Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Estimating Strength of SCC Using Non-Destructive Combined Method

Dallshad K.H. Bzeni[1], Muhammed A. Ihsan[2]

[1]*University of Salahaddin, Iraq*
[2]*University of Salahaddin, Iraq*
[*]*College of Engineering,Civil Department, Erbil, dillshadbzeni@yahoo.com*
en.msaber@gmail.com

ABSTRACT

In this paper non destructive test methods such as rebound hammer, ultrasonic pulse velocity and combined method are correlated with destructive test method; crushing strength of SCC cubes. Six mixes of SCC were prepared, with different mix proportions starting from cementitious material content 297 up to 500 kg/m^3. Flowability and passing ability of fresh SCC mixes were approved. Prior to crushing of test specimens, ultrasonic pulse velocity and rebound hammer numbers were recorded for different ages. Different equations were proposed correlating the strength of concrete to rebound number and pulse velocity passing through the concrete. Statistical analysis includes type of fit, correlation coefficient and sum of square residuals were determined for the proposed equations. Results showed that ultrasonic pulse velocity (UPV) is not sensitive to the variations of SCC strength and the accuracy of prediction were improved significantly by combining UPV values with rebound number numbers.

Keywords. Rebound number, ultrasonic pulse velocity, combined method, SCC, compressive strength.

INTRODUCTION

The need for in-situ testing of concrete has long been realized for quality control and compliance purposes. The quality of concrete is commonly described in terms of compressive strength. Non-destructive test methods are applied to concrete construction for several purposes; such as quality control and trouble shooting of new construction, evaluation of older concrete for rehabilitation purposes and quality assurance of concrete repairs. This method increasingly applied for concrete structures. The NDT method has seemed to be the standards of many countries.
Among the most popular NDTs that usually used to evaluate concrete properties in structure are ultrasonic pulse velocity (UPV) and Schimidit hammer. The UPV test measures the velocity of

an ultrasonic wave passing through the concrete, the average velocity of wave propagation determined by measuring the path length of the wave (Distance between transducer and receiver) divided by the travel time. The UPV method has been conducted successfully to evaluate the quality of concrete more than seven decades. (Qasrawi 2000) reported the appropriate standards. This method has been used also for detecting internal cracking, void and variation of the physical properties in concrete due to severe chemical environment or freezing and thawing. The pulse velocity method is also used to estimate the strength of concrete test specimens. Several previous studies (Tanigawa et al., 1984; Kheder 1999.; Popovics et al., 1990; Turgut, 2004) concluded that there is a good correlation between ultrasonic pulse velocity and the compressive strength. The interpretation of the pulse velocity measurements in concrete is complicated by the heterogeneous. ASTM Method C597 and B.S.1881: Part 203 describes the standard test methods for determination of pulse velocity through concrete.

Rebound hammer test which also known as Schmidt Hammer test , measures the hardness of the concrete member surface , harder concrete surface produce larger number of rebound and this, indication for better quality of concrete surface. ASTM Method C 805 describes the test method for determining the rebound number of hardened concrete. Methods of hammer use and calibration are also given in the B.S. 1881:Part 202. It has been concluded that rebound hammer test, was not a satisfactory method for predicting strength development of concrete at early ages (Carette and Malhotra, 1984), and there was a wide degree of disagreement among various researchers concerning the accuracy of the estimation of strength from rebound readings and the correlation relationship (Malhotra and Carino , 2004).

These two methods are known for more than 50 years (Bungey and Millard ,1996). A number of Investigators have tried to apply more than one nondestructive method at the same time in order to predict the strength of in situ concrete more accurately. Combined method which is known also as SONREB was suggested (Facaoaru, 1984) , which is based on rebound number and pulse velocity measurements for in situ evaluation of concrete strength, this method developed largely due to the efforts of RILEM technical committees 7 NDT and 43 CND. The method summarized by taking average of three readings for the UPV and average of six readings for Rebound No. Compressive strength were determined by using three dimensional curves which is known by Iso-strength curves in the form of nomo-gram between compressive strength of concrete, rebound hammer number and ultrasonic pulse velocity formed the bases of SONREB technique. This method is only recorded as practical application till now to evaluate the strength of concrete. A series of correction coefficients developed for a specific concrete grade and type was applied to improve the accuracy of prediction obtained from the nomogram.

