# Evaluation of Correlative Factors between Destructive and Non- Destructive Tests of Concrete

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## Abstract:

The assessment of new and old structures requires spending money to recognize the actual state for safe using them and to satisfy that the using of nondestructive testing become a favored tool to be applied for the function and quality control for the structures. One of the most effective and least costly methods is using Ultrasonic Pulse Velocity (UPV) method. The target of this paper is to find a mathematical relationship between the Ultrasonic Pulse Velocity (UPV) and the compressive strength of concrete. Therefore, the important variables which have a sensible effect on this relationship shall be investigated. These parameters include the test type of UPV testing method (direct, semi direct, indirect), concrete strength.

To achieve the goal of this paper, an experimental study has been conducted to preparation six different concrete mixtures (from C20 to C45) at casting the specimens which consist of 6 concrete blocks of dimension 40×40×100 cm and for each one 9 cubes are cast of size 15 cm which has been tested at ages of 7, 28, and 60 days. For the obtained results, a statistical experimental program has been carried out in order to establish a fairly accurate relation between the ultrasonic pulse velocity and the concrete compressive strength using both MathLab and Microsoft Excel programs for extracting and plotting the final relationship models.

From the obtained results, the relationships between the direct UPV, semi direct UPV, and indirect UPV in the concrete blocks and cubes with the compressive strength of concrete were found. It is found that the type of an equations is exponential type which has the similar trend of given a relationship of ACI committee 228so these results indicate that direct, semi direct, and indirect model methods can be used to assess the actual state of in-situ structures.

The direct UPV is 5% and 8.7 % higher than the average semi direct and indirect UPV respectively. Moreover, the small UPV paths give higher overestimations of concrete strength. Finally, the suggested equation in this paper is compared with the other researcher's equations to indicate the accuracy using a verification study.

**Keywords:** Concrete, Compressive strength, ND Nondestructive tests, UPV ultrasonic Pulse Velocity,Regression analysis.

**Nomenclature**

| Symbol | Description | Units |
|---|---|---|
| C | Cement | kg |
| $f_{cu}$ | Cube Concrete Strength | N/mm² |
| G | Gravel | kg |
| L | Length | m |
| S | Sand | kg |
| Sp | Super plasticizer | kg |
| T | Time | s |
| UPV | Ultrasonic Pulse Velocity | m/s |
| V | Velocity | m/s |
| W | Water | kg |
| w/c | Water Cement Ratio | ---- |
| $E$ | Dynamic elastic modulus | N/mm² |
| $\rho$ | Density | kg/m³ |
| $\mu$ | Dynamic Poisson's ratio | ---- |
| Vd | Direct Ultrasonic Pulse Velocity | m/s |
| Vs | Semi Direct Ultrasonic Pulse Velocity | m/s |
| Vi | Indirect Ultrasonic Pulse Velocity | m/s |

**Subscript**

**d= direct, s=semi direct, i=indirect**

## 1. Introduction:

Different non-destructive test (NDT) methods have been developed for determining the elastic and mechanical properties of concrete so that the using of these methods is not disturbing the ability of tested structures to perform their planned functions. Ultrasonic Pulse Velocity (UPV) is considered as the main nondestructive method of testing of the concrete quality, homogeneity, and compressive strength of existing structures. It is applicable to both new and existing structures in which the principal application for new structures is for quality control while for old structures is for the assessment of structural integrity (Grawford, 1997).

The story of NDT methods was started at 1930s when several tests had been proposed for use in laboratory-tested specimens. Later, in World War II a great accelerated of sonic method had been done in England and Canada at the same time. Since 1960s, pulse velocity equipment had been moved from the laboratory to the field. Many researchers have made an extensive survey about UPV method such as (Malhotra, 1976) who has compiled an extensive list of papers published on this subject and (Leshchinsky, 1991) who summarized the advantages of nondestructive tests.

Many nations have adopted standardized procedures to measure the pulse velocity in concrete such as (RILEM, 1972), (ASTM C 597, 2003),(ACI Committee 228, 2003),(BS 1881-203, 1986), and (BS EN 12504-4, 2004).

The UPV method is applicable for many purposes corresponding to assess the uniformity and relative quality of concrete, to indicate the presence of voids and cracks, to estimate micro crack growth in concrete and hence to study mechanical damage to evaluate the changes in the properties of concrete, and in the survey of structures, to estimate the severity of deterioration or cracking, to determine member dimensions, to locate of cracking, to find deboned, to discover voids and honeycomb, to confirm the state of surface hardness and surface absorption, to determine steel reinforcement location and size, to define corrosion activity of reinforcement, and extent of damage from freezing and thawing, fire, or aggressive chemical environment, density, dynamic modulus of elasticity and Poison's ratio(Bungey, 2006) and (Helal et al., 2015). But the most important using of the pulse velocity method it is to estimate the strength of concrete test specimens and in-place concrete (ACI Committee 228, 2003).

Because many factors the concrete compressive strength test results in the laboratory might not be representative for the in situ cast concrete such as concrete transportation, placement, tamping, and curing, in other words, pulse velocity measurements relate directly to the concrete in the structure rather than to laboratory (Rajan and Amarsinh, 2013). Consequently, the other procedure is to carry out the core tests which provide the most reliable in-situ strength assessment but also cause the most damage, slow , and more expensive noting that in some conditions the core test is not applicable. The benefits of UPV test than core test is given by (Leshchinsky, 1991) such as a reduction in the labor consumption of testing, a decrease in labor consumption of preparatory work, a smaller amount of structural damage, a possibility of testing concrete strength in structures where cores cannot be drilled and application of less expensive testing equipment, as compared to core testing. These benefits are of no value if the results are not represented as close as possible to the actual strength of the tested part of the structure.

A typical relationship between pulse velocity and compressive strength of a given concrete mixture is given by (ACI Committee 228, 2003) but this relationship is influenced by a number of factors such as the type of cement, cement content, added admixtures, type and size of aggregate, curing conditions, moisture content, age of concrete, temperature of the concrete, shape and size of specimen, and length of path used for velocity measurement (Nivelle, 2005), therefore a caution should be exercised when attempting to express the results of the pulse velocity tests in terms of strengths or elastic properties. Additional problem of applicable UPV test in real structure is the presence reinforcement bars which cause increasing in the pulse velocity values because the pulse velocity in steel is up to double that in concrete, the pulse-velocity measured in the vicinity of the reinforcing steel will be higher than in plain concrete of the same composition. Hence, where possible, avoid measurements close to steel parallel to the direction of pulse propagation (Andrew et al., 2005).

For decades, many researchers investigated UPV strength relationship and a number of different empirical equations have been proposed for different types of materials in order to overcome the above limitations, the test results have to be correlated with the outcomes of destructive tests and (Baqer, 2008) listed some of them.

The aim of this research is to find an empirical relationship, in some references called model or equation, between UPV and the concrete strength for the normally cured concrete blocks without presence of reinforcement bars in order to take inherent clear picture about the main variables which affect the relationship between UPV and concrete strength. (ACI Committee 228, 2003) gives a typical nonlinear trend for UPV – concrete strength relationship but it is not obviously speaking about the nature of this relation, i.e. the kind of curve (polynomials, exponential, power, or another type) in other side, some studies give a linear relationship such as (Turgut and Kucuk, 2006) and (Mahure, 2011) while other adopts a exponential relationship as (Baqer, 2008).And here in these variables involve the test type of UPV testing method (direct, semi direct, indirect), concrete strength, age of tested specimens, and the specimen size. Below some work in previous literature made use of the ultrasonic Pulse Velocity (UPV) of concrete to predict compressive strength is given in many references and below some examples of these works.

(Galan, 1967) reported a regression analysis to predict compressive strength of concrete based on sound characteristics like UPV and estimated concrete strength.

