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Research Article

Influence of Embedded Reinforcement in a High Strength Concrete on Ultrasonic Pulse Velocity and Core Test

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Abstract: In this study attempt made to asset the strength of normal and high quality strength concrete with embedded reinforcement bars in two locations and directions using ultrasonic pulse velocity and equivalent core test. Reinforcement bars are always too dense with small spacing in reinforced concrete structures. Any semi or non-destructive test by core test or by ultrasonic pulse velocity has high probability influence by the embedded reinforcement. A study was carried out on 54 cubic models divided to three lines. The first line consists from 18 samples as control specimens which represent the plain concrete for six concrete grades. The other two lines represents the concrete with embedded bar in two different positions. The results indicates the pulse velocity and the core strength test of the normal and high strength concrete with embedded bar is usually higher than in plain concrete of the same grade. The difference became significant when the bar axis in the same direction of the applied pulse or load. While, a negligible affect noticed when, the pulse or the load axis is perpendicular to the bar axis direction.

Keywords: Core test, high strength concrete, non-destructive test, semi-destructive test, ultrasonic pulse velocity

INTRODUCTION

The production of concrete with specific quality relative to final one affected by many factors; quality of raw materials, curing conditions, mixing method, degree of compaction and distribution uniformity of its components. Standard tests are usually performed to produce the assessment of concrete quality. Concrete core test used to find the ultimate concrete compressive strength usually gives results altered by many uncertainties. Several non-destructive testing methods have been developed in the literature for assessment of concrete strength. These methods must calibrate through a good knowledge of concrete properties and several non-destructive tests must be done to obtain such information.

Recently, high strength concrete has been used in different structural applications. Unfortunately, there are a poor literature on non-destructive tests and semi-destructive tests for assessment of high strength concrete. In this study, influence of embedded reinforcement of a high strength concrete on ultrasonic pulse velocity and equivalent core test was experimentally studied. American standard in general is not allowed to test any specimen core containing embedded reinforcement (ASTM C-42, 2003). While some correction factors are used by British standard (BS 1881-120, 1983) to take into consideration the effect of embedded bars on core test. Most (ASTM C-597, 2002; BS 1881-120, 1983; BS 1881-203, 1986) standards are not covered high strength concrete correction factors for none and semi destructive tests. An investigation for the assessment of normal and high strength concrete with embedded reinforcement bars have been created in this study. The ultrasonic heartbeat speed in cement can be controlled by applying roundabout transmission (alleged surface sounding) and direct transmission, the sounding through the material. Thereto, the surface (Rayleigh), shear (transverse) and longitudinal (compressional) waves can be transmitted in materials (Malhotra and Carino, 2004; Mindess *et al*., 2003; Hellier, 2001).

RESEARCH SIGNIFICANCE

An attempt was experimentally made to asset the strength of high quality concrete with embedded reinforcement bars in two locations and directions using ultrasonic pulse velocity and equivalent core test. A reference design curves in term of wave velocity and equivalent core strength with and without reinforcement bars was produced for different concrete strength grads.

Concrete materials: Ordinary Portland cement manufactured in Iraq with a commercial name of (Tasluga) is used in this study for both normal and high

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Table 1: Concrete ingredients for six concrete grates

Strength f_{cu}, MPa	Cement (C), kG	Silica Fume (F), kG	Sand (S), kG	Gravel (G), kG	Superplasticizer (P), kG	Water (W), kG
20	250	Zero	842	1263	Zero	125
30	350	Zero	755	1133	Zero	175
40	450	Zero	668	1002	Zero	225
50	475	47.5	683	1024	10.45	171
60	475	47.5	696	1044	10.45	159
70	475	47.5	708	1062	10.45	148

