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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/mm ²
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/mm ²
ρ	Density	kg/m ³
μ	Dynamic Poisson's ratio	----
V _d	Direct Ultrasonic Pulse Velocity	m/s
V _s	Semi Direct Ultrasonic Pulse Velocity	m/s
V _i	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 Poisson'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 (Baquer, 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 (Baquer, 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.

(Sturup 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/m³ in 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.

(Baquer, 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:

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

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:

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

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

ρ = is the density in kg/m³,

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

μ = 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.

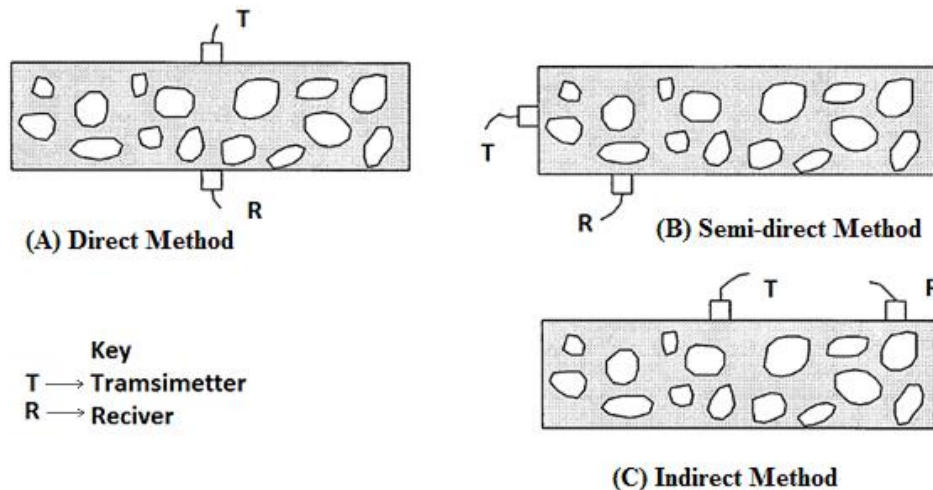


Fig. 1 Methods of propagating and receiving ultrasonic pulse velocity

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 by 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

