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Experimental determination of the initial compressive strength of concrete using a rebound test hammer

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Abstract. This paper deals with rebound hammer testing of concrete in the early stage of ageing. Six types of concrete were produced for the purpose of the presented experiment and differed in the water/cement ratio and were otherwise identical as to the input components. SilverSchmidt PC L test hammer was used to determine the rebound coefficient Q and compressive strength of cube test specimens. The aim of the experiment was to verify the possibility of creating a conversion relationship between the determined parameter of the used non-destructive method and the real compressive strength of concrete in the first days of ageing of concrete. Based on the conducted experiment, it may be stated that the SilverSchmidt PC L test hammer with a mushroom plunger is a suitable instrument for determining the initial compressive strength of concrete, starting from the value of about 5 N/mm^2 . An important conclusion is the fact that it is possible to create a regression model with relatively high accuracy, in this case approximately $\pm 3 \text{ N/mm}^2$.

1. Introduction

Rebound hammer test of concrete is one of the most widely used non-destructive methods (NDT) in the construction industry since the measurement is relatively simple and the character of the method is practically non-destructive [1,2]. It is essentially a surface test of a concrete element with measurements and evaluation of a prescribed number of local failures or elastic reactions caused by the impact.

The rebound hammer test method is in practice used principally in two basic ways. The first is the use of a rebound test hammer to diagnose older structures with the main purpose being the determination of the strength class of the tested concrete. In case of such structures, however, it is usually necessary to remove not only the plaster, but also the surface layer of concrete to prevent possible negative influence of the rebound hammer measurement due to carbonation. Furthermore, it is also necessary to supplement the non-destructive measurements with compressive testing of core samples taken from the tested concrete. The second way of using the rebound hammer test method is more advantageous and focuses on quality control of concrete of new constructions, especially those which have a smooth surface and which therefore eliminate the need of grinding. Concrete is tested at sufficient age, at least 28 days of age, and the compressive strength estimation is best carried out using a conversion relationship (i.e. the regression dependence between the NDT parameter and the actually determined compressive strength) created especially for the tested type of concrete.

In addition to quality control of already aged concrete, new types of hardness testers can also provide estimates of the relatively low, so-called formwork-removal, strength of non-aged concrete, e.g. at the age of several hours or a few days after concreting the construction element. This paper



deals with the issue of creating the conversion relationship to estimate the initial strengths of concrete and to determine the appropriate moment for removing the formwork from the structure.

2. Types of rebound test hammer

A number of rebound hammers have been developed over the past few years but the ones used the most are the Schmidt type test hammers. There are several types of rebound test hammers that differ from each other in the energy of the impact, the size and the shape of the plunger, or the mechanical design. The usability of the basic rebound test hammers with respect to compressive strength and the thickness of the concrete layer is presented in table 1 [3], which also includes new data relating to new digital instruments SilverSchmidt.

Table 1. Range of use of rebound test hammers [3].

Used test hammers	Cube strength of concrete [N/mm ²]	The smallest concrete layer thickness [mm]	Smallest grouting width [mm]
Original Schmidt N	17 – 60	100	30
Original Schmidt L	13 – 50	60	30
Schmidt M	25 – 60	200	not used
SilverSchmidt PC N	10 – 100	100	30
SilverSchmidt PC L	5 – 30	60	30

The rebound test hammer SilverSchmidt is a modern variant of the original Schmidt N test hammer. The rebound coefficient *Q* is the test indicator and is calculated from the equation (1):

$$Q = 100 \cdot \frac{\text{energyrecovered}}{\text{energyinput}} \tag{1}$$

The SilverSchmidt test hammer uses optical sensors to measures the speed of the impact as well as of the rebound immediately before and after the impact while calculating the amount of energy that can be recovered. The *Q* value allows to extend the range of standard conversion relationships for concrete strength at both ends of the scale. The strength range of the SilverSchmidt test hammer is from 10 N/mm² to 100 N/mm², which allows testing of modern high strength concrete. When using the mushroom plunger for SilverSchmidt PC L (see figure 1), even a low compressive strength from 5 N/mm² can be determined. The described experiment deals particularly with concrete tests with this mushroom plunger.