strength concrete mixes. The cement is tested to compile the Iraq specification (IQS, 1984a, 1984b). The coarse aggregate from Al-Nibaii area with a maximum size of 20 mm is used throughout the present study. The coarse aggregate is tested according to Iraqi specification (ASTM A-615, 2000). The natural sand is brought from Al-Akhaider district in Iraq and used for all mixes. The sand is tested to satisfy with zone (2) of Iraqi specification above. Tap water is used for all mixes and for curing purposes. Ukraine made steel bars are used as reinforcement in the present study with grade 75 according to American standard for testing materials (ASTM A-615, 2000). To produce a high strength concrete, Silica Fume is used with 10% by the weight of cement replacement. Silica Fume is complied with the recommendation of the manufacturing company. Superplasticizer is used also as additive to high strength concrete. The Superplasticizer quantity is 2% by weight from the total weight of cement plus Silica Fume. The Superplasticizer used in this study is complied with American Standard for Testing Material [ASTM C494 Type F]. Superplasticizer is used to satisfy the practical workability of concrete.

MIX DESIGN

The concrete mix is designed according to American standard (ACI Committee 211, 1991) based on absolute volume method for both normal and high strength concrete. This method is assumed that the final absolute volume of concrete is the sum of the absolute volumes of the concrete ingredient as:

$$\frac{C}{G_c}+\frac{F}{G_f}+\frac{S}{G_s}+\frac{G}{G_g}+\frac{W}{1.0}+\frac{P}{G_p}=1000 \quad (1)$$

where:

C, S, G, W = Weight of cement, sand, gravel and water in kilograms for one cubic meter concrete respectively.

F = Weight of Silica Fume in Kilograms for one cubic meter concrete in high strength concrete.

P = Weight of Superplasticizer in kilograms for one cubic meter concrete used only in high strength concrete.

G_c, G_f, G_g, G_p = Specific weight for cement, Silica Fume, Sand, Gravel and Superplasticizer respectively.

Where G_c = 3.10, G_s = G_g = 2.65, G_f 2.15, G_p= 1.15 is used to obtain the weights of concrete ingredients throughout this study. Different levels of concrete strength grade is used to cover the full range from normal to high strength concrete as shown in Table 1 with all the concrete ingredient weights that based on the above equation. The cement quantity in the normal strength concrete is based on practical experience as (Neville, 1995):

$$C = f_{cu}\ (kG/m^3) + 50 \quad (2)$$

And the weight of gravel as a function to the weight of sand is assumed as:

$$G = 1.5 \times S \quad (3)$$

The water-cement ratio of normal concrete is assumed 0.5 throughout this study. While the water-cementation ratio of a high strength concrete is based on experimental equation (Shetty, 1982) as:

$$W/CM = \frac{\log\left\{\frac{13(1000-C-F)}{f_{cu}}\right\}}{3.0\times\log(13)} \quad (4)$$

where:

W/CM = weight of water to the total weight of cementation material (cement plusSilica Fume).

Usually Silica Fume is assumed 10% from the weight of cement as (Shetty, 1982):

$$F = 0.1 \times C \quad (5)$$

Practically the weight of cement in high strength concrete is determined based on Silica Fume as a percentage added from cement weight. 475 kG cement weight is complied with 10% Silica Fume as from old experience in high strength concrete (Shetty, 1982). Finally the Superplasticizer weight ratio is assumed 2% from the cementation material (cement plus Silica Fume) (Shetty, 1982) as:

$$P = 0.02(C+P) \quad (6)$$

ULTRASONIC PULSE VELOCITY

The principle of this test is a pulse of longitudinal vibrations is produced by an electro-acoustical transducer which is held in contact with one surface of