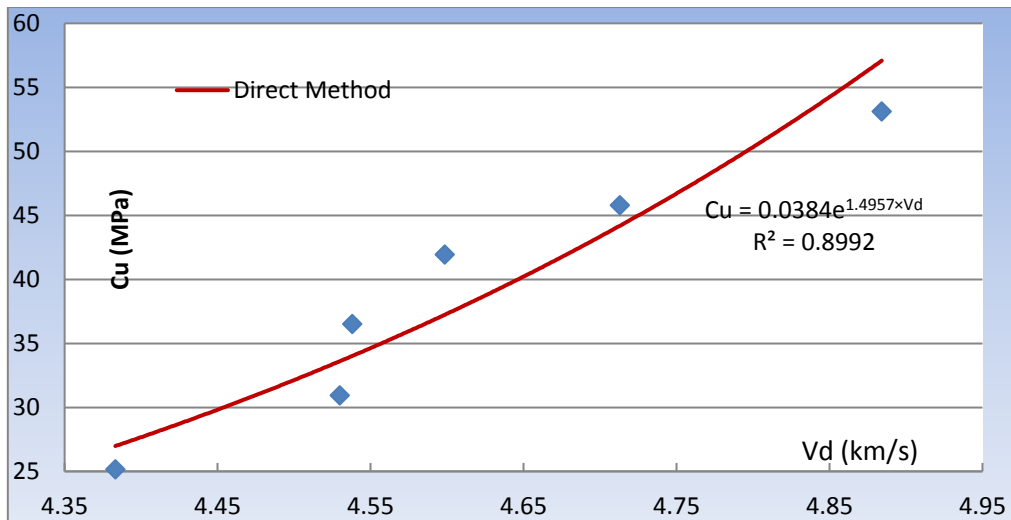


Fig.3a: Direct method

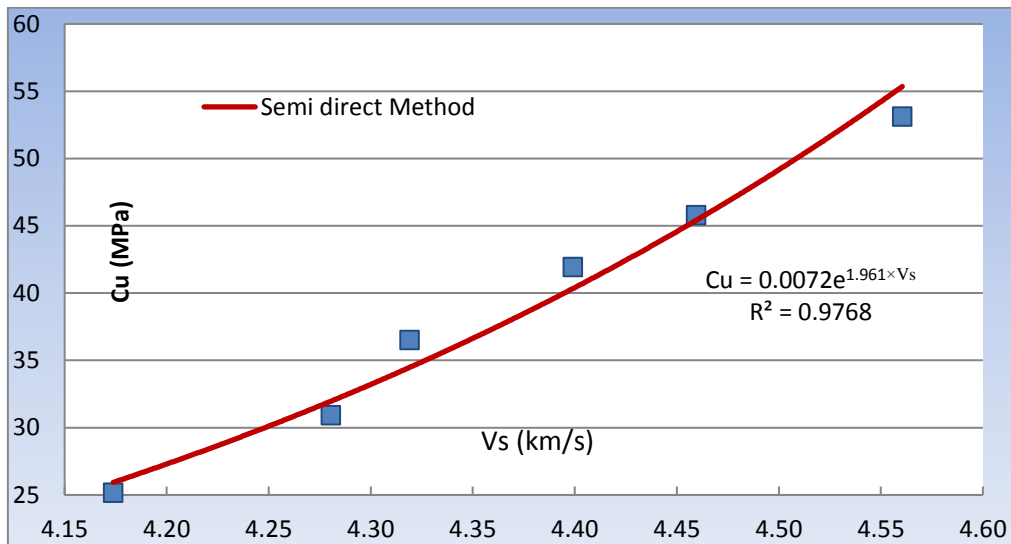


Fig.3b: Semi direct method

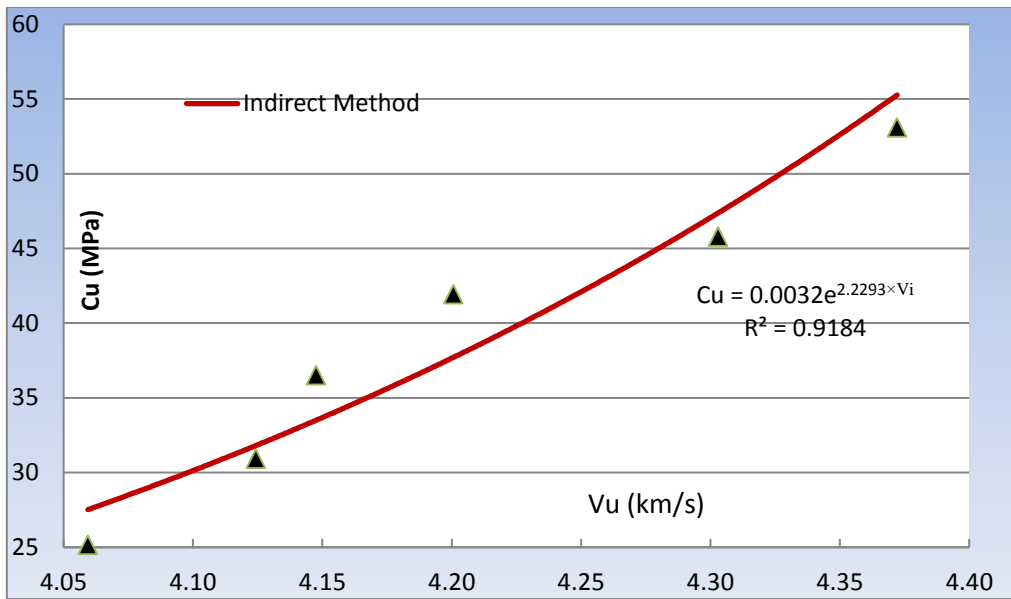


Fig. 3c: Indirect method

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

