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Relationships between Actual Compressive Strength, Modulus of Elasticity and Non-Destructive Tests of High Strength Concrete

***Abstract**-The present research investigate with Nondestructive testing (NDT) of high strength concrete (HSC). An experiential work was carried out including both destructive and nondestructive test methods utilized to various concrete mixes with compressive strength ranged from 44 to 84.4MPa.Correlation curves were derived as pulse velocity and modulus of elasticity vs. compressive strength for high strength concrete. Two empirical relations were proposed for foretelling the modulus of elasticity Ec = 0.4141f`c + 8.6077, and compressive strengths fcu = 320.85ln (V) – 467.73 with a good coefficient of determination R2 for these equations 0.94and 0.90 respectively. Obtained from cubic and cylinders using locally available materials, therefore; it has been observed that NDT is rationally good and credible tool to measure the property of concrete and gives acceptable indication of the compressive strength development. Comparisons with the ACI 318 and the ACI 363 empirical equations for the prediction of the modulus of elasticity were performed. It was observed that the ACI 363 equation underestimates the modulus of elasticity, while the ACI 318 equation overestimates.*

***Keywords**: High strength concrete, compressive strength, modulus of elasticity, ultrasonic pulse velocity (UPV), empirical relations.*

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1. Introduction

The evaluation of concrete strength and modulus of elasticity in high strength concrete are based on empirical relations between concrete strength and ultrasonic pulse velocity and concrete strength with modulus of elasticity, therefore; many trials were carried out by Tumendembere and Baigalimaa [1], to develop exact relationship between concrete strength and UPV test in the laboratories to observe the behavior of the concrete materials and to produce a good function between concrete compressive strength and modulus of elasticity in HSC, and they obtained better correlation represented by the following power equation:

$$S = 1.356*10^{-5}V^2 - 0.076V + 111.502 \qquad (1)$$

The ultrasonic pulse technique (UPV) is a tool for controlling and evaluating performance the quality of products that are presumed to be made of homogeneous concrete whose proportions are known in advance, especially if there is no compacting and change in water/cement ratio will be easily detected. However, it is difficult to use this technique to determine the strength of concrete made of different materials with unknown mixing ratios. Although there is a wide inclination for high density, concrete to obtain higher strength (if the specific gravity of the aggregates is constant) so that the concrete quality rating based on pulse speed is possible.

Some classifications suggested by Malhotra and Carino [2] for concrete with a density of approximately 2400 kg/m3 are given as the follow in Table 1. According to Jones and Gatfield [3], however, the lower limit for good quality concrete is between 4.1 and 4.7 Km/s. Further examination of high strength concrete reported by Carrasquillo et al. [4] concluded that the ACI 318 equation:

$$Ec = 4730\sqrt{f`c} \qquad (2)$$

Express overestimates the modulus of elasticity for concretes with compressive strength above 40- 45 MPa [5]. Hence, a modified equation was recommended for compressive strength up to 83 MPa that predicts a lower modulus of elasticity than the one by ACI 318.

Table 1: Tabulation of the quality of concrete on the bases of pulse velocity

Longitudinal pulse Velocity		Quality of concrete
km/s.10^3	**ft/s**	
>4.5	>15	excellent
3.5-4.5	12-15	good
3.0-3.5	10-12	doubtful
2.0-3.0	7-10	poor
<2.0	<7	Very poor

Aydin and Saribiyik [6], suggested a correlation among non-destructive testing (NDT) named as Schmidt rebound hammer test and concrete destructive compression test. The equation is:

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$$y = 11.612A–52.033 \quad (3)$$

Where y, compressive strength; A, rebound number) R^2 value is found to be 0.856. R^2 value of 90-days specimens is found to be 0.9449 and its equation is:

$$y = 16.674A–238.31 \quad (4)$$

Khan et al. [7], studied static elastic modulus assessment of in-situ concrete using non-destructive technique. The paper presented a research finding that establish a regression model between Ultrasonic Pulse Velocity (UPV) using direct method(Vd) and actual static elastic modulus (Ec) of high strength concrete (HSC). They suggested two equations to predict modulus of elasticity, the regression models shown in Equations below are meant for two different concrete series:

$$Ec = 13.57Vd-39.77 \quad (5)$$

$$Ec = 15.05Vd-35.65 \quad (6)$$

2. Research Significance

The aim of the present study is to propose correlation relationships that can estimate modulus of elasticity for HSC obtained using locally available material, directly from the compressive strength, and to estimate concrete compressive strength directly from reading of ultrasonic pulse velocity. In addition, this study suggests the establishment of a clear correlation curves among UPV, modulus of elasticity and compressive strength of concrete to make efficient the application of UPV method for performance analysis over the entire period of service of concrete structures. In this research the validity of using the ACI 318 and ACI 363 equations for evaluate the effectiveness of elasticity for high strength concrete was investigated. In the next section an experimental program is presented, five mixes have been adopted, for purpose to obtain concretes with compressive strengths varied from 50 MPa to as high as 90 MPa.

3. Experimental Program

I. Materials

The materials used in present study and their characteristics are briefly summarized as follow:

A. Cement

Ordinary Portland produced by Sinjar Company for manufacturing cement Ltd and it is characteristics are listed in Table 2, the test results show that the cement conforms to the provisions of Iraqi specification No (5) [8].

B. Silica fume

Commercially powder of silica fume available in local markets was used in this work. Physical properties of silica fume are shown in Table 3.

C. Super plasticizer

According to the ASTM C494/C494M–05a [10] a new super plasticizers type "F" high range water reducing was used in this research, with technical data as listed in Table 4.

D. KUTPLAST RNA

A new chemical material is used in this research, which is meeting with ASTM C494/C494M–05a [10], Type (G) KUTPLAST RNA is based on a blend of polymers. It is a brown liquid; KUT PLAST has the following properties as listed in Table 5.

E. Fine aggregate

Locally available river sand complied with BS.882: 1992 [11], used in this research. Table 6 shows the grading of this sand. The fineness modulus, specific gravity, on a saturated and surface-dried basis, and water absorption were 2.99, 2.72 and 0.23% respectively.

Table 2: Characteristics of the cement used throughout this work

Chemical properties	Weight percentage %	Iraqi specifications 1984 limits
SiO_2	20.03	-
AL_2O_3	6.32	-
Fe_2O_3	2.84	-
CaO	64.02	-
MgO	3.05	5.0 max.
SO_3	2.04	2.8 max
In. SUL.R	0.51	1.5 max.
L.O.I %	0.8	4.0 max
Free Lime	0.95	0.66-1.02 max.
L.S.F %	95.54	
Bugue Composition	**Weight percentage,%**	
C3S	49.83	
C2S	20.12	
C3A	11.95	
C4AF	8.63	
Physical properties		
3 Day compressive strength	29.0MPa	15 min
7Day compressive strength	38.7MPa	23 min
Autoclave expansion %	0.03	0.8 max.
Fineness Blaine	299.6	230 min
Specific	3.08	

*The table was supplied by Sinjar Company for Manufacturing Cement Ltd.

Table 3: Physical properties of silica fume

Physical characteristics	Typical values
Appearance	Grey powder

Specific gravity	2.2
Average particle size	0.1 micron
Bulk density	240 kg/m³
Particle size	0.1μ -0.5μ
Specific surface area	20,000 Kg/m^2

Table 4: Physical properties of Superplasticizer

Structure of the material	Naphthalene Sulphonate based
Color	Brown
Density	(1.15-1.21) Kg/liter
Chloride content %(EN480-10)	<0.1
Alkaline content % (EN480-12)	<10

*The Table above was supplied by BASF.

Table 5: Properties of KUT PLAST

Calcium Chloride content	Nil.
Specific gravity	1.17 at 20 ºC.
Air entrainment	Less than 1% additional air is entrained
Setting time	1- 4 hours retardation dependent upon dosage.
Cement compatibility	Compatible with sulphate resisting and other Portland cement and high alumina cements.
Compressive strength	Reducing W/C ratio and as a result increasing compressive in early age.