Table 2: Test description

Test name	Strength based on mix design, MPa	Strength based on standard test, MPa	Embedded bar status
T1	20	23.43	None
	30	30.30	Control specimens
	40	40.26	
	50	48.10	
	60	58.66	
	70	65.74	
T2	20		One ∅12 mm steel bar is placed at the center of the cubic face with a length coincides with the cubic length. The bar axis position parallel to the casting axis, pulse path and applied load direction. a/L = 0 (a = 0, distance from the bar axis to the center of the cubic. while L = 15 cm, cubic length)
	30		
	40		
	50		
	60		
	70		
T3	20		One ∅12 mm steel bar is placed at a distance 25 mm from the edge of the cubic with a length coincides with the cubic length. The bar position parallel to the casting axis, pulse velocity and applied load direction. a/L = 1/3.
	30		
	40		
	50		
	60		
	70		
T4	20	24.57	Same T2 test except the bar is position perpendicular to the casting axis and applied load direction.
	30	31.85	
	40	41.80	
	50	52.60	
	60	62.21	
	70	69.53	
T5	20	22.92	Same T3 test except the bar is position perpendicular to the casting axis and applied load direction.
	30	30.78	
	40	40.85	
	50	50.15	
	60	60.81	
	70	67.29	

the concrete under test. After traversing a known path length in the concrete, the pulse of vibrations is converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time of the pulse to be measured. When the pulse is coupled into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes both longitudinal and shear waves propagating throughout the concrete. Transducer with a frequency of 50 kHz is used throughout this study. This test is carried out according to British Standard (BS 1881-203, 1986). ASTM standard (ASTM C-597, 2002) test method for pulse velocity through concrete is not considered the effect of reinforcing bars in concrete. British standard adopted many factors and especially the effect of steel bars in concrete but with a caution that the equation or the results is based on normal strength concrete. This caution encourages the authors to do this research.

CORE TEST

This test method provides standardized procedures for obtaining and testing specimens to determine the compressive strength of in-place concrete. Generally, test specimens are obtained when doubt exists about the in-place concrete quality due either or low strength test results during construction or signs of distress in the structure. Another use of this method is to provide strength information on older structures. There is no universal relationship between the compressive strength of a core and the corresponding compressive strength of standard-cured molded cubes or cylinders. The relationship is affected by many factors such as the strength level of the concrete, the in-place temperature and moisture history, embedded reinforcement and the strength gain characteristics of the concrete. The acceptance criteria for core strength are to be established by the specifier of the tests. American Standards Code provides core strength acceptance criteria for new construction. Unfortunately, American standard (ASTM C-42, 2003) prevents using specimens containing embedded reinforcement. British Standard (BS 1881-120, 1983) allows testing specimens with steel bar. A correction equations and charts are available in this standard but not for all full level of concrete grades. This research covers both normal and high strength concrete.

EXPERIMENTALPROGRAM

Six grade of concrete (20 MPa, 30, 40, 50, 60 and 70) was tested in the present experimental program using standardcubic size (15 cm). The test program was done in Al-Nahrain University at College of Engineering, Civil Engineering Laboratory. Five test types were conducted. Each test covers six levels of concrete strengths from normal to high strength. Definitely each individual test represents the average of three cubes. The first type of test is performed on a control specimen without embedded reinforcement. The second and third tests type included the one reinforcement bar parallel to the direction of casting, pulse path and load applied axis with two different positions. The first position is in the center of the cube while the second one is far away 2.5 cm from the edge of the cube. Fourth and fifth tests, the steel bar placed perpendicular to the axis of casting, pulse path and load applied direction. The test definition and description shown in Table 2. The standard test results of the ultimate compressive strength of the normal and high strength concrete without and with embedded bars are also mentioned in Table 2 for comparison purposes. Figure 1 shows the typical sample setup before and after test, the ultrasonic pulse device used in this study and the digital compressive machine which is available at Al-Nahrain University Civil Engineering Laboratory. The reinforcement bar ∅12 mm is clearly shown in its side and middle positions in the last two plate of Fig. 1.

