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Strength Estimation of Concrete in Different Environments Using UPV

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ABSTRAK

Kelusuhan konkrit dalam satu struktur disebabkan oleh beberapa mekanisme dalaman dan luaran mengurangkan kekuatan atau keutuhan struktur. Kertas ini mengemukakan keputusan ujian-ujian tanpa musnah halaju denyut ultrasonik (UPV) unutk menentukan kekuatan konkrit dalam tiga keadaan yang berbeza iaitu keadaan kering ketuhar, kering udara dan tepu kerana potensi sebenar penggunaan UPV dalam berbagai-bagai keadaan masih belum dipelopori. Kandungan lembapan keberkesanan UPV bagi meramal kekuatan konkrit, darjah kandungan lembapan dalam konkrit perlu dipertimbangkan. Laluan halaju dalam beberapa keadaan juga perlu dikaji. Dalam kajian ini terdapat empat gred konkrit yang didedahkan kepada tiga keadaan yang berbeza. Banyak siri ujian makmal yang telah dilakukan untuk mendapatkan hubung kait antara keputusan ujian UPV dan kekuatan sebenar konkrit. Sebanyak 108 kiub telah disediakan. Simen yang digunakan adalah simen Portland biasa dan agregat kasar adalah batu granit dengan saiz maksimum 19mm seperti mana yang digunakan dalam kebanyakan binaan struktur konkrit. Kaedah reka bentuk campuran DOE telah digunakan untuk menghasilkan empat gred konkrit yang biasa digunakan dalam amalan binaan konkrit. Keputusan uji kaji menunjukkan kehadiran lembapan dalam konkrit mengubah nilai-nilai UPV dengan ketara. Ujian-ujian UPV melalui ukuran secara langsung menunjukkan ramalan yang lebih baik berbanding ukuran secara tidak langsung. Beberapa persamaan telah dicadangkan untuk meramal kekuatan konkrit dalam keadaan kering ketuhar dan kering udara.

ABSTRACT

Deterioration of concrete in a structure is a result of several internal and external degradation mechanisms which decrease the strength or the integrity of the structure. This paper presents results of use of non-destructive ultrasonic pulse velocity tests (UPV) to determine the strength of concrete in three different environments, namely oven-dry, air-dry and saturated conditions, as the full potential of UPV in different environments is still not fully explored. Moisture is known to have a significant effect on ultrasonic pulse velocity. In order to improve the efficiency of UPV in estimating the concrete strength, the degree of moisture present in the concrete i.e. the physical condition of the concrete is to be considered. Pulse velocity path in the different physical conditions of concrete also has to be examined. In the present investigations, four different grades of concrete in three different environments were considered. Extensive series of tests were carried out in the laboratory to obtain a correlation of the UPV test results with the actual compressive strength of concrete. A total of 108 cubes were cast. The cement used was the ordinary

Portland cement and the coarse aggregate consisted of granite with the maximum aggregate size of 19mm as is generally used in conventional R.C structures. The DOE-method of mix-design was used to design four different grades of concrete in order to simulate concrete strengths found in practice. Test results indicated that the presence of moisture in concrete changes the UPV values significantly. The UPV tests through the direct transmission measurements display better estimates compared to the indirect measurements. Exponential expressions have been proposed for the strength estimation of concrete under oven dry and air dry conditions.

Keywords: Concrete, compressive strength, ultrasonic pulse velocity (UPV)

INTRODUCTION

The strength of in-situ concrete may be measured using semi-destructive and non-destructive test techniques. Ultrasonic Pulse Velocity (UPV) is one of the most frequently used NDT techniques to measure the physical properties of concrete. The reliability of UPV technique to estimate the compressive strength of concrete has come about as a result of enormous data gained through extensive testing. UPV test technique has been used for more than two decades for concrete quality evaluation and concrete compressive strength (f_{cu}) determination. UPV test provides indirect data that can be empirically related to standard cube compressive strength. Factors influencing the test results and their interpretation have been widely reported.