Figure 1. Test hammer SilverSchmidt PC L with the mushroom plunger [1].

3. Experiment

Conversion relationships can be created in numerous ways. The given experiment followed the principles of the standard ČSN 73 1370 [4] and therefore non-destructively and destructively tested 150 mm concrete cubes.

4. Material and test specimens

Concrete cubes based on six concrete formulas were created for the experiment and differed only in the amount of cement, water and admixtures, and therefore differed only in the water/cement ratio. The production of the six types of concrete, designated letters A to F, used the same components – cement CEM I 42.5 from the cement plant Mokra, 0/4 mm sand from the Bratcice area, crushed natural aggregate with the grain size 4/8 mm and 8/16 mm from Olbramovice, plasticiser SikaViscoCrete 4035 and air-entraining agent Sika LPS A 94. Concrete A and B contained the plasticiser in the amount of 0.25% of the cement weight and concrete C and D contained the plasticiser in the amount of 0.50% of the cement weight. These two types of concrete were not air-entrained. Concrete designated E and F contained the same amount of plasticiser as concrete C and D, but contained also the air-entraining agent. The amount of used water was always adjusted according to the amount of other ingredients so that all six types of concrete were similarly workable. The formulas for all the concrete types are given in table 2 and table 3 presents the determined basic parameters of the concrete in the fresh state, including the water/cement ratio. The properties of fresh concrete were determined in accordance with the standards EN 12350 [5].

Table 2. Composition of concrete used in the experiment.

Component	kg / 1 m ³ of fresh concrete					
	A	B	C	D	E	F
CEM I 42.5 R (Mokra)	350	400	350	400	350	400
Sand 0/4 mm (Bratcice)	875	825	875	825	875	825
Aggregate 4/8 mm (Olbramovice)	185	185	185	185	185	185
Aggregate 8/16 mm (Olbramovice)	695	695	695	695	695	695
Water – mixing	165	165	160	160	150	150
Water – in aggregate	14	14	14	14	14	14
Water – total	179	179	174	174	164	164
Plasticiser (Sika ViscoCrete 4035)	0.88	1.00	1.75	2.00	1.75	2.00
Air-entraining agent (Sika LPSA 94)	-	-	-	-	0.75	0.75

Table 3. Properties of the concrete in the fresh state.

Property	Concrete					
	A	B	C	D	E	F
Flow table test [mm]	350	370	340	330	330	320
Slump-test [mm]	50	60	70	50	60	50
Air content [%]	2.8	3.2	3.5	3.0	6.2	5.7
Density [kg/m ³]	2300	2300	2270	2300	2190	2260
Water/cement ratio ($w_{\text{mixing}}/\text{cement}$)	0.47	0.41	0.46	0.40	0.43	0.38

In addition to the cubes that were designed for the purposes of the described experiment, additional test specimens were produced for control tests at the age of 28 days. These specimens were removed from the moulds after 24 hours and placed into a water bath with the temperature of (20 ± 2) °C. Table 4 presents the results of the tests of hardened concrete at the age of 28 days that were carried out in accordance with the standards EN 12390 [6].

Table 4. Properties of concrete in hardened state – average values with sample standard deviation in the brackets.

Property	Concrete					
	A	B	C	D	E	F
Density [kg/m ³]	2330 (4)	2360 (2)	2340 (16)	2320 (6)	2280 (31)	2320 (16)
Compressive strength [N/mm ²]	50.8 (0.2)	56.4 (2.2)	52.2 (4.8)	57.2 (1.7)	53.7 (0.9)	63.7 (1.4)
Flexural strength [N/mm ²]	4.9 (0.1)	5.6 (0.4)	5.6 (0.2)	5.7 (0.1)	5.3 (0.1)	6.7 (0.3)

The described experiment used 6 concrete cubes from each concrete type produced in laboratories of the Faculty of Civil Engineering BUT, totalling 36 test specimens. Concrete was placed in polyurethane moulds, where it aged until the time of demoulding and testing. The filled moulds were covered with a lid of the same material and stored under standard laboratory conditions. The aim of the experiment was to determine the conversion relationship for the initial compressive strength of concrete, also known as "formwork-removal strength" – which is the compressive strength of concrete (usually 5 to 10 N/mm²) defined by the manufacturer of the concrete as the limit when it is possible to remove the formwork from the concrete element.

