Journal of Engineering Sciences, Assiut University, Vol. 36, No. 1, pp. 51-59, January 2008

RELATIONSHIP BETWEEN ULTRASONIC PULSE VELOCITY AND STANDARD CONCRETE CUBE CRUSHING STRENGTH

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(Received September 2, 2007 Accepted October 16, 2007)

In Jordan as well as in most countries, many concrete structures are becoming old. The question of whether they are safe to be utilized by people or is it feasible to spend money to rehabilitate them, requires conducting a quality survey to assess the integrity of all critical structural items without undermining the safety of the structures. Moreover the nondestructive testing is beneficial for the quality control of new constructions.

One of the most effective and least expensive techniques is using Ultrasonic Pulse Velocity (UPV), utilizing Pulse ultrasonic nondestructive indicator tester (Pundit) - a simple non-destructive testing device – that is used to assess the integrity of the structures without causing any damage.

Thus the aim of this study is to give forth a mathematical relationship that relates UPV with standard concrete cube crushing strength (f_{cu}) in a step to reinforce the credibility of nondestructive compressive strength investigations on concrete containing local materials.

To accomplish this task, 135 standard concrete cubes of 150 mm dimensions were prepared using various concrete mixes in order to cover all types of concrete locally produced. The UPV and the relevant crushing strength for each cube were documented. Regression analysis was carried out to study the correlation among observed data. Finally a mathematical relationship between Pundit readings and the corresponding cube compressive strengths was derived.

KEYWORDS: *Nondestructive tests – Structure Evaluation – Concrete quality – ultrasonic Pulse Velocity.*

1- INTRODUCTION

It is well established that compressive strength is an excellent indicator of concrete quality. It invariably forms the most important basis of specifications and quality control. However, the conventional methods of determining compressive strength of actual structure have some limitations, typified by the inherent errors in sampling of concrete at construction site. Thus quality control using standard cube test is always doubtful as the sample may not represent the actual concrete on site. Contrary to the aforementioned, UPV has the advantage of directly testing the concrete structural elements, rather than to samples which may not be always truly representative of the concrete used in the construction process

One main advantage of non-destructive testing is that it may be applied to both new and existing structures. With respect to new structures the principal application is for quality control, whereas for existing structures non-destructive testing is carried out to assess structural integrity [1].

The UPV is influenced by those properties of concrete which determine its elastic stiffness and mechanical strength. The relation between elastic constants and the velocity of an ultrasonic pulse traveling in concrete (assumed to be an isotropic elastic medium of infinite dimension) is described in BS 1881: part 203: 1986 by the following equation:

$$Ed=\rho v^2(1+\upsilon)(1-2\upsilon)/(1-\upsilon)$$

where Ed is the dynamic elastic modulus in MN/m^2

ρ is the density in kg/m^3

v is the pulse velocity in Km/sec

υ is the dynamic Poisson's ratio.

Neville [2] reported that lack of compaction and the change in the water/cement (w/c) ratio would be easily detected by ultrasonic pulse velocity technique. Moreover, a general classification of the quality of concrete based on the pulse velocity is possible. Both type and quantity of coarse aggregate influence the pulse velocity for a constant w/c ratio; however, variation of the strength in this regard is insignificant comparatively. Thus, for different mix proportions, a different relation between strength and pulse velocity would be obtained.

Pulse velocity determination specified in all standards is based on the same principle. Three types of waves are generated by an impulse among those, longitudinal waves with particle displacement in the direction of travel are the most important, since these are the fastest and provided more information [3]. After traversing through the concrete, the pulses are received by a second transducer. There are three possible arrangements that are recommended by most of the standards; however, direct transmission is the most effective. Figure (1) shows the different arrangements of the transducers for UPV test setup.

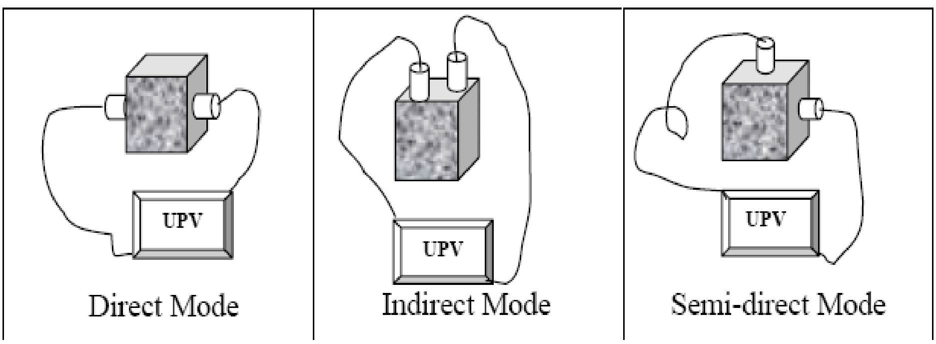

Figure (1): Different arrangement of transducers for UPV

Table (1): Standards for the determination of longitudinal ultrasonic pulse velocity in concrete

