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Determination of concrete quality with destructive and non-destructive methods

Hakan Kibar[1*] and Turgut Öztürk[2]

[1]*Department of Seed Science and Technology, Faculty of Agriculture and Natural Sciences, Abant Izzet Baysal University, Bolu, Turkey*
[2]*Department of Agricultural Structures and Irrigation, Faculty of Agriculture, Ondokuz Mayis University, Samsun, Turkey*

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Abstract. In this study, the availability of Schmidt hammer has been investigated as a reliable method to determine the quality of concrete in irrigation networks. For this purpose, the 28-day compressive strength of concrete material used in the construction irrigation channel of Bafra lowland, which is one of the most fertile plains in Turkey was examined by means of concrete compression and as well as concrete Schmidt hammer in laboratory conditions. This study was carried out on cylindrical samples to represent the everyday concrete party (150 m^3) produced by contractor firm as 3 replications. The statistical analysis of experimental data showed that the correlations between the values of 28-day compressive strength of Schmidt hammer and the rebound number was found to be 0.98. Differences of the compressive strength between compression testing and Schmidt hammer were statistically significant at $P<0.01$. In this context, it was found that the reliability of compressive strength of the concrete compression test are excellent, also the reliability of compressive strength of Schmidt hammer are fair in assessing the quality of concrete irrigation channels.

Keywords: Irrigation channel; compressive strength; impact rebound hammer (IRH); non-destructive testing (NDT)

1. Introduction

In concrete structures, the strength of concrete is one of the most important properties. Ways to evaluate this property in finished structures or structures in use, without damage to its functionality or appearance, have been the concern of engineering professionals over the years. There are many test methods to evaluate the strength of concrete. The most frequently used test is to measure the compressive strength of concrete at age of 28 days using simple compression in cylindrical and prismatic specimens (Pereira and De Medeiros 2012).

The compressive strength of concrete is one of the most important technical properties. In most structural applications, concrete is employed primarily to resist compressive stress. In those cases where other stresses (tensile, etc.) are of primary importance, the compressive strength is still

∗Corresponding author, Assistant Professor, E-mail: hakan.kibar@ibu.edu.tr
Professor, E-mail: turgutoz@omu.edu.tr

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frequently used as a measure of the resistance because this strength is the most convenient to measure. For the same reason, the compressive strength is generally used as a measure of the overall quality of the concrete, even when strength itself may be relatively unimportant. Finally, the concrete-making properties of the various ingredients of the mixture are usually measured in terms of the compressive strength (Popovics 1998).

In the inspection and testing of concrete, the use of non-destructive testing (NDT) has been making slow but steady progress since the 1940s. The slow development of these testing methods for concrete is due to the fact that, unlike steel, concrete is a highly nonhomogenous composite material and most concrete is produced in ready-mixed plants and delivered to the construction site. These tests also provide an estimate for the compressive strength of the measured concrete in situ, eliminating the need of extraction of many specimens for determination of the compressive strength of the inspected structures (Pereira and De Medeiros 2012). The most popular tests are the rebound hammer. The Schmidt rebound hammer weighs about 1.8 kg and is suitable for use both in a laboratory and in the field. The main components include the outer body, the plunger, the hammer mass, and the main spring. Other features include a latching mechanism that locks the hammer mass to the plunger rod and a sliding rider to measure the rebound of the hammer mass. The rebound distance is measured on an arbitrary scale marked from 10 to 100. The rebound distance is recorded as a “rebound number” corresponding to the position of the rider on the scale. The rebound principle, on the other hand, is more widely accepted: the most popular equipment, the Schmidt rebound hammer, has been in use worldwide for many years. Recommendations for the use of the rebound method are given in ASTM C 805 (1997), BS EN 12504-2 (2012) and Bungey *et al.* (2006).

In concrete design and quality control, strength is the property generally specified. This is because, compared to most other properties, testing of strength is relatively easy. Furthermore, many properties of concrete, such as elastic modulus, water tightness or impermeability, and resistance to weathering agents including aggressive waters, are believed to be dependent on strength and may therefore be deduced from the strength data. Although in practice most concrete is subjected simultaneously to a combination of compression, shearing, and tensile stresses in two or more directions, the uniaxial compression tests (destructive) are the easiest to perform in laboratory, and the 28-day compression strength of concrete determined by a standard uniaxial compression test is accepted universally as a general index of the concrete strength.

