STRENGTH ESTIMATION OF CONCRETE PRODUCED IN KURDISTAN REGION USING COMBINED METHOD

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***Abstract*- the measurement of concrete strength is generally done by normal destructive tests in Kurdistan Region. However load tests or core tests are not always possible or practicable. Since last decade, non-destructive testing (NDT) has been widely accepted throughout the world to assess the quality of in-situ concrete.**

In this paper experimental work was carried out to estimate strength of in situ concrete using NDT method. Therefore, 216 cubes were cast and tested in a laboratory for different grades of concrete, curing conditions, type of coarse aggregate used and age of concrete. 167, 120 cubes were tested in Hawler and Duhok cities of Kurdistan Region as an effort to represent most of materials resources used in this Region, and then to obtain correlation equations of concrete strength with RN and UPV results.

Statistical regressions have been applied for the gathered data (503 cubes) from different resources. A number of Correlation equations between RN test and UPV test results have been developed to obtain reliable results in order to estimate the strength of doubt concrete in site. However, it has been concluded that none of these tests can be used independently to yield reliable quantitative results. Therefore, adopting the test results a combined method has been developed to predict concrete strength with a reasonable accuracy.

This was approved in two cases studies. They have shown that when both RN and UPV test results combined together yields to estimated concrete strength within an acceptable degree of accuracy reached 90%. Supplementary core test results confirmed the reliability of the correlation between the different NDT techniques used.

Keywords: Rebound number; UPV; Combined method; Nondestructive; Compressive strength

1. INTRODUCTION

Whilst the testing of standard specimens according to National Standards and Codes of practices is suitable for quality control and compliance with specifications of the concrete as a material, the data obtained do not necessarily reflect the quality of that concrete in a structure. The need for in-situ testing of concrete has long been realized in many countries, even now it is seldom used in Kurdistan Region in its own right for quality control and compliance purposes. The quality of concrete in practice is still commonly described in terms of its uniaxial compressive strength, the assumption being that most other important properties are related to strength.

By referring to the definition given in BS 1881: Part 201 [1], *nondestructive test* defines as a test which does not impair the intended performance of the element or member under investigations. It also states that non-destructive test can be applied to both old and new structures, where for new structures the principle applications are likely to be for quality control or resolution of doubts about the quality of materials or construction.

Among the most popular NDT that usually used to evaluate concrete properties in structure are ultrasonic pulse velocity (UPV) and rebound hammer (RH). The UPV test measures the velocity of an ultrasonic wave passing through the concrete. To determine the average velocity of wave propagation, the path length between transducers is divided by the travel time. Although the test is very simple and easy to apply but the interpretation of the test results is very difficult since the ultrasonic pulse velocity values are influenced by a number of factors. Many nations have adopted standardized procedures to measure pulse velocity in concrete. Complete description of this method is provided in ASTM Test Method C 597[2].

The Rebound hammer test which is developed in 1948 by a Swiss engineer Ernst Schmidt, known as Schmidt hammer test is principally a surface hardness test [3].

According to BS 1881-202 [4], the measurements of the rebound number obtained may be used for several applications such as determination of concrete uniformity, strength development monitoring, in situ strength estimations and assessment of abrasion resistance of concrete. The standard shows that the results of the rebound hammer are affected by smoothness of the surface, size and shape of specimen, age of concrete, moisture conditions of concrete, type of coarse aggregate and cement, type of mold, and carbonation of concrete. Logically, harder concrete surface will produce larger number of rebound and shows greater strength of concrete. This test also can be applied to check the uniformity of the concrete surface. Each hammer is furnished with correlation curves developed by the manufacturer using standard cube or cylinder specimens. However, the use of these curves is not recommended because material and testing conditions may not be similar to those in effect when the calibration of the instrument was performed. The same problems are occurred when using the equation furnished with the UPV device.

To avoid such problems, a new correlation between both RN and UPV tests and strength should be prepared before using the devices.

Wu and Lin [5] in 1998 concluded that the pulse velocity is not affected by the level of stress in the element under test. In 2002, **Jaafar, Thanoon, Khan, and Trikha** [6] studied the compressive strength of concrete in different environments using UPV, Test results indicated that the presence of moisture in concrete changes the UPV values significantly. They found that the direct transmission tests are usually 1.5 times higher than those through indirect transmission test values. **Phoon**, **Wee** and **Loi** [7] in 1999 proposed a probabilistic model to predict compressive strength from ultrasonic pulse velocity.