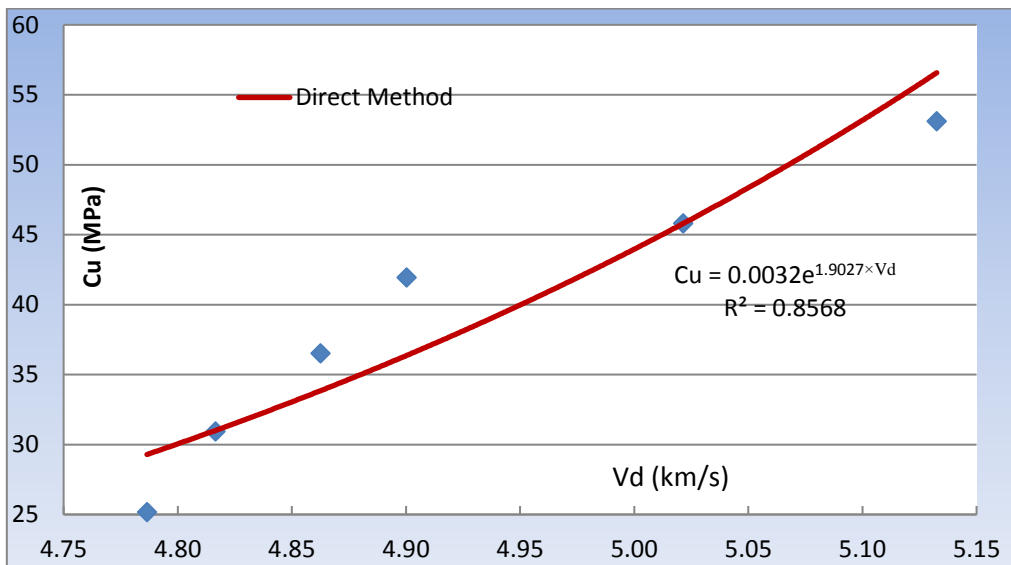


Fig. 4a: Direct method

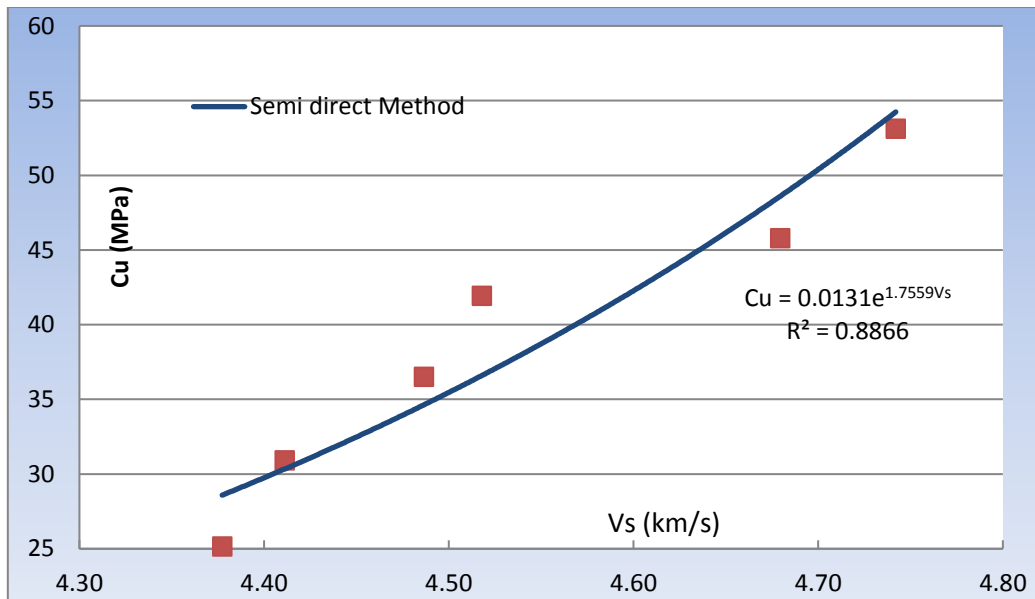


Fig.4b: Semi direct method

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

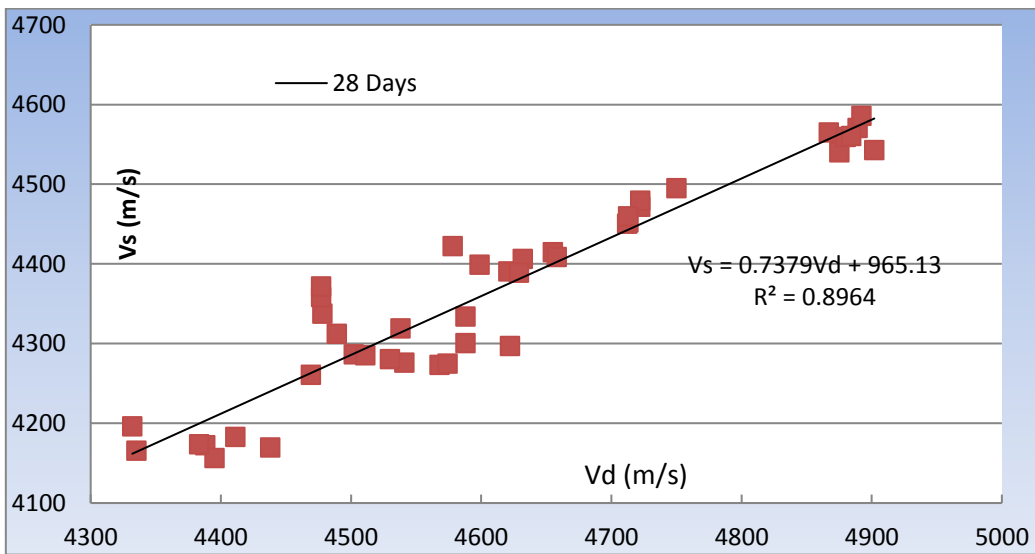


