds aggregate grains by entering into a chemical reaction with water. Aggregate constitutes approximately 75% of concrete [3]. Depending on the grain size, aggregate is named as coarse and fine. The most important point to be considered in aggregates is that they should be free from harmful substances. In addition, the aggregate must also meet other criteria stipulated by the standards [4,5].

Concrete is produced by adding cement, aggregate and water, as well as some additives when necessary. Additives can increase the workability and durability of concrete. It also plays an important role in hardening time. Thermal expansion and permeability can also be controlled with additives [6].

The properties of concrete are divided into fresh and hardened properties. Fresh concrete should be easy to mix, transport, place, compact and smooth the surface. During these processes, there should be no segregation between aggregates and cement mortar. Hardened concrete should not show a strength less than the minimum strength for any age such as 7, 14 and 28 days targeted by the standards [7]. The main criterion for defining concrete, in other words, for its classification, is its compressive strength value. It is known that the other concrete properties with high compressive strength are also positively affected [8,9].

Concrete compressive strength is characterized as concrete strength under axial compressive load in order not to break [10]. Among the mechanical properties of concrete, compressive strength is the most important [11,12]. In this regard, it can be said that compressive strength is a function of composition for a given state of the composition. In addition, it is important to remember that concrete compressive strength is a function of time and that it gains its final strength after a long time [13]. The properties of the constituent materials and mixing ratios affect concrete compressive strength. Therefore, it is essential to know the characteristics of the constituent materials [14].

In Şengül's (2000) study, it is stated that while there is a difference of four times between the compressive strengths of the highest and lowest concrete classes, the difference between the elasticity modulus is not even two times. This indicates that the elasticity modulus is not as sensitive as the compressive strength to changes in the internal structure caused by a decrease in the water-cement ratio [15]. Türkel (2002) reported that the elasticity modulus increases with decreasing water cement ratio in concretes [16]. Felekoğlu and Türkel (2004) stated in their study that samples of the same strength class show different stress-strain behavior with the change in loading rate, in parallel with this, the elasticity modulus is also affected by the loading rate and the elasticity modulus increases as the loading rate increases [17].

The purpose of present study is to investigate experimentally and statistically the relationship between concrete compressive strength and concrete dynamic elasticity modulus. To this end, the compressive strength of a series of concrete specimens was determined experimentally. Then, it was compared with the dynamic elasticity modulus values calculated in accordance with international regulations. As it is known, the dynamic elasticity modulus is characterized as the ratio of stress to deformation in the region where Hooke's law is valid. As can be seen from this definition, dynamic elasticity modulus is a concept related to compressive strength. However, in addition to the known definitions and concepts, the relationship between concrete compressive strength and concrete dynamic elasticity modulus was analyzed based on the experiments and the findings of these experiments, and it was aimed to calculate concrete dynamic elasticity modulus using concrete compressive strength by different methods.

Materials and method

In the present study, limestone aggregate from Elazığ in Turkey was used for the production of concrete specimens (Figure 1). The granulometry curve for the aggregate mixture to be used in the calculation of concrete mix design according to TS 802 [18] for aggregate mixtures with the largest grain diameter of 31.5 mm is shown in Figure 2. With the curve graph of the mixture falling in the A-B region, maximum capacity was achieved.

CEM I 42.5 N Portland cement produced in Elazığ Cement Factory was used in the experimental studies. The present study was carried out at Fırat University, Engineering Faculty, Building Materials Laboratory (Figure 3).

Figure 1. A view of the laboratory of limestone aggregates.