(Sturrup et al., 1984) investigated the relationship between the ultrasonic pulse velocity (UPV) and the compressive strength of concrete with varied aggregate contents from 1000 to 1400 kg/m³in which the UPV measurement and compressive strength tests were carried out at the concrete age of 28 days. The experimental results show that the relationship between UPV and the compressive strength of concrete is significantly influenced by the coarse aggregate content.

(Carino, 1994) reported a brief history of nondestructive testing of hard concrete over 50 years and his work was contributed to the Malhotra effort in 1971.

(Turgut, and Kucuk, 2006)2006 conducted an experimental study to compare direct, indirect and semi-direct ultrasonic pulse velocity (UPV) measurements on a total of 30 concrete blocks came from different mix batches and have different cube compressive strengths. The correlations are established between the direct UPV and indirect UPV in the concrete casting direction as well as in the horizontal direction and semi-direct UPV measurements via statistical analysis.

(Baqer, 2008)conducted a statistical experimental program in order to establish a fairly accurate relation between the ultrasonic pulse velocity and the concrete compressive strength by investigation some factors such as the concrete mix properties, the direction (direct and indirect method) of velocity measurement, curing method, and salt content.

(Mahureet.al.,2011)studied variables which affected the relationship between the ultrasonic pulse velocity (UPV) and the compressive strength of concrete. Some variables had been found a reassemble influence on this relationship, such as the cement content, water-cement ratios (w/c), coarse aggregate contents and quality, and age of tested specimens.

(Bayan et al., 2015)investigated the relationship between the ultrasonic pulse velocity (UPV) and the compressive strength of concrete. The specimens used in the study were made of concrete with a varied cube compressive strength from 18 to 55MPa. Number of specimens were over 800 received from various construction projects of controlled concrete quality and tested by the Hawler Construction Laboratories (HCLabs) in Erbil, Kurdistan Region of Iraq, during the last half of 2014.

(Raoet.al.,2016) presented an experimental investigation result of Ultrasonic Pulse Velocity(UPV) testing conducted on Roller compacted concrete (RCC) containing Ground Granulated Blast furnace Slag(GGBS) as mineral admixture. The UPV was determined at the ages of 24 hours, 3 days, 7 days, 14 days, 28 days and 90 days for seven RCC mixtures using cube specimens of plain and GGBS Roller Compacted Concrete (GRCC). Relationship between strength of GRCC and UPV was proposed.

## 2. Methodology

Many standards of practice illustrate the UPV test procedure similar as (ASTM C 597, 2003), (ACI Committee 228, 2003),and (BS 1881-203, 1986). The UPV principle is based on the propagation of stress waves through the solid material and this is done by introducing a pulse in the concrete using a pulse generator and transmitter. A receiver detects a transmitted pulse and the travel time is measured through the concrete.

Since the direction of maximum energy is propagated is at right angles to the face of the transmitting transducer, but in many cases it is possible to detect pulses, which have travelled through the concrete in some other direction. Therefore, a pulse measurement can be used quite satisfactorily by placing the two transducers on either opposite faces (direct transmission), or adjacent faces (semi-direct transmission), or the same face (indirect or surface transmission) as shown in Fig 1.For direct and semi direct method, the pulse velocity (V) is estimated from the following equation:

$$V = L / T \quad \text{------------------------------------------ } 1$$

Where L is the distance of pulse travelled over a known distance from the transmitter to the receiver and T is the corresponding travel time. For indirect method, the procedure of clause 6.4 of (BS 1881-203, 1986) is used.

The relation between elastic constants and the velocity of an ultrasonic pulse traveling in concrete is described in (BS 1881-203, 1986) by the following equation by assuming the concrete as an isotropic elastic medium of infinite dimension:

$$E = \rho \cdot V^2 \cdot \frac{(1+\mu)\cdot(1-2\mu)}{1-\mu} \quad \text{------------------------------------------}2$$

where E=is the dynamic elastic modulus in N/mm²,

$\rho$ = is the density in kg/m³,

$V$= is the pulse velocity in Km/Sec, and

$\mu$ =is the dynamic Poisson's ratio.

Portable Ultrasonic Non-destructive Digital Indicating Test (PUNDIT) is used for this work in which transducers with a frequency of 54 kHz are selected for test applications.

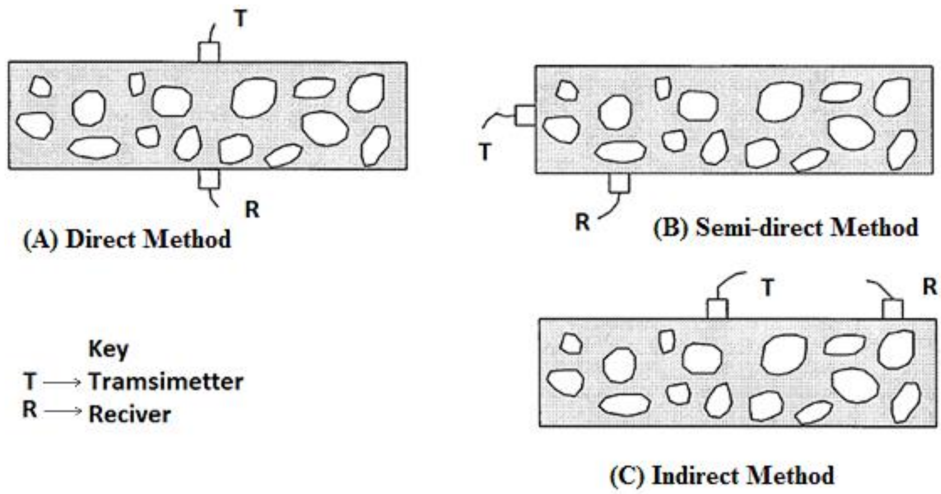


**Fig. 1 Methods of propagating and receiving ultrasonic pulse velocity**

## 3. Experimental Work

To achieve the paper goal, an experimental program is employed, which involved casting of concrete blocks and cubes from different six mixtures as illustrated in the following paragraphs.

### 3.1 Material

The materials were used in present paper involved the ordinary Portland cement compatible with (ASTM C150, 2004) requirements and both concrete aggregate (fine and coarse) were compatible with (ASTM C33, 2003)requirements in which the maximum size of the coarse is 20 mm while the fine aggregate had a fineness modulus of 2.80. The drinking water and free from impurities was used. The Polycarp Oxig base on type super plasticizer was used.

### 3.2 Mix Design

Concrete ingredients of aggregates, cement, additive and water were mixed in laboratory horizontal drumming mixer of size 0.25 m³. The design slump would be limited from 100 to 150 mm and the mix job components are given in table 1.

**Table 1 the components of 6 mixtures used in the paper**

| Class | w/c | Mix materials quantities (kg) | | | | Super Plasticizer % of cement weight |
|---|---|---|---|---|---|---|
| | | W | C | S | G | |
| C20 | 0.54 | 189 | 350 | 780 | 1081 | 0.70 |
| C25 | 0.51 | 187 | 370 | 775 | 1072 | 0.80 |
| C30 | 0.46 | 185 | 400 | 760 | 1055 | 0.85 |
| C35 | 0.44 | 183 | 417 | 735 | 1065 | 1.00 |
| C40 | 0.40 | 180 | 450 | 710 | 1060 | 1.20 |
| C45 | 0.38 | 178 | 467 | 700 | 1055 | 1.50 |

### 3.3 Specimen Preparations

Six concrete blocks (sometimes-called prisms or plain beams) of dimensions (0.40×0.40×1.00) m were cast through three layers and compacted mechanical vibrator, later cubes and the specimens were cured in wet condition for seven days. After that, the specimens were kept in laboratory air for more than 7 days, then stay in laboratory. For each beam, 9 cubes of dimensions 150x150 x150 mm are cast in steel molds and kept in their molds about approximately 24 hours in the laboratory which both are made from the same concrete mixture so that the total concrete cast work is six beams with 54 cubes. The concrete specimens (blocks and cubes) are being cured in the open weather like the actual weather in situ.

