

***Civil and Architectural Engineering***

**Using Ultrasonic Pulse Velocity Test to Assess the Effect of Water-Cement Ratio on the Compressive Strength of Concrete**

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**ABSTRACT**

**T**his study aims to find the effect of water-cement ratio on the compressive strength of concrete by using ultrasonic pulse velocity test (UPVT). Over 230 standard cube specimens were used in this study, with dimensions of 150mm, and concrete cubes were cured in water at 20 °C. Also, the specimens used in the study were made of concrete with varied water-cement ratio contents from 0.48 to 0.59. The specimens were taken from Diyarbakir-Turkey concrete centers and tested at the structure and material science lab, civil engineering, faculty of engineering from Dicle University. The UPV measurement and compressive strength tests were carried out at the concrete age of 28 days. Their UPV and compressive strength ranged between (3.89-4.66km/s) and (17.74-40.56MPa) respectively. The experimental results showed that although the UPV and the compressive strength of concrete are related, also, the UPV and compressive strength have a relation with the rate of the water-cement ratio of concrete.

**Keywords:** Concrete, water-cement ratio, ultrasonic pulse velocity, compressive strength.

**1. INTRODUCTION**

Concrete is a composite material for constructing buildings and structures. It is widely used worldwide because it hardens over a limited period and it can take many shapes and forms as well. However, many factors may spoil concrete leaving behind many cracks in it like earthquakes and fire accidents. So, when using concrete in any field or even in case of doubt started showing signs of danger against it, concrete should be well tested to discover its quality and detect how serious the danger represents; **Neville and Brooks, 2010**. Various tests are used for this purpose; group test destructive testing (DT), semi-destructive testing (semi-DT), non-destructive testing (NDT). The DT test and Semi-DT are expensive and complicated. The NDT test is easier and less expensive, yet it needs more concentration and organization, **Sudarshan, 2013, Malek, and Machta, 2014, and Hola, et al., 2015**. Ultrasonic pulse velocity test (UPVT) is one of the NDT group tests that was used in the past half-century to check the kind and the quality of concrete. One of the advantages of the UPVT lies in its ability to be used in the place of destination as well as its usage in the laboratories. Other Advantages of ultrasonic inspection as a method of Non-Destructive Examination are, **IS, 1992**:

- Internal defects can be detected and sized when a validated procedure is applied.

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- Thick specimens take no more time to examine than thin ones, assuming correct instrumentation set up.
- Access to only one side of the component is needed.
- There is no radiation hazard in the ultrasonic examination, and hence no disruption of work as there is with radiography.
- Volumetric and crack similar to defects can be detected, irrespective of their orientation.

It is worth mentioning that many factors and concrete composites affect the UPVT, like the effect of aggregate content, aggregate size, aggregate type, type of cement, curing type, temperature and the water-cement ratio of concrete,... etc. So, using UPVT in concrete assess of compressive strength and finding the relationship between them became the focus of attention of the researchers in the past few years, **Naik, et al., 2004, Ramazan, et al., 2004 and Turgut, 2004.**

It was found in the past researches that the relationship between compressive strength and UPV is a direct one. Therefore, when any of the factors above affect UPV, it will directly affect compressive strength, **Zebari, 2018, Zebari, et al., 2017, and Naik, et al., 2004.** In previous years, some researchers have worked on the effect of water-cement ratio on each of the two tests, but differently, because in this research different rates of water-cement ratio have been used.

**Kaplan, 1959,** during his work had shown that when the rate of W/C ratio increases, the concrete strength in compression and the assessment of the propagation of ultrasonic pulse velocity related decreases are presuming the same concrete composition.

**Malek and Kaouther, 2014,** determined the compressive strength of concrete by destructive testing and non-destructive testing by using the rebound hammer technique at ages 7, 14 and 28 days. Also, the effect of numerous factors on the elasticity modulus determined by ultrasonic pulse velocity test was considered. These influences mostly involved the age and the water-cement ratio of concrete with the assessment that the UPV increases with the decreases of w/c ratio. Generally; w/c ratio increase decreases ultrasonic pulse velocity because of decreases in density and compressive strength, **Crawford, 1997.**

This study will shed light on observing the effect of water-cement ratio on the compressive strength and UPVT measurements of concrete.

## 2. MATERIALS AND METHODS

### 2.1 Mix Proportion

Ready-mixed concrete was used in this study. It has been taken from concrete centers in the city center of Diyarbakir-Turkey. Natural and crushed aggregates and crushing material have been used in the concrete of these centers in the Tigris River.

Also, throughout Diyarbakir; CEM II 42.5 R Portland cement was used. All kinds of physical-mechanical tests and chemical analysis results of this cement were made in the quality control laboratory of the factory and presented in **Table 1** and **2.**

The water used in the study is natural water, and it is also used as drinking water in the region.