Country	Designation	Year
Belgium	NBN 15-229 1976	1976
Brazil	ABNT 18:04.08.001 1983	1983
Bulgaria	BDS 15013-80 1980	1980
Czech Republic	CSN 731371 1981	1981
Denmark	DS 423.33 1984	1984
Germany	Draft same as ISO/DIS 8047 1983	1983
Hungary	MI 07-3318 1994	1994
International	ISO/DIS 8047 1983	1983
Mexico	NOM-C-275-1986 1986	1986
Poland	PN-B-06261	1974
RILEM	NDT 1 1972	1972
Rumania	C-26-72 1972	1972
Russia	GOST 17624 1987	1987
Scandinavia	NT BUILD 213 1984	1984
Spain	UNE 83-308-86 1986	1986
Sweden	SS 137240 1983	1983
United Kingdom	BS 1881: Part 203 1986	1986
USA	ASTM C 597 1983	1983
Venezuela	COVENIN 1681-80 1980	1980
Yugoslavia	JUS U.M1.042 1982	1982

Several international standards have already recognized some of the nondestructive test techniques, especially those associated with predicting strength of the concrete. K.Komlos *et al.* [4] have summarized those standards concerned with ultrasonic pulse velocity measurements as illustrated in Table 1.

According to Giovanni et al [5], evaluation of Actual Nondestructive testing provides indirect data that can be empirically related to compressive strength by calibration with strength measurements from a number of cast specimens

Thus this study involves an experimental program that comprises carrying out non-destructive testing on 135 standard 150 mm concrete cubes using Pundit, and thereafter applying destructive testing on these cubes using compression testing machine. The standard concrete cubes had been prepared with various mix proportions intended to yield crushing strengths (f_{cu}) within a range of 10 to 50 MPa; a measure intended to duplicate strengths found in construction practice.

Regression analysis was carried out to investigate the correlation and how significant is the relationship between the pulse velocity utilizing Pundit and crushing strength of standard concrete cube. The fit of chosen curve was evaluated, prior to finally deriving the mathematical relationship.

2- RESEARCH SIGNIFICANCE

In Jordan as well as in most countries many concrete structures are becoming old. The question of whether they are safe to be utilized by people or it is feasible to spend money to rehabilitate them, requires conducting a quality survey to assess the integrity of all critical structural items without undermining the safety of the structures. One of the most effective tools is nondestructive testing using UPV technique. Thus the objective of this study is to give forth a mathematical relationship that relates UPV with standard concrete cube crushing strength (f_{cu}) in a step that will assert the credibility of nondestructive investigations on concrete containing local materials.

3- EXPERIMENTAL PROGRAM

3.1- Materials

A representative sample of the construction materials used in Jordan was randomly collected and used to prepare the concrete cubes. Their properties are summarized in Tables (1) to (4).

3.1.1- Cement

Table (2): Cement chemical analysis

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	L.O.I.	I.R.	F. LIME	CHLORIDE
Percentage by weight	19.64	5.04	3.20	63.91	3.12	3.10	0.63	0.08	1.52	0.32	122.0	0.01

Table (3): Cement physical characteristics

Specific gravity	3.1
Fineness modulus	89%
Strength after 28 days (MPa)	53.9

3.1.2- Fine aggregate

Locally available suweileh sand was used, having properties shown in table below:

Table (4): Properties of Suweileh Sand

Specific gravity	2.4
Absorption	1.9 %
Fineness modulus	2.97

3.1.3- Coarse aggregate

Locally used crushed limestone was used, having properties shown in table below:

Table (5) Properties of limestone coarse aggregates

Abrasion	25.65 %
Impact factor	13.1 %
Bulk Specific gravity	2.7
Absorption	3.2 %
Maximum nominal size	2 cm

3.2- Experimental work

Concrete ingredients of aggregates, cement, and water were mixed in laboratory horizontal drum mixer of size 0.25 cu.m. In order to reduce the impact of confounding variables that might influence the results, certain factors were kept constant such as compaction method, specimen size, age, Portland cement and crushed limestone. An amount of 135 standard 150 mm Concrete cubes were prepared for testing. At age of 28 days and in accordance with B.S. 1881[6], UPV readings were recorded for sides which have been lying sideward during concreting.

