TIME-DEPENDENT CHANGE OF SEISMIC VELOCITIES ON LOW-STRENGTH CONCRETE

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Abstract: In this study, time-dependent change of Seismic velocities on low-strength concrete samples was investigated. For this purpose, 150x150x150 mm sizes 9 cubic samples were prepared for each of 4 different concrete designs. Water cure was applied on prepared samples. Seismic Ultrasonic P and S waves travel time measurements were made on the two opposed surfaces of the samples for 90 days during specific time periods and P and S wave velocities were calculated. Time dependent curves of Seismic velocity values that obtained from performed these studies depending on the time were formed. While Seismic velocities of saturated samples increased depending on the time, thought to be after 72nd day very few decline in Seismic velocities were observed. Reasons of this decrease in Seismic velocity values, bring thought of samples remain more water than required and the long-term exposed to water adversely affect characteristics of concrete samples.
*This study was supported with OYP05277-DR-14 Project No. by SDU Project No.
Keywords: Concrete, Cubic sample, P wave, S wave, Water cure, Time

INTRODUCTION

Concrete strength is determined with coring and subjected this core to the compressive strength test destructively. To determine the time-dependent change of the same sample is not possible with the conventional method as compressive strength test. But alternatively determining the time-dependent change of the concrete strength is possible non-destructively by Seismic velocities. At the result of several studies concrete strength can be determined from the Seismic pressure wave (P) velocity. However, the P wave velocity is affected with water or gas saturated voids or fractures of the concrete. So, it is clear that a third parameter is needed which unaffected from the water or gas saturation and controller of the relationship between P wave velocity and concrete strength dispersion. This parameter may be shear (S) wave velocity which depends on several features such as concrete strength, aggregate type and cement properties. Also by using of pressure and shear wave velocities together can be interpreted pores of the concrete to dry or water saturated. We can identify cracks, voids and decomposition situation in the concrete with Seismic Ultrasonic method. After determining P and S wave velocities of the concrete the dynamic elastic properties of concrete (shear modulus, Poisson ratio, modulus of elasticity, bulk modulus) can be determined from the elasticity theory (Bahadır, 1984; Swamy, 1984; Keiller, 1985; Jenkins, 1985; Akça, 1991; Uyanık, 1991, Uyanık et al., 2013).

Before prepared cubic concrete samples of being subjected to Uniaxial Compressive Strength test, the effect of time-dependent change of the pressure (P) and shear (S) wave measurements have been tried to be observed by the Seismic Ultrasonic method. In the literature, time-dependent change of concrete samples was evaluated from different points of view. Relationship between concrete strength and aggregate gradation, different water/cement rates, cement type, moisture and temperature, effect of shrinkage and creep events were tried to be observed time-dependently on concrete samples (Istanbulluoğlu, 1988; Cheng et al., 2004; Kerr, 2007; Phan and Carino, 2001; Keleştemur and Star, 2005; Vittorio, 2011; Soykan and Özel, 2014). However, determining the time-dependent change of Seismic Ultrasonic P and S wave measurements were not done before. Performed study constitutes a first in this regard. Scope of the study three different concrete designs indicates low strength approximately 5, 10 and 15 MPa were compared to one prepared concrete design with normal strength approximately 30 MPa (Taşdemir et al., 2004). Thus, the effect of Seismic velocities on low-strength concrete could be put forward more clearly.

ULTRASONIC SEISMIC METHOD

Non-destructive Ultrasonic Seismic method can be used for determine the mechanical properties of concrete in-situ and in laboratory. In this method, Seismic P wave known as sound wave, as well as Seismic S wave measurements are made. P-waves, also known as primary, longitudinal, pressure or sound wave, move compress and dilates to the particles. These waves can be spread in the solid, liquid and gas environment. But S waves can only spread in environments that resistant to the change of shape. As is known, S waves are not propagation in

these liquid and gas environments due to absence of resistant against the change of shape. This wave velocity values depend on the rigidity and density of their spreading body (Uyanık, 1991; Öztürk, 1993; Pampal, 2000).
Zero setting of the device should be performed before starting of the P and S wave measurement by ultrasonic equipment. Zero setting is process of receive the electric pulse and convert to a Seismic pulse by transducer. This process takes a few micro-seconds and this delay should be removed. However, the zero setting must be carried out separately for P and S waves.