**The properties above supplied by "Specialties Construction Chemicals Factory"*

Table 6: Grading of fine aggregate (medium)

Sieve size (mm)	Fine Aggregate %passing	BS882:1992 passing (%)	Iraqi Specification No.45 (zone1)
4.75	100	------	90 -100
2.36	90.5	65 - 100	60 - 95
1.18	67.1	45-100	30 -70
0.6	32.9	25-80	15 -34
0.3	9	5-48	5 - 20
0.15	------	------	0 - 10
Organic materials	0.5	1	

F. Coarse aggregate

Natural river coarse aggregate with a maximum aggregate size of 19mm was used. Washed with water and dried in the air. The fineness modulus, specific gravity, on a saturated and surface-dried basis and water absorption were 6.8, 2.7 and 1% respectively. Table 7 shows the grading of the coarse aggregate used in this study.

G. Water

Tap water was used in this research for mixing and carrying of with 23ºC ±2ºC.

4. Concrete Mix Proportions

In the present study, five concrete mixes have been adopted, for purpose to obtain concretes with compressive strengths varied from 50 MPa to 90MPa. Five concrete mixes were prepared with different water/(cement+ silica fume) ratio. 0%, 5%, 6%, 8% and 10% of silica fume by wt. of cement were adopted. The curing regime of 23 ±2ºC and was adopted. The concrete mix proportions are summarized in Table 8. Mix 1 was chosen as reference mix and the others were obtained changing silica fume, KUT PLAST and super plasticizer and, as inevitable result the designed concrete compressive strength.

5. Specimens and Schedule of Test

For every mix, various specimens were carried out, as function of the specific characterization as follow:

a – six 150mm Cubes for density, pulse velocity, and standard compressive tests at 28 days;

b– Four 150×300 mm Cylinders for pulse velocity and standard modulus of elasticity tests.

The real dimensions of concrete specimens were taken into consideration in calculations.

I. Procedure of test

After 28days the specimens were bring out from curing tanks and the cylinders were ends grinding. The compressive strength and the modulus of elasticity were measured in accordance with C39/C39M–05 [12] and ASTM C469-02 [13], respectively.

Table 7: Shows the grading of the coarse aggregate which is complied with BS882:1992

Sieve size (mm)	Coarse Aggregate % passing	BS.882: 1992	Iraqi Specification No.45 (max agg. 19)
19	100	100	100
14	90.4	85-100	85 -100
9.5	40.4	0-50	0 - 50
4.75	0	0-10	0 -10
2.36	0	------	------

Table 8: Mix Proportions of High-strength Concrete

Mix	1	2	3	4	5
W/(C+S)	0.34	0.32	0.28	0.28	0.28
Water (Kg/m³)	129.2	150.2	148.4	160.2	177.1
Cement (Kg/m³)	380	450	500	530	575
Silica fume (Kg/m³)	0	22.5	30.0	42.4	57.5
Silica fume % of cement	0	5	6	8	10
Super plasticizer L/m³	0	0	2.5	3.5	5
Super plasticizer% of cement	0	0	0.5	0.67	0.87
(KUTPLAST RNA L/m³)	0	4.5	5.0	5.3	5.75
Coarse Aggregate (Kg/m³)	1170	1150	1120	1250	1400
Fine Aggregate (Kg/m³)	700	680	600	510	400
Nominal strength (MPa) at 28days	50	60	70	80	90

II. Test Results

The measured values of concrete compressive strength and the modulus of elasticity for 150x150 mm cubes and 150x300 mm cylinders respectively are given in Table 9.

The compressive strength ranged from 44MPa to 84.4 MPa for concrete manufactured using local cement and aggregate. The compressive strength was adopted as an average strength of six cubes.

The measurement of modulus of elasticity were made in compliance to ASTM C469 at 40% of the ultimate load for 150x300 mm concrete cylinders tested in axial compression at a constant load rate 0.25 MPa/sec. The values of the modulus of elasticity were reported as an average of two cylinders.

What can be seen from Table 9, that the higher the concrete compressive strength the higher the modulus of elasticity, as expected.

In addition, It can be seen from Table 10 that the higher the concrete strength the greater the ultrasonic pulse velocity (UPV), as expected.