### 3.4 Test procedures

The present study involves 6 concrete mixes (C20, C25, C30, C35, C40, and C45) in which for each mix 9 cubes were casted. For each block, 6 points were selected to be taken for the UPV test so that on each one under consideration a three UPV methods of measurements (direct, semi direct, indirect) at three different ages (7, 28, 60 days) is employed. Therefore, for each mix, the total UPV values are 30 results at each age in which 18 values (6 direct, 6 semi direct, 6 indirect) for concrete blocks and 12 values (6 direct, 6 semi direct) values for concrete cubes and consequently the total UPV values during three ages (7, 28, 60) days were 90 values and consequently the research involved 540 UPV test results divided to 324 results associated the concrete blocks and 216 results for its cubes. The compressive cube test was 54 test results which divided into 9 results for each concrete mixture (3 at each age).

The measurements of the ultrasonic pulse velocity were made to both the concrete specimens (blocks and cubes)by using (BS 1881-203, 1986)at three ages of 7, 28, and 60 days due to the importance of these ages in assessing of concrete strength for the most standards and particular projects. The cubes were tested for determining compressive strength accordance with (BS 1881-116, 1983). In order to reduce the possibility of errors occur which caused by concrete heterogeneity, it is preferable to average the UPV value by the reversing of a pulse generator and transmitter location. In addition, the ultrasound wave path is maximized as possible. The sample of UPV measurements is shown in Fig 2.

**Fig.2: Photographs for sample UPV measurements related to the concrete block.**

## 4. Results and Discussion

In this paper, the statistical methods were carried out to interpretation and description the test results relationships and applicable standard tools. The regression analysis method was used in the analysis results of the process by using MATHCAD 2000 professional and Microsoft Excel 2010 whereas these programs depend on least square theory in the analysis process.

The paper results are summarized in Tables 2 which shows the UPV values for concrete blocks and in similar manner Table 3 for concrete cubes. In addition, Table 3 displays the ratios between UPV methods for the concrete blocks whereas Table 4 shows the ratio of direct and semi direct UPV results at three testing age. Finally, Table 5 shows the comparison between the concrete blocks UPV with the concrete cubes at three testing ages. The results and its discussions are divided into four sections which are given in the following paragraphs.

### 4.1 Evaluation of Correlative Factors

The results of table 2 and 3 at age 28 days are plotted to display the relationship between average UPV values of the concrete blocks for each mix and cubes crushing strength using three measurement methods.

Figure 3 demonstrates the approximately relationship between UPV values of the concrete blocks using direct, semi direct, and indirect method with cube strength at 28days whereas figure 4 shows the same relationship between UPV values of the concrete cubes using direct, and semi direct method with cube strength at 28days.

In figure 3, the relationships are gained with the good correlation factor and this curve takes the exponential model type which is convenient for many studies. The gotten relationships are compatible and conformed with the general guidelines of the (ACI Committee 228, 2003). Also, from figure 3 and 4, the results show that the concrete blocks are more correlated than the concrete cubes because of the size effect which discussed later in details.

The age affects UPV values for blocks and cubes samples under consideration on form three methods. Table 4 shows the results of the UPV values obtained from the concrete blocks for three different measurement methods. It is an important note to distinguish between two time effects on the concrete results in which the first linked to the concrete strength which is increased with time while the second is the rate of strength gained that its effect had been reflected upon UPV used method. In table 4, the average value of ratio of three methods of UPV gave approximately the same regardless of time passing and this result can be explained be the fact that the concrete strength (cement water paste) is increased in all directions by the same amount in other words its variation are naturally distributed through the member domain so that the time effect on the UPV method used can be ignored.

The relationship between UPV values from three methods at 28 day, for concrete blocks are shown in figure 4 which display a good trend for the obtained result and a linear agreement has been shown for three relationships with the correlation coefficient.

From Fig. 3 and 4, the UPV- Strength relationship has a similar trend for all types of the UPV values regardless of type method of measurement or the specimen size. Table 5 display the ratio UPV values from concrete cubes using the direct and demi direct method, also this table compare the UPV values between the concrete cubes and blocks of the same previously three aged times. It is shown from this table that the average ratio of cube/block for UPV direct and semi direct method are 6.8 and 4.1 over 60 days respectively. In addition, the UPV values for the ratio of cube direct and semi direct is higher than the block values (7.7 verses 5.0). The above results can be attributed to the difference between the path length of measurements for cube and block. For example, for UPV direct method, the cube path is 150 mm while equals to 400 mm for blocks and consequently the path ratio between them is 2.67 which leads to the fact is the longer path of waves travelling via any specimen mean the increasing the risks of wave dispersion through that specimen.

**Table 2 the UPV values for concrete blocks using 3 methods at 7, 28, 60 days**

| Mix Design | Age (Days) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7 | | | 28 | | | 60 | | |
| | Direct Method (m/sec) | Semi Method (m/sec) | Indirect Method (m/sec) | Direct Method (m/sec) | Semi Method (m/sec) | Indirect Method (m/sec) | Direct Method (m/sec) | Semi Method (m/sec) | Indirect Method (m/sec) |
| C 20 | 4288 | 4094 | 3942 | 4335 | 4166 | 4066 | 4427 | 4225.92 | 4093 |
| | 4303 | 4050 | 3913 | 4388 | 4172 | 4066 | 4422 | 4209.6 | 4087 |
| | 4158 | 4094 | 3950 | 4332 | 4196 | 4084 | 4482 | 4292.16 | 4153 |
| | 4358 | 4126 | 3980 | 4411 | 4183 | 4063 | 4502 | 4292.16 | 4168 |
| | 4390 | 4051 | 3899 | 4395 | 4156 | 4054 | 4468 | 4270.08 | 4103 |
| | 4291 | 4116 | 3960 | 4438 | 4170 | 4024 | 4463 | 4217.28 | 4088 |
| **Average** | **4298** | **4088** | **3941** | **4383** | **4174** | **4059** | **4461** | **4251** | **4115** |
| C 25 | 4422 | 4137 | 3944 | 4502 | 4286 | 4091 | 4587 | 4411.2 | 4167 |
| | 4418 | 4152 | 3969 | 4541 | 4276 | 4143 | 4580 | 4341.12 | 4214 |
| | 4369 | 4114 | 3991 | 4469 | 4261 | 4166 | 4578 | 4310.4 | 4228 |
| | 4412 | 4153 | 3940 | 4588 | 4301 | 4104 | 4590 | 4351.68 | 4169 |
| | 4420 | 4162 | 3980 | 4511 | 4285 | 4109 | 4601 | 4331.52 | 4180 |
| | 4369 | 4128 | 3960 | 4568 | 4273 | 4134 | 4621 | 4368 | 4197 |
| **Average** | **4402** | **4141** | **3964** | **4530** | **4280** | **4124** | **4593** | **4352** | **4193** |
| C 30 | 4439 | 4149 | 4014 | 4588 | 4334 | 4164 | 4620 | 4386.24 | 4228 |
| | 4334 | 4157 | 4000 | 4478 | 4338 | 4142 | 4611 | 4403.52 | 4206 |
| | 4312 | 4136 | 3983 | 4622 | 4297 | 4149 | 4632 | 4446.72 | 4219 |
| | 4422 | 4150 | 3967 | 4489 | 4312 | 4139 | 4672 | 4397.76 | 4187 |
| | 4337 | 4160 | 4005 | 4574 | 4275 | 4136 | 4588 | 4396.8 | 4200 |
| | 4445 | 4163 | 3993 | 4477 | 4359 | 4156 | 4602 | 4426.56 | 4237 |
| **Average** | **4381** | **4152** | **3994** | **4538** | **4319** | **4148** | **4621** | **4410** | **4213** |
| C 35 | 4387 | 4208 | 4056 | 4621 | 4391 | 4208 | 4672 | 4477.5605 | 4266 |
| | 4502 | 4220 | 4066 | 4632 | 4406 | 4193 | 4680 | 4470.7925 | 4251 |
| | 4374 | 4196 | 4037 | 4655 | 4415 | 4186 | 4688 | 4481.428 | 4264 |
| | 4478 | 4233 | 4052 | 4629 | 4389 | 4189 | 4671 | 4471.7593 | 4244 |
| | 4353 | 4175 | 4054 | 4477 | 4372 | 4225 | 4638 | 4448.5545 | 4268 |
| | 4395 | 4216 | 4049 | 4578 | 4422 | 4203 | 4645 | 4476.5937 | 4276 |
| **Average** | **4415** | **4208** | **4052** | **4599** | **4399** | **4201** | **4666** | **4471** | **4261** |
| C 40 | 4536 | 4351 | 4192 | 4722 | 4472 | 4307 | 4730 | 4522.592 | 4382 |
| | 4595 | 4368 | 4197 | 4750 | 4495 | 4303 | 4766 | 4553.9648 | 4387 |
| | 4571 | 4353 | 4182 | 4722 | 4479 | 4312 | 4749 | 4531.4156 | 4402 |
| | 4569 | 4382 | 4195 | 4712 | 4450 | 4311 | 4744 | 4553.9648 | 4409 |
| | 4527 | 4342 | 4161 | 4658 | 4409 | 4294 | 4778 | 4552.9844 | 4371 |
| | 4566 | 4379 | 4202 | 4713 | 4452 | 4290 | 4722 | 4531.4156 | 4386 |
| **Average** | **4561** | **4362** | **4188** | **4713** | **4459** | **4303** | **4748** | **4541** | **4389** |
| C 45 | 4657 | 4467 | 4245 | 4875 | 4540 | 4350 | 4902 | 4629.12 | 4409 |
| | 4711 | 4504 | 4252 | 4889 | 4570 | 4373 | 4914 | 4637.76 | 4449 |
| | 4700 | 4477 | 4249 | 4867 | 4565 | 4384 | 4895 | 4641.6 | 4453 |
| | 4679 | 4488 | 4221 | 4880 | 4559 | 4374 | 4923 | 4648.32 | 4438 |
| | 4696 | 4504 | 4236 | 4892 | 4586 | 4363 | 4934 | 4656.96 | 4440 |
| | 4670 | 4479 | 4234 | 4902 | 4543 | 4390 | 4941 | 4633.92 | 4458 |
| **Average** | **4685** | **4487** | **4239** | **4884** | **4560** | **4372** | **4918** | **4641** | **4441** |