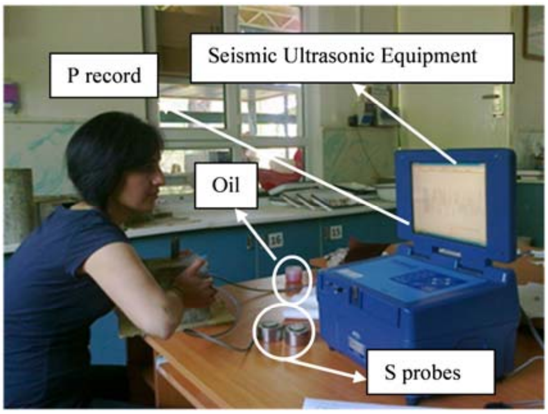

Fig. 1 Seismic Ultrasonic P and S wave measurement equipment and taking measures

After zero setting is finished, the required settings from the P or S wave options are made. So, it is possible to pass the P or S wave travel time measurements. Ultrasonic energy has been delayed by an air gap. Therefore, to provide a very good transmission is necessary between the sample and the receiver-transmitter probe. In order to ensure fully transmission must be used improver transmission substance grease oil, etc. However, such materials should not be used in the S-wave travel time measurement. Smooth and even surface of the samples is one of the most important factors affecting the measurement. Transmitter and receiver probes are available in Seismic Ultrasonic devices. The arrival time is recorded one side by sending a wave the other side of the sample (Figure 1). The velocity (V) is determined from ratio of the distance (length) between the transmitter and receiver probes (L) to the arrival time (t) (Uyanık, 1991; IAEA, 2002; Sabbağ et. al., 2014).

$$V = \frac{L}{t} \tag{1}$$

Ultrasonic Seismic P and S wave measurements can be done on samples in laboratory or in-situ. By this method measurement can be determined cracks, void and alteration situation of the concrete, as well as to the mechanical properties of concrete (Figure 2). One of the most important features of the method is to achieve results quickly without any damage to the structure. However, it is important for the interpretation of the concrete quality that to determine whether it is received on the reinforcement in-situ measurement. After the determination P and S wave velocities of concrete, elastic properties of the concrete (modulus of elasticity, shear modulus, bulk modulus, Poisson ratio) are determined from the elasticity theory (Uyanık, 2012).

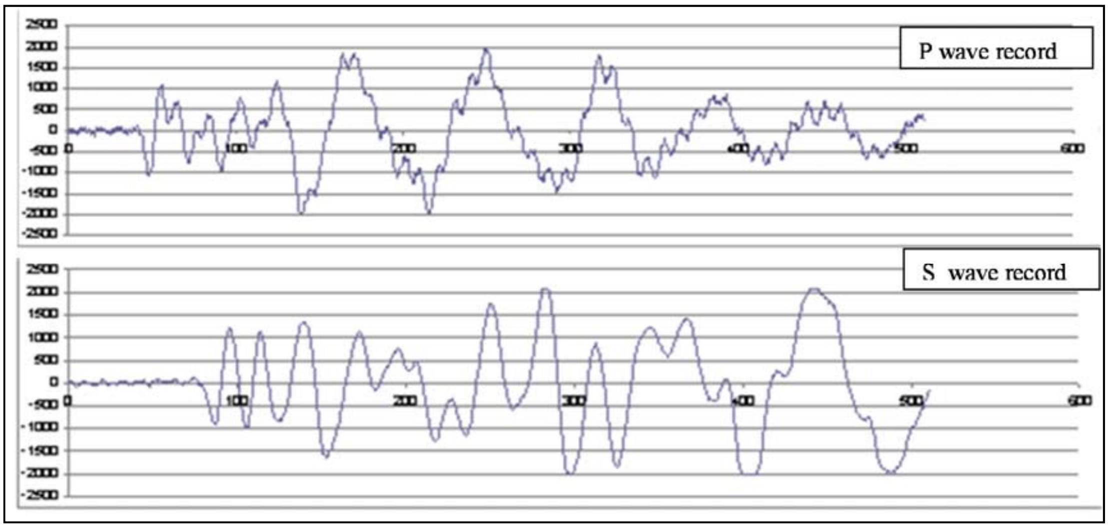

Fig. 2 Ultrasonic Seismic P and S waves travel time records (Uyanık et. al., 2015b)

Voids in the concrete are the most important factor of affecting the Seismic velocities. As is known, passing of the Seismic P waves in the porous material of the concrete are slow. Therefore, height of the Seismic velocity indicating that the concrete quality is high, low of the Seismic velocity indicating that the quality is low. Also, because of S waves are not spread in the voids and the available liquid in the voids provide to us having a review about the concrete is stringent or loose (Leslie and Cheesman, 1950; Whitehurst, 1951; Uyanık, 2012).