**Table 1.** Chemical properties of CEM II 42.5 R Portland cement.

Components	Cement %
MgO	1.91
Al <sub>2</sub> O <sub>3</sub>	6.20



SiO <sub>2</sub>	20.60
CaO	61.40
Fe <sub>2</sub> O	3.01
SO <sub>3</sub>	2.68
K <sub>2</sub> O	1.03
Na <sub>2</sub> O	0.19
Cl	0.0007
Leakage loss	3.89
Insoluble residue	0.30

**Table 2.** Physical and mechanical properties of CEM II 42.5 R Portland cement.

Components	(%) 42.5 PC
Specific gravity (g/cm <sup>3</sup> )	3.12
Thinness (g/cm <sup>2</sup> )	2919
Bending strength (MPa)	7.88
Two-day compressive strength (N/mm <sup>2</sup> )	24.8
Seven-day compressive strength (N/mm <sup>2</sup> )	37.7
28-day compressive strength (N/mm <sup>2</sup> )	50.1
Seven-day bending tensile strength (N/mm <sup>2</sup> )	5.9
28-day bending tensile strength (N/mm <sup>2</sup> )	7.5
Socket start time (min)	186
Expansion (mm)	1

**2.2 Specimens**

Two hundred thirty standard cube specimens with a dimension of 150mm were used in investigational works. These specimens were taken from four concrete centers in Diyarbakir, with different mix proportions, as shown in **Table 3**. The concrete of these specimens was used in different projects and apartments in Turkey, Diyarbakir city. Plastic moulds were used to make specimens, after preparing the specimens; they are kept in working place, and after 24 hours, they were moved to the Structure and Material Science Lab, Faculty of Engineering, Dicle University. After that, specimens were removed from the moulds and were sunk into a normal water tank. The specimens were tested at age 28 days, with normal water curing. Its task is showing the effect of water-cement ratios on the compressive strength and UPV. Both UPV and compression tests have been done according to IS 13311, part1, 1992. The UPV and compressive strength ranges were between (3.89-4.66km/s) and (17.74-40.56MPa) respectively. The UPV test results show that the concrete which was used in building these projects has a good quality, according to (IS 13311, part (1) ultrasonic pulse velocity of concrete, 1992). The ultrasonic pulse velocity test and compressive strength of concrete were measured according to the condition of IS, part 1, 13311 and IS 516, respectively **IS, 1992**.

**Table 3.** The mix proportions of concrete, **Baran, 2017.**

Concrete Centers	Concrete Grade	7-0 sand (kg)	7-15 Fine aggregate (kg)	15-25 Coarse aggregate (kg)	Cement (kg)	Water (kg)	Additive Materials (L)	Water-cement ratio
Emirler star concrete	C25	1060	300	580	300	170	2.40	0.57
Bes concrete	C25	1040	255	655	290	170	3.10	0.59
Bes concrete	C30	1010	270	650	330	180	3.50	0.54
Ceylan concrete	C25	1010	310	560	340	165	3.40	0.48
Nural concrete	C25	1150	240	540	300	165	3.00	0.55

### 2.3 Ultrasonic Pulse Velocity

The fundamental of ultrasonic pulse velocity measurement includes sending an ultrasonic wave pulse through concrete and measuring the intermission time for the wave pulse to propagate through the concrete. The ultrasonic pulse wave is generated by a transmitter transducer and received by a receiver transducer.

Ultrasonic pulse velocities were measured by a commercially available pulse meter with an associated transducer pair through a direct transmission mode. The transducer pair had a nominal frequency of 55 kHz. In the experimental work, the transmitter and receiver were placed at the top and bottom surfaces of a cube specimen, in a parallel direction to the destructive load. Knowing the path length ( $L$ ), the measured interval time ( $T$ ) can be used to calculate the pulse velocity ( $v$ ) as in **eq. (1)**, where  $L$  is the travel path length of ultrasound in the cube. The concrete surface must be prepared in advance for a proper coupling agent (Ultrasonic gel). Hard contact of the transducers touching the concrete surface is needed.

$$v = \frac{L}{T} \quad (1)$$

Direct ultrasonic pulse velocity (DUPV) measurements were taken as the average of 6 readings for each cube tested. The direct path length for these measurements was through the cube thickness of 150 mm. DUPV was calculated by dividing the path length of cube specimen to the time of the trip.

**Table 4.** Velocity criterion for concrete quality grading, **IS,1992.**

UPV pulsing by transducers (km/s)	Concrete Quality Grading
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Bellow 3.0	Poor



### 3. RESULTS AND DISCUSSION

#### 3.1 Experimental Results

The experimental results of this study are summarized in the **Table 5**, they represented the test to find the effect of water cement-ratio on the compressive strength and UPV. Each data in the **Table 5**, is the mean value of 46 data.