In the scientific literature many previous trials were carried out (Samarin and Maynink, 1981, Tanigawa, et, al., 1984) to determine concrete compressive strength by using a combined method in testing concrete, hence various expressions to estimate compressive strength by this method are available, most of the recent research work using the above technique has been conducted in the Eastern European countries.

(ACI Committee 2003), referred also to the combined method, combining results from more than one in place test, it was confirmed that this method have resulted in strength relationships with higher correlation coefficients than when individual methods are used.

All investigations of NDT were made till now on conventional concrete only, while the use of SCC recently has gained wide acceptance in many countries. Initially, it was developed in Japan since the late 1980s, so that to ensure proper consolidation in applications where concrete durability and service life were of concern. The use of SCC in many countries has grown

dramatically in the precast industry. For quality control, it is often necessary to test the concrete member after it has been hardened to determine whether the member is suitable for its designed use and to determine the time at which the formwork can be removed. In the literature there is no research has been done on using NDT methods to evaluate SCC.
The objective of this research is to contribute to the development of the non-destructive testing specifically combined method to be used to estimate compressive strength of SCC members. Specimens of SCC Prepared in the Laboratory using different mixes and tested at different ages, the purpose is to find best fit non linear regression between compressive strength and other parameters without damaging of concrete.

EXPERIMENTAL WORK

Material. Materials that are used for the preparation of self compacting concrete specimens include: Ordinary Portland cements (OPC): Obtained from Mass cement factory-Iraq, confirmed the requirements of ASTM type I grade and having a specific gravity of 3.16.; Silica fume: type SikaFume-HR was used to increase the stability of SCC mixtures with a replacement rate approximately 15 %. Size of particles extremely was 0.1 µ and specific gravity of 2.24; Superplasticizer: A polycarboxylates based polymer type Sika ViscoCrete-PC 15 having a specific gravity of 1.09 used in all the mixtures to obtain the required flowability; Stone Powder: obtained by grinding limestone rocks , particles passing sieve 150 µ were used as inert filler to enhance the particle size distribution of Portland cement; Fine Aggregate (FA): Clean natural river sand from Erbil city, with a maximum size of 5 mm was used . Fine aggregate conformed the requirements of ASTM C-33 , with the apparent specific gravity 2.67 and fineness modulus of 2.85; Coarse Aggregate (CA): Natural river gravel, uncrashed, with a maximum size of 12.5 mm was used and their gradation in accordance with ASTM C-33.

Selection of Mix Proportions. A total of six mixtures were designed, their water-to-powder ratios ranged from 0.30 to 0.40. Different Trial batches were performed, their initial slump were less than 75 mm before adding the superplasticzer. Fine and coarse aggregate used were at SSD condition. Table (1) shows the selected mix proportions and some properties of fresh concrete.

Table 1. Selected Mix Proportion and Some Properties of Fresh Concrete

Materials (kg/m3)	Mixes					
	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6
Cement	252	280	350	360	370	425
Silica Fume	45	50	62.5	65	68	75
Stone Powder	152	59	73	72	78	63
Fine Aggregate	943	920	921	931	910	816
Coarse Aggregate	871	900	850	859	874	884
Added Water	175	178	181.5	174.5	170	160
Superplasticizer	3.5	3.8	3.5	5.5	6.5	7.2
Fresh concrete Properies						
Slump Flow(mm) With J-Ring	500	550	600	705	730	700
T_{50} (sec)	5.1	5.0	3.2	4.56	5.2	5.1

Test Specimens. Concrete specimens 150 mm cubes were prepared to measure concrete compressive strength; three specimens were cast in plastic test moulds for each mix and each specified age, then covered by a polyethylene sheets for 24 hours. The cubes were then stored in curing tanks for different times, tested at different ages at moist condition. The following tests were carried out for all specimens.