Table 9: Measured Compressive Strength and Modulus of Elasticity

Mix	1	2	3	4	5
Designed Compressive strength MPa at 28days	50	60	70	80	90
Measured Compressive strength MPa at 28days of cubes	44.04	60.44	69.93	78.67	84.4
Slump (mm)	50	40	40	52	68
Measured Modulus of Elasticity GPa at 28days	28.43	31.04	37.56	40.89	44.87
Measured Compressive strength MPa at 28days of cylinders	34.36	49.20	58.45	62.43	66.33

Table 10: Measured Compressive Strength and UPV

Mix	1	2	3	4	5
Measured Compressive strength MPa at 28days of cubes	44.04	60.44	69.93	78.67	84.4
Wet Density kg/m³	2463.20	2467.23	2479.01	2475.85	2510.12
UPV km/sec. Cubes 150x150mm	5.03	5.1	5.31	5.42	5.66
UPV km/sec. Cylinders 150x300mm	4.875	4.92	4.98	5.23	5.29

6. Discussion

I. Modulus of Elasticity

Figure 1 shows the values for the modulus of elasticity plotted as function of the compressive strength for 150x300 mm cylinders. It is observed that there is a linear relationship between modulus of elasticity and compressive strength, therefore; a simple analysis has been done using "Excel program". Figure 1, show graphically the best-fit curve for indicate modulus of elasticity From the test data The regression curve was established according to the law:

$$Ec = a*f'c + b \quad (7)$$

Where (a) and (b) were determined using Excel program '

$f'c$ is concrete compressive strength

Based on the data tested a tentative proposed relationship, as shown in Fig.1, The trend line of those test data could be closely approximated using the following equation:

$$Ec = 0.4141f'c + 8.6077 \quad (8)$$

for 40 MPa< $f'c$ < 90 MPa, to be used with compressive strengths obtained from 150x300 mm cylinders for normal weight concretes. This was obtained by fitting the best line among modulus of elasticity and concrete compressive strength. The determination coefficient (R^2) of this equation is 0.94.

Although these tentative proposed equations seem to fit the tested data, further investigation will be carried out with more data points to confirm these findings.

II. Compressive Strength vs UPV

Based on the experimental results, there is a considerable increase in concrete compressive strength about 90% due to increasing silica fume ratio from 0% to 10% of cement, and as a result increasing in modulus of elasticity about 57% due to increasing in compressive strength. The explanation of this behavior is back to the major merit of silica fume and its high content of amorphous SiO_2 ranging from 85 to 98%. From another side, super plasticizers (high–range water reducer) improved concrete compressive strength as observed from test results, by reducing the mixing water requirement, and by squandering cement particles, with or without a variation in mixing water content, allowance more efficient hydration. Therefore; based on the experimental result, there is a considerable increase in concrete compressive strength about 90% because of increasing super plasticizers ratio from 0% to 0.87% of cement.

A correlation has been put up and clarifies with data acquired from cube specimens used for concrete strength and ultrasonic pulse velocity (UPV) tests. When UPV test on cube specimens was carried out, the load was applied up to failure. The results were found to be in agreement with the results as shown in Fig 2, therefore; similarly, another simple analysis has been done using "Excel program". Figure 2 show graphically the best-fit curves for indicate concrete compressive strength from the test data. The regression curve was established according to the law:

$$fcu = a * ln(V) - b \quad (9)$$

Where (a) and (b) were determined using Excel program, Based on the data tested a tentative proposed relationship, as shown in Fig.2, between the compressive strength and UPV is given by the equation:

$$f_{cu} = 320.85\ln(V) - 467.73 \quad (10)$$

(where f_{cu}, compressive strength; V is UPV in km/sec,).

In addition, the correlation coefficient value is found to be 0.90.Although these tentative proposed equations seem to fit the tested data, further investigation will be carried out with more data points to confirm these findings.

All results, for all mixes were treated together in order to obtain correlation curves between destructive and non-destructive parameters. Fig 3 shows the relationship between concrete compressive strength, modulus of elasticity as a function of mix type, it is seems there is a linear behavior between compressive strength and modulus of elasticity.

It can be seen from Figure 3 that the higher the concrete strength the greater the modulus of elasticity, as expected.