Combined methods refer to techniques in which one test improves the reliability and precision of the other in evaluating a property of concrete e.g. strength or elastic modulus. The most popular combination is the method based on the measurement of UPV in conjunction with RN. A classic example of this application is the SonReb method, developed largely due to the efforts of RILEM Technical Committee 7 NDT under the chairmanship of **Facaoaru** [8]

Many researchers in different countries overall the world have used this method in order to increase the reliability and accuracy to predict the strength using combined nondestructive tests. Table (I) shows the proposed model suggested by different researchers reviewed.

2. OBJECTIVE OF THE STUDY

The effort of this study must answer the question "which of the equations listed in table (1) and many others must be used in practice to determine the in-situ compressive strength of concrete in Kurdistan Region?", thus; this study is intended to find the correlation equations between nondestructive tests (RN, UPV) and the destructive compression test, and then use the combined method to increase the accuracy and reliability of the proposed equation. Results of the proposed equations compared with the core samples taken from concrete members produced by local materials to determine the accuracy and reliability of NDT for in-situ estimation of concrete strength.

On the other hand to increase the reliability of the proposed equations to estimate compressive strength, standard cubes were collected from different field projects in Hawler and Duhok to apply the method and then modify the proposed equations

TABLE 1 VARIOUS SINGLE AND MULTIPLE REGRESSIN EQUATIONS SUGGESTED BY DIFFERENT RESEARCHERS

Table Head	Correlation With Strength		
	Rebound Number	*UPV*	*Combined Method*
Samarin [9]	$fcy= A_0+ A_1.R$	$f_{cy} = A_2 V^4$	$f_{cy}=A_0+A_1R+A_2V^4$
Raouf [10]	$C=0.74R^{1.12}$	$C= 2.8e^{(0.53U)}$	$C= 0.93.R^{0.63} e^{(0.31 U)}$
Teodoru [11]	$fc= a_3 . R^{b3}$	$fc= a_1e^{(b1 .U)}$	$fc= a. e^{(b.V-cA).} R^d$
Qasrawi [12]	$S= 1.35RN–17.393$	$S= 36.72U-129.077$	*Graphically represented*
Nash't [13]	$Sc=0.788 R^{1.03}$	$1.19 e^{0.715U}$	$Sc= 0.356R^{0.866}. e^{0.302 V}$
Hobbs & Kebir [14]	$fc =2.1684R-27.747$	$fc= 12.29U^2-49.02U+24.271$	$fc=-173.0-4.069V^2+57.693V+1.307R.$

3. EXPERIMENTAL WORK

3.1 Materials

Cement: Ordinary Portland cement (OPC) CEM I 42.5 N manufactured by ELZAGE factory/ Turkey was used. **Aggregate** Clean, natural river sand and two types of coarse aggregate (crushed and uncrushed) of normal weight type extracted from Asky-Kalak /Hawler pit were used throughout the experimental work. Grading of fine aggregate showed that 96 percent passing through sieve of size (4.75 mm). The apparent specific gravities and water absorption determined was 2.7 and 1.26 % respectively, and its gradation in accordance to the requirement limits of (BS 882),

The apparent specific gravity and absorption of natural gravel determined was 2.74 and 0.55 % and of crushed aggregate was 2.69 and 0.67 % respectively. Maximum size of both aggregate was 19 mm. grading of coarse aggregate confirmed the requirement limits of BS 882 and ASTM C-33

Super-plasticizer manufactured by Sika and known as ViscoCrete-Hi-Tech 30 was used for mixes M5 and N5. Trial dosages were used to obtain the required workability.

3.2 Mix Proportion and Specimens Preparation

Table (2) and (3) shows the final selected mix proportions after a series of trial mixes. :

At this stage, 216 cubes of dimension (150) mm, and four columns (200×200×1000) mm were decided to be cast. In addition 169 cubes from Hawler and 120 cubes From Duhok cities were also gathered from different projects produced by different ready mixed concrete factories. BS 1881-125 method for sampling and mixing was followed. Properties of fresh concrete are measured and listed in Table (4).