UNIAXIAL COMPRESSIVE STRENGTH TEST

Most commonly used of non-destructive method is receiving of cylindrical samples (cores) from the concrete of the structure and subjected to breakage effect under the axial force. This method gives concrete strength in structure/in-situ with highest reliance despite of drawbacks such as cost, speed and its ruin in the structure (Arıoğlu and Arıoğlu, 1998; Erdoğan, 2003, Başka, 2006; Uyanık et. al., 2015a). Unless otherwise indicated Compressive strength is determined at 28 days samples. Uniaxial compressive strength of the concrete sample is described as its resistance of against breakage. According to the standard of related to sample sizes length/diameter ratio of cylindrical samples should be 2- 2.5 in the test. Generally for this 150x300mm size cylindrical or 150x150x150mm dimensional cubes are used. Because of the size effect, visible strengths of material vary for different sizes examples. Small of the sample size is relatively increases strength and leads to increasing volatility in the results.

Fig. 3 Applying Uniaxial Compressive Strength Test on samples (Sabbag and Uyanık, 2015)

The prepared samples are placed between the steel plates of the hydraulic press. If load of applying at the time of sample breakage is called P and the surface area of the sample is called A, Uniaxial Compressive Strength is found as P/A (Figure 3). The water content of the sample can significantly influence the compressive strength test results during the test. After preparation, samples must be kept under normal atmospheric conditions at room temperature until testing is performed. In order to make the compressive strength test, samples are dried in an oven at 105 ± 5 °C until the weights unchanged. Different water content ratio of the sample may be required to be tested.

Compressive strength varies with coming stress of perpendicular or parallel direction to the discontinuities and layer surface. Strength in perpendicular direction to the discontinuity surface is greater than the strength of obtained in parallel (Köse and Kahraman, 1998). The compressive strength of concrete is affected by changes of loading speed. While the applied speed of application stress to the concrete sample decreases (load is applied upon a longer period) the sample is broken under a smaller stress. In other words, the pressure obtaining in the low-load speed of the sample strength is lower. This case occurs with the amount of creep due to the load stay longer on the sample. On the other hand, the high loading rate applied on samples is broken under a big load, that is, higher compressive strength value is obtained (Erdoğan, 2003; Felekoğlu and Türkel, 2004).

THE EFFECT OF WATER CONTENT

The water content of the concrete (w) is expressed as the ratio of the water mass in the concrete to the mass of solid particles. The amount of water contained in unit volume of material can be expressed by mass or volume. Concrete strength decreases with increasing water/cement ratio (Mertol, 2010). Also the water must fill the spaces between particles except from the particle surfaces absorption. The excess water provides fluidity as separating of the particle by a water layer. Increasing the amount of water will increase fluidity and will provide that concrete to be compressed easily. Indeed, the total water content is the most important parameter that provides the main binding. However, the excess water is reduced the binding and causes decomposition and desorption.

There are two types of voids in cement paste. One of these is small void between the gel particles; the other is large capillary void between gel particles and aggregates. In order to the hydration of cement using redundant water remains in the space of mass concrete and can significantly affect the durability of concrete. The excess water is lost along with the drying of the concrete and reduces the resistance when causing an increase in the porosity of the concrete. Interconnected voids which create channels to pass of harmful substances from outside and thus interconnected spaces increase the permeability of concrete. Because of the void ratio and therefore permeability of concrete are very high, unable to protect the reinforcement (Bayazıt and Yalçın, 1970).