Aydin and Saribiyik (2010) stated that a relationship is determined and correlated between non-destructive testing (NDT) named as Schmidt rebound hammer test and concrete destructive compression test. This study showed that the Schmidt rebound hammer is principally a surface hardness tester with an apparent theoretical relationship between the strength of concrete and the rebound number of the hammer.

Hamidian *et al.* (2012) reported that Schmidt rebound hammer is given a method for health assessment by a suitable correlation between this tests with test by compressive testing machine. The experimental investigation using non-destructive testing methods showed that a good correlation exists from compressive strength of Schmidt rebound hammer.

The compressive strength with rebound hammer ve the compression testing at concrete varieties in different cement content have been investigated by Pereira and De Medeiros (2012). These research results demonstrate that the compression testing have been achieved higher compressive strength.

This paper discusses the relationship between compression being tested (destructive) and the Schmidt rebound hammer (non-destructive) to determine the concrete quality in the manufacturing of concrete irrigation channels.

2. Experimental method

The study was conducted in Bafra lowland (41^0 35' N, 35^0 56' E, approx. altitude 20m), which is one of the most fertile plains in Turkey. The study material is the concrete material of channels used in the irrigation network of Bafra lowland. In the manufacture of concrete channels, the Portland cement and 0/4, 4/8 and 8/6 mm aggregates were used. All-in-aggregate used for concrete manufacture was provided from Red River basin. The size, the number, and the continuity of the pores through an aggregate particle may affect the uncompact bulk density, compact bulk density, frost resistance, abrasion. The irrigation channel ready-mixed concretes of Aydiner Ready-Mixed Concrete Contractor were used as material in the project. The specimens were taken during 40 days in concrete contractor (BS EN 206-1 2001). Their descriptions are presented in Table 1. Cure the cylinders under standard moist-curing room conditions (28-day) and keep the curing period the same as the specified control age in the field. The experiments have been conducted with removal from the pool of cure at the end of 28-day of the specimens taken every day. Using concrete mixes were used to prepare the standard cylinder specimens in the laboratory to compare with compression test (destructive) with the Schmidt rebound hammer (non-destructive). The tests were conducted in the VIIth Region Directorate of State Hydraulic Works.

In experiments, the concrete compression testing machine of 200 kN capacity has been used (Fig. 1). During experiment, loading speed was 0.196 MPa/s. The dimensions of the frame allow the testing of concrete cylinders up to 15×30 cm diameter cylinders (BS EN 12390-3 2000). Compressive strength is calculated using Eq. (1) as follows:

Table 1 The compressive strength and their description used in the different days

Traits	Description
D1	1-day compressive strength of concrete
D2	2-day compressive strength of concrete
D3	3- day compressive strength of concrete
D40	40-day compressive strength of concrete

Fig. 1 The concrete compression testing machine

$$CCS = \frac{F}{A_s} \quad (1)$$

where

CCS : Concrete compressive strength, MPa

F :Destruction force, N

A_s : Area of pressure surface, mm^2

The compressive strength of the rebound hammer is 10 to 70 N/mm^2 measuring interval. This study was used type-N the Schmidt rebound hammer. Ten beatings on surfaces of the cylinder specimens were made. More than one beating was not made on the same point or no beatings were made on aggregate pieces and voids in concrete (Bideci *et al.* 2009). The BS EN 12504-2 (2012) standard allows the usage of a rebound hammer for the estimation of concrete compressive strength providing a suitable correlation is used.

The calibration chart may then be used to convert rebound numbers to strength. It is unlikely that 95% confidence limits on the estimation of the in-situ concrete strength by rebound hammer will be better than ±25% under ideal conditions. The conversion of rebound number to compressive strength can be achieved by producing a calibration chart for the concrete concerned, as provided by the equipment manufacturers, will be of any practical value. A typical curve established by for cylindrical concrete is shown in Fig. 2 (ELE 1998). This chart was based on tests performed at 28-day by using different concrete (ASTM C 805 1997). The use of the rebound hammer for strength estimation of in-situ concrete must never be attempted unless specific calibration charts are available, and even then, the use of this method alone is not recommended, although the value of results may be improved if used in conjunction with other forms of testing (Bungey *et al*. 2006).