According to Castro (1985) age, mix proportions, water/cement ratio, cement type and aggregate type have an influence on the pulse velocity test results and their relationship to f_{cu}. Using different concrete mixes, but with the same ingredients Castro (1987) showed similar relationship for the cylindrical specimens. In their research, the effect of UPV on the concrete constituent material was established. But the concrete physical condition was ignored and the mode of test was not investigated. Ferreira *et al.* (1999) established the UPV and other NDT correlations with compressive strength of concrete. They considered different mix proportions of concrete with different compressive strength of coarse aggregate in their investigations. The concrete physical conditions were, however, not reported.

This paper describes the results of an experimental program on the use of UPV for assessing concrete strength. The concrete specimens have varying strengths of 10 to 40MPa and have been subjected to oven dry, air dry and saturated conditions. Direct and indirect modes of measurements have been used on all the cubes as shown in *Fig. 1.* Table 1 gives the number of the cube samples of size 150×150×150mm used in the investigations. A total of 108 cubes have been cast for testing. The cement used in this experiment was ordinary Portland cement, which is mostly used in the R.C structure. The aggregate used in this experiment was broken granite stone with compressive strength of 95 to 120MPa.

TABLE 1
Schedule of test specimen 150×150×150 mm test cubes

Concrete Grade	Physical Condition	Number of Cubes at the Age of Testing 7 days	14 days	28 days	Sub-total
	Oven dry	3	3	3	9
Grade 10	Air dry	3	3	3	9
	Saturated	3	3	3	9
	Oven dry	3	3	3	9
Grade 20	Air dry	3	3	3	9
	Saturated	3	3	3	9
	Oven dry	3	3	3	9
Grade 30	Air dry	3	3	3	9
	Saturated	3	3	3	9
	Oven dry	3	3	3	9
Grade 40	Air dry	3	3	3	9
	Saturated	3	3	3	9

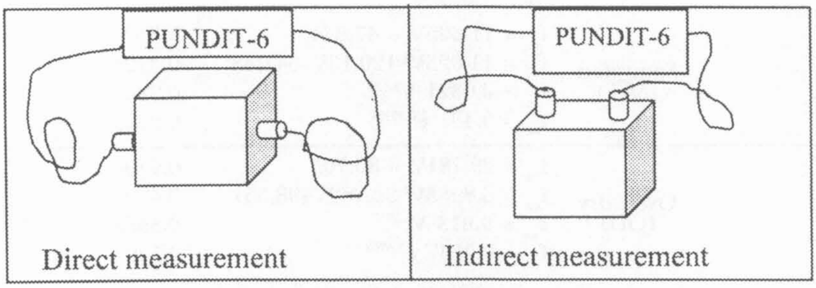

Fig. 1: UPV mode of tests on specimen

TEST RESULTS AND DISCUSSION

The UPV measurements as obtained during the investigations for different concrete grades and different physical conditions using direct and indirect methods of measurements are not reported but available Shibli (2001). Similarly, the corresponding actual cube strengths are also not reported. Both exponential and polynomial expressions have been tried to co-relate the UPV values and the cube strength to best fit through regression analysis. The best-fit expression is obviously the one which has correlation coefficient value nearly equal to 1.0. It was found that the correlation between[1] UPV values and the[2] concrete strength for any measurement made and[3] the physical conditions did not improve when such correlations were developed separately for different grades of concrete. It was then thought advisable to determine expressions, which would be identical for all grades of concrete as considered in the present investigation. Separate expressions were, however, determined for different measurement modes and physical conditions.

Table 2 gives the polynomial/exponential expressions for each measurement mode and physical condition valid for concrete strengths ranging from 10MPa to 40MPa. The correlation coefficient values are also given in each case to select the best-fit expression, which is highlighted in bold.