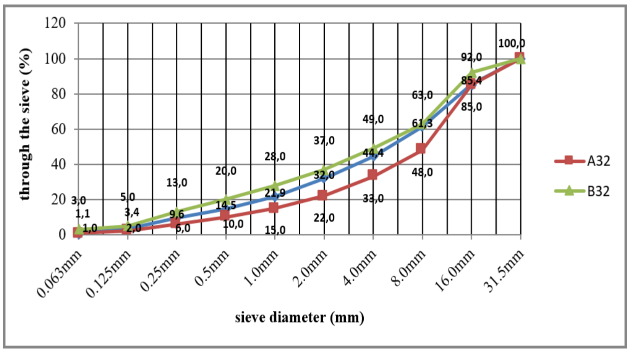

Figure 2. Granulometry of the mixture aggregate prepared according to TS 802.

Figure 3. Fırat University Faculty of Engineering Building Materials Laboratory.

Concrete compressive strength test

The specimens removed from the curing pool at the end of the 28th day. Concrete compressive strength tests were performed on 150×150×150 mm sized concrete cubic specimens with dry surface according to TS EN 12390-3 standard [19]. The same compressive strength apparatus with constant loading rate was used for the crushing of the concrete specimens obtained (Figure 4).

According to TS EN 12390-3 standard, P (kN) fracture loads and fc (N/mm^2) compressive strengths obtained by dividing the load by the cross-sectional area A (mm^2) were calculated using Equation (1).

$$f_c = \frac{P}{A} \quad (1)$$

Figure 4. Concrete compressive strength test.

Dynamic elasticity modulus

Since the stress-strain curve (σ - $\mathcal{E}$) of concrete, a brittle composite material, does not contain a line, two types of elasticity modulus are defined. One of them is the static elasticity modulus and the other is the dynamic elasticity modulus. If the stress applied to the concrete is much smaller than the compressive strength, these two moduli are close to each other [20,21]. Since it is difficult to determine the elasticity modulus from the σ - $\mathcal{E}$ relationship, concrete dynamic elasticity modulus of the specimens manufactured in the present study was calculated using empirical formulas according to TS 500-2000 - ACI 318-95 and CEB-FIP 1978 [22-24] based on the experimental data in this study (Equation 2-4).

E_c for TS 500;

$$E_c = 3250 \times \sqrt{f_c} + 14000 \quad (2)$$

E_c for ACI 318-95;

$$E_c = 4730 \times \sqrt{f_c} \quad (3)$$

E_c for CEB-FIP;

$$E_c = 9500 \times (f_c + 8)^{1/3} \quad (4)$$

In Equation (2-4); f_c = 28-day compressive strength (GPa) and E_c = dynamic elasticity modulus (GPa).

Results and discussion

Within the scope of the present study, the compressive strengths of a total series of concrete specimens produced for different cement dosages (300, 350 and 400 kg/m^3) using limestone aggregate were determined. Using these experimental compressive strength values, the dynamic elasticity modulus was calculated accordingly relevant regulations TS 500-2000, ACI 318-95 and CEB-FIP 1978. The relevant data used and obtained in the present study are presented in Table 1.

Cement content (kg/m^3)	w/c (-)	f_c (MPa)	E_c TS 500 (GPa)	E_c ACI 318-95 (GPa)	E_c CEB-FIP (GPa)
300	0.25	26.9	30.86	24.53	31.05
300	0.25	24.2	29.99	23.27	30.22
300	0.25	27.3	30.98	24.71	31.16
300	0.30	22.4	29.38	22.39	29.65
300	0.30	23.8	29.86	23.08	30.10
300	0.30	22.9	29.55	22.63	29.81
350	0.25	34.3	33.03	27.70	33.10
350	0.25	32.1	32.41	26.80	32.52
350	0.25	31.3	32.18	26.46	32.30
350	0.30	30.8	32.04	26.25	32.16
350	0.30	29.1	31.53	25.52	31.68
350	0.30	30.2	31.86	25.99	31.99
400	0.25	41.6	34.96	30.51	34.90
400	0.25	38.1	34.06	29.20	34.06
400	0.25	42.8	35.26	30.94	35.18
400	0.30	37.1	33.80	28.81	33.82
400	0.30	34.3	33.03	27.70	33.10
400	0.30	35.5	33.36	28.18	33.41