TABLE 2 LIST OF MATERIALS USED FOR M-MIXES

Mix Num.	Nominal Strength (MPa)	Quantities of Materials in kg/m^3					
		W/C	C	W	S	CA	SP
M1	10	0.85	230	195	870	1100	-
M2	20	0.75	265	200	870	1055	-
M3	30	0.63	315	200	795	1080	-
M4	40	0.52	380	200	725	1085	-
M5	50	0.44	465	205	670	1050	1.16

TABLE 3 LIST OF MATERIALS USED FOR N-MIX

Mix No.	Nominal Strength (MPa)	Quantities of Materials in kg/m^3					
		W/C	C	W	S	G	SP**
N1	10	0.79	220	175	805	1210	-
N2	20	0.66	265	175	795	1185	-
N3	30	0.53	330	175	745	1170	-
N4	40	0.45	410	185	695	1130	-
N5	50	0.36	515	185	620	1100	2.57

**** SP refers to the super-plasticizer used within mix-5(M5 and N5) in both tables, in order to reach the required workability. The ratio was 0.25 % and 0.5% by weight of cement respectively. C: Cement, W: Water, S: Sand, G: gravel and CA: Crushed Coarse aggregate*

Four reinforced concrete columns where cast. The columns were reinforced with minimum reinforcement area as per ACI 318 [15]. This was done in order to simulate the concrete in actual structures and then determine the in situ concrete strength by extracting cores from the columns and compare its actual strength with the predicted one using correlation equations proposed. the specimens were removed from the molds after 24 hours then curing was continued for about 27 days, and then was left in air temperature and humidity inside the laboratory. For ages (7, 14, and 28) days the specimens were in saturated surface dry conditions prior to testing, while for later ages (56 and 90) days, the specimens were rewetted for at least 48 hours prior to testing in order to maintain the same internal moisture content.

TABLE 4 PROPERTIES OF FRESH CONCRETE

Mix	Lab Conditions			Fresh Concrete properties		
	Air Temp. (C^0)	Water Temp.	Relative Humidity (%)	Slump (mm)	Density (kg/m^3)	Conc. Temp. (C^0)
M1	18	16	37	125	2400	19.4
M2	23	17	28	110	2410	22.7
M3	23	19	28	100	2415	22.2
M4	21	16	46	95	2415	22.2
M5	22	18	45	105	2410	23.4
N1	19	17	36	120	2440	20.5
N2	24	20	25	90	2450	24.8
N3	23	19	52	115	2445	24.6
N4	22	19	48	100	2445	24.4
N5	20	18	60	125	2445	25

3.3 Nondestructive Tests (UPV and RN):

The UPV and Rebound hammer test have been firstly carried out using the Portable Ultrasonic Nondestructive Digital Indicating Tester, commercially known as (PUNDIT E49) produced by CONTROL

3.4 Compressive Strength:

After recording the required data from both nondestructive tests, cubes were tested destructively using AMSLER testing machine of 2000 kN capacity. The cubes were tested in accordance with BS 1881: Part 116 .

4. RESULTS AND DISCUSSION

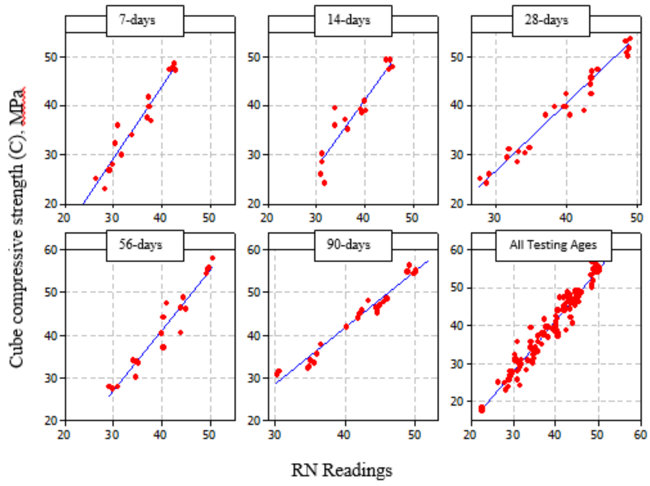
4.1 Experimental Results:

The Research covers 503 cubes. 216 cubes were prepared under laboratory conditions using ten different mix proportions designed to cover the required range of strength variation in different site projects in Hawler and Duhok Cities. OP cement type N has been used. Two types (natural and crushed) of coarse aggregate and natural fine aggregate have been used in this study. Two types of moulds (Steel and Plastic) were also used in order to obtain different degree of compaction using vibrated table.