RESULTS AND DISCUSSION

The ultrasonic wave velocity for all the test types shown above was conducted. The transmitter and receiver are placed at the middle of all samples ensuring that they are connected perfectly and the reading of the wave is stable. The reading of the wave velocity is recorded in Table 3 and represented in Fig. 2a for pulse path parallel to the reinforcement bar and in Fig. 2b for Pulse path perpendicular to the bar. It can be seen from Table 3 and Fig. 2a when the bar is

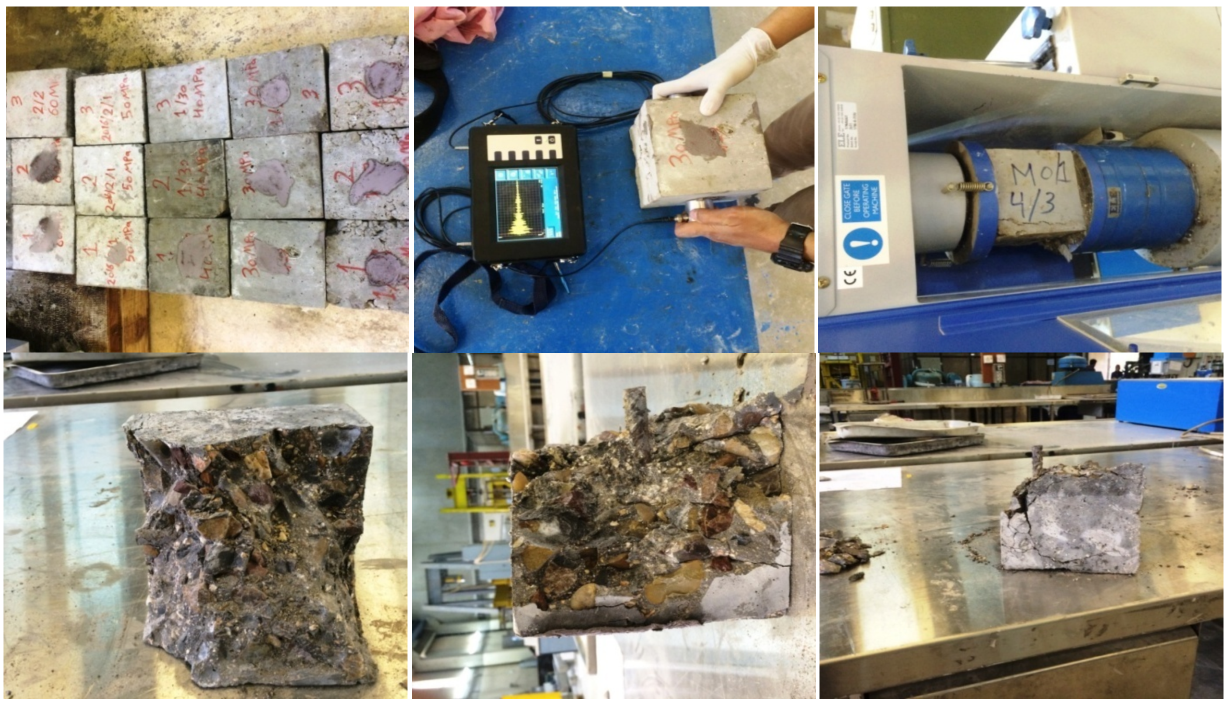
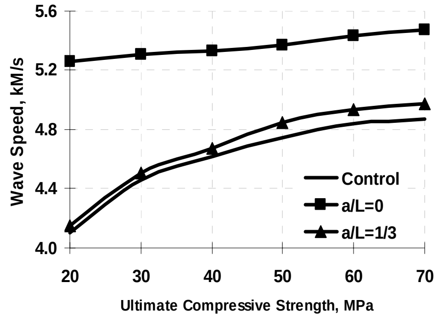


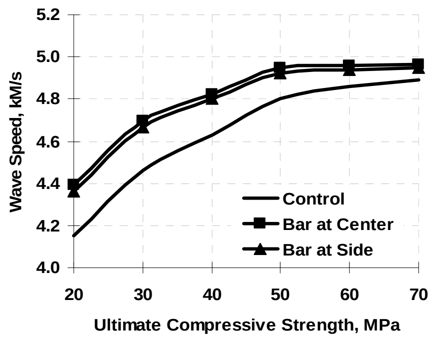
Fig. 1: Typical sample test and procedure