Figure 5 shows the change of compressive strength of concrete specimens tested in the present study with water cement ratio. Accordingly, it was determined that the compressive strength decreased by approximately 10% on average as the water cement ratio increased from 0.25 to 0.30. For C=300 kg/m^3 and w/c=0.25, the average compressive strength of concrete was 26.1 MPa; for C=300 kg/m^3 and w/c=0.30, the average compressive strength of concrete was 23.0 MPa. The average compressive strength of concrete for C=350 kg/m^3 and w/c=0.25 was 32.6 MPa; the average compressive strength of concrete for C=350 kg/m^3 and w/c=0.30 was 30.0 MPa. The average compressive strength of concrete for C=400 kg/m^3 and w/c=0.25 was 40.8 MPa; the average compressive strength of concrete for C=400 kg/m^3 and w/c=0.30 was 35.6 MPa. With the increase in the w/c ratio from 0.25 to 0.30; an average decrease of approximately 12% for C=300 kg/m^3, an average decrease of approximately 8% for C=350 kg/m^3 and an average decrease of approximately 13% for C=400 kg/m^3 was determined in concrete compressive strengths.

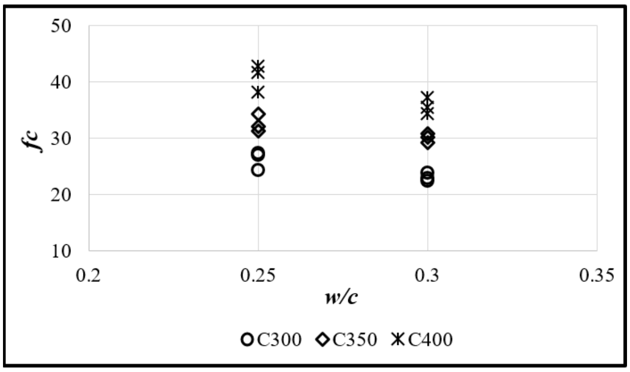

Figure 5. Variation of concrete compressive strength with water-cement ratio

In Figure 6, the variation of dynamic elasticity modulus (E_c) with water-cement ratio (w/c). Accordingly, it is calculated that when w/c increases from 0.25 to 0.30, E_c value decreases approximately 3.2% for TS500, 5.6% for ACI 318-95 and 3% for CEB-FIP. Considering all three regulations, it was determined that E_c value decreased with the increase in the w/c.

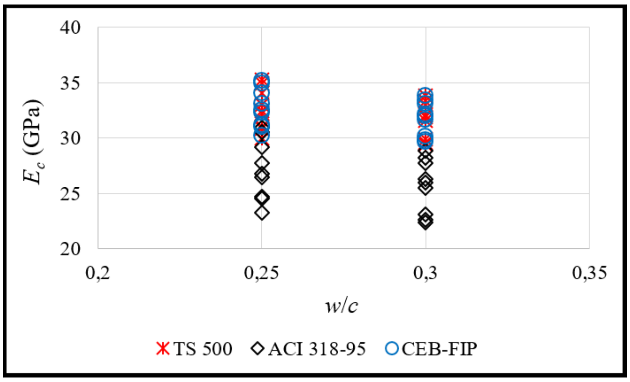

Figure 6. Variation of dynamic elasticity modulus of concrete with water-cement ratio

In Figure 7, it is observed that the dynamic elasticity modulus values, calculated in accordance with the calculations and rules in TS500 (2000) regulation, vary between 29.38 GPa and 35.26 GPa for concrete compressive strength values ranging between 22.4 and 42.8 MPa. Thus, it is seen that there is an increase of approximately 20% in the dynamic elasticity modulus values in response to approximately 91% increase in concrete compressive strength.