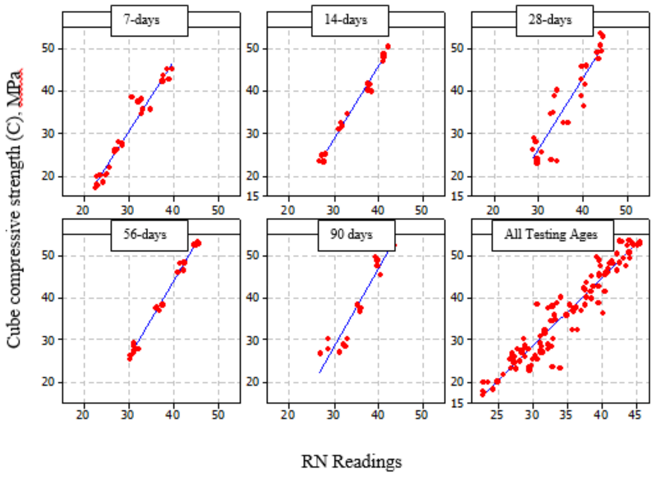
4.2 Relation between RN and Strength at Different Ages:

Figure (1-a) shows the relations between rebound hammer and strength at each tested days separately. As shown that when the age of concrete increased from 7 to 90 days, the correlation of RN with strength is good and the scatter of data is low. Thus, when combining all data together, a high coefficient of correlation was obtained. The correlation of RN with strength was 0.972 for type N-mixes, while for M-Mixes it was somewhat less compared to N-mixes, as shown in figure (1-b) that the scatter of data was somewhat higher and then lower correlation coefficient was obtained equal to 0.953.

Also, it has been shown that as the strength increased, RN increased also in all tested ages, but the ratio of RN to strength was changed, i.e. for low mixes (N1, N2, M1, and M2) the ratio of RN to strength was greater than 1.0 in all tested ages from 7 to 90 days, while for the remaining mixes, the ratio of RN to strength has kept below 1.0.



a- for N-Mixes

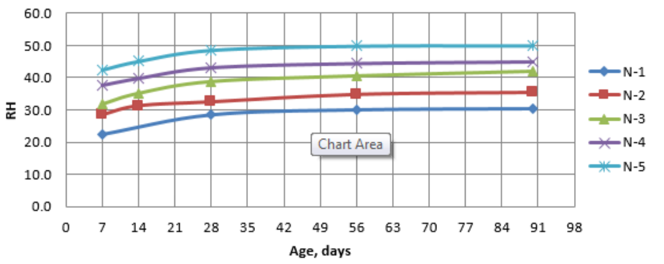


b- for M-Mixes

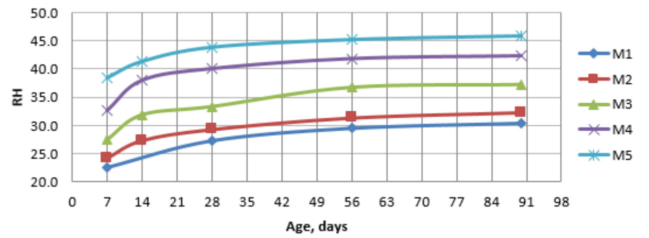
Figure (1) RN and Strength relationships at different ages.

The rate of increase of RN with time has the same behavior of strength gain with time as shown in figure (2- a & b), because as shown in previous section, that RN is directly proportioned to strength of concrete. As it is known that RN measure surface hardening of the tested object, it has been shown that the average increase in RN from 7 to 90 days was approximately about 8-10 readings. For example, mixes N3 and M3, the average RN was about 31.7 and 27.5 respectively at age 7day, and when this mixes reach 90 days, the average rebound hammer was about 41.9, and 37.2 readings respectively. From this concept one can conclude that RN is still sensitive as the age of concrete increased, and this rate of increase in RN hammer depend on the rate of increase of surface strength. Thus, when concrete strength is correlated with RN, age of concrete can be neglected.

One of the greatest factors that affect the correlation between RN and Strength is the source of aggregate used. the scatter of results is higher at 7days and the lines has become more interacted when the age of concrete is increased to 28 days. The goal of using a large number of cubes from different resources is that when correlation curves are derived, will then represent most Kurdistan Regions when these equation are used and keeping the errors as less as possible. Also it has been shown that when all data were combined together, the correlation coefficient was 0.908. It is clear that the type of coarse aggregate used has an influence on RN readings. This effect is lower for low concrete strengths up to 35MPa, while for higher strengths, this difference has become higher. For strength level 35 MPa, the RN for N- Mixes is 33.5 and for M-mixes are 34.8, which represent 1.3 RN difference which represents (3.8 %). While for strength level 50 MPa, the RN is 43 and 45.5 for N and M-mixes respectively. And this represents 2.5 differences in RN or (5.8 %). Thus it is important before using the NDT, that the type of aggregate must be known in order to use the correct correlation equations