Rebound HammerTest. The rebound number was measured on the cube specimens using digital Schmidt hammer according to ASTM C 805-02. Each cube was fixed in the compression machine by applying a pressure of approximately 5 MPa. Five readings were taken on each side of two opposite smooth surfaces of the cube, thus a total of 10 readings were taken on each cube. The average reading was then used for each cube.

Ultrasonic Pulse Velocity Test. The ultra sonic pulse velocities of the cast SCC cubes were measured according to ASTM C597-02. Two readings on each cube were measured (using the opposite smooth surfaces of the cube). The average pulse velocity was recorded used for each cube. Specimens were at a saturated condition during the test.

Compressive Strength. The compressive strengths of the concrete mixes were determined using a compression machine with ultimate capacity of 2000 kN. The compressive strength of each mix at any age was the average of the compressive strength of three cubes. The results of the compressive strengths of all the 72 concrete cubes were used for statistical analysis.

RESULTS AND ANALYSIS.

The research covered 72 cubes of SCC mixtures prepared under laboratory conditions, it was required to cover different Strength levels by changing water to powder ratio and curing for different times before testing the specimens.

Rebound Number and Compressive Strength. Fig (1) shows the relationship between rebound number and compressive strength of SCC specimens at different ages. As a general trend it is shown, that when the rebound number increases, compressive strength also increases for different ages. It was found that the existing relation between rebound number and compressive strength is scattered and the correlation coefficient was restricted to 0.3. The highest rate of scattering was shown by mix-1, this due to the nature of mix-1which is prepared using high amount of stone powder (152 kg/m^3) and low cement content. Based on the above observation, a new approach was applied to increase the accuracy of the obtained correlation. Excluding the results of mix -1 led to an improved relationship between the compressive strength and rebound numbers. This increased the correlation coefficient R^2 to 0.61. The rate of increase of rebound number with time was not followed the same behaviour of strength gain at different ages. For the process of regression analysis SPSS-version 18 was used which is based on least square theory. The goal is to increase correlation coefficient and minimizing sum of square residuals (SSR). The following formula was obtained as the best fit equation as shown below.

$$S = 0.045 * R^{1.82} \quad (1)$$

Where ;
S is compressive strength (MPa)
R: Rebound Number

Despite the above mentioned approach the established relationship is still weak and need to be improved. A second trial was made to increase the correlation coefficient by including the age of concrete in the relationship. Hence the predicted compressive strength of all cubes except mix-1 became a function of rebound numbers and the age of concrete in days (t) at the time of test. Combining Rebound Number and age of concrete increased the correlation coefficient R^2 to 0.79. The equation is shown below

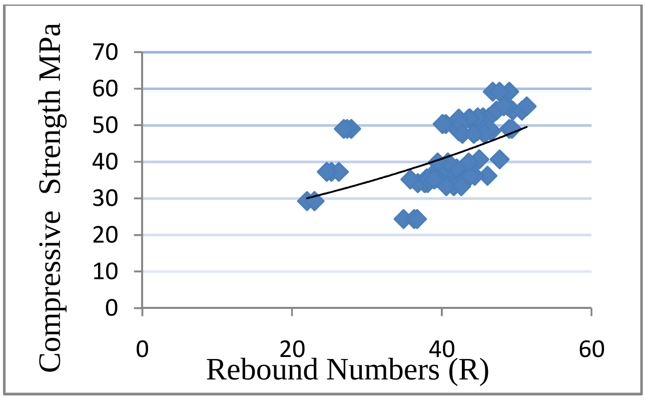

Figure 1. Relationship between rebound number and compressive strength of SCC

$$S = 0.223 * \frac{t}{t+2.55} * R^{1.43} \quad (2)$$

This equation indicates that strength development of SCC specimens can be explained by a hyperbolic relation approximately resembles the behaviour of conventional vibrated concrete but at a higher rate. The long term compressive strength is a function of rebound hammer number.

Ultrasonic Pulse Velocity and Compressive Strength

The UPV measurements of compressional waves were conducted using MATEST ultrasonic pulse generator instrument with the transducers of 25 mm diameter, and maximum resonant frequency of 54 kHz. The pulse velocity was measured by pressing the transducer end, covered by some viscous lubricant to the smooth surfaces of the cubes.