Table (6) Experimental values of UPV, (f_{cu}) and calculated values of (f_{cu})

		Exp*	Calc**			Exp*	Calc**
	UPV	fcu	fcu		UPV	fcu	fcu
#	Km/s	MPa	MPa	#	Km/s	MPa	MPa
1	4.262	11.1	24.0	28	4.114	19.0	19.2
2	4.060	13.3	17.7	29	4.060	20.0	17.7
3	4.135	12.4	19.8	30	4.228	22.0	22.9
4	4.025	12.0	16.7	31	4.032	17.3	16.9
5	3.990	11.1	15.8	32	4.034	18.7	17.0
6	3.940	12.9	14.6	33	4.115	21.3	19.3
7	3.809	8.9	11.8	34	4.060	18.7	17.7
8	3.990	8.4	15.8	35	4.152	20.0	20.4
9	3.873	11.6	13.1	36	4.143	17.8	20.1
10	3.871	12.0	13.1	37	4.189	18.2	21.6
11	3.920	12.0	14.2	38	4.190	18.2	21.6
12	4.042	9.8	17.2	39	4.453	16.9	31.8
13	3.938	13.6	14.6	40	4.317	15.1	26.1
14	3.889	12.2	13.5	41	4.175	18.7	21.1
15	3.939	11.1	14.6	42	4.219	16.9	22.6
16	4.201	18.9	22.0	43	4.115	16.4	19.2
17	4.161	20.7	20.7	44	4.133	21.3	19.8
18	4.180	20.9	21.3	45	4.096	16.7	18.7
19	4.180	21.8	21.3	46	4.378	21.3	28.5

20	4.069	21.3	17.9	47	4.308	23.6	25.8
21	4.152	19.1	20.4	48	4.307	23.1	25.7
22	4.042	17.8	17.2	49	4.151	22.7	20.4
23	4.089	20.0	18.5	50	4.209	21.3	22.2
24	4.116	21.3	19.3	51	4.091	17.3	18.6
25	4.199	16.4	21.9	52	4.124	23.1	19.5
26	4.114	20.0	19.2	53	4.172	16.4	21.0
27	4.078	20.4	18.2	54	4.229	17.3	22.9

* Experimental
** Calculated

#	UPV Km/s	Exp* fcu MPa	Calc** fcu MPa	#	UPV Km/s	Exp* fcu MPa	Calc** fcu MPa
55	4.081	24.4	18.3	96	4.662	35.6	42.5
56	4.107	17.8	19.0	97	4.642	42.7	41.3
57	4.086	18.7	18.4	98	4.700	37.8	44.7
58	4.277	17.3	24.6	99	4.805	40.0	51.4
59	4.257	19.6	23.9	100	4.702	47.1	44.8
60	4.317	18.7	26.1	101	4.726	41.8	46.3
61	4.431	40.0	30.8	102	4.702	38.7	44.8
62	4.474	42.2	32.7	103	4.800	42.7	51.1
63	4.381	40.0	28.7	104	4.750	42.2	47.8
64	4.378	44.4	28.5	105	4.726	40.4	46.3
65	4.633	43.1	40.8	106	4.592	48.4	38.6
66	4.575	25.8	37.7	107	4.495	27.1	33.7
67	4.443	39.6	31.3	108	4.584	40.4	38.1
68	4.400	39.6	29.4	109	4.518	47.1	34.8
69	4.432	39.8	30.8	110	4.562	38.2	37.0
70	4.332	37.3	26.7	111	4.631	36.0	40.7
71	4.517	41.8	34.8	112	4.608	45.3	39.5
72	4.452	38.7	31.7	113	4.585	39.6	38.2
73	4.563	45.3	37.1	114	4.608	44.9	39.5
74	4.464	43.6	32.3	115	4.540	39.8	35.9
75	4.378	43.6	28.5	116	4.517	44.9	34.8
76	4.495	18.7	33.7	117	4.655	43.1	42.1
77	4.388	24.9	28.9	118	4.702	43.6	44.8
78	4.475	22.2	32.8	119	4.606	45.6	39.3
79	4.368	27.1	28.1	120	4.642	44.0	41.3
80	4.477	31.1	32.9	121	4.562	43.8	37.0
81	4.475	25.3	32.8	122	4.586	40.0	38.2
82	4.452	25.4	31.7	123	4.631	43.3	40.7
83	4.389	31.6	29.0	124	4.540	37.8	35.9
84	4.568	34.9	37.3	125	4.540	50.0	35.9
85	4.474	30.7	32.7	126	4.637	45.3	41.0
86	4.409	37.3	29.8	127	4.586	46.2	38.2

87	4.585	31.1	38.2	128	4.604	49.8	39.2
88	4.608	28.4	39.5	129	4.518	37.8	34.8
89	4.409	26.2	29.8	130	4.655	47.1	42.1
90	4.540	27.6	35.9	131	4.632	55.1	40.8
91	4.638	40.0	41.1	132	4.540	44.2	35.9
92	4.726	35.6	46.3	133	4.518	40.8	34.8
93	4.751	37.8	47.9	134	4.631	50.0	40.7
94	4.726	44.4	46.3	135	4.496	38.7	33.7
95	4.702	40.0	44.8				

4- DATA ANALYSIS

The scatter plot representing both the Pulse velocity and the rebound index versus concrete cubic compressive strength indicated that the expected relation could take the general expression:

$$Y = \alpha \times X^{\beta} \qquad (1)$$

In which the independent variable (x) represented the nondestructive test result, the dependent variable (Y) represented the concrete compressive strength.