b- For type N-mixes



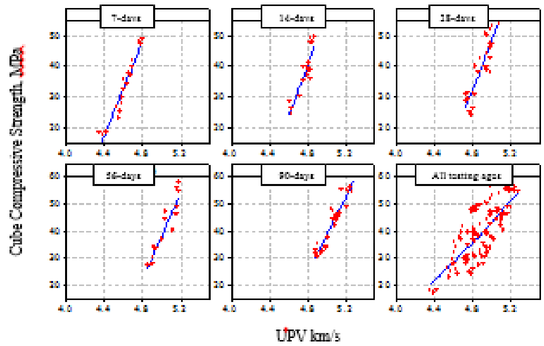
b- For type M-Mixes.

Figure (2) Rate of increase of RN with time.

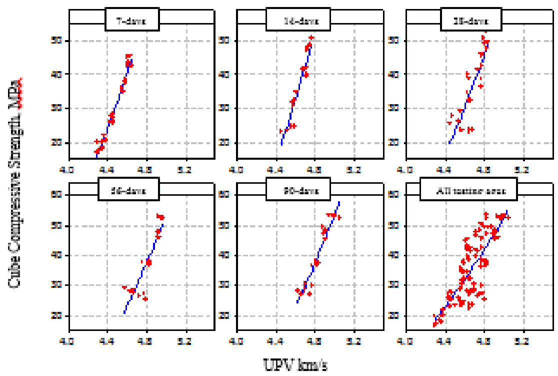
4.3 Relation between UPV and Strength at Different Ages

The relation between UPV and strength are shown in figure (3-a&b) for N and M-mixes for each single age separately. In these figures, the UPV seems to have good correlation with strength, except that the scatter of results is higher compared with RN. Thus; leading to lower correlation coefficient which has found to be 0.772 and 0.818 for N and M- mixes respectively. As it is known that UPV propagates into the concrete thickness between the transducers unlike RN which is greatly affected by the top surface, thus UPV it greatly affected by the degree of hydration of concrete and the porosity of the concrete.
The effect of age of concrete on the UPV is similar to the effect on strength development of concrete, except some interactions at lower strength levels. The rate of increase of UPV was greatly affected by the rate of increase in strength. the UPV continued to increase noticeably until the age of 56 days and at 90 days the rate of increase in UPV with time was little or ceased for both concrete mixes.

The UPV for field samples in Duhok and Hawler are greatly scattered from those prepared in laboratory, this difference arises from using several aggregate resources available, and also the mix design process. As it's known that most ready mixed concrete companies use admixtures according to the followed mix design process, the used admixtures will influence the UPV in approximately the same manner as they would influence the rate of hydration. Even though all these factors affected UPV, but a suitable correlation coefficient was obtained equal to 0.77.



a- for type N-Mixes



b- for type M-Mixes

Figure (3) UPV and Strength relationships at different ages.

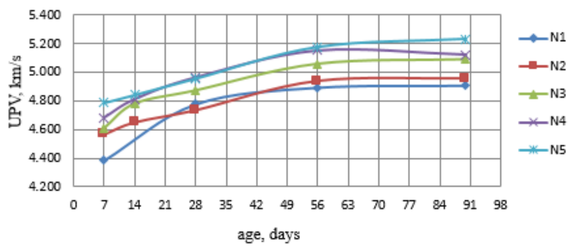
The relations between strength and UPV at different ages are shown in Figure (4) for both mixes. It is shown that for the same strength level, concrete containing crushed coarse aggregates, will have lower UPV as compared to concretes containing rounded coarse aggregates and this difference becomes more at higher strength levels. For example, at strength level 30 MPa, the UPV was approximately 4.63 and 4.62 km/s respectively for N and M-Mixes (which represents 0.2% difference), while for higher strength says 45 MPa the UPV was 5.017 and 4.906 km/s (represents 2.5% difference).

This behavior was the same as for RN, but the latter showed fewer scattering in results between low and high strength levels.

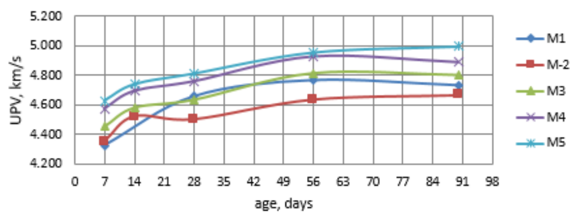
4.4 Statistical Modeling:

In statistical modeling, the overall objective is to develop a predictive ***equation*** relating a variable criterion to one or more predictor variables. In this research the variables criteria included for laboratory specimens are the compressive strength, the rebound hammer readings, the direct ultrasonic wave, water to cement ratio, age of Concrete, total aggregate to cement ratio, and density. While for cubes of unknown mix proportion the three major variables criteria are compressive strength, rebound hammer, and direct ultrasonic pulse velocity.