Figure (2) shows the relationship between ultrasonic pulse velocity and compressive strength of all the mixes investigated. It is shown in the figure that as a general trend the compressive strength increased with the increase of UPV. But the obtained correlation indicates a scattered pattern, which gives an invalid relationship with respect to the strength of concrete. Indicating a higher level of scatter than the relation obtained between the strength and the rebound numbers. Having different concrete ages lead to the formation of large discrepancies in strength and UPV values. This can be explained as through the decrease in the sensitivity of the ultrasonic pulse velocity with increase in concrete age and also with increase in concrete strength, (Samarin and Ravindra,1984). The best relation was obtained using an exponential equation with a correlation coefficient R^2 =0.35. Several trials were made to increase the degree of accuracy by dividing the specimens into different age groups and taking the effect of cement content, however none of these regressions increased the correlation coefficient significantly.

For conventional vibrated concrete a slight change in UPV resulted in a significant change in the compressive strength of concrete. For the majority of concrete in Australia the general equation used to explain this relationship was the power equation of fourth degree. It is known that UPV propagates into the concrete thickness between the transducers unlike rebound number, which is greatly affected by the surface of concrete. Also UPV is profoundly affected by the presence of pores, voids and flaws. For conventional concrete the formation of pores and voids are due to the insufficient compaction. Therefore, in SCC mixtures, Most of pores and voids are significantly minimized, in addition, the inclusion of silica fume in concrete mixture reduced the microcracks and improved the transition zone of concrete. These factors decrease the sensitivity of UPV values inflicted on the concrete specimens to the strength variations. Hence the correlation coefficient was decreased between the UPV and the strength of concrete.

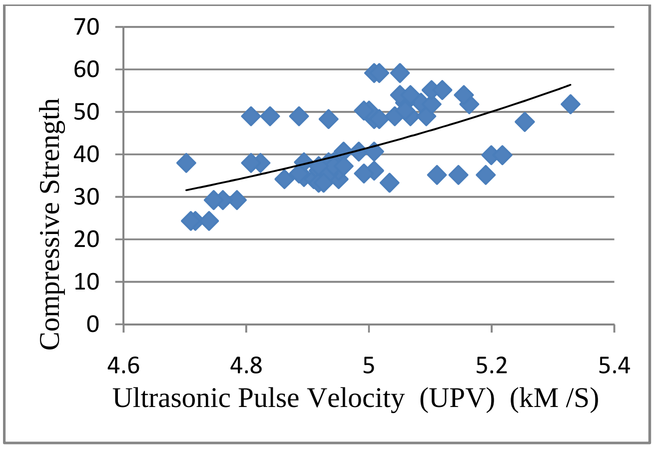

Figure 2. Relationship between ultrasonic pulse velocity and compressive strength of SCC

Combined Method. As It is reported the use of this method reduce the effects of (i) aggregate size, (i) cement type and content, (ii) water-to-cement ratio, and (iii) moisture content. All these methods employed local materials and were made for conventional concrete which cannot be applied for SCC. In order to obtain a good relationships more suitable for SCC, to correlate compressive strength of SCC to rebound numbers and ultrasonic pulse velocity readings, multiple regression (Non linear curve estimation) were used. The equation developed for the assessment of in-situ SCC strength, specimens were prepared laboratory from a particular cement and aggregate type with different water to cementitious material ratio and tested at different ages. Different forms of relationships with different combinations of independent variables were obtained to predict the compressive strength of SCC. These independent variables are: Ultrasonic pulse velocity, rebound hammer numbers, age of concrete, cementitious material content and density. The best fit non-linear equations proposed with a correlation coefficient $R^2 = 0.7$ for eq. (3) and 0.75 for eq.(4) are as shown below;

$$S = 0.025 * R^{1.48} * EXP(0.37 * V) \tag{3}$$

$$S = 0.070 * R^{1.8} * EXP(0.506 * V) * Cm^{-0.480} \tag{4}$$

Where; *Cm* : Cementitious material content (kg/m3)