Nonlinear regression analysis was carried out to study the correlation, and how significant is the effect of pulse velocity on the crushing strength of standard concrete cube.

The following equation is concluded for the predicted values of f_{cu}.

$$f_{cu} = 0.0025 \times V_d^{\,6.38} \qquad (2)$$

Where

fcu is the crushing strength of standard concrete cube in MPa

V_d is the UPV pulse velocity in Km/sec.

The regression curve in figure (2) shows the variation of standard concrete cubes crushing strengths at the age of 28 days with respect to UPV readings. The curve also exemplifies that the relationship is not linear. The Pvalues for regression coefficients are less than 0.001 indicating that the predictors are statically significant.

The calculated R-squared value is 0.7, implying that the regression curve acceptably fits the observed data.

5- CONCLUSIONS

1- The present study puts forward a useful mathematical nonlinear relationship that enables the engineer to predict confidently the crushing strength of standard concrete cubes at the age of 28 days, upon measuring the Pundit velocity utilizing Pundit.
2- The derived mathematical expression is applicable for a wide spectrum of concrete strengths.
3- The dispersion of obtained results may be attributed to the size and shape and distribution of gravel, in addition to several other factors such as voids, micro cracks, etc.

4- It is also concluded that the easiness of handling such a device and the simplicity of utilizing it in recording readings, permits to carry out a large number of tests in almost all required locations without undermining the integrity of the structure.

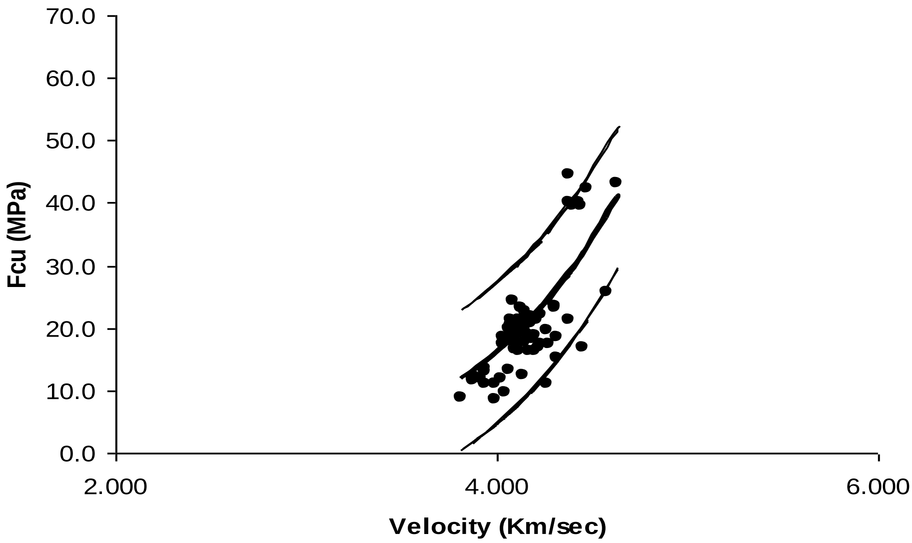

Figure (2) : Pundit velocity in Km/sec

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العلاقة بين سرعة الأمواج فوق الصوتية و مقاومة الكسر المكعبية

في الأردن كما في كثير من الدول توجد عدد كبير من المنشآت الخرسانية و التي مضى على بنائها فترة طويلة مما يطرح اسئلة حول سلامتها نتيجة القدم و امكانية اعادة تأهيل بعضها بغرض الاستخدام. و يستدعي هذا الأمر اجراء فحوصات جودة على المنشأ بدون احداث أية أضرار. و تأتي الفحوصات غير الاتلافية كوسيلة جيدة لتحقيق هذا الغرض. و يستخدم جهاز الأمواج فوق الصوتية لهذا الغرض. و بناءا عليه تأتي هذه الدراسة و التي تتضمن استخدام 135 مكعبا خرسانيا تم اعدادها للحصول على خرسانة بدرجة تبدأ من 10 نيوتن/ملم^2 و تصل الى 50 نيوتن/ملم^2 حيث تم فحصها بجهاز الأمواج فوق الصوتية و من ثم تم استخدام جهاز الضغط لفحص مقاومتها للكسر. بعد ذلك تم عمل دراسة احصائية لكافة البيانات المستخرجة وبموجبها تم استنباط علاقة رياضية تمكننا من ايجاد المقاومة المكعبية للخرسانة اعتمادا على سرعة الأمواج فوق الصوتية.

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