**Table 3 the UPV values for concrete cubes using 2 methods with compressive strength for cube at 7, 28, 60 days.**

| Mix Design | Age (Days) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7 | | | 28 | | | 60 | | |
| | Direct Method (m/sec) | Semi Method (m/sec) | Cube Strength (Mpa) | Direct Method (m/sec) | Semi Method (m/sec) | Cube Strength (Mpa) | Direct Method (m/sec) | Semi Method (m/sec) | Cube Strength (Mpa) |
| C 20 | 4503 | 4256 | 18.95 | 4759 | 4337 | 24.70 | 4861 | 4378 | 27.11 |
| | 4704 | 4322 | | 4784 | 4367 | | 4873 | 4390 | |
| | 4722 | 4311 | 19.24 | 4797 | 4378 | 25.25 | 4890 | 4407 | 27.62 |
| | 4682 | 4378 | | 4782 | 4437 | | 4881 | 4471 | |
| | 4711 | 4354 | 18.20 | 4803 | 4358 | 25.52 | 4856 | 4457 | 26.89 |
| | 4714 | 4383 | | 4794 | 4387 | | 4842 | 4444 | |
| **Average** | **4673** | **4334** | **18.80** | **4787** | **4377** | **25.16** | **4867** | **4425** | **27.21** |
| C 25 | 4716 | 4436 | 23.54 | 4815 | 4386 | 30.44 | 4867 | 4462 | 32.09 |
| | 4722 | 4403 | | 4779 | 4400 | | 4901 | 4484 | |
| | 4727 | 4430 | 24.11 | 4810 | 4415 | 30.96 | 4915 | 4460 | 33.76 |
| | 4733 | 4426 | | 4821 | 4440 | | 4910 | 4444 | |
| | 4738 | 4441 | 24.78 | 4834 | 4390 | 31.38 | 4878 | 4482 | 33.72 |
| | 4747 | 4407 | | 4841 | 4437 | | 4890 | 4454 | |
| **Average** | **4730** | **4424** | **24.14** | **4817** | **4411** | **30.93** | **4893** | **4464** | **33.19** |
| C 30 | 4774 | 4324 | 27.36 | 4863 | 4485 | 36.55 | 4901 | 4557 | 39.17 |
| | 4788 | 4474 | | 4849 | 4507 | | 4893 | 4511 | |
| | 4805 | 4435 | 28.67 | 4867 | 4468 | 37.09 | 4936 | 4533 | 39.25 |
| | 4778 | 4421 | | 4841 | 4477 | | 4868 | 4497 | |
| | 4768 | 4423 | 27.56 | 4876 | 4514 | 35.89 | 4924 | 4520 | 38.77 |
| | 4922 | 4379 | | 4880 | 4468 | | 4916 | 4534 | |
| **Average** | **4806** | **4409** | **27.86** | **4863** | **4486** | **36.51** | **4906** | **4525** | **39.06** |
| C 35 | 4852 | 4482 | 32.09 | 4890 | 4522 | 41.90 | 4939 | 4563 | 44.23 |
| | 4841 | 4495 | | 4896 | 4530 | | 4921 | 4589 | |
| | 4863 | 4504 | 33.89 | 4907 | 4491 | 41.11 | 4943 | 4622 | 45.87 |
| | 4836 | 4494 | | 4893 | 4542 | | 4921 | 4578 | |
| | 4822 | 4503 | 34.51 | 4905 | 4532 | 42.78 | 4939 | 4529 | 45.95 |
| | 4789 | 4519 | | 4911 | 4491 | | 4932 | 4578 | |
| **Average** | **4834** | **4499** | **33.50** | **4900** | **4518** | **41.93** | **4932** | **4577** | **45.35** |
| C 40 | 4911 | 4524 | 36.87 | 5040 | 4678 | 45.66 | 5076 | 4668 | 48.55 |
| | 4932 | 4554 | | 5002 | 4697 | | 5095 | 4650 | |
| | 4957 | 4561 | 35.23 | 5037 | 4712 | 44.98 | 5081 | 4709 | 48.27 |
| | 4902 | 4534 | | 4990 | 4657 | | 5057 | 4660 | |
| | 4912 | 4576 | 35.79 | 5011 | 4679 | 46.75 | 5083 | 4744 | 48.97 |
| | 4987 | 4547 | | 5048 | 4653 | | 5110 | 4758 | |
| **Average** | **4933** | **4549** | **35.96** | **5021** | **4679** | **45.80** | **5084** | **4698** | **48.60** |
| C 45 | 4973 | 4655 | 40.23 | 5128 | 4700 | 52.89 | 5197 | 4809 | 56.33 |
| | 5002 | 4602 | | 5152 | 4754 | | 5214 | 4822 | |
| | 5047 | 4600 | 42.09 | 5140 | 4690 | 52.67 | 5201 | 4789 | 56.89 |
| | 4985 | 4643 | | 5100 | 4752 | | 5167 | 4833 | |
| | 5100 | 4690 | 41.74 | 5128 | 4790 | 53.77 | 5169 | 4875 | 55.78 |
| | 5047 | 4658 | | 5146 | 4766 | | 5239 | 4765 | |
| **Average** | **5026** | **4641** | **41.35** | **5133** | **4742** | **53.11** | **5198** | **4816** | **56.33** |