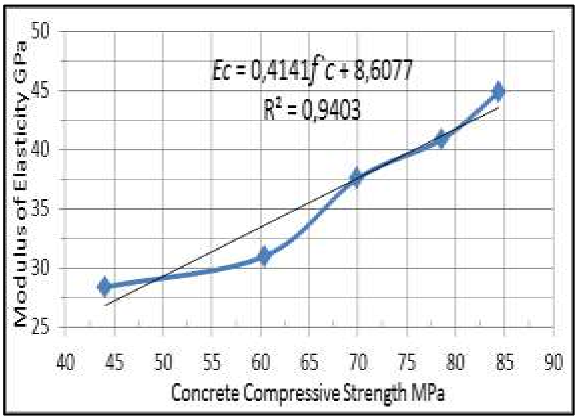

Figure 1: The Relationship between concrete compressive strength and Modulus of Elasticity

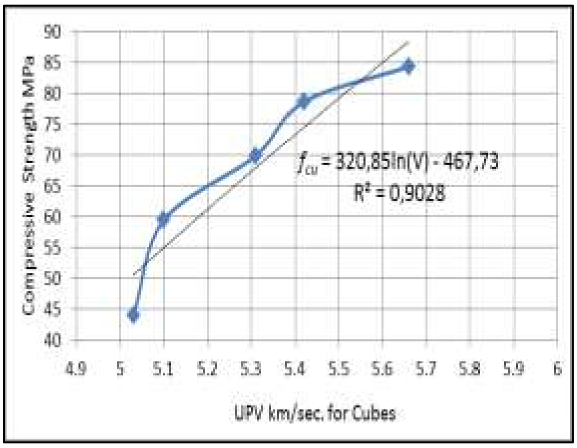

Figure 2: The Relationship between concrete compressive strength and UPV for Cubes

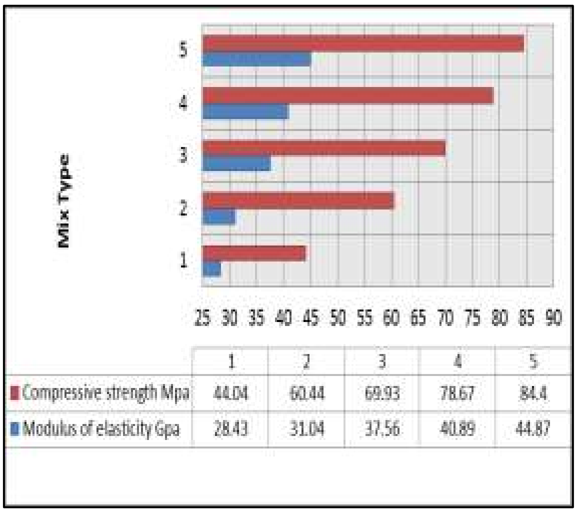

Figure 3: Bar chart of mix type vs. concrete compressive strength and modulus of elasticity at age 28 days

III. Slump

The values of slump test were reported in Table 9, the results show that the slump test for all mixes ranged between 40 to 60mm, (except mix No.5). This range is accept and the slump define as medium according to ACI 318-05 which is suitable to use in columns, beams, manually compacted flat slabs using crushed aggregates, normal reinforced concrete manually compacted and heavily reinforced sections with vibration and retaining walls. Base on the experimental results the slump test in mixes No.4 and No.5, slightly increased due to increase in silica fume and super plasticizers.

IV. *Density of Concrete*

The aggregate, which is used in this work, does not give a wide range of density; therefore, the densities obtained have a range only from 2463 - 2510 kg/m^3 as shown in Table 10. However, B. Abdul Hussein. [14] concluded if the density is within the range of (2300-2523 kg/m^3), there is no need to use a separate equation for each density range and the following model between concrete compressive strength and UPV can be used with a coefficient of correlation R^2 is 0.716 .

$$C = 0.26e^{S} - 0.83 \quad (11)$$

Where:

C = Concrete compressive strength MPa,

S = Indirect UPV in km/s.

7. Comparison with ACI 318 and ACI 363

The modulus of elasticity data from 150 x 300 mm cylinders is plotted in Figure 4 with respect to the compressive strength test results. The same figure shows plots of the ACI 318 equation:

$$Ec=4730\sqrt{f`c} \text{ MPa} \quad (12)$$

and the ACI 363 equation:

$$Ec=3320\sqrt{f`c} + 6900 \text{ MPa} \quad (13)$$

For (21 MPa< $f`c$ < 83 MPa). These equations are normally used for the prediction of the modulus of elasticity of normal weight concrete.