In Figure 8, it is observed that the dynamic elasticity modulus values calculated in accordance with the calculations and rules in the ACI 318 (1995) regulation vary between 22.39 GPa and 30.94 GPa for concrete compressive strength values ranging between 22.4 and 42.8 MPa. Thus, it is seen that there is an increase of approximately 38% in the dynamic elasticity modulus values against approximately 91% increase in concrete compressive strength.

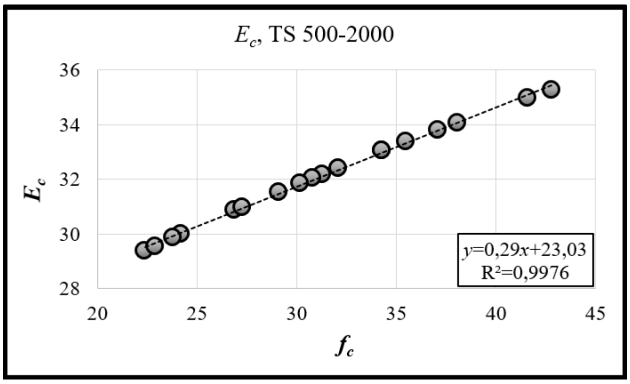

Figure 7. Variation of dynamic elasticity modulus calculated from TS 500-2000 with compressive strength.

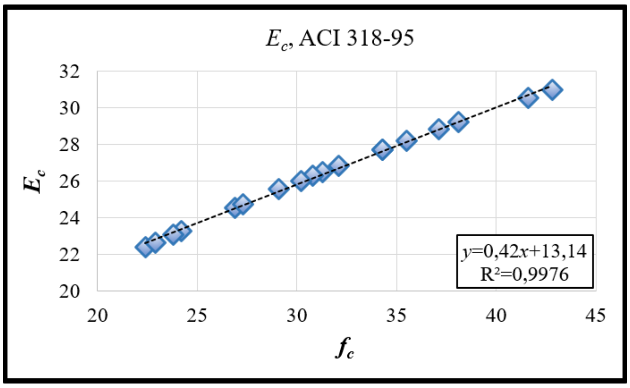

Figure 8. Variation of dynamic elasticity modulus calculated from ACI 318-95 with compressive strength.

In Figure 9, it is observed that the dynamic elasticity modulus values calculated in accordance with the calculations and rules in the CEB-FIP (1978) regulations range between 29.65 GPa and 35.18 GPa for concrete compressive strength values ranging between 22.4 and 42.8 MPa. Thus, it is seen that there is an increase of approximately 19% in the dynamic elasticity modulus values against approximately 91% increase in concrete compressive strength.

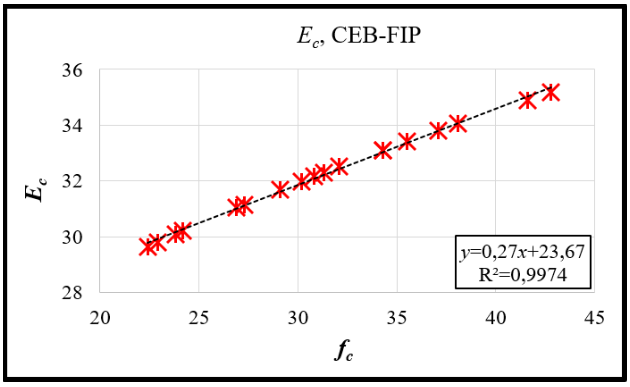

Figure 9. Variation of dynamic elasticity modulus calculated from CEB-FIP with compressive strength.

The fact that the coefficients of determination $R^2 \approx 0.998$, i.e. very close to 1, shows that the curves fitted in the graphs are close to the line of perfection. Thus, it can be said that a very good fit has been achieved.