Fig. 5.a: Direct method with Semi direct method

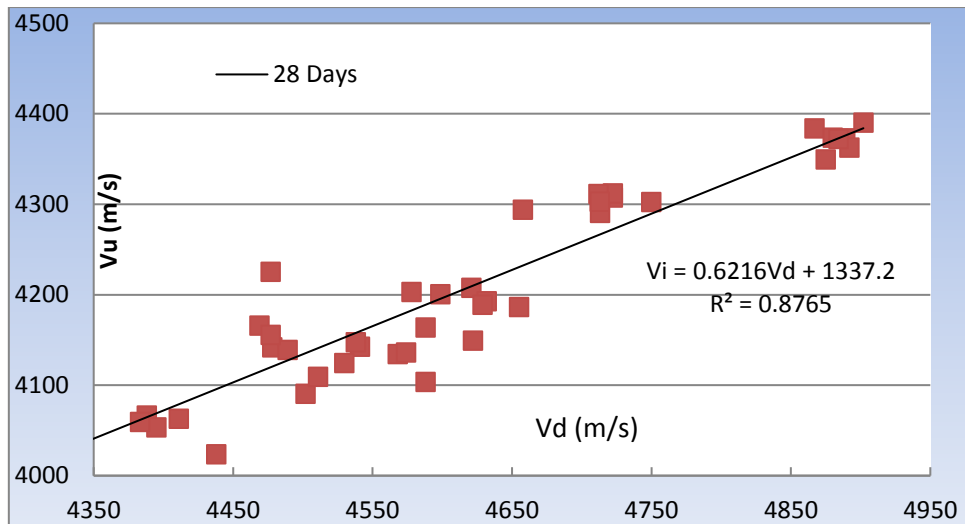


Fig. 5b: Direct method with indirect method

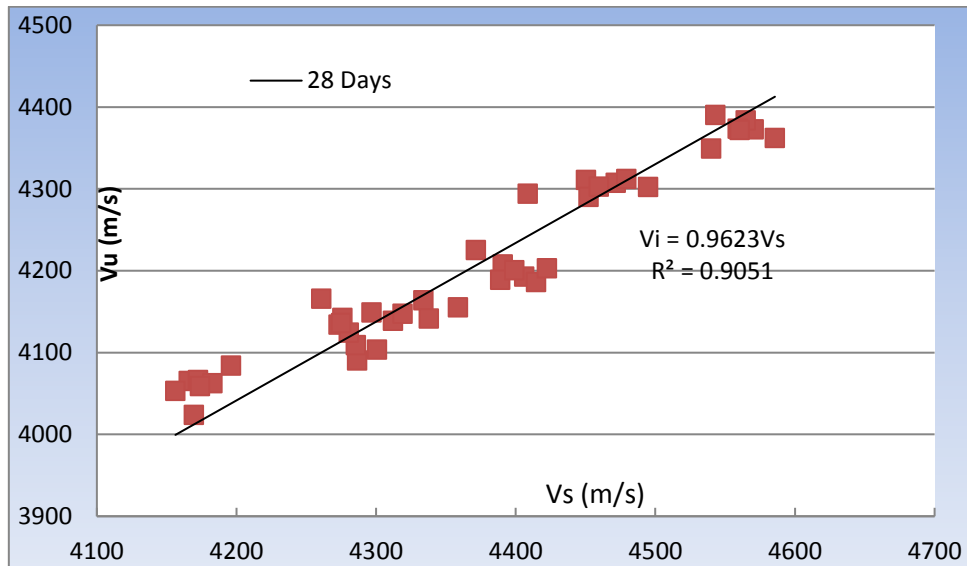


Fig. 5c: Semi direct method with indirect method