TABLE 2
Co-relation expressions for direct and indirect transmission measurement

Mode of Test	Physical conditions	Regression Equations	Correlation coefficient	Remarks
Direct Transmission	Oven dry (OD)	$f_{cu} = 21.04V - 90.63$	0.8403	
		$\mathbf{f_{cu} = 3.441V^2 - 16.073V + 8.874}$	**0.8451**	Best-fit
		$f_{cu} = 0.0019\ V^{5.5237}$	0.8125	
		$f_{cu} = 0.0831\ e^{1.0239V}$	0.8035	
	Air dry (AD)	$f_{cu} = 14.378V - 61.594$	0.5238	
		$\mathbf{f_{cu} = 12.124V^2 - 126.18V + 342.79}$	**0.5901**	Best-fit
		$f_{cu} = 0.0135\ V^{4.1414}$	0.4617	
		$f_{cu} = 0.292\ e^{0.7222V}$	0.4672	
	Saturated (SAT)	$f_{cu} = 11.395V - 47.844$	0.3176	
		$f_{cu} = 11.023V^2 - 120.13V + 341.38$	0.3722	
		$f_{cu} = 0.0321\ V^{3.526}$	0.2842	
		$f_{cu} = 0.481\ e^{0.5995V}$	0.2895	
Indirect Transmission	Oven dry (OD)	$f_{cu} = 29.781V - 86.705$	0.4894	
		$f_{cu} = 0.8983V^2 - 36.262V + 98.351$	0.4895	
		$\mathbf{f_{cu} = 0.013\ V^{5.6747}}$	**0.5558**	Best-fit
		$f_{cu} = 0.0647\ e^{1.5702V}$	0.5493	
	Air dry (AD)	$f_{cu} = 26.758V - 79.409$	0.4516	
		$\mathbf{f_{cu} = 0.5359V^2 - 22.694V - 71.74}$	**0.4516**	Best-fit
		$f_{cu} = 0.0187\ V^{5.2218}$	0.4267	
		$f_{cu} = 0.1069\ e^{1.3731V}$	0.4205	
	Saturated (SAT)	$f_{cu} = 32.582V - 106.6$	0.603	
		$\mathbf{f_{cu} = 21.447V^2 - 134.78V + 218.51}$	**0.6275**	Best-fit
		$f_{cu} = 0.0019\ V^{6.7338}$	0.5619	
		$f_{cu} = 0.020\ e^{1.7365V}$	0.5641	

Figs. 2a, 2b and *2c* show the best-fit curve on the test values for the direct mode of transmission with regard to three physical conditions. From the figures and the respective regression equations, it is observed that the UPV test techniques using direct measurement cannot estimate the concrete strength to any acceptable level of accuracy in a saturated environment. The method, however, does estimate the concrete strength sufficiently accurately when concrete is subjected to the oven dry or air-dry environment. It is also observed that the UPV values are affected by the presence of moisture in the structure and this must be considered in estimating the compressive strength of concrete from the UPV values.

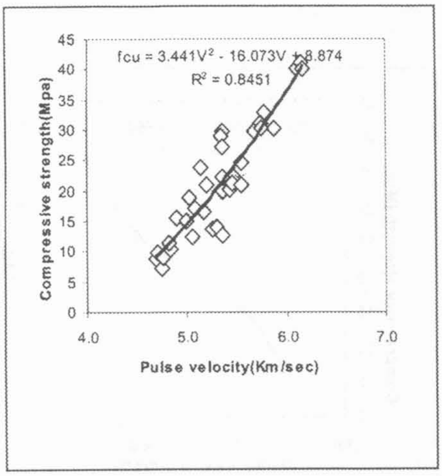

Fig. 2a: UPV vs fcu graph for concrete at OD condition (Direct method)

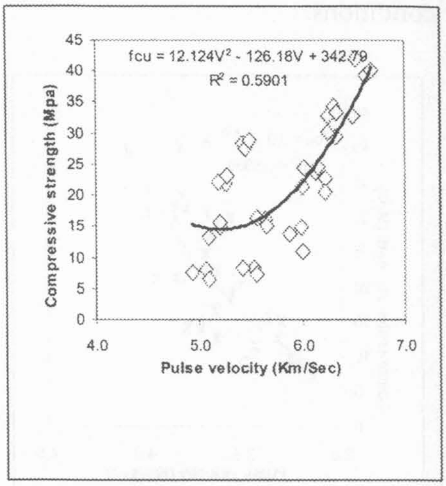

Fig. 2b: UPV vs fcu graph for concrete at AD condition (Direct method)