Figure 10 shows that the dynamic elasticity modulus (E_c) values calculated by TS500 (2000) and CEB-FIP (1978) almost coincide with each other. However, the E_c values calculated by ACI 318 (1995) were found to be approximately 18% lower on average. It was observed that the dynamic elasticity modulus increased with increasing concrete compressive strength. It was determined that the rate of increase in concrete compressive strength was higher than the rate of increase in dynamic elasticity modulus.

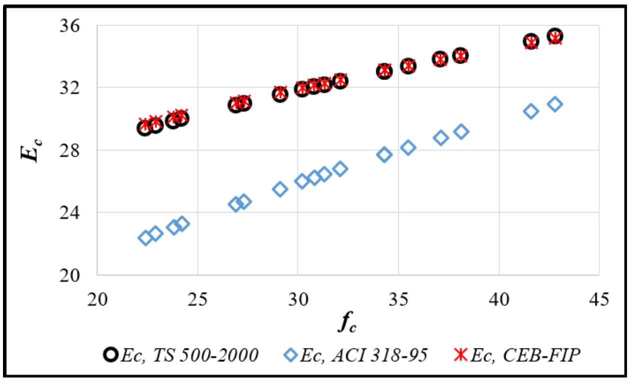

Figure 10. Variation of calculated dynamic elasticity modulus values with compressive strength values.

Conclusions

The main conclusions are listed below:

- ✓ As the water cement ratio increased from 0.25 to 0.30, the compressive strength of concrete decreased by approximately 12% for C=300 kg/m^3, 8% for C=350 kg/m^3 and 13% for C=400 kg/m^3.
- ✓ The mean compressive strength of concrete for C=300 kg/m^3 and w/c=0.25 was 26.1 MPa; the mean compressive strength of concrete for C=300 kg/m^3 and w/c=0.30 was 23.0 MPa.
- ✓ The mean compressive strength of concrete for C=350 kg/m^3 and w/c=0.25 was 32.6 MPa; the mean compressive strength of concrete for C=350 kg/m^3 and w/c=0.30 was 30.0 MPa.
- ✓ The mean compressive strength of concrete for C=400 kg/m^3 and w/c=0.25 was 40.8 MPa; the mean compressive strength of concrete for C=400 kg/m^3 and w/c=0.30 was 35.6 MPa.
- ✓ It is seen that there is about 91% increase in the compressive strength of concrete, about 20% increase in the dynamic elasticity modulus (E_c) values calculated according to TS500 (2000), about 38% increase in E_c values calculated according to ACI 318 (1995) and about 19% increase in E_c values calculated according to CEB-FIP (1978).
- ✓ It is seen that the dynamic elasticity modulus (E_c) values calculated by TS 500 (2000) and CEB-FIP (1978) almost coincide with each other.
- ✓ The E_c values calculated with ACI 318 (1995) are approximately 18% lower than the E_c values calculated with other regulations.

Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared

There is no conflict of interest with any person / institution in the article prepared

Authors' Contributions

Tuğrul Tunç E: Study conception and design, visualization, analysis, and interpretation of data, drafting of manuscript

References

[1] Ersoy U, "*Reinforced Concrete Basic Principles and Bearing Strength Calculation*" Volume-1 Evrim Publishing House, 643 pp, 1985, Ankara (in Turkish).

[2] Tugrul Tunc, E, "*Strength properties of hardened concrete produced with natural aggregates for different water/cement ratios*" Avrupa Bilim ve Teknoloji Dergisi, (14), 2018a, 280-287.

[3] Tugrul Tunc, E, "*Effects of basalt aggregates on concrete properties*" Qualitative Studies, 13(2), 2018b, 68-79.

[4] Özden, A. V, "*A Research on the Relationship Between Compressive and Tensile Strength of Concrete with Modulus of Elasticity*" Master's thesis, Namık Kemal University, 2010 (in Turkish).

[5] Tugrul Tunc, E, "*An experimental investigation on the abrasion strength of aggregate: Elazığ province calcareous aggregate*" Bitlis Eren University Journal of Science and Technology, 8(2), 2018c, 75-80.