**Table 5.** Experimental results, **Baran, 2017.**

Concrete Centers	Concrete Grade	Age (days)	UPV (km/s)	Actual Compressive Strength (MPa)	Water-Cement ratio
EMIRLER STAR concrete	C25	28	4.15	29.44	0.57
BES Concrete	C25	28	4.23	28.76	0.59
BES Concrete	C30	28	4.25	30.00	0.54
CEYLAN Concrete	C25	28	4.32	31.12	0.48
NURAL Concrete	C25	28	4.18	29.53	0.55

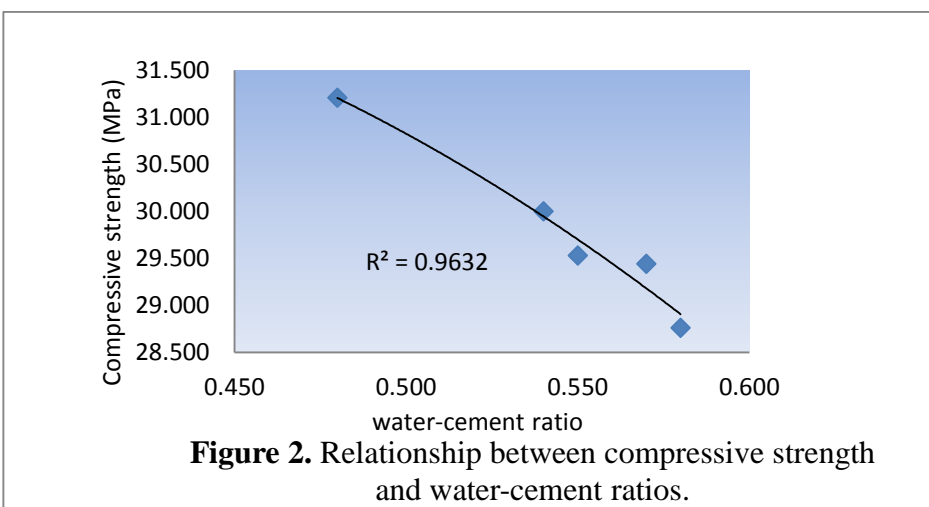
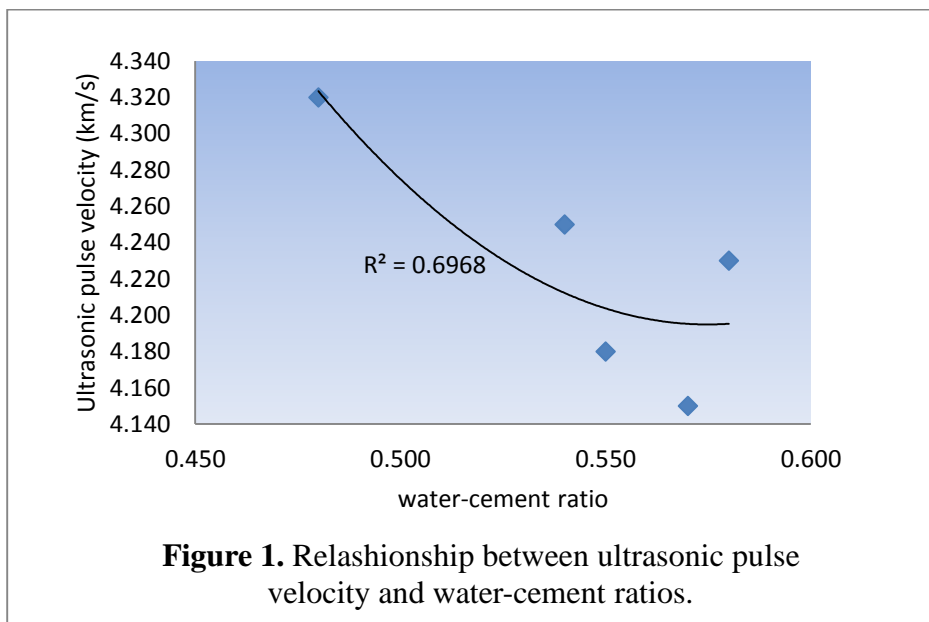
#### 3.2 Discussion