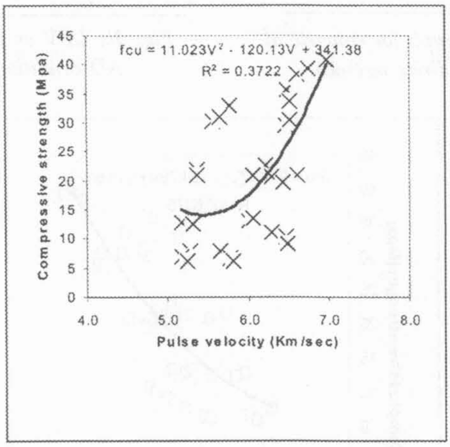

Fig. 2c: UPV vs fcu graph for concrete at SAT condition (Direct method)

Figs. 3a, 3b and *3c* similarly show graphically the best-fit curves for indirect mode of transmission with regard to three physical conditions with the UPV test values. From the figures and respective regression equations, it is observed that the co-relation is not very satisfactory between the best-fit values and the test values, as indicated by correlation coefficient values for concrete in dry conditions.

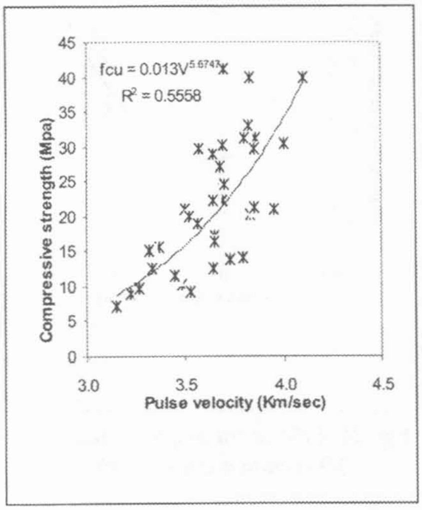

Fig. 3a: UPV vs fcu graph for concrete at OD condition (Indirect method)

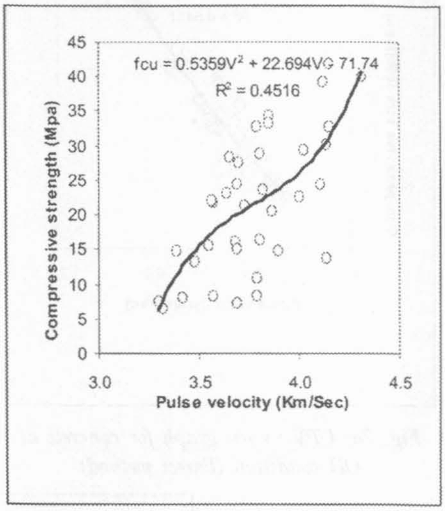

Fig. 3b: UPV vs fcu graph for concrete at AD condition (Indirect method)

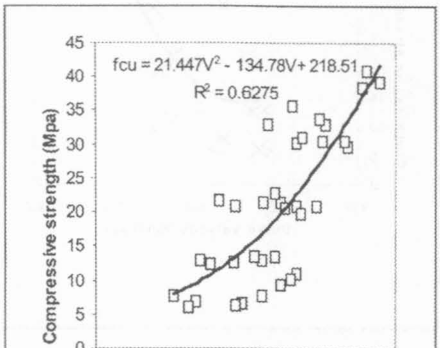

Fig. 3c: UPV vs fcu graph for concrete at SAT condition (Indirect method)

As indicated earlier, attempts were made to recommend as few expressions as possible that are valid in different conditions. One such attempt is shown in *Figs. 4a* and *4b*, which display the best-fit curves to the UPV values obtained for all three different physical conditions and concrete grades. Various regression analysis equations to fit the aggregate data are tabulated in Table 3, where the most accurate expressions are highlighted in bold. It is noted that these expressions have less accuracy than would be possible if different expressions for different physical conditions are used to estimate concrete strength using UPV.