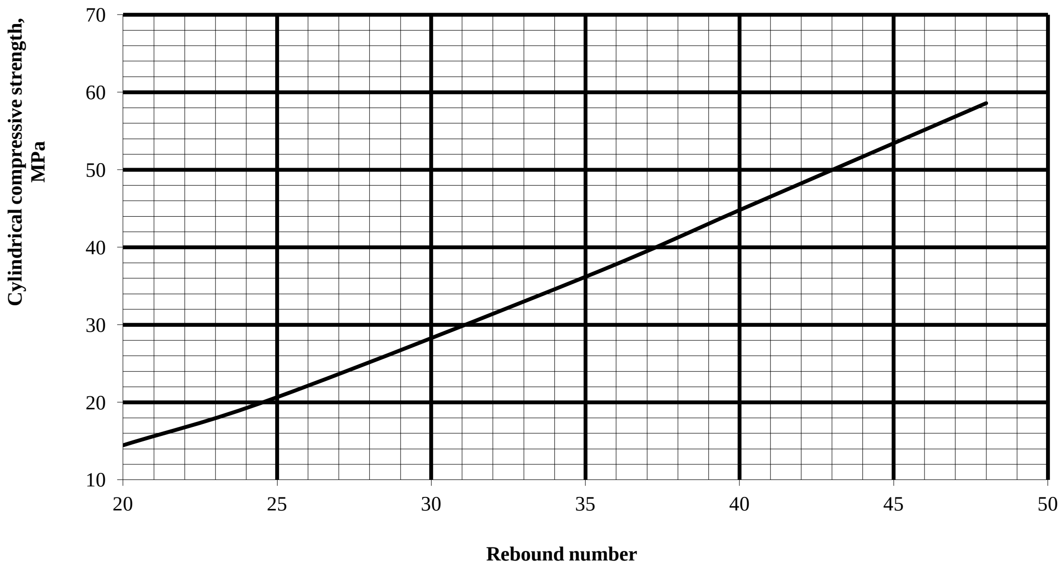

Fig. 2 The calibration chart related to 28-day the compressive strength of concrete with the rebound number

The data were analyzed statistically using SPSS software and figure was plotted in Excel software. In this context, the correlations between compressive strengths obtained depend on the rebound hammer and rebound number was investigated. The coefficient of variation of test specimens was determined according to compression test and the rebound hammer. The assessments regarding the quality in laboratory conditions (to provide the desired compressive strength) at the manufacturing stage of concretes used in the irrigation network of Bafra lowland were made. The Principal Component Analysis (PCA) statistical analysis was used for compressive strength with the rebound test hammer at different days and these data were statistically analysed. PCA was applied to investigate the factor structure of these fortieth days.

3. Results and discussion

The Portland cement, the chief ingredient in cement paste, is the most widely used building material in the world. The compare between the typical chemical and physical composition of the Portland cement selected for the work is showed in Table 2. All the adequate typical chemical and physical composition was carried out in accordance with Pereira and De Medeiros (2012), BS EN 812 (1994).

Some properties of aggregates used the concrete channel manufacturing is presented in Table 3. The properties of aggregates are those that refer to the physical structure of the particles that make up the aggregate. The results obtained are similar to the values given by BS EN 196-2 (1995).

Table 2 Some properties of Portland cement used the concrete channel manufacturing

Characteristic	Unit	Value
SiO_2	%	32.40
Al_2O_3	%	4.71
Fe_2O_3	%	3.18
CaO	%	51.35
MgO	%	1.35
SO_3	%	2.51
Cl	%	0.0089
Free CaO	%	0.85
Specific gravity	g/cm^3	3.03
Specific surface	m^2/kg	313.2
Volume expansion	mm	4.00

Table 3 Some properties of aggregates used the concrete channel manufacturing

Characteristic	Unit	Value
Moisture content	%	2.68
Clay-silt	%	1.81
Uncompact bulk density	kg/m^3	1860
Compact bulk density	kg/m^3	1940
Frost resistance	%	4.55
Abrasion	%	20.60