**Table 4 the ratios between UPV methods for the concrete blocks at age 7, 28, 60 days.**

| Mix Design | UPV Direct/Semi direct % | | | UPV Direct/Indirect % | | | UPV Semi Direct/Indirect % | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7 Day | 28 Day | 60 Day | 7 Day | 28 Day | 60 Day | 7 Day | 28 Day | 60 Day |
| C20 | 4.9 | 4.8 | 4.7 | 8.3 | 7.4 | 7.7 | 3.6 | 2.7 | 3.2 |
| C25 | 5.9 | 5.5 | 5.2 | 9.9 | 9.0 | 8.7 | 4.3 | 3.6 | 3.7 |
| C30 | 5.2 | 4.8 | 4.6 | 8.8 | 8.6 | 8.8 | 3.8 | 4.0 | 4.5 |
| C35 | 4.7 | 4.3 | 4.2 | 8.2 | 8.7 | 8.7 | 3.7 | 4.5 | 4.7 |
| C40 | 4.3 | 5.4 | 4.4 | 8.2 | 8.7 | 7.6 | 4.0 | 3.5 | 3.3 |
| C45 | 4.2 | 6.6 | 5.6 | 9.5 | 10.5 | 9.7 | 5.5 | 4.1 | 4.3 |
| Average Age | **4.9** | **5.2** | **4.8** | **8.8** | **8.8** | **8.5** | **4.2** | **3.8** | **3.9** |
| Average over 60 Day | **5.0** | | | **8.7** | | | **3.9** | | |

**Table 5 the comparison between methods for the concrete blocks UPV with the concrete cubes age 7, 28, 60 days.**

| Mix Design | UPV Cube Direct /Semi direct% | | | UPV Direct Cube/Direct Block % | | | UPV Semi Direct Cube/Block % | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7 Day | 28 Day | 60 Day | 7 Day | 28 Day | 60 Day | 7 Day | 28 Day | 60 Day |
| C20 | 7.2 | 8.5 | 9.1 | 8.0 | 8.4 | 8.4 | 5.7 | 4.6 | 3.9 |
| C25 | 6.5 | 7.4 | 8.8 | 7.0 | 6.0 | 6.1 | 6.4 | 4.0 | 2.5 |
| C30 | 8.3 | 7.7 | 7.8 | 8.8 | 6.7 | 5.8 | 5.8 | 3.7 | 2.6 |
| C35 | 6.9 | 7.8 | 7.2 | 8.7 | 6.2 | 5.4 | 6.5 | 2.6 | 2.3 |
| C40 | 7.8 | 6.8 | 7.6 | 7.6 | 6.1 | 6.6 | 4.1 | 4.7 | 3.3 |
| C45 | 7.6 | 7.6 | 7.4 | 6.8 | 4.8 | 5.4 | 3.3 | 3.8 | 3.6 |
| Average Age | **7.4** | **7.7** | **8.0** | **7.8** | **6.4** | **6.3** | **5.3** | **3.9** | **3.0** |
| Average over 60 Day | **7.7** | | | **6.8** | | | **4.1** | | |

**Table 6 the summary of gotten relationships**

| Item | Description of Relationship | Relation Type | Regression Model | $R^2$ |
|---|---|---|---|---|
| 1 | Relationship between UPV values from concrete blocks using Direct method and cube strength at 28days | Exponential | $Cu = 0.0384e^{1.4957\times Vd}$ | 0.899 |
| 2 | Relationship between UPV values from concrete blocks using semi direct method and cube strength at 28days | Exponential | $Cu = 0.0072e^{1.961\times Vs}$ | 0.977 |
| 3 | Relationship between UPV values from concrete blocks using indirect method and cube strength at 28days | Exponential | $Cu = 0.0032e^{2.2293\times Vi}$ | 0.918 |
| 4 | Relationship between UPV values from concrete cubes using direct method and cube strength at 28days | Exponential | $Cu = 0.0032e^{1.9027\times Vd}$ | 0.857 |
| 5 | Relationship between UPV values from concrete cubes using semi direct method and cube strength at 28days | Exponential | $Cu = 0.0131e^{1.7559\times Vs}$ | 0.887 |
| 6 | Relationship between UPV values from direct method and Semi direct method at 28 day for concrete blocks | Linear | $Vs = 0.7379Vd + 965.13$ | 0.896 |
| 7 | Relationship between UPV values from direct method and indirect method at 28 day for concrete blocks | Linear | $Vi = 0.6216Vd + 1337.2$ | 0.875 |
| 8 | Relationship between UPV values from semi direct method and indirect method at 28 day for concrete blocks | Linear | $Vi=0.9623Vs$ | 0.951 |
| 9 | Relationship between UPV values from Direct method and Semi direct method at 28 day for concrete cubes | Linear | $Vs = 1.0749Vd - 752.73$ | 0.937 |