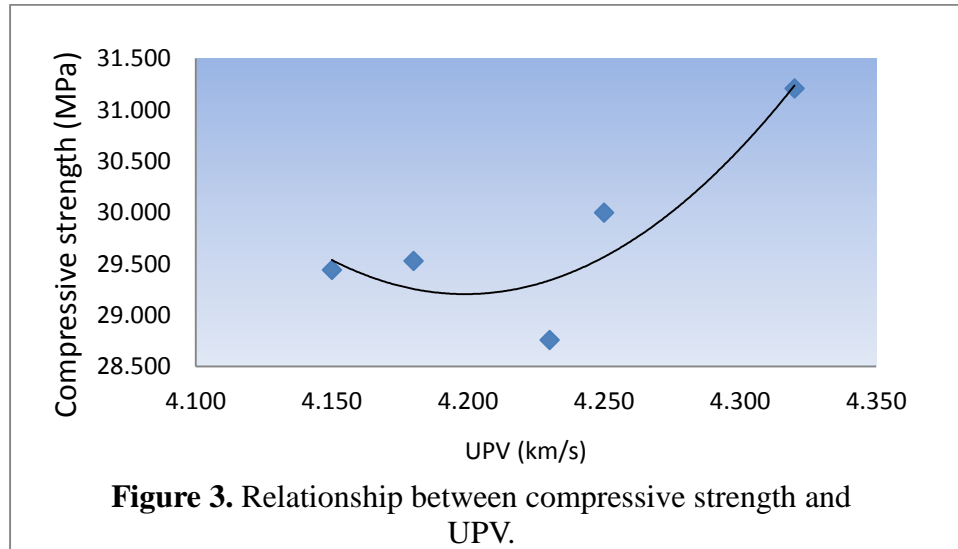
As explained in the first part that many factors are affecting the UPV and the compressive strength of the concrete. That is why the UPV test was conducted on specimens, as it was known that researchers have proved in the past that the relationship between both tests (UPVT and compressive strength) is a good one. This means that the more the UPV increases, the compressive strength increases too. But this might not be correct for all data. It was illustrated that the aim of this study is to study and monitor the effect of water-cement ratio on compressive strength and UPV of normal concrete which has been used. The results were carefully studied, and they have been summarized to consider the results further, as it is clear in the **Table 3**. All tests have been conducted in day 28<sup>th</sup>. And their average of water-cement ratio were 0.48, 0.54, 0.55, 0.57, and 0.59.

It is clear from the results that the lowest average of water-cement ratio has registered the highest value of each compressive strength and UPV. The average of 0.48 of its compressive strength and UPV successively is 31.21 MPa and 4.32 km. And the second group of the average of 0.48, 0.54, 0.55, 0.57, and 0.59 of water-cement ratio has shown the same relationship, but this process would not apply to all data. The result here is that the relationship between water-cement ratio in one hand, and compressive strength and UPV, on the other hand, is the opposite relationship. Or by increasing of water-cement ratio, each of compressive strength and UPV of concrete decrease. These averages of water-cement ratio that have been used are close to each other, though if these averages were not that close to each other; this relationship would be more clear. And as mentioned above that UPV test is an (NDT) test, and it needs much accuracy, therefore the relationship between UPV and water-cement ratio is the opposite one, but in spite of that the data have not been distributed on the Curve, that its R<sup>2</sup> is (0.697), as in the **Fig. 1**. Also, the relationship between compressive strength and (water-cement ratio) is the opposite



relationship. The data are also distributed on the curve properly, and its  $R^2$  is 0.963 as in **Fig. (2)**. But, as it is explained above that the relationship between compressive strength and UPV is a direct relationship, for this reason, it is clear that the relationship of water-cement ratio to each one of compressive strength and UPV is the same one, as in **Fig. 1** and **2** successively. In the case of the lowest average of (water-cement ratio), there is the highest value of compressive strength and UPV. But, whenever this average of water-cement ratio changes; a big opposite change happens directly in both compressive strength and UPV. But, due to the other values of the average of the water-cement ratio which are very close to each other, the opposite change of compressive strength and UPV changes gradually. It is clear in this part that the relationship between compressive strength and UPV changes directly as it is clear above. Therefore, the effect of water-cement ratio on compressive strength and UPV is the same, as shown in **Fig. 3**. It is interesting to say that the concrete C25 of the center CEYLAN is the in first position in its quality, due to the low average of the water-cement ratio which is (0.48).





#### 4. CONCLUSIONS

It is confirmed that the relationship between compressive strength and UPV is a direct one. And, the low average of water-cement ratio causes the increase in the value of each one of compressive strength and UPVT measurements, and it makes the quality better.

Also, the quality of the concrete from all four centers used is of good quality. The concrete from the center CEYLAN C25 came first in its quality for its high strength, and in the velocity of the ultrasonic wave through the concrete, due to the low average of water-cement ratio. It is important to give these proposals:

Using the UPV technique on other factors which affect the compressive strength of concrete.

And it is also important to propose to take different rates, more or less than those of the water-cement ratio of this research and to indicate the effect of such different rates on each of the two tests.

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