Table 3: Ultrasonic pulse velocity with different concrete strengths and test type

	Wave speed velocity (Pulse path parallel to the bar), kM/s		
Strength based on mix design, MPa	Plain (T1-Test)	Central bar (T2-Test)	Side bar (T3-Test)
20	4.100	5.256	4.150
30	4.459	5.309	4.509
40	4.620	5.330	4.670
50	4.745	5.370	4.845
60	4.836	5.434	4.936
70	4.872	5.474	4.972
	Wave speed velocity (Pulse path perpendicular to the bar), kM/s		
Strength based on mix design, MPa	Plain (T1-Test)	Central bar (T4-Test)	Side bar (T5-Test)
20	4.150	4.392	4.362
30	4.460	4.695	4.665
40	4.630	4.823	4.800
50	4.800	4.948	4.920
60	4.860	4.959	4.940
70	4.890	4.964	4.950



(a)



(b)

Fig. 2: Ultrasonic pulse velocity with different concrete strengths and bar locations; (a): Pulse path parallel to the bar; (b): Pulse path perpendicular to the bar

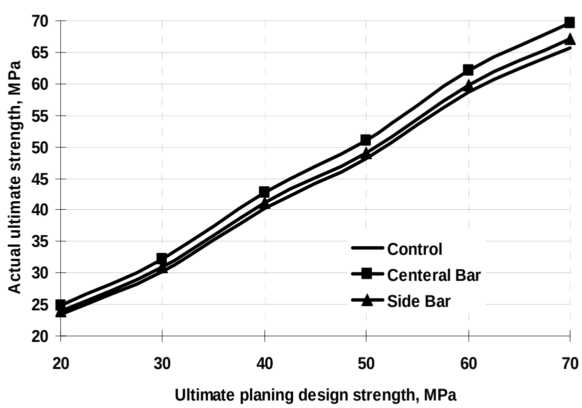


Fig. 3: Ultimate strength of a plain concrete with and without embedded bar

placed at the center of the cubic and the reading direction is in the same direction of the bar (i.e., the line pass through transmitter to receiver aliened with the axis of bar) the pulse velocity similar to the reading in steel. It is also seen from the same figure, when the axis of the bar is shifted by 5 cm from the center of the cubic the pulse velocity was approximately in the same order of plain concrete of the same grade. The two reading is not coinciding perfectly because logically the pulse velocity in steel is higher than the velocity in plain concrete. It is expected that the wave pulse travels partially in concrete and partially in steel bar. In the other hand when the pulse path becomes perpendicular to the steel bar the pulse velocity is recorded and drawn in Table 3 and Fig. 2b. It is shown from this figure there is no significant difference between the control and the treated elements at fixed concrete grade. It is clearly shown that there is a tuned behavior in the pulse velocity for both two sceneries (i.e., the bar exists either in the middle or at some distance from the edge).

Finally Fig. 3 show the ultimate compressive strength of the normal and high strength concrete without and with embedded bar perpendicular to the direction of the load applied. This figure used as a reference for predication of the core strength in present of embedded reinforcement bar. The bar is positioned in the same configuration above. It is clearly observed there is no significant change in the strength of concrete without or with embedded one bar perpendicular to load axis.

CONCLUSION

- When the line passes through transmitter to receiver of the ultrasonic pulse velocity aliened perfectly with the axis of reinforcement bar, the pulse velocity reading is steel wave velocity reading.
- When the axis of the reinforcement bar is shifted by 5 cm from the center of pulse path (i.e., a/L = 1/3), the pulse velocity reading was approximately in the same order of plain concrete of the same grade.
- When the pulse path or the load direction becomes perpendicular to the steel bar, it is proved there is no significant difference between the control and the treated elements at fixed concrete grade using both ultrasonic pulse velocity and equivalent core test for normal and high strength concrete.

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