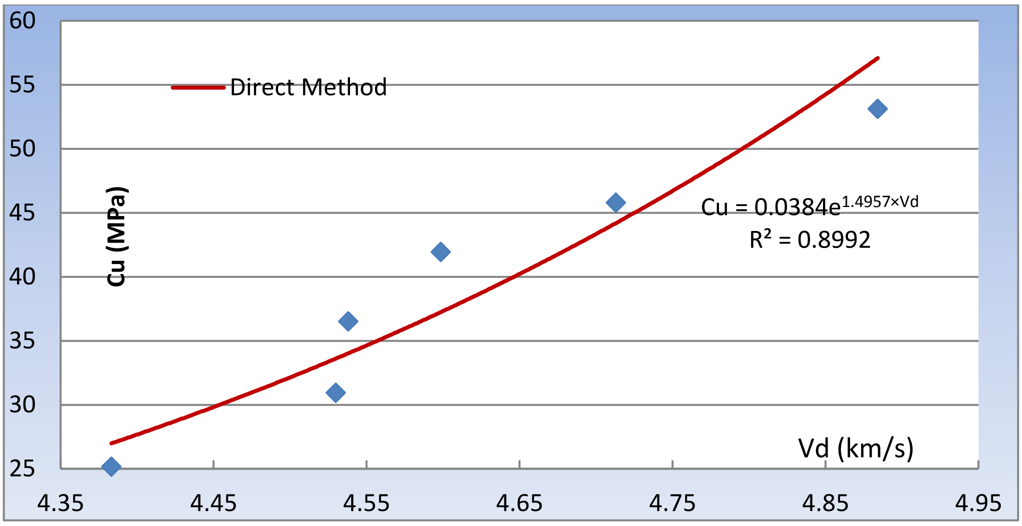


**Fig.3a: Direct method**

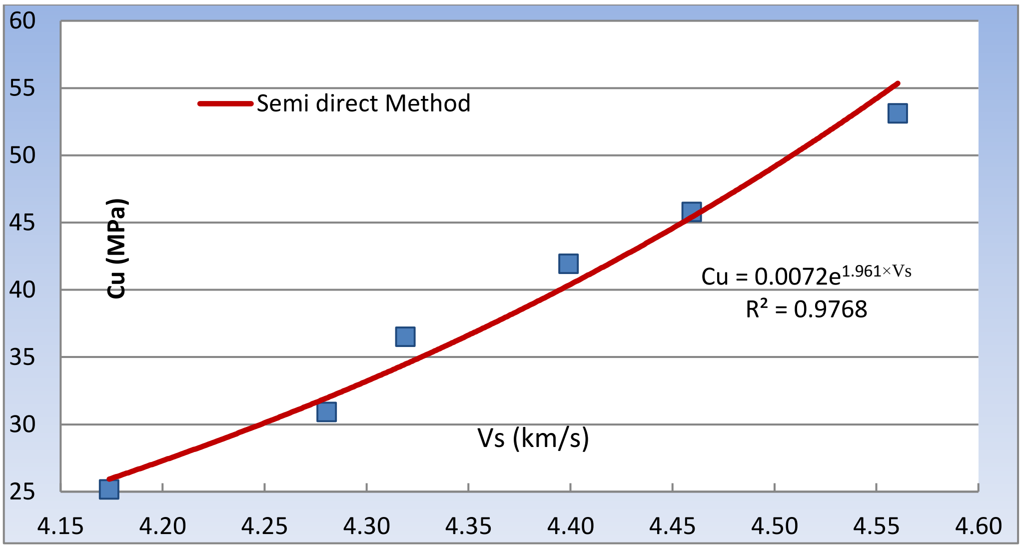


**Fig.3b: Semi direct method**

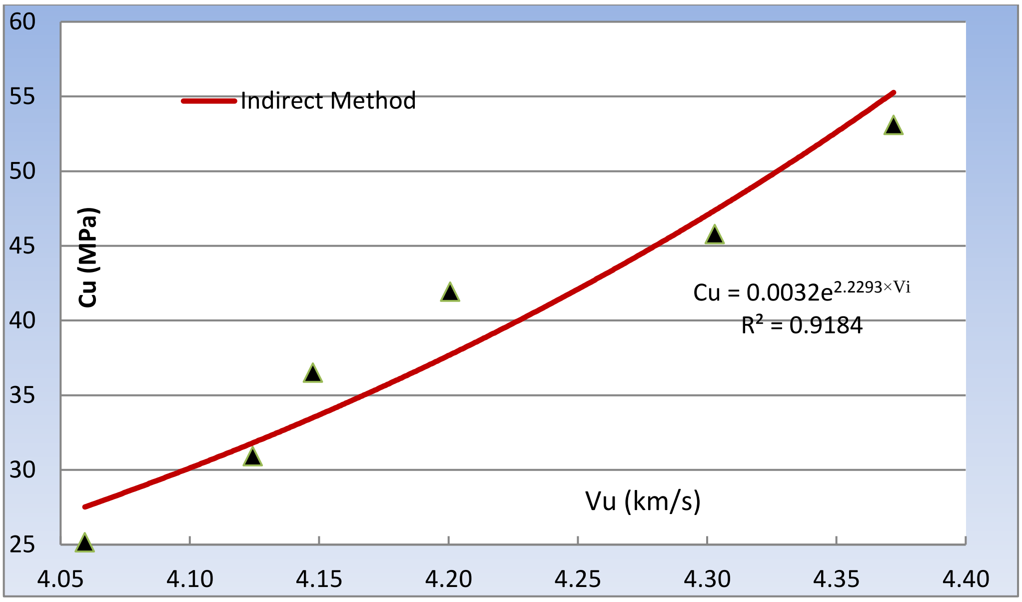


**Fig. 3c: Indirect method**

**Fig. 3: Relationship between UPV values of the concrete blocks using direct, semi direct, and indirect method with cube strength at 28days**

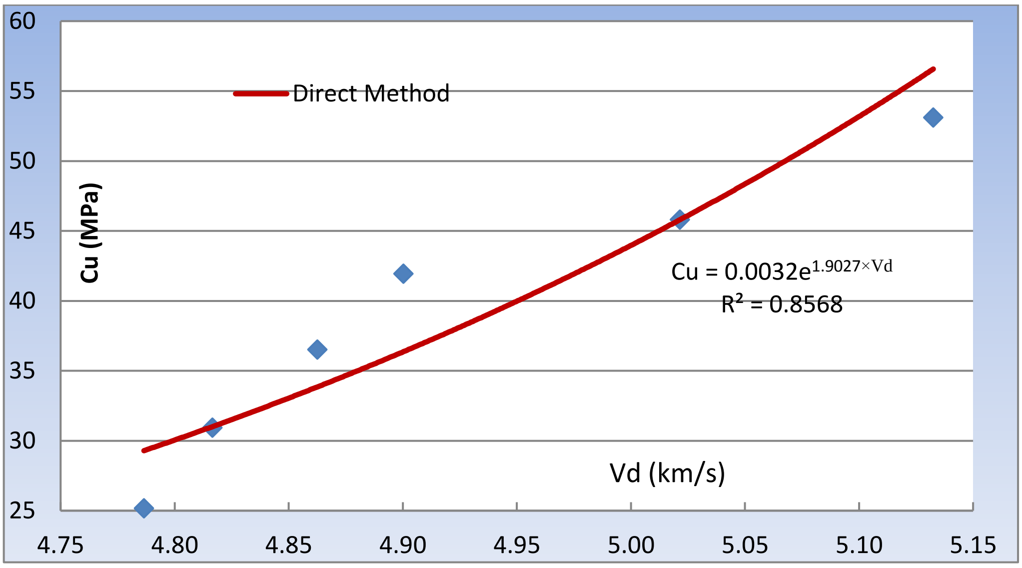


**Fig. 4a: Direct method**

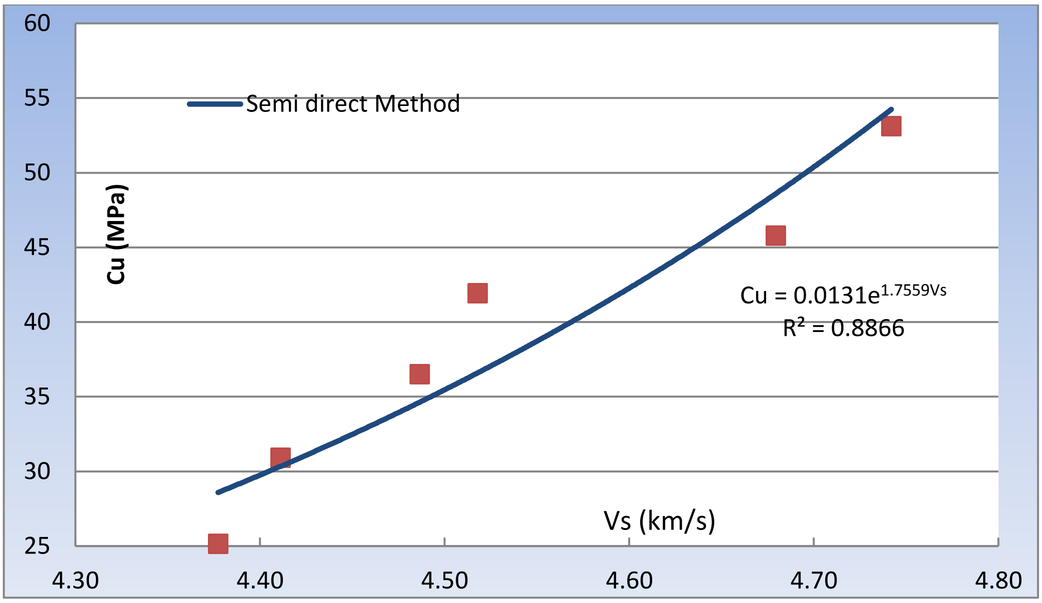


**Fig.4b: Semi direct method**

**Fig.4: Relationship between UPV values of the concrete cubes using direct, and semi direct method with cube strength at 28days**