[6] Tugrul Tunc, E, "*An Experimental Study Based on the Strength Properties of Concrete Containing Chemical Admixture*" European Journal of Science and Technology, (17), 2019, 901-908.

[7] Shah, H. A., Yuan, Q., & Zuo, S, "*Air entrainment in fresh concrete and its effects on hardened concrete-a review*" Construction and Building Materials, 274, 2021, 121835.

[8] Mata, R., Ruiz, R. O., & Nuñez, E, "*Correlation between compressive strength of concrete and ultrasonic pulse velocity: A case of study and a new correlation method*" Construction and Building Materials, 369, 2023, 130569.

[9] Ince, R., & Çetin, S. Y, "*Effect of grading type of aggregate on fracture parameters of concrete*" Magazine of Concrete Research, 71(16), 2019, 860-868.

[10] Tang, Y., Xiao, J., Zhang, H., Duan, Z., Xia, B, "*Mechanical properties and uniaxial compressive stress-strain behavior of fully recycled aggregate concrete*" Construction and Building Materials, 323, 2022, 126546.

[11] Shangguan, M., Xie, Y., Xu, S., Gao, C., Long, G., Wang, F., & Liu, M, "*Mechanical properties characteristics of high strength concrete exposed to low vacuum environment*" Journal of Building Engineering, 63, 2023, 105438.

[12] Wei, C., Sun, X., Yu, Z., & Zhang, P, "*Experimental study and mechanism analysis on basic mechanical properties of basalt fiber reinforced concrete*" Structural Concrete, 24(3), 2023, 4199-4226.

[13] Mardani-Aghabaglou, A., Karakuzu, K., Kobya, V., & Hatungimana, D, "*Durability performance and dimensional stability of road concrete containing dry-shake surface hardener admixture*" Construction and Building Materials, 274, 2021, 121789.

[14] Görgün, H., Kaya, D., Öncü, M. E., & Çetin, S. Y, "*On performance-based seismic assessment method for medium-rise RC buildings*" Građevinar, 71(08.), 2019, 663-672.

[15] Şengül Ö, "*The Influence of Aggregate Type on the Mechanical Behaviour of Normal and High Strength Concrete*" Master's Thesis, Istanbul Technical University, 2000, İstanbul (in Turkish).

[16] Türkel B, "*The Relation Between Compressive Strength and Modulus of Elasticity in Concrete*" Master's Thesis, Istanbul Technical University, 2002, İstanbul (in Turkish).

[17] Felekoğlu, B., & Türkel, S, "*The Effect of Loading Rate on Compressive Strength and Modulus of Elasticity of Concrete*" Dokuz Eylul University Faculty of Engineering Journal of Science and Engineering, 6(1), 2004, 65-75 (in Turkish).

[18] TS 802, "*Calculation principles of concrete mix design*" Turkish Standards Institute, 2016, Ankara.

[19] TS EN 12390–3, "*Concrete-Hardened Concrete Tests-Part 3: Determination of Compressive Strength in Test Specimens*" Turkish Standards Institute, 2003, Ankara.

[20] Neville, A. M, "*Properties of Concrete*" Jhon Wiley and Sons.ınc. Fourth edition, 800p., 1994, New York.

[21] Aitcin, P. C, "*High-Performance Concrete*" E and FN SPON, 650p., 1998, London and Newyork. doi: 10.4324/9780203475034.

[22] T. S., "*Design and Construction Rules of Reinforced Concrete Structures*" (TS 500-2000), Turkish Standards Institute, Ankara,2000.

[23] ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-95) and Commentary (318R-95)," American Concrete Institute, Farmington Hills, Mich., 1995, 369 pp.

[24] Du Beton, C. E. I., & de la Précontrainte, F, CEB-FIP model code for concrete structures. CEB Bulletin, 1978, (124/125).