DATA PROCESSING

Concrete is a composite building material which obtained as a result of gaining strength harden over time of different sizes aggregates such as sand, gravel, granular mineral materials (gravel etc.) mixing with water and cement paste. In this study the type of aggregate was used as crushed stone aggregate. The rocks broken and crushed desired sizes of form which taken from the quarry of near Antalya Boyali pond by stone crusher, so that the aggregate was formed by using materials such as crystallized limestone, marble etc. taken from rock stockyard, per unit volume mass, specific weight, mass of water absorption, volume of water absorption, pressure loss after freeze, determination of the frost strength with sodium sulfate, Los Angeles abrasion (100 rpm/500 rpm) laboratory tests were carried out. 25% coarse aggregate, 23% medium gravel, 52% sand prepared using aggregate grain size of the largest aggregate Dmax = 63 mm. A kind of cement as CEM II/B-LL composite Portland cement (limestone (total organic carbon): 0.2%) were used for preparation of the designs. As chemical additives Aermix was used for air-entraining admixture and Fluico was used for super plasticizer concrete admixture. The mixtures were prepared by using of the potable water supply. Slump (crash) test value was taken as 12 for all mixtures.

This study was conducted with the different mixing ratio of concrete. Accordingly, showing different concrete strength four designs 150x150x150mm size cubic samples were prepared. 9 cubic samples were available for each design. Scope of study three different concrete designs indicates low strength approximately 5, 10 and 15 MPa were compared to one prepared concrete design with normal strength approximately 30 MPa (Taşdemir et al., 2004). Thus the effect of Seismic Velocities on low strength concrete could be more clearly.

Fig. 4 Drying in an oven and applying water cure of the samples for the determination of water content

In order to preparation of the cubic samples, different proportions of water, cement, aggregates and additives were used with approximately 5 MPa, 10 MPa and 15 MPa three low-strength concrete designs and with approximately 30 MPa normal strength concrete design. After the determination of the weight and density Ultrasonic seismic P and S wave measurements were taken from two opposing surfaces of the samples for determine the water content of the samples 3rd, 7th, 28th, 41st, 56th, 65th, 72nd and 90th days. Then it dried in an oven at 105°C for 24 hour. Then removed dry form weight measurements of samples made enacted, Seismic Ultrasonic measurements were taken. The data were grouped for monitoring velocity changes depending on the time. Until specified time period of the measurement day samples are waited in the curing pool (Figure 4). 3 samples of each design were broken 7th, 28th and 90th days by Uniaxial Compressive Strength Test and averages of values were obtained.

EVALUATIONS

The studies carried out on 4 different concrete designs that the first arrival times of P and S records were determined by Seismic Ultrasonic device before samples being subjected to uniaxial compressive test. Seismic velocities were obtained by using size and the first arrival time of these samples. Measurements have repeated at predetermined time intervals in order to observe the time-dependent change of these velocities. In this context, it is possible to observe the change of the samples in Figure 5.