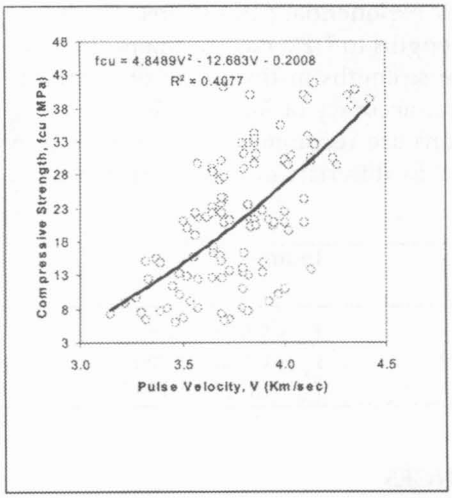

Fig. 4a: Pulse velocity vs concrete strength combined graph of OD, AD & SAT (Indirect method)

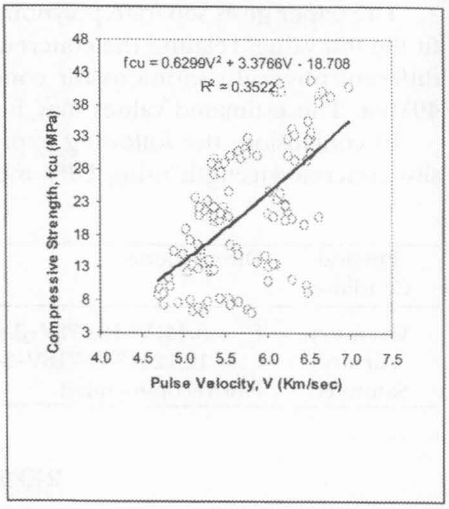

Fig. 4b: Pulse velocity vs concrete strength combined graph of OD, AD & SAT (Direct method)

TABLE 3
Co-relation expressions for combined conditions

Mode of Tests	Regression equation	Correlation coefficient	Remarks
Indirect transmission	$f_{cu} = 24.034V - 69.37$	0.4058	
	$\mathbf{f_{cu} = 4.8489V^2 - 12.683V - 0.2008}$	**0.4077**	Better
	$f_{cu} = 0.0398\ V^{4.6448}$	0.3790	
	$f_{cu} = 0.1817e^{1.2293V}$	0.3764	
Direct transmission	$f_{cu} = 10.638V - 39.44$	0.3518	
	$\mathbf{f_{cu} = 0.6299V^2 + 3.3766V - 18.708}$	**0.3522**	Better
	$f_{cu} = 0.107\ V^{2.9737}$	0.2977	
	$f_{cu} = 0.9787\ e^{0.5173V}$	0.2950	

CONCLUSIONS

It may be concluded that it is necessary to use different expressions for predicting concrete strength using UPV method for different physical conditions. It is also concluded that presence of moisture in concrete may change the UPV values significantly and as such expressions developed from co-relation tests on saturated concrete may not be suitable. Similarly, the UPV values obtained through direct transmission tests are usually 1.50 times higher than those through indirect transmission test values. Separated expressions are needed for the two modes of measurements.

The paper gives separate polynomial or exponential expressions, which best fit the test values relating the concrete strengths to UPV measurements in three different physical conditions for concrete strengths in the range of 10Mpa to 40Mpa. The estimated values may have an accuracy of 50 to 60%.

In conclusion, the following expressions are recommended to estimate in-situ concrete strength using UPV method in different physical conditions:

Physical Condition	Direct Mode	Indirect Mode
Oven dry	$f_{cu} = 3.441V^2-16.073V+8.874$	$f_{cu} = 0.013\ V^{5.6747}$
Air dry	$f_{cu} = 12.124V^2-126.18V+342.79$	$f_{cu} = 0.5359V^2-22.694V-71.74$
Saturated	Not recommended	$f_{cu} = 21.447V^2-134.78V+218.51$

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