Based on the descriptive statistical and graphical analysis which has assisted in the identification of the general trends in the data, the Bivaritate correlation coefficients are determined to identify the underlying from the relationship between the variable criterion and each of the predictor variables. Ideally, predictor variables are selected that have a high correlation with the variable criterion and low correlation with the other predictor variables. The following terms shown in equation-1 and are defined as follows:



a- For type N-Mixes



b-For type M-Mixes

Figure (4) Rate of increase of UPV with time.

4.5 Multiple Correlation Equations:

In order to obtain useful mathematical relationships, that yield good prediction accuracy, multiple regressions (non-linear regression) were used for this purpose, due to their efficiency in derivation of exponential equations, which are extremely useful for fitting experimental data with more than one independent variable. This type of analysis is suited for type N and M mixes (laboratory samples), because the necessary variables are known such as W/C, A/C, and (D). While for Hawler and Duhok samples, only RN and U are known so that the combined non-destructive method is more suitable. The exponential equations used were of the following general form:

$$C=a_0.(RN)^{a1}.(U)^{a2}.(W/C)^{a3}.(A/C)^{a4}.(D)^{a5} \qquad (1)$$

Where;
C= concrete cube compressive strength (MPa),
RN= rebound hammer reading,
U=direct ultrasonic pulse velocity (km/s),
W/C=water cement ratio,
D=density of the concrete (kg/m^3),
A=age of concrete in (Days), and
A/C= total aggregate to cement ratio.
a_0, a_1, a_2, a_3, a_4, a_5, are empirical constants

It is important to mention here that the age of concrete was not included in equation (1), because it was preferred to depend only on the results of the RN and U to represent the degree of hardening of concrete. This approach was adopted depending on experimental results reported by Sturrup et al. and Zivkovic et al [10] .They showed that for a given concrete mix, strength–ultrasonic pulse velocity can fairly be related regardless of the age of concrete. Such correlation equations cannot be used for practical purposes, because sometimes it is difficult to know the properties of the concrete (W/C, A/C, and D) under question. The summary of the multiple correlation constants for equation (1) are shown in tables (5-a&b) for N and M-mixes respectively.

Table 5 COEFFICIENTS OF EXPONENTIAL REGRESSION

a-For Type N-Mixes

a_0	a_1	a_2	a_3	a_4	a_5	R^2
50.2	0.616	1.215	-1.751	1.01	-0.936	0.959
0.04	0.671	1.11	-1.62	0.94	-	0.958
0.427	0.775	0.928	-0.314	-	-	0.953

b-For Type M-Mixes

a_0	a1	a2	a3	a4	a5	R^2
5.633×10^{-6}	0.533	0.419	-1.59	0.768	1.242	0.964
0.079	0.411	0.463	-1.753	0.859	-	0.96
0.572	0.456	0.463	-0.652	-	-	0.957

4.6 Selection and Assessment of Best Correlation Equations:

In this study, the effort is done to develop more accurate equations in order to increase the confidence limit for predicting in-situ concrete strength in Kurdistan Region using the materials available. This was done by conducting NDT on samples prepared and gathered from three different locations in order to be applied in most Kurdistan Regions. Also the numbers of cubes tested were much higher compared to the previous equations. Different variables were also added such as crushed coarse aggregate, curing under wet burlaps, plastic and steel cubes subjected to the same vibration time for obtaining different degrees of compaction were the first time being included. Different proposed models (from 1 to 6) derived. In general, all the equations derived from experimental test results can be used for practical purposes to anticipate the concrete compressive strength within a rational degree of confidence. Thus, the best correlation equations that give good interpretation of results should be derived under a wide variety of variables. In this study, a number of variables, (different source`s and types of aggregates, cement content, curing conditions, type and degree of compaction, a wide range of compressive strength variation, and sample size) which can be combined together, when all test results are used together. This is the case when using the equations (2), (3), (4), (5), (6), (7). The mentioned equations can be divided into two categories in order to use them for prediction of concrete compressive strength in Kurdistan region:

A. The case when the type of coarse aggregate is known (for Natural Coarse Aggregate), the following models must be used,