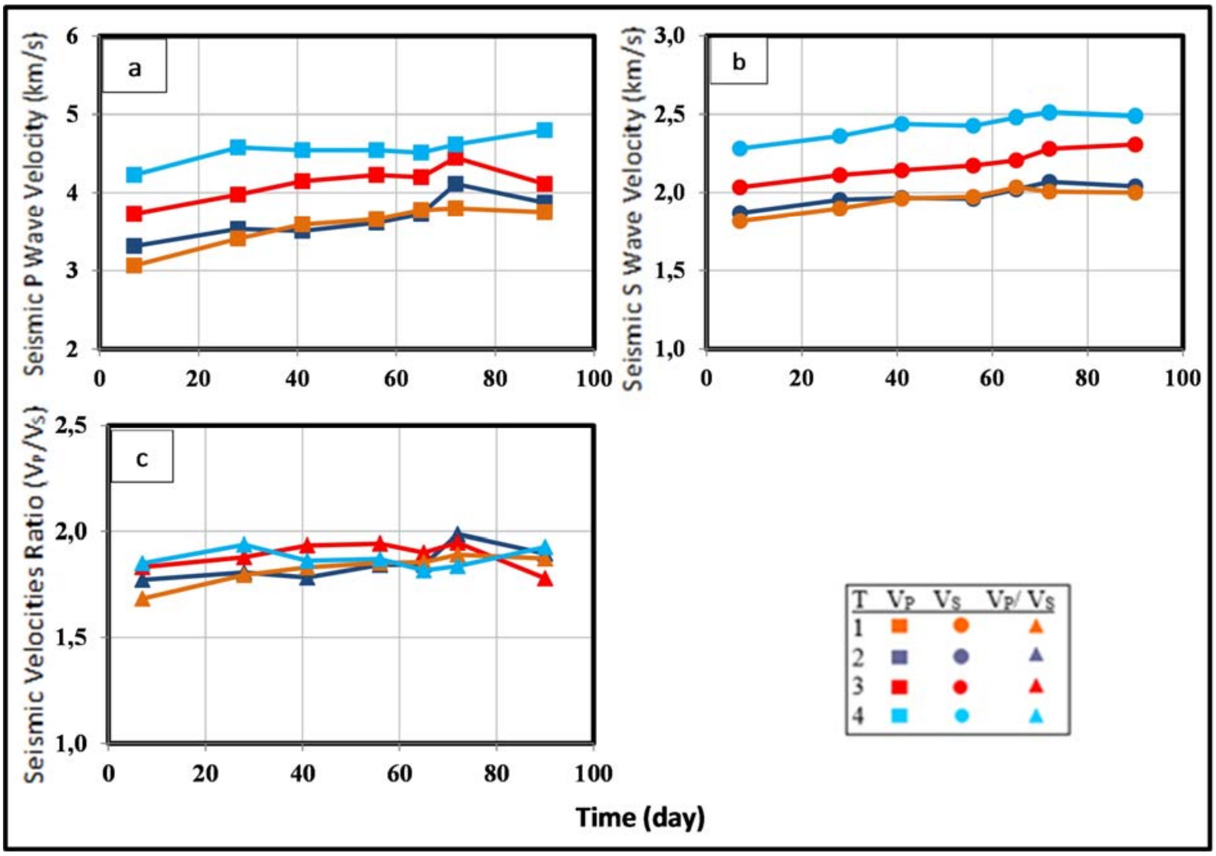

Fig. 5 Time-dependent change of Seismic P wave Velocity (a) Seismic S wave Velocity (b) and Seismic Velocities ratio (c) for 4 designs

When the obtained data were analyzed; we could say Seismic velocities increase depending on the time. Reduction of P wave velocity at 7th day was due to samples in the out of water as a result of oven-dried. Accordingly these, density values are also reduced. But after 28th or 41st days density values were almost fixed. Although Seismic velocities of the water cured samples have increased depending on the time, this increase rate was greater in the P wave velocity due to its ability to spread in all kinds of environment. While the samples strength increased, also the velocities increased with the time-dependent. These increases were observed up to 72nd days in all designs. Particularly after this date less decrease or fixing were observed in velocities. We could say that for this situation, after a specific time the water negatively affected to the concrete samples. Because of T1 design samples filled with more water in the pores that decrease could be seen more clearly in the P-wave velocity. However, as concrete was stringent (T4) due to less water content in it, at the rate of decrease in the P velocity was less.

The lower strength of the concrete designs, the more pores in the samples, and so the samples can take much more water into. Because of after the 41st days generally sample voids were completely filled with water, parameters such as the water content and porosity began to fixed values (Figure 6).