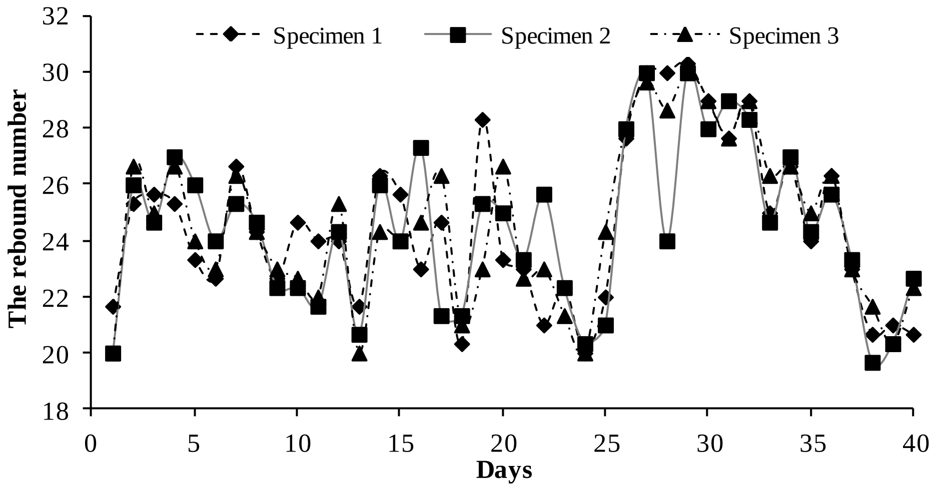

Fig. 3 The rebound numbers of channel concrete produced in different days

The calibration chart in Fig. 2 are used to evaluate compressive strength at points where only rebound hammer was performed. The results of measuring rebound numbers for the type-N of Schmidt rebound hammer for channel concretes in different days are presented in Fig. 3. The rebound numbers for specimens 1, 2 and 3 was the parallel to each other and the difference between rebound values in different specimens was low. The rebound numbers for concrete channels were determined from 20 to 30. The variation of rebound numbers among the specimens was 4%. This value is acceptable because lower than is suggested (10%) by Kolek (1969).

The compressive strength relating to channel concretes for both the mean rebound hammer related to specimens 1, 2 and 3 given in Fig. 3 and the compression testing are presented in Fig. 4. According to the compression testing, the highest value (32.04 MPa) were measured for channel concretes manufactured in 27-day, and also lowest value (14.72 MPa) were determined for channel concretes manufactured in 18-day. According to the rebound hammer testing, the highest value (28.26 MPa) were measured for channel concretes manufactured in 26, 28 and 40-days, and also lowest value (14.48 MPa) were determined for channel concretes manufactured in 23-day. The compressive strength of the rebound hammer testing was lower than the compression testing. Similar results have been reported by Lopes *et al.* (2001), Oymael *et al.* (2009). Differences of the compressive strength between the compression test and rebound hammer test were statistically significant at $P < 0.01$. However, the difference of the average compressive strength between both methods was 18%. This difference is acceptable regarding to the values suggested (15-20%) by Chu (2011). The rebound hammer test results can be influenced by many factors; such as the characteristics of the mix proportions, size, shape, and rigidity of the specimens, age and type of curing, surface smoothness of test surface, moisture condition, type of coarse aggregate, type of cement (Portland, high alumina, super sulfated), surface carbonation, stiffness of the member, location of the plunger, compaction, and stress state and temperature (Mehta and Monteiro 2006, Aydin and Saribiyik 2010). It has been found that actual compressive strength can predicted precisely with compression test rather than test hammer. There is an advantage in using the rebound hammer as a means of evaluating concrete to assess the in-place uniformity, to delineate regions in a structure of poor quality or deteriorated concrete, and to estimate in-place strength. The unit is easy to use and a large number of readings can be obtained in a relatively short amount of time. The method is for the most part non-destructive and typically more economical than compression test method. According to Baalbaki *et al.* (1991), Malhotra and Carino (2004), Hobbs and Kebir (2006) and Brozovsky (2014) there are inappropriateness of using calibration relationships elaborated for testing normal-weight concrete with Schmidt rebound hammers for the determination of the compressive strength of concretes. Their findings were confirmed by the results presented in this paper. However, with these advantages come disadvantages related to limitations on accuracy, and the need for proper calibration and correlation with cores for evaluation of an existing structure.

The availability and reliability of strength correlations and the accuracy required from the strength predictions may be important factors in selecting the most appropriate methods to use (Bungey *et al*. 2006). The correlation between compressive strength and rebound number is found to be 0.98. Similarly, a significant relationship between mean compressive strength and mean rebound number by Pereira and De Medeiros (2012), Brožovský *et al.* (2005), Aydın *et al.* (2007) was determined. The rebound hammer is the most popular non-destructive test. However, there is a wide degree of disagreement among various researchers concerning the accuracy of the estimation of strength from the rebound readings and the empirical relationship (Malhotra 2006, Pereira and De Medeiros 2012).

