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Prediction of reinforced concrete strength by ultrasonic velocities

Nevbahar Sabbağ, Osman Uyanık *

Suleyman Demirel University, Faculty of Engineering, Department of Geophysical Engineering, West Campus, 32260 Çünür, Isparta, Turkey

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ABSTRACT

This study was aimed to determine the strength of the reinforced concrete and to reveal the reinforcement effect on the concrete strength by Ultrasonic P and S wave velocities. Studies were conducted with prepared 9 different concrete designs of showing low, medium and high strength features. 4 kinds of cubic samples which unreinforced and including 10, 14 or 20 mm diameter reinforcement were prepared for these designs. Studies were carried out on total 324 samples including 9 samples for each design of these 4 kinds. The prepared samples of these designs were subjected to water curing. On some days of the 90-day period, P and S wave measurements were repeated to reveal the changes in seismic velocities of samples depending on whether reinforced or unreinforced of samples and diameter of reinforcement. Besides, comparisons were done by performing uniaxial compressive strength test with crushing of 3 samples on 7th, 28th and 90th days. As a result of studies and evaluations, it was seen that values of seismic velocities and uniaxial compressive strength increased depending on reinforcement and diameter of reinforcement in low strength concretes. However, while the seismic velocities were not markedly affected from reinforcement or reinforcement diameter in high strength concrete, uniaxial compressive strength values were negatively affected.

1. Introduction

Destructive, semi-destructive and non-destructive methods can be used for determination of concrete strength in existing reinforced concrete structures. Taking core samples from these structures and subjected to the uniaxial compression test are processes that cause damage to the structure. So as to minimize the damage Ultrasonic method is preferred as it provides fewer sampling which is a non-destructive method. In this method, concrete strength can be determined with evaluation of velocity results that are obtained by measuring travel time of P and S waves of known size concrete sample in the laboratory or in-situ concrete structure. Unreinforced samples are used for acquiring uniaxial compressive strength of core samples obtained from the existing structure. However, the obtained core strength should be converted to standard sample strength. While these transformations are occurred, the effects of reinforcement on the concrete strength are usually ignored or later added to the calculations. As is known, the reinforcement can both improve and reduce the concrete strength. Especially in old constructions or constructions of non-protected against to the humidity, reinforcements give way to decrease in concrete strength due to being exposed to corrosion. Additionally, concrete strength can be decreased in case of establishing bad bond between concrete and reinforcement.

The concrete protects the rebar in the reinforced concrete. If concrete has poor quality, that is, to say if it has voids and permeability, it cannot protect reinforcement. It has become certain that a close relationship between seismic loads and fissuring that occurs due to reinforcement corrosion in the concrete appears. Cheesman (1949), Jones (1949) and Whitehurst (1951) are perhaps the first people to apply ultrasonic wave transmission experiments in the process of initial set of concrete. Jones (1949) has stated that measurement results of wave velocity on concrete after setting process has dramatically increased and the increase rate has remarkably decreased after one-day cure period. Furthermore, the relationship between P wave velocity and concrete strength was quite similar in the measurements made on two different concrete mixtures. It was also revealed that quantity of cement and coarse aggregate are a quiet effective factor.

Al-Chlabi et al. (1986) described a method and a design for a digital tester suitable for concrete strength test by employing ultrasonic users. This shows that the experimental data demonstrates moderate accuracy figure in such device. In their study, Martin and Forde (1995) have taken non-destructively the P wave measurements in order to determine the properties of concrete. While concrete is kept in curing pool, wave velocity and concrete compressive strength increase in conducted study on cubic samples. Furthermore, concrete velocities were higher in concrete of made with mortar of excess percentage aggregate. 150 m/s velocity difference was observed in the same age concrete mixture. Demirboğa et al. (2004) have investigated the relationship between

Abbreviations: Ø, Reinforcement diameter (mm); UCS, Uniaxial compressive strength; W, Weight; V, Volume; w, Water content; V_P, P wave velocity; V_S, S wave velocity; t_p, Transient time of P wave; t_s, Transient time of S wave; T, Time (day); D1,…, D9, Type of concrete design; RMSE, Root mean square error.

* Corresponding author.
E-mail address: osmanuyanik@sdu.edu.tr (O. Uyanık).

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concrete compressive strength and ultrasonic velocity of concrete containing high volume mineral mixture. Compressive strength and ultrasonic wave velocity were determined for 3, 7, 28 and 120 days of curing time. Ultrasonic wave velocity and compressive strength of an early age concrete containing high volume fly ash were very low. However, it was observed that both values indirectly increase with the increase in curing time. Correlation coefficient between compressive strength and velocities said to be very well connected with the rate of 96%. Krauß and Hariri (2006) dealt with the determination of the end of the dormant phase under adiabatic curing conditions for different concrete compositions by using ultrasonic compressional wave and shear wave velocities. Beutel et al. (2008) expressed that it is necessary to compare the results of different measurement systems to establish the reliability of non-destructive testing methods, and ultrasonic method can be performed reliably in measuring of concretes in varying size, shape and density. Cassidy et al. (2011) determined voids located under steel reinforced concrete sections in realistic survey conditions using array-based, shear wave, pulse-echo ultrasonic surveys a proprietary instruments and they expressed that ultrasonic surveys can be used across a much wider range of geotechnical application areas with results. Breysse (2012) suggested that the number of cores can be considerably reduced without deteriorating the quality of assessment by non-destructive testes such ultrasonic pulse velocity. Pfister et al. (2014) have conducted a study on the determination of concrete compressive strength with ultrasonic method depending on coring place. The most important factors of assessing the concrete properties in a building are the safety and to protect structural integrity. Sufficient information about the quality of concrete in the structure can be obtained by means of taking many other core samples through destructive tests. Non-destructive ultrasonic methods can be applied in order to determine the concrete quality without any damage before any other applicable destructive testing. Sharma and Mukherjee (2015) investigated pours of concrete using ultrasonic in-situ monitoring technique through the propagation of ultrasonic waves and they said that as concrete solidified and cured, more wave energy escaped into the surrounding concrete resulting in signal attenuation. Li et al. (2016) investigated concrete structures using ultrasonic surface wave technique and they used to assess the condition of a reinforced concrete bridge and determined that could be potentially effective for estimating the thicknesses of concrete using this technique.