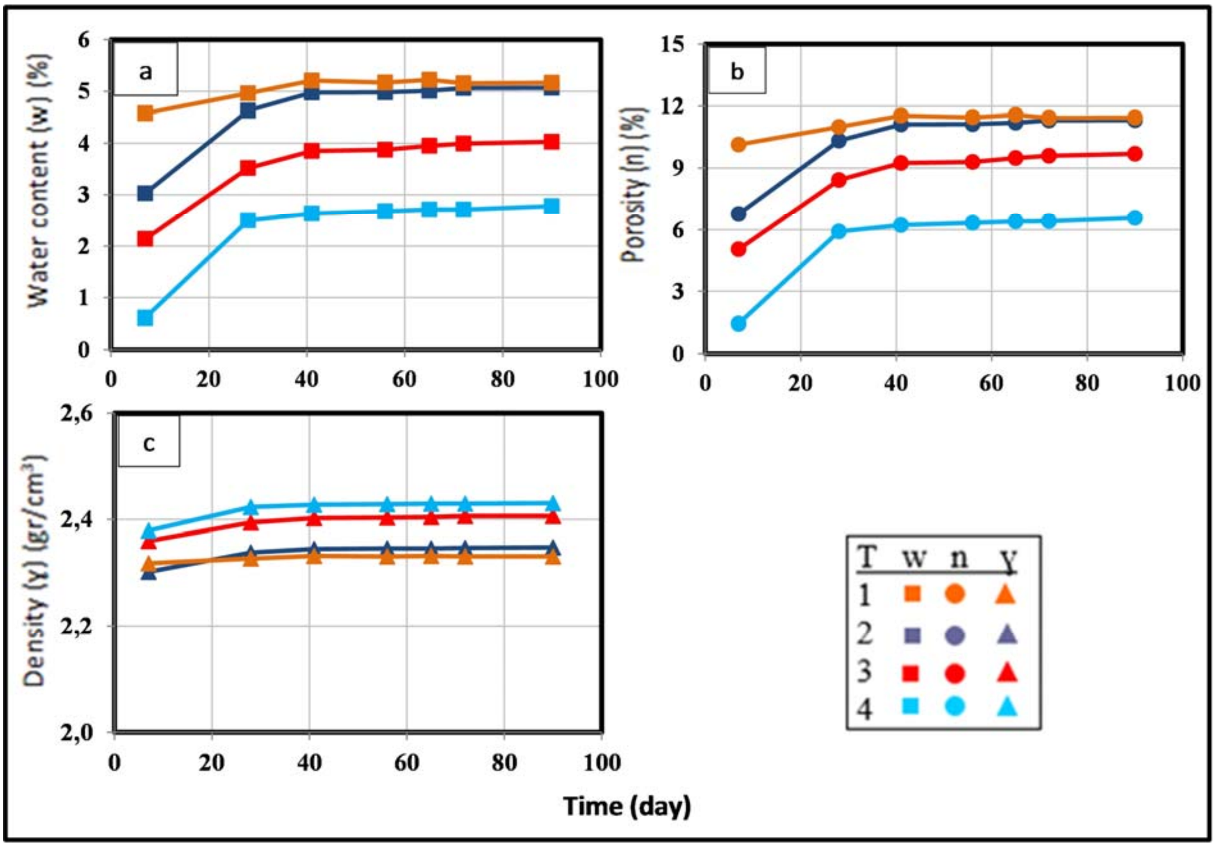

Fig. 6 Time-dependent change of water contents (a), porosities (b) and densities (c) for 4 designs.

Elasticity modulus of the concrete must be known in order to determine the deformation or displacement in the considering elastic calculation of the structural design.

Static Elastic Modules (Modulus of Elasticity, Shear Modulus, Bulk Modulus, Poisson Ratio) obtained from samples subjected to Uniaxial Compressive Strength Test. These modules calculate for 28-day strength of concrete. Also Poisson Ratio is assumed as 0.2 (TS 500, 2000). However, Dynamic Elastic Modules calculated from Seismic P and S waves;

Density: $\gamma = 0.76{V_p}^{0.074}{V_s}^{0.074}$ (Uyanık and Çatlıoğlu, 2010) (2)

Dynamic Modulus of Elasticity: $E = \frac{3G\left[\left(\frac{V_p}{V_s}\right)^2 - \frac{4}{3}\right]}{\left(\frac{V_p}{V_s}\right)^2 - 1}$ (3)

Dynamic Shear Modulus: $G = \frac{\gamma {V_s}^2}{g}$ (4)

Dynamic Bulk Modulus: $K = G\left[\left(\frac{V_p}{V_s}\right)^2 - \frac{4}{3}\right]$ (5)

Poisson Ratio: $\mu = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{2\left(\frac{V_p}{V_s}\right)^2 - 2}$ (6)

Dynamic modulus of elasticity is equal to changing of a very small deformation. Usually this is greater than static modulus of elasticity from 20% to 40% by Sonic Resonant frequency method. The initial static modulus of elasticity is approximately equal to dynamic modulus of elasticity. Using the dynamic modulus is suitable for Seismic and blast loadings of structures (Mc Cormac and Nelson, 2005).

While Static Elastic Modules calculated from Uniaxial Compressive Strength test destructively, Dynamic Elastic Modules calculated from Seismic P and S wave velocities non-destructively. Dynamic Elastic modules calculate for the same concrete samples every time. For this purpose, these modules could be calculated up to 90 days. As well as the P-wave velocity also obtaining of S-wave velocity enables to reach dynamic elastic parameters (Figure 7).