The variation in mean compressive strength and mean rebound number for channel concrete was described by the following Eq. (2):

$$CCS = 1.39RN - 13.82 \tag{2}$$

where

CCS : Concrete compressive strength, MPa

RN : The rebound number

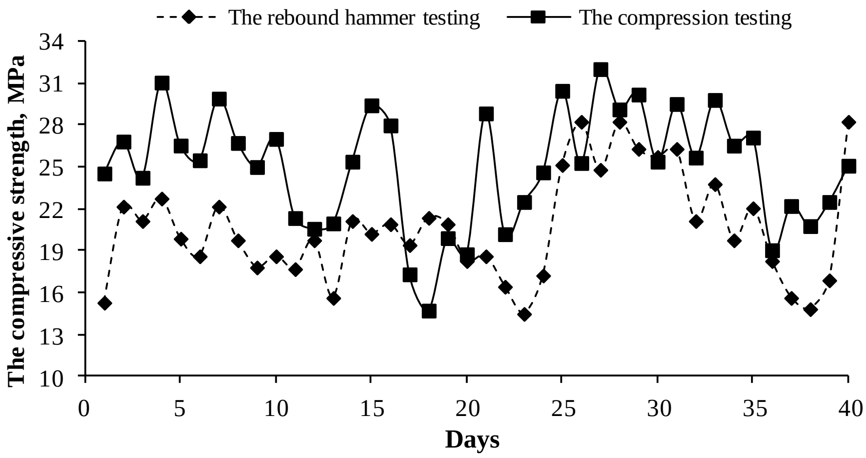

Fig. 4 The compressive strength of channel concrete produced in different days

At the end of PCA, factor coefficients of identifying qualities were evaluated and the attributes scoring a coefficient value higher than 0.7 in the first three PCA were determined. The results of the PCA were presented in Table 4. The first three principal components (PCs) accounted for 100% of the total variability among the 40 day for all the traits investigated. The first principal component (PC1), which is the most important component, explained 38.18% of the total variability and was related to D1 – 4, D9 – 11, D13, D24, D28, D30 – 31, D35, D37, and D39. These traits have a great influence on compressive strength. The principal component (PC2) had 34.19% of the total variation in different shear speed. D5 – 6, D8, D16, D20 – 21, D23 and D36 contributed positively to PC2. In contrast, D15, D29, and D40 contributed negatively to PC2. The third principal component (PC3) exhibited 27.62% of the all shear speeds and was associated with D14, D17, D19, D25 – 26, D32 and D38. The plot of the angles of internal friction on the first three PCs obtained from analysis of 40-day traits were presented in Fig. 5. The scatter diagram of the compressive strength showed that there was high a level of diversity.

Table 4 Principal component analysis (for the first three PCs) of compressive strength with the rebound hammer test in different days

	PC axis		
	PC 1	PC 2	PC 3
Eigen values	15.273	13.676	11.051
Proportion of variation (%)	38.181	34.190	27.629
Cumulative variation (%)	38.181	72.371	100.00
Traits		Eigen vectors	
D1	**0.926**	0.158	-0.342
D2	**-0.727**	0.045	-0.685
D3	**0.945**	0.050	0.324
D4	**-0.842**	0.426	-0.331
D5	-0.436	**0.739**	0.513
D6	0.492	**0.731**	0.473
D7	-0.058	-0.958	-0.282
D8	0.264	**0.758**	0.597
D9	**0.952**	0.167	-0.256
D10	**0.964**	-0.259	0.056
D11	**0.775**	-0.546	0.319
D12	0.570	0.652	-0.499
D13	**0.827**	0.046	0.560
D14	-0.290	-0.516	**0.806**
D15	0.600	**-0.750**	0.277
D16	-0.583	**0.744**	0.326
D17	0.383	-0.404	**-0.831**
D18	0.530	-0.601	0.598
D19	-0.221	0.645	**-0.731**

Table 4 Continued

	PC axis		
	PC 1	PC 2	PC 3
Eigen values	15.273	13.676	11.051
Proportion of variation (%)	38.181	34.190	27.629
Cumulative variation (%)	38.181	72.371	100.00
Traits		Eigen vectors	
D20	0.046	**0.818**	-0.573
D21	-0.392	**0.839**	0.377
D22	0.667	0.348	0.659
D23	-0.114	**0.993**	-0.014
D24	**0.719**	0.445	-0.533
D25	-0.044	-0.559	**0.828**
D26	0.075	-0.660	**0.747**
D27	0.575	-0.573	-0.584
D28	**0.723**	-0.691	0.000
D29	-0.172	**-0.754**	-0.634
D30	**-0.939**	-0.076	0.336
D31	**0.844**	-0.157	-0.513
D32	0.339	0.545	**-0.767**
D33	**-0.778**	-0.590	-0.217
D34	0.639	0.670	-0.378
D35	**-0.953**	-0.238	0.189
D36	0.357	**0.753**	0.553
D37	**0.809**	0.491	-0.324
D38	-0.129	0.589	**0.798**
D39	**0.716**	-0.199	0.669
D40	-0.333	**-0.755**	-0.565