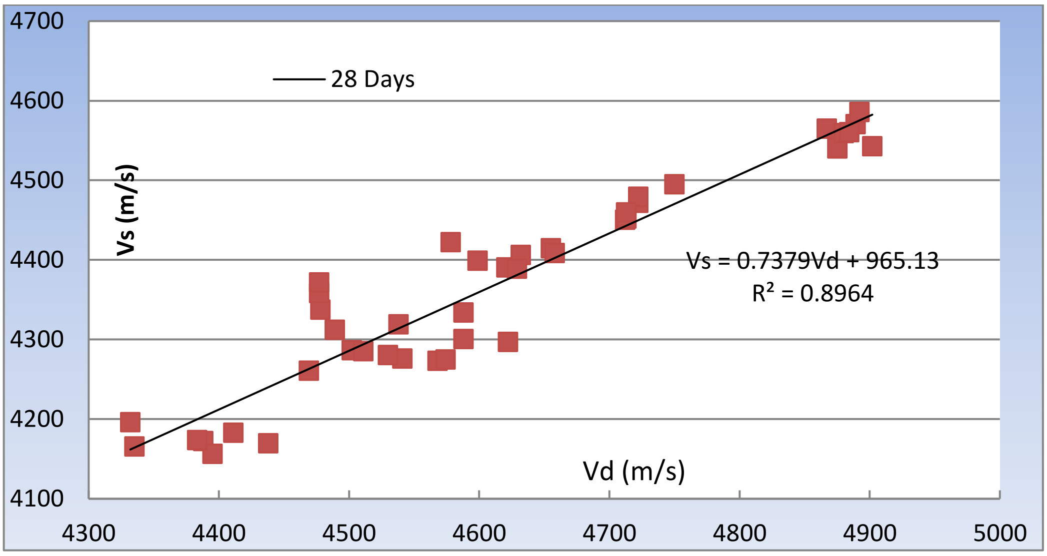


**Fig. 5.a: Direct method with Semi direct method**

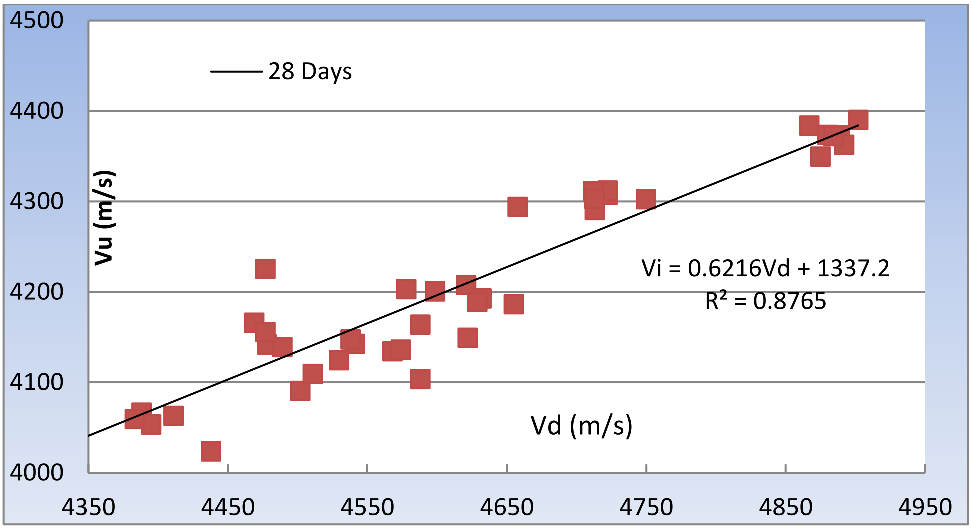


**Fig. 5b: Direct method with indirect method**

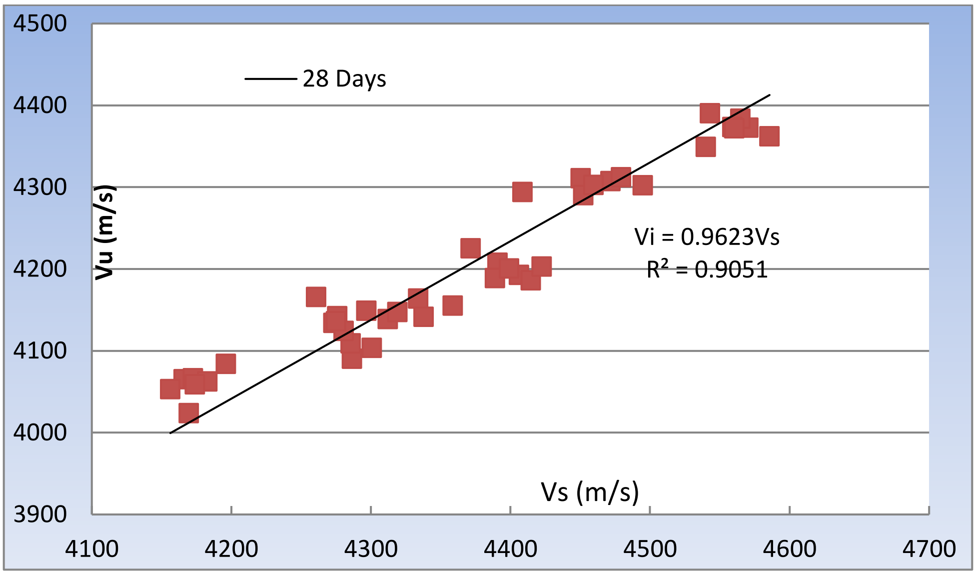


**Fig. 5c: Semi direct method with indirect method**

**Figure 5 the relationship between UPV methods for the concrete blocks at 28 days**

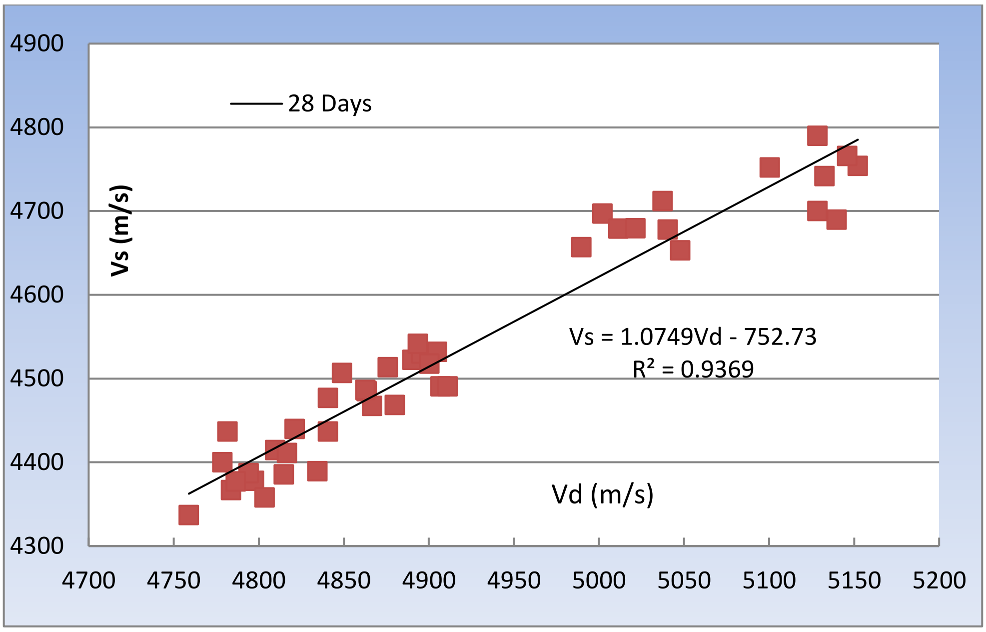


**Fig.6: Relationship between UPV values from direct method and Semi direct method at 28 day for concrete cubes**

### 4.4 Combined Effect

Figure 5 displays the relationships between UPV methods for the concrete blocks at 28 days while figure 6 relates to the concrete cubes at the same age. Figure 5 shows the development of UPV values for both the concrete blocks and cubes using direct method so that an important note is depicted which the lower is gained of UPV values during time from 7 days to 60 days compared with the cube crushing strength. As an example, UPV average increase 3.3% compared with 29.0% for cubes. This result may be explained from the different activities of the cement water pastes changing with time on both adhesions (cube strength) compared with its ability of waves travelling through it. From age 7 to 60 days in the concrete blocks, the UPV gains 4.7%, which is more than 50% than the concrete cube and this difference may be linked to size effect as illustrated earlier. The summary of gotten relationships in this paper is shown in table 5. From this table, it is clear that the semi direct method in concrete prisms is more correlated to concrete strength than direct and indirect method regardless of model type of the relationship.