It is noticeable from Figure 4 that ACI 363 underestimates the modulus of elasticity for the range used in this study. This equation is too conservative since it lies below all the measured data. The range of the observed differentials was 22 to 32% underestimates between the measured and ACI 363 predicted modulus values. The ACI 318 provided a better estimation of the modulus of elasticity, but it seems to overestimate the modulus for compressive strengths for all cases. The range of observed differentials was 10 to -3% between the measured and ACI 318 predicted modulus values. Further investigation will be carried out with more data points to confirm these findings.

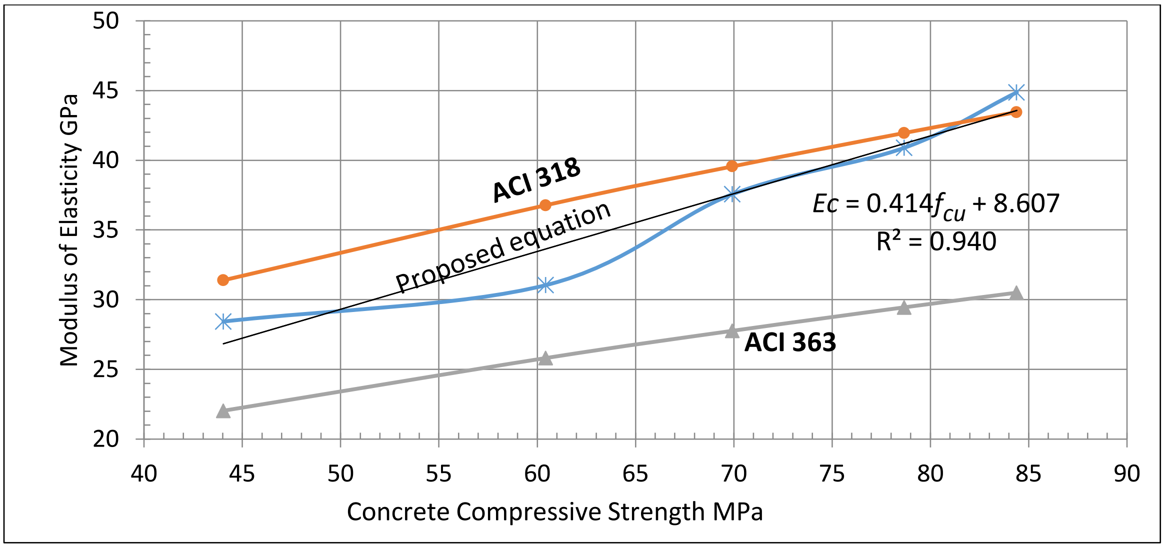

Figure 4: Comparisons with the ACI 318 and the ACI 363

8. Conclusions

The correlation among the strength and modulus of elasticity results acquired by destructive and NDT test method on high strength concrete has been confirmed. UPV test method has been utilized as a non-destructive test. The findings presented in this paper are summarized as follows:

1- Several tests and attempts have been made to adopt and develop the relationship between compressive resistance and elasticity coefficient of samples, The best possible correlation was obtained with the following tentative formula *Ec = 0.4141f'c + 8. 6077*

In addition, a determination coefficient (R^2) of this equation is 0.94, which means that could clarify 94% of the variability for the data around the regression line and 6 % remained without explanation.

2- Based on the data tested a tentative proposed relationship between the compressive strength and UPV is given by the equation:

$f_{cu} = 320.85 \ln (V) - 467.73$

(Where f_{cu} is compressive strength, V is UPV in km/sec,).

In addition, the determination coefficient value is found to be 0.90. This means that we could clarify 90% of the variability for the data around the regression line and 10 % remained without explanation.

3- It is observed that the ACI 318 substantially overestimates the proposed equation to predict modulus of elasticity for concrete using local available materials. While the ACI 363 is underestimates the proposed equation to predict modulus of elasticity.

4- Based on the experimental results, it has been observed that NDT is a reasonable perfect and credible gadget to measure the properties of concrete and grant acceptable indication of the concrete compressive strength development.

5- The broad implementation of this technique is earning admission on a large scale; it supply contracting authorities with accurate and objective information for monitoring quality control of concrete construction.

6- Further investigation need to be carried to include more data points to verify the proposed equations. The data points would include concrete mixes obtained from ready mix plants.

7- The density of high strength concrete can be further studied to indicate its effect on the relationship between concrete compressive strength and non-destructive tests.

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