When determining of concrete strength by using only P wave velocity causes a mess in the relationship because of ability to spread in any environment. In the relationship between concrete strength and P wave velocity it is clear that the third parameter is quiet necessary to control the dispersion that will allow more information about the internal structure of concrete. This parameter may be shear (S) wave velocity which depends on several features such as the strength of the concrete, properties of the cement, and aggregate type. Also, water saturation or dryness in concrete pores can be interpreted by using compressive and shear wave velocities together. In addition, fracture, void and alteration status of concrete can be determined by means of ultrasonic method. After calculation of the P and S wave velocity of concrete, the elastic properties of the concrete (shear modulus, Poisson ratio, modulus of elasticity, bulk modulus) are determined through the elasticity theory (Uyanık, 2012; Uyanık et al., 2013).

The reinforcement in concrete affects the strength. While concrete strength was determined by destructive methods, it is significant to the use the cores not having reinforcement. Because, reinforced core subjected to the uniaxial compressive strength test can either damage to the device or the applied load can more quickly break the core by creating internal stresses on the reinforcement in the core, thus producing lower strength values. Academic studies that support or do not support this idea are available in the literature (Bahadır, 1984; Akça, 1991; Sabbağ and Uyanık, 2015). Petersons (1971) said that the reinforcement part may remain when core is taken in practice, but these parts will generally not affect the strength because of perpendicular to the loading direction. Lewandowski (1970) said that while the amount of reinforcement in the core increases, strength decreases, but this decrease is on a negligible level. According to Gaynor (1969) and Malhotra (1977), the presence of reinforcement in coring process leads to 8–13% decrease in strength. According to the ASTM C42, 2004, core of including reinforcement should not be used in compressive strength; therefore, it should be avoided as much as possible. In the received core samples in order to determine compressive strength, the absence of reinforcement should be provided in longitudinal axis direction or in very close to this axis direction. Hence, the cores taken from the structure are unreinforced. The effect of reinforcement on concrete strength is subsequently added to the result of calculations. However, reinforced concrete strength, without an extra calculation, can be found non-destructively by the ultrasonic study.

There are many studies as to the concrete strength in literature. When determining the concrete strength, only P wave measurements were used in the most of these studies (Klieger, 1957; Elvery and Ibrahim, 1976; Ravindrajah et al., 1988; Pessiki and Carino, 1988; Kheder, 1999; Ferreira and Castro, 1999; Pascale et al., 2000; Lorenzi et al., 2007; Carcano and Moreno, 2008; Yoo and Ryu, 2008; Machado et al., 2009; Atici, 2011; Uyanık and Tezcan, 2012; Uyanık et al., 2011, 2013). However, in this study both P and S wave measurements were used to predict concrete resistance. The reason why these waves are used together are that the elastic properties of concrete can theoretically be calculated and the physical properties of the concrete can be interpreted (Uyanık, 2010, 2011), as well as the prediction of the concrete resistance. Also, effect of reinforcement on the concrete strength was investigated by measuring the ultrasonic P wave and S wave in the laboratory before preparation of reinforced and unreinforced samples exposed to uniaxial compressive strength test. The reason why ultrasonic P and S wave measurement method is non-destructive method is very advantageous for the purpose of observing reinforcement effect depending on time and water content. It is possible to provide an interpretation with measurements on the same sample without any damage at any time, but not by destructive test methods. Beside, in this study, ultrasonic P and S wave measurements and uniaxial compressive strength tests on reinforced and unreinforced concrete were made with different concrete designs that have low, normal and high strength characteristics. In addition, time and water content-dependently changes of seismic velocities and compressive strength of concrete were investigated on unreinforced and reinforced samples of including one piece of 10, 14 or 20 mm diameter reinforcement. As a result of this study, concrete strength with different reinforcement diameter was calculated from experimental relationships among uniaxial compressive test, seismic velocities and reinforcement diameter.

2. Methods

2.1. Non-destructive ultrasonic method

Ultrasonic method is used for determine the mechanic and dynamic properties of concrete structure in-situ and in laboratory. This method is based on the theory of elastic wave propagation. In the laboratory, passing time of high frequency elastic waves through inside of sample is measured to determine the compressive (P) and shear (S) wave velocities (V_P and V_S); wave velocities can be calculated from known length of sample. In-situ velocities are determined by measuring of passing time of the elastic wave and distance between receiver and transmitter. While P waves are spread in any environment such as solids, liquids and gas; S waves propagate in only solid environment. Due to the lack of any resistance to the form changing of liquids and gases, S waves can not pass such environment.

Zero setting of the device should be done before starting the measurement with ultrasonic devices. Zero setting is the process of inverting the received electrical pulse to the ultrasonic pulse by means of a transducer. It takes a few micro-seconds and this delay should be