5. Testing method

The test cubes of each concrete type were tested sequentially on the second day after pouring concrete – the age of the concrete was therefore always in the range from 20 to 36 hours. After removing the cubes from the moulds, they were immediately subjected to weight and dimension measurements. Each cube was then clamped to compression testing machine and 10 values of the Q coefficient were determined with the test hammer SilverSchmidt PC L with the mushroom plunger – each time in a series of five on the two opposite sides of the test cube. Compressive strength was then determined on the test specimens.

6. Results and discussion

The test results from the rebound test hammer on the individual specimens were first assessed separately. After verifying the normality of the data, the Grubbs test at the significance level of 0.05 was used to identify the outlying values. These values were removed from the experiment.

Figure 2 presents a regression relationship created from all non-outlying Q values. A linear regression model in the form of a straight line $f_c = b_0 + b_1 \cdot Q$ seems to be the most appropriate means, where b_0 and b_1 are the sought after regression coefficients. In addition to the linear regression model, two regression bands are also presented in the graph. The narrower band, the so-called confidence band, defines the limits in which we can expect the obtained curve (linear model) with 95% confidence. This band is determined by interval estimates of regression coefficients. The wider band, the so-called predictive band, indicates the limits in which we can expect the f_c value estimated on the basis of the obtained Q value. The prediction band forms a 95% interval estimation of the mean value of f_c determined based on the observation of the Q value. This regression model allows us to estimate the compressive strength with a 95% confidence and accuracy of approximately ± 5 N/mm².

The graph in figure 3 presents a regression model created from the average Q values obtained from individual specimens. This model allows us to estimate the compressive strength of concrete with 95% confidence and accuracy of approximately ± 3 N/mm².

The results of the conducted regression analysis indicate that due to the high variability of the measured Q values, the model compiled from the average Q values obtained always on one specimen / test point seems to be a more appropriate model for practical purposes. Such a regression model can be used to estimate the initial compressive strength with the accuracy of ± 3 N/mm² and 95% confidence. Assuming the initial compressive strength of 10 N/mm², it can be stated on the basis of the created model that the minimum Q value to guarantee 95% confidence is for the used concrete 22.