## 5Verification Study

The model obtained in this study is compared with other similar trend models developed by associated researchers so in order to indicate its accuracy of applying the proposed model into real structures, an experimental study carried out by Neville(1995) which is demonstrated by [14] is taken as verification study criteria. The results of different models of Neville (1995) study are shown in figure 7 in which the paper model gives a good modulus of correlation (0.9614) than the other models (0.9607 Popovics, 0.9508 Turgut, 0.9495 Nash't, 0.9468 Raouf, 0.9447 Jones).

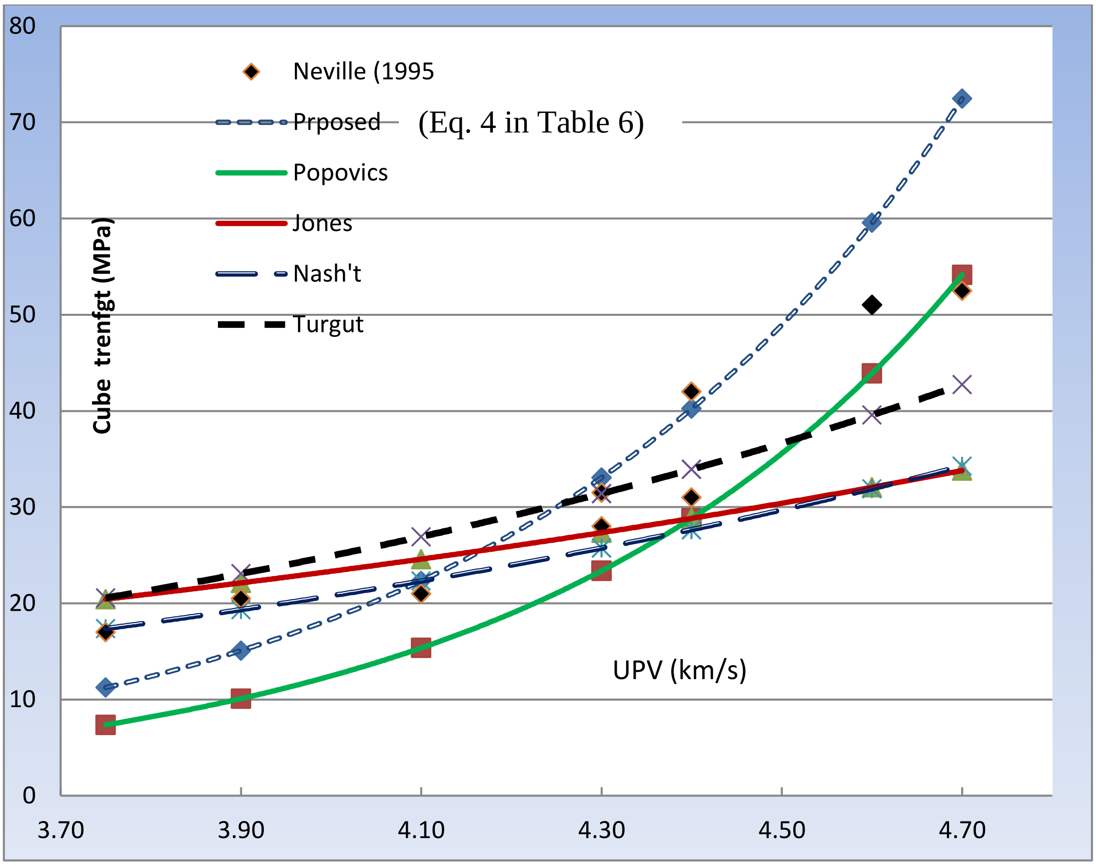


**Fig. 7: Relation between ultrasonic pulse velocity and concrete compressive strength based on the paper proposed model and researchers model.**

## 6. Conclusions

The obtained results show that the ultrasonic pulse velocity is a valuable technique for the estimation of concrete strength. From this study, the following conclusions can be summarized in the following points:

1- The different regression models, linear trend and exponential trend of equations, have been derived and developed for three UPV methods in concrete blocks and cubes which can be used for the calculation and prediction of concrete strength for a wide range of concrete strengths in the real structures during both the construction stage or under the action of service loads.

2-The semi direct method in concrete prisms is more correlated to concrete strength than direct and indirect method regardless of model type of the relationship.

3- The average direct UPV is 5% and 8.7 % higher than the average semi direct and indirect UPV respectively in concrete blocks while the average direct UPV is 7.7 % higher than the average semi direct in concrete cubes.

4- The more accurate strength correlation is conversions to direct UPV and semi-direct UPV than indirect UPV measured in concrete blocks.

5-The age effect has less influence on UPV values than the strength gained regardless of the type of UPV method used in the strength estimation because UPV average increase 3.3% compared with 29.0% for cubes during age 7 days to 60 days.

6- The size effect play an important role for controlling the accuracy of UPV results.

Small UPV paths give higher over estimations of concrete strength. A special consideration shall be given for thin concrete member.

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# تقييم العوامل الرابطة بين الفحوصات الاتلافية واللااتلافية للخرسانة

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## الخلاصة

تتطلب عملية تقييم المنشات الجديدة والقديمة إنفاق المال للتعرف على الحالة الفعلية المنشا لاستخدامه بصورة امنة من خلال استخدام الاختبارات الغير اتلافية حيث تصبح أدوات مفضلة لمراقبة كفاءة وجودة المنشات. ان إحدى الطرق الأكثر فعالية والأقل كلفة هو استخدام سرعة نبض الموجات فوق الصوتية (UPV). ان الهدف من هذا البحث هو ايجاد علاقة رياضية بين سرعة نبض الموجات فوق الصوتية وقوة انضغاط الخرسانة. لذا يتم التقصي للمتغيرات الهامة التي لها تأثير ملحوظ على هذه العلاقة اذ تشمل هذه المتغيرات نوع طريقة الفحص UPV (المباشرة، شبه المباشرة، وغير مباشرة)، ومقاومة الانضغاط.

ولتحقيق الهدف من هذه البحث لذا فقد تم إجراء دراسة تجريبية لاعداد ستة الخلطات الخراسانية المختلفة (من C20 إلى C45) التي تستخدم في صب عينات الاختبار تتكون من ٦ كتل خراسانية بابعاد ٤٠ × ٤٠ × ١٠٠ سم ولكل واحدة ٩ مكعبات بقياس ١٥ سم والتي تم اختبارها في عمر ٧، ٢٨، و٦٠ يوما. من نتائج الفحوصات المختبرية التي تم الحصول عليها تمت عملية التحليل الإحصائي لمعالجة تلك النتائج باستخدام البرنامجين MathLab وMicrosoft Excel لايجاد واستخراج العلاقات والرسوم للعلاقات الرياضية المختلفة.

وتبين نتائج الدراسة وجود علاقة بين سرعة نبض الموجات فوق الصوتية (UPV) لكل انواع الفحص وقوة انضغاط الكتل والمكعبات الخراسانية وهذه العلاقة تاخذ نوع العلاقة الاسية والتي تكون متوافقة مع نوع العلاقة المعطاة للمدونة ٢٢٨ ACIوبالنتيجة يمكن استخدام العلاقة في هذا البحث لتقييم الواقع الفعلي للمنشات. تم ملاحظة ان قيمة UPVبالطريقة المباشرة هو اعلى بنسبة ٥٪ و٨,٧٪ مقارنة بطريقتي UPVشبه المباشر، وغير مباشرة على التوالي. وعلاوة على ذلك، فإن المسارات الصغيرة لطريقة UPV تعطي تقديرات عليا لمقاومة انضغاط الخرسانة.وأخيرا، تمت مقارنة المعادلة المشتقة في هذا البحث مع معادلة باحثين آخرين للتاكد من دقة نتائج البحث باستخدام تجارب موثوقة.

**كلمات المفتاحية:** خرسانة، مقاومة انضغاط، والفحوصات غير اتلافية، سرعة نبض الموجات فوق الصوتية، وتحليل الانحدار.