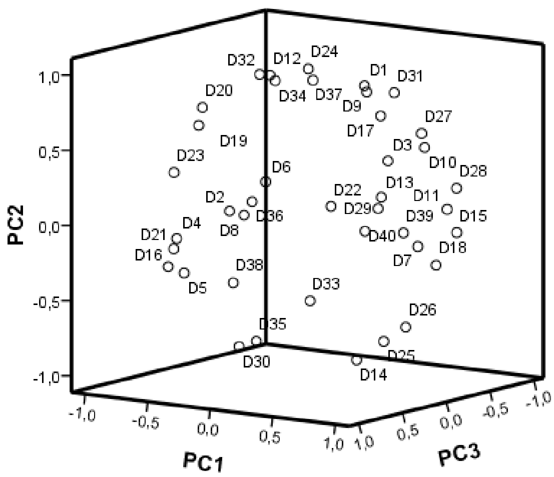

Fig. 5 Scatter diagram based on the first three principal components (PC) axes in 40-day

Table 5 Coefficient of variation for different control standards

Reference	Coefficient of variation (%)				
	Excellent	Very Good	Good	Fair	Poor
ACI Committee 214 (1997)	< 3	3 to 4	4 to 5	5 to 6	> 6
Gambhir (1993)	< 5	5 to 12	12 to 15	15 to 18	> 18

Table 6 The statistical quality control parameters in the experimental specimens

Methods	CCS[1] (MPa)	SD[2](MPa)	CV[3](%)
Compression testing	25.03	4.14	2.35
The rebound test hammer	20.64	4.02	8.21

[1] : Mean concrete compressive strength
[2] : Standard deviation
[3] : Coefficient of variation

The coefficient of variation as the degree of quality control in concrete manufacture provides important information about the quality of the production (Chung 1993). The coefficient of variation of concrete strength is not constant with varying strength for a given level of control because it is calculated using the average strength (Bungey *et al.* 2006). In this context, the quality of manufacture according to both methods used in this study was evaluated. The degrees of quality control suggested by ACI Committee 214 (1997) and Gambhir (1993) in concrete manufacture are given in Table 5.

The statistical parameters determined depending on the experimental data are given in Table 6. When reference assessments in Table 5 based on, the quality in laboratory conditions at the manufacture stage of concretes used in the irrigation network of Bafra lowland at the result of compression test was excellent according to ACI Committee 214 (1997) and Gambhir (1993). At the result of was poor according to ACI Committee 214 (1997) and the rebound hammer it was very good according to Gambhir (1993). Similarly, in the studies done the reliability of the rebound hammer had been found lower than compression test (Gaynor 1969, Kıyomı 2006, Kadiroğlu and Erbakan 2009).

4. Conclusions

At the result of this study, the following conclusions were obtained;

1) Taking into consideration the compressive strength of 28-day for irrigation channel concrete, the correlation between the values of 28-day compressive strength of the rebound hammer and the rebound number was found to be 0.98. Differences of compressive strength between compression test and the rebound hammer were statistically significant at $P<0.01$.

2) This correlation value is important about used and not used of concrete in accord with specification conditions in the completed irrigation channels followed by public sector. Furthermore, this value show getting quick results and the availability of pre-estimate.

3) The quality in laboratory conditions at the manufacture stage of concretes used in the irrigation network was excellent according to compression test and it was poor according to the rebound hammer.

4) The use of the rebound hammer method (IRH) on the existing channel concrete is not suitable to estimate the strength of concrete. Direct use of the rebound test hammer demonstrates high variations, which makes engineering judgment quite difficult. The rebound hammer method could only be used as a reliable instrument to calculate the compressive strength, if the required compression tests are performed.

5) In today's construction industry, ready-mixed concretes preferred for time and economical reasons are subjected to the required quality control procedures before they are cast in buildings; therefore, differences among the compressive strengths of concretes were statistically significant according to both methods ($P<0.01$).

6) To determine the concrete quality in irrigation networks, the reliability of the rebound hammer has been found lower than compression test. However, because the rebound hammer method is non-destructive method, it can be used in the pre-assessment works to get quick results in areas which have problem in the concrete quality.

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