$C=0.362\ (RN)^{1.269}$ $R^2=0.82$, SE=4.68 (2)
$C=0.677\ EXP(0.818U)$ $R^2=0.59$, SE=7.49 (3)
$C=0.16\ (RN)1.091 \times EXP\ (0.308U)$ $R^2=0.87$, SE = 4.27 (4)

B. The case when the type of coarse aggregate used is unknown, the following models must be used as shown in Table (5):

$C=0.319\ (RN)^{1.31}$ $R^2=0.82$, SE=4.68 (5)
$C=0.571\ EXP\ (0.859U)$ $R^2=0.59$, SE=7.53 (6)
$C=0.163\ (RN)1.132\times EXP\ (0.277U)$ $R^2=0.85$, SE=4.4 (7)

Number of data used for the purpose of correlation of category A was 309 and for category B was 503, Statistical analysis by f-test proved that null hypothesis is rejected, and possibility for a relation between points and the curves is possible. The coefficient of determination R^2 for the predicted models has shown to be satisfactory and standard error was minimized when using combined method.

The statistical assessment using diagnostic plots for these models are shown in figures (5) to (7). It is shown that for all models, the relation between predictive and actual values is very close to 45˚ line, especially for RN and combined method. The UPV gives slightly more dispersion of predicted results around the 45˚ line. In addition, standardize residuals followed the normal distribution curve.

5. CASE STUDY

In this case study, 84 cubes were tested in lab using the RN and UPV test then were crushed in order to find its actual compressive strength. 20 cubes have unknown mix proportions and were cured in moist conditions for 28 days, then were left to dry in air until the date of testing. The cubes were collected in lab, which are the remains of several trial mixes which have been done before.

The age of cubes was more than 120 days. 24 cubes were cast with the columns in first case study. Half were cured similar to the columns condition, and the rest were cured in moist condition. The remaining 40 cubes are from Hawler and Duhok having unknown mix proportion tested in 7 and 28 days. Before testing cubes older than 28 days, they were immersed in water for about 48 hours in order to get SSD conditions before testing The type of coarse aggregate was unknown for the most cubes, thus models 4, 5, and 6 were used for the purpose of comparison with actual crushing compressive strength. While for 24 cubes cast with columns, the proper model was used according to coarse aggregate used. The differences between predicted and actual compressive strength is shown graphically in Figure (8,9, and 10). From these figures, it can be concluded that these models give reasonable results and agreement between predictive and actual strengths, except when using UPV alone, the scatter is higher compared to RN, and these differences had become less when combined non-destructive test method was used.

6. CONCLUSIONS

From the experimental test results and statistical analysis presented in this research, the following conclusions may be drawn:

1. In general, it was found that Rebound hammer test give more reliable results than ultrasonic pulse velocity test for strength estimation purposes.
2. The rate of increase of hammer readings and ultrasonic pulse velocity with time was quite similar to strength gain but the percentage was different. Also both tests were sensitive to strength gain as the age of concrete increased.
3. Test results of ultrasonic and hammer in Hawler and Duhok samples where quite different from laboratory Samples, and this difference was higher at 7days tests cubes, and it becomes closer at 28 days test age.
4. The use of more than one nondestructive test for testing concrete has shown to give more reliable results, especially when variation of properties of concrete affects the test results in opposite directions such as moisture conditions of the tested concrete.
5. The proposed equations are deviated from other researchers equations derived in Baghdad; therefore the new derived equations are recommended to be used in Kurdistan Region.

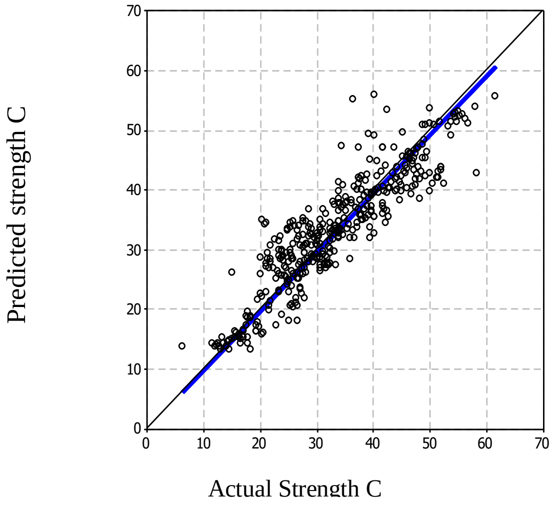


Figure (5) Predicted versus actual compressive strength by equation (1)