These equations indicates that compressive strength of SCC is influenced by the changes of rebound numbers and UPV values more than the change in the mix proportion. It is clearly shown that the combined usage of UPV and Schmidit hammer methods improved the predicted values of concrete compressive strength, compared to using individual test method. Based on eq.(4), for the fixed rebound number and UPV, strength of concrete decreases with increase in cementious material content. This because if concrete containing higher cementitious material content, should have higher degree of hydration at the specified age as a result the surface will be harder and the percentage of pores will be lower which would be reflected by both higher rebound numbers and higher UPV values. If rebound numbers and UPV values were fixed or slightly changed, this indicates lower degree of hydration produced at the specified age and hence, lower strength would be obtained.

Limitations of the Developed Regressions. In order to obtain a realistic predicted value for the concrete compressive strength, the general ranges of the independent variables introduced in the derivation of these regressions must be taken into consideration. These final ranges are given in Table 2.

Independent Variables				
	RN	UPV (km /S)	Cemntitious (kg/m3)	Age of concrete (days)
Range of variables	34 – 51	4.7 – 5.3	330 – 500	3 – 75

CONCLUSIONS

On the basis of the experimental results obtained in this work, using two different
Non-destructive test methods for predicting compressive strength of SCC, the following conclusions can be withdrawn:

1. Schmidit hammer readings are less sensitive to assess compressive strength of SCC compared to conventional vibrated concrete.
2. As a general trend increasing in water to cementitious material ratio decreases rebound number and UPV values, while there is no generalized formula that can be used because of low correlation coefficient resulted
3. Introducing information about the age of concrete at the time of test with rebound numbers of hammer test into the regression equation, improved the predicted values of compressive strength of SCC.

4. Rebound Number and Ultrasonic pulse velocity are slightly affected by cementitious material content.
5. The combined usage of UPV and rebound hammer methods improved the predicted values of concrete compressive strength, compared to a single in-situ test.
6. Results of UPV test alone cannot be used to estimate compressive strength of SCC.

REFERENCES

ACI Committee, (2003). "In-place methods to estimate concrete strength" ACI 228.1R, American Concrete Institute, Farmington Hills, MI,

Bungey, J.H., Millard, S.G., (1996). "Testing of concrete in structures" , Third Edition, New York: Taylor and Francis, pp. 1- 138.

Carette, G.G. and Malhotra, V.M., (1984). "In-situ tests: variability and strength prediction of concrete at early ages", Malhotra, V.M., Ed., American Concrete Institute, Special Publication SP-82, 111.

Facaoaru, I., (1984). " Romanian achievements in non-destructive strength testing of concrete", ACI SP 82-3, Detroit, pp.35 – 56

Khedir, G.F., (1999). " A two stage procedure for assessment of in situ concrete strength using combined nondestructive testing", Materials and Structure, V. 32, No. 6 , July, pp. 410 – 417.

Malhotra, V.M., Carino, N.J., (2004)." Handbook of non-destructive testing of concrete" ASTM international publication, second edition.

Popovics, S., Rose, J.L., and Popovics, J.S., (1990) " The behaviour of ultrasonic pulses in concrete" Cement and Concrete Research , V. 20 , No. 259,

Qasrawi, H. Y., (2000). " Concrete strength by combined nondestructive methods simply and reliably predicted" Cement and Concrete Research , No. 3 , pp. 739 – 746 .

Samarin, A. and Maynink, P., (1981). " Use of combined ultrasonic and rebound hammer method for determining strength of concrete structural members", Concrete International, No.3 (3), pp. 25 – 29 .

Samarin, A. and Ravindra K.D., (1984). "Determination of in situ concrete strength: Rapidly and confidently by non-destructive testing" , ACI SP 82-5 , pp. 77 – 94 .

Tanigawa, Y., Baba, K., and Mori, H., (1984). " Estimation of concrete strength by combined nondestructive testing method" ACI SP 82-4, , pp. 57 – 67 .

Turgut, P., (2004). "Research into the correlation between concrete strength and UPV values", www.NDT.net, Vol.12, No.12, Dec.