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

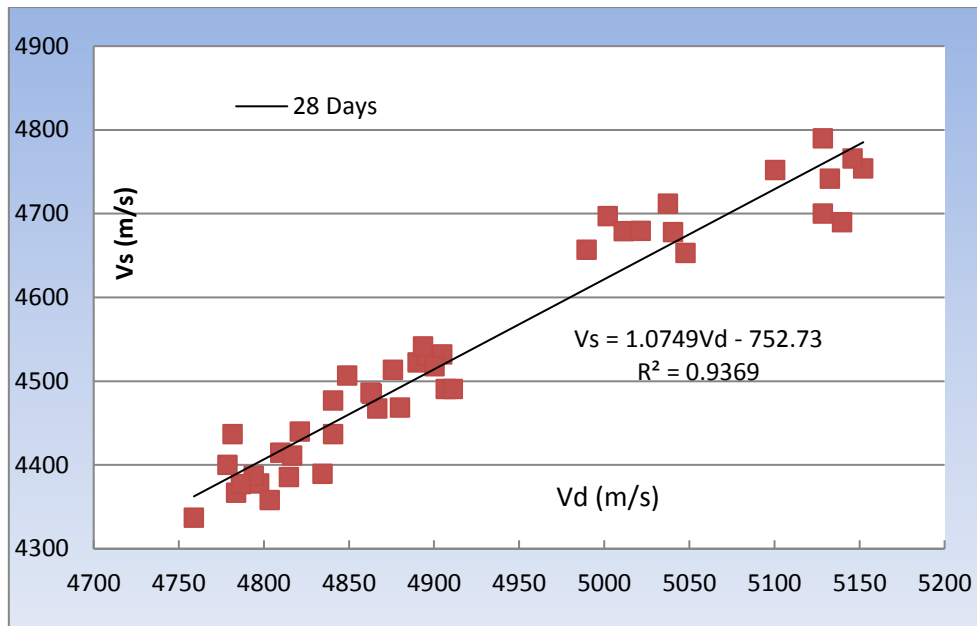


Fig.6: Relationship between UPV values from direct method and Semi direct method at 28 day for concrete cubes

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.