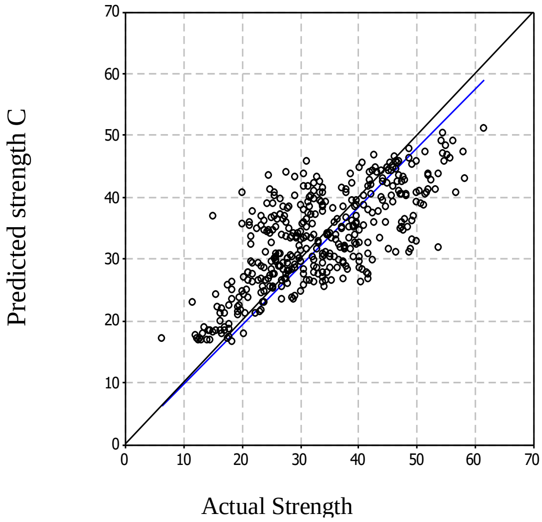


Figure (6) Predicted versus actual compressive strength by equation (2)

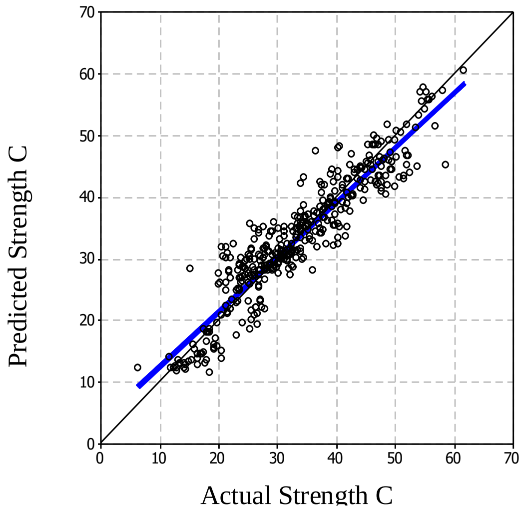


Figure (7) Predicted versus measured compressive strength by equation (3)

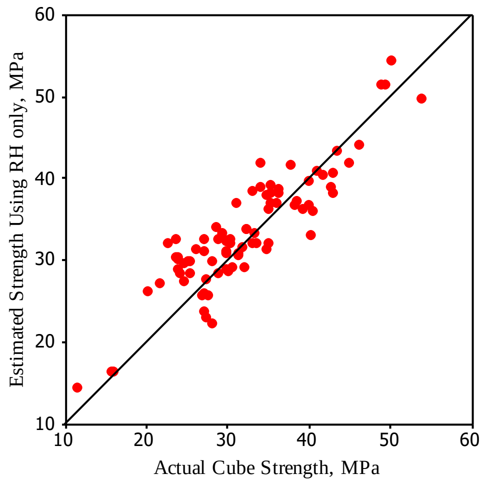


Figure (8) Predicted versus measured compressive strength by equation (5)

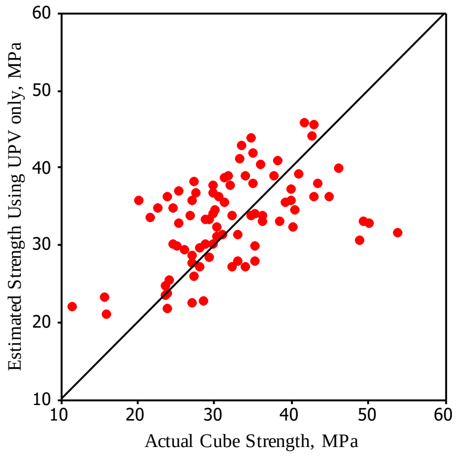


Figure (9) Predicted versus measured compressive strength by equation (6)

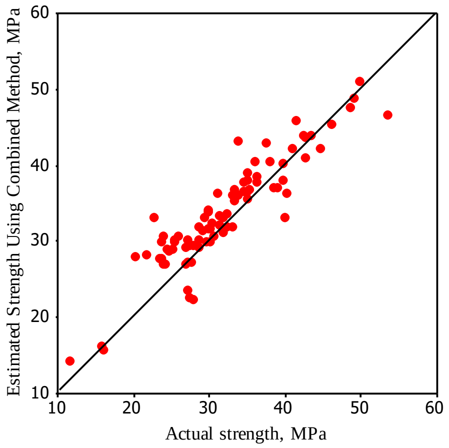


Figure (10) Predicted versus measured compressive strength by equation (7)

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