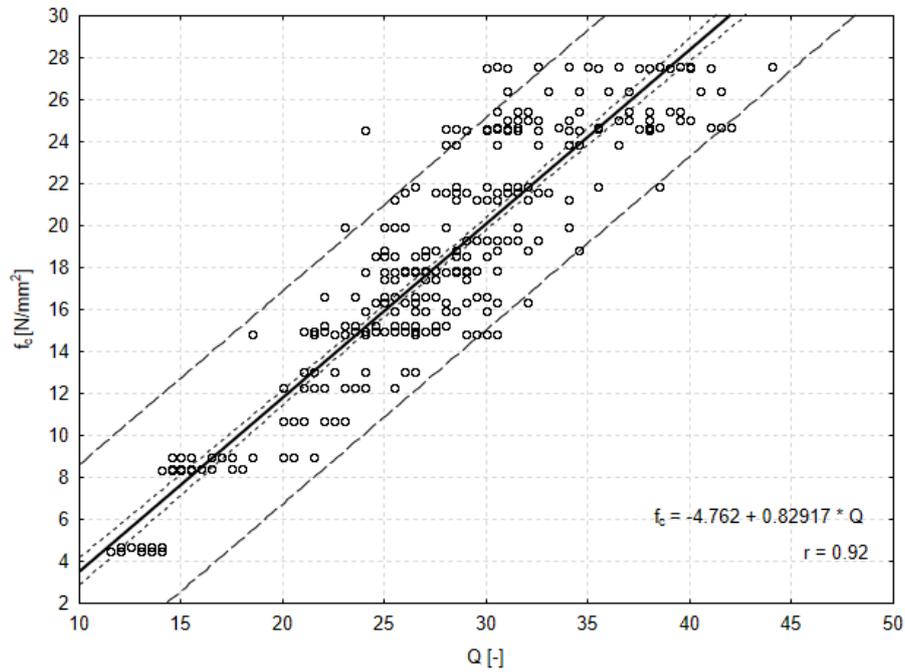


Figure 2. Linear regression model of dependence of the rebound value Q and compressive strength f_c ; the confidence and predictive regression bands are dashed; r - correlation coefficient.

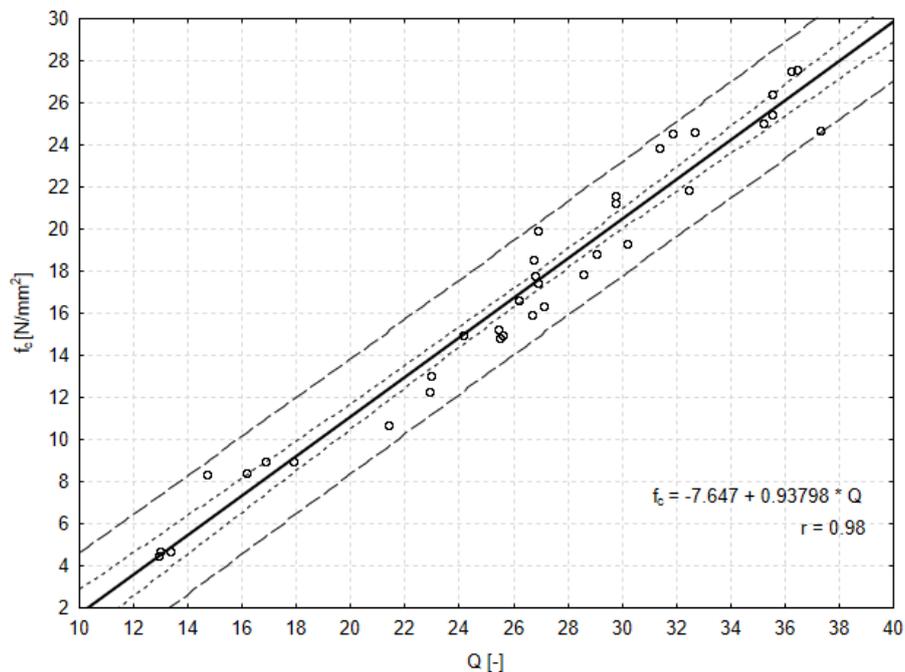


Figure 3. Linear regression model of the relationship of the mean rebound Q values and compressive strength f_c ; the confidence and predictive regression bands are dashed; r - correlation coefficient.

It is important to mention that the established conversion relationship may not work on concrete of different composition. However, the evaluation process revealed that the regression model may not

only apply to a single concrete formula or a single concrete strength class. If the same components are used for the production of concrete, the decisive factor is neither the amount of cement, nor the amount of water, nor the amount of admixtures that the fresh concrete contains. It would seem appropriate to supplement the conducted experiment with concrete tests that will use concrete of varying amounts of sand and varying aggregates grain sizes. This experiment employed the same amount of coarse aggregate in all six different concrete types.

7. Conclusions

Based on the conducted experiment, it may be stated that the SilverSchmidt PC L test hammer with a mushroom plunger is a suitable instrument for determining the initial compressive strength of concrete, starting from the value of about 5 N/mm². The advantage of the rebound hammer test method is the simplicity of the measurements and the non-destructive (non-invasive) character of the test when using the selected instrument since its large mushroom plunger leaves only a slight trace of the impact on relatively slightly hardened concrete. In addition, the test can be repeated on the same place over time and thus provide an overview of the real course of ageing of concrete directly in the construction. An important conclusion is the fact that it is possible to create a regression model with relatively high accuracy (in this case approximately ± 3 N/mm²) for more concrete formulas. However, the use of the same input materials is essential.

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