5 Verification 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).

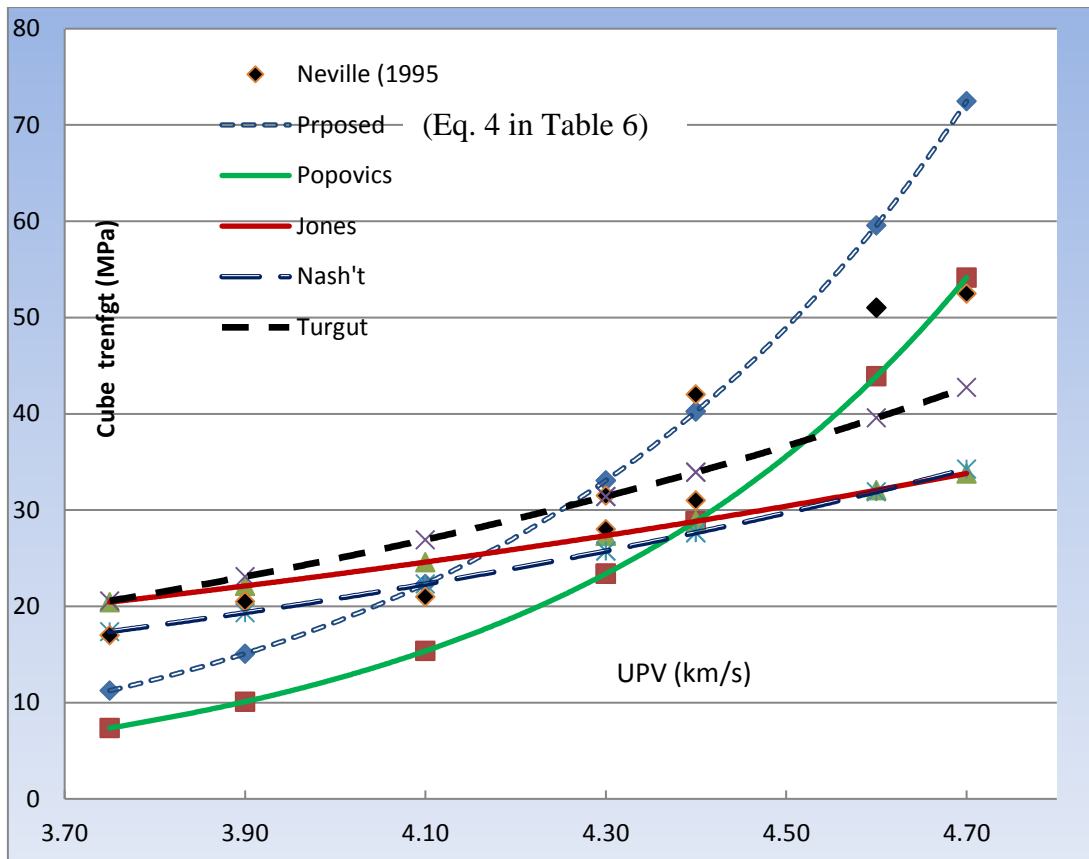


Fig. 7: Relation between ultrasonic pulse velocity and concrete compressive strength based on the paper proposed model and researchers model.

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 واللاتلافية للخرسانة

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الخلاصة

تتطلب عملية تقييم المنشآت الجديدة والقديمة إنفاق المال للتعرف على الحالة الفعلية المنشأ لاستخدامه بصورة امنة من خلال استخدام الاختبارات الغير اتلافية حيث تصبح أدوات مفضلة لمراقبة كفاءة وجودة المنشآت. 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 و Excel Microsoft 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 ACI ٢٢٨ وبالنتيجة يمكن استخدام العلاقة في هذا البحث لتقييم الواقع الفعلي للمنشآت. تم ملاحظة ان قيمة UPV بالطريقة المباشرة هو اعلى بنسبة ٥٪ و٨,٧٪ مقارنة بطريقتي UPV شبه المباشرة، 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 للتأكد من دقة نتائج البحث باستخدام تجارب موثوقة.

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