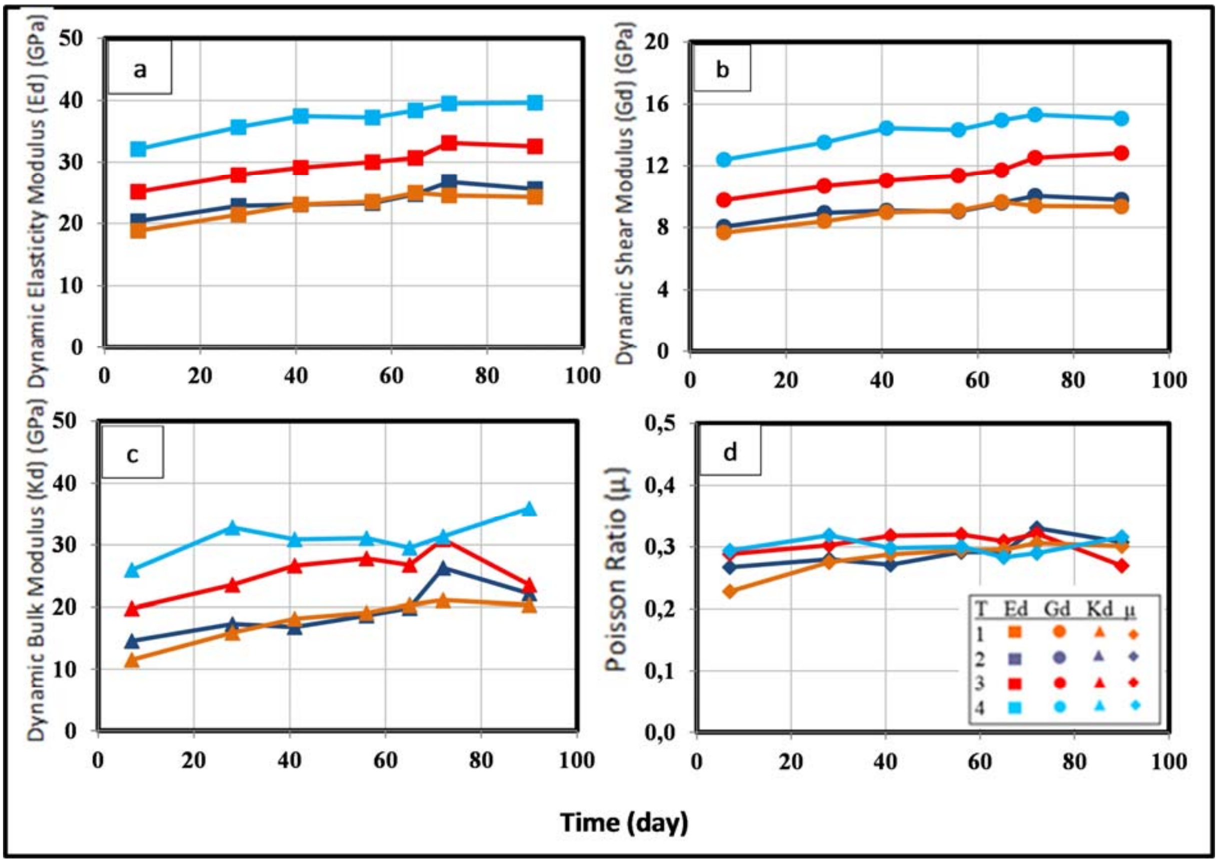

Fig. 7 Time-dependent change of (a) Dynamic Elasticity Modulus (b) Dynamic Shear modulus (c) Dynamic Bulk Modulus and (d) Poisson Ratio for 4 designs.

CONCLUSIONS

Seismic velocities of same water-saturated concrete increase depend on time. P and S wave velocities of water-saturated concrete designe under 50MPa change between 2.8-4.6km/s and 1.6-2.5 km/s, respectively. Densities increases depend on concrete strength time dependently. After saturation (41st days) water content and porosity are fixed depend on time. Dynamic modules are increases with increasing of strength time dependently.

Dynamic Elasticity modulus (Ed) change between 18-40 GPa, Dynamic Shear modulus change between (Gd) 8-16 GPa, Dynamic Bulk modulus change between 10-37 GPa for low-strength concretes. Poisson Ratio changes between 0.22-0.35 depend on time. This result show that Poisson ratio not stable as agreed 0.2 value in static elastic module accounts of concrete. Poisson ratio changes with water saturation of concrete.

Concrete strength can be calculated from Seismic velocities (P and S wave) non-destructively. Moreover, dynamic elastic modules are also calculated from Seismic velocities easily. Also, this study is a first for determining of dynamic elasticity modules by Ultrasonic Seismic method and time dependent change of these modules. Dynamic modules of water-saturated concrete take different values depend on time.

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