APPLICATION OF THE ULTRASONIC AND SCLEROMETRIC MEASUREMENT DATA FOR DETERMINING THE COMPRESSIVE STRENGTH OF THE CONSTRUCTION CONCRETE

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Abstract. Constantly there is a necessity for carrying out tests on hardened concrete to determine the parameters of concrete strength in structure. Nowadays for concrete control quality testing nondestructive test methods are widely used. For this purpose mostly used methods are ultrasonic pulse velocity and rebound hardness by applying portable devices ultrasonic tester and Schmidt rebound hammer. Although, many such tests have been carried out, they all still lead to difficulties in interpretation of the results, because they are affected by a number of factors. During the inspections of different building objects, comprehensive information on technical condition of concrete and reinforced concrete constructions have collected, simultaneously applying the nondestructive test methods and testing specimens taken from constructions of buildings until failure. It has been defined some novelties by working with two aforesaid nondestructive test methods in conformity with determination of concrete actual strength. And namely, there are comparing dispersions of the measurement data by ultrasonic tester and Schmidt rebound hammer. Besides, compliance of the groups of measurement data for these testing methods to the normal distribution nature is to be related. Simultaneously it is established also how the amount of measurements affected to correlation relations between results of the concrete nondestructive test methods and the strength destructive testing data. Finally, obtained test results are compared to the interpretation of measuring data for concrete strength theoretical calculation by other scientists from countries outside the Europe.

Keywords: concrete structures, nondestructive test methods, ultrasonic, rebound hardness, statistical characteristics, strength of concrete.

Introduction

During inspections of different building objects, this paper authors have collected comprehensive information on technical condition of concrete and reinforced concrete constructions, simultaneously applying the nondestructive test methods and testing specimens taken from constructions of buildings until failure. Data on the tested concrete strength have to be employed as one of the main factors for characterizing technical condition of the structures at the reports of experts. Afterwards they were used both for determining the construction load carrying capacity and for developing the reconstruction projects, etc. At the same time, replies to several questions quite often remain unanswered – a) how extensive the obtained database is to be, in order to consider it to be sufficient for objective exploration of the situation; b) whether determining of the concrete strength can be based only on information obtained from applying the construction nondestructive test methods; c) how accurate can concrete strength be calculated theoretically by applying multiregression equations.

Analyzing the general situation with regards to the considered problems, to evaluate the obtained data and their correlation relations, two in some way similar objects have been used in this paper, their construction was started in the 1990s but has not yet been completed. The first investigated structure is the multistoried residential building in Jelgava manufactured of two interconnected structures in a monolithic solution, and the second one is the industrial administrative building in Riga constructed with the reinforced concrete framework. At the first object, walls produced of the in situ reinforced concrete have been tested by using the nondestructive test measuring devices, and in the second case – the precast reinforced concrete columns. Simultaneously, a certain amount of cylinder cores have been drilled out of the aforesaid constructions and later compressed at the laboratory. Performing the nondestructive tests, for the concrete in structures was determined both the velocity of longitudinal waves propagation (by using portable ultrasonic tester

«UK-1401») and the rebound hardness, ie., sclerometric testing (by using Schmidt rebound hammer). At the same time, statistical comparison of the obtained results has been realized, determining the corresponding correlations. It must be emphasized that the corresponding investigated places were tested by the nondestructive test measuring devices yet prior to the cores drilling. As, when performing these, micro cracks can appear in concrete, and this, in its turn, undoubtedly, affects results of the measurements. Hence, correlation relations of the analyzed data are to be qualified as ambiguously determined.

The statistical processing form of the research results

Prior to analyzing the obtained data and clarifying the related regularities, the statistical processing form of the research results is required to be determined: it is to be defined how the corresponding characteristic values are determined at each group of measurements, in order to achieve the desirable final mathematical expressions. Initially, series of numbers characterizing the mean arithmetic values of the researched object are obtained for the corresponding group of measurements, as well as dispersion of results of the measurements (dispersion S^2, standard deviation or root-mean-square S and the coefficient of variation v). It should be noted, that the 95 % confidence P is selected for accuracy of measurements and the unilateral confidence probability value of the Student quantile distribution of 0.975 (Pommers 1979). Wherewith, with the sufficiently large amount of measurement variations, in case of normal or the so-called Gaussian distribution, only about 5 % of all the results remain beyond the characterizing interval $\pm 2S$ of the measurement error Δx. By observing the chosen confidence probability and amount of measurements, the confidence interval ε is determined for the corresponding group. Blunder of measurement or the so-called dubious measurements, which are to be discarded and excluded from the measurement amount in conformity with the 5 % materiality level conditions, are determined as well. The mean arithmetical error of the measurement series is used, characterizing accuracy of experiments with the coefficient of variation expressed in percentage. The measurement accuracy analysis for correct determining of the correlation relations is realized by observing the experiment accuracy characterizers provided for testing by manufacturers of the used measuring devices: the coefficient of variation v cannot exceed 15 % (in some cases, the maximal allowed value is 20 %); value of the correlation coefficient r is to be no less than 0.7 (Proceq 1996, Акустические Контрольные Системы 2005). As for both inspected building objects, a large amount of measurements have been performed with the material nondestructive test methods, determining the selection distribution of the corresponding measurements, the obtained data are expedient to be transformed into the variation row form. For this purpose, the number of intervals k and their width h_m have been successively determined, and, after distribution at intervals, the amount of cases at each interval n_m and the relative frequency at the corresponding interval P_m have been estimated, giving each element of the interval m the mean value x_m. On the basis of the amount of multiplying the values of each interval x_m and P_m, the mathematical expectation rating χ has been calculated for the variation row (Pommers 1979). As has been confirmed by many experiments performed up to now (Mindess *et al.* 2003, Иносов and Городжа 1980, Филипсонс and Новикс 1976), interrelation or correlation of the investigated variable parameters (argument x, function y) for the products, to manufacture which cement is used as a binder, usually gets the form of the nonlinear function regression curve equation $y = kx^m$. Therefore, also in this paper correlations are determined in a similar way.

Taking into account a large amount of the experimental data, the measurement results are summarized in this paper in a concentrated form, showing the characteristic parameters either by the corresponding sectors, for instance, floors of the buildings, or, as well, by the most significant measurement places, and correspondingly determining the correlations. The variation rows curves for the corresponding groups of measurements provided to determine distribution of the random nature are presented in a comparative way. Nonlinear correlation relations are shown in a graphical way.

The first object (the building in Jelgava) – two interconnected construction volumes A and B

Inspection of the internal wall in situ reinforced concrete at the object was performed in 2005. For the volume A measurements were done on the floors 1 – 9, while for the volume B – on the floors 1 – 10. On every floor, 6 places for inspecting were selected, which were performed tests with ultrasonic tester and Schmidt rebound hammer (carrying out 9 measurements with each device on each place). Thus, 486 measurements have been done by each measuring device at the volume A, and 540 measurements at the volume B. The total amount of fixed measurements is 2052. To determine the actual compressive strength of the wall concrete at each volume, by 8 cores have been drilled out from the structures at characteristic places.

1026 measurements have been done by each measuring device at both volumes in total. 13 measurements fixed by the ultrasonic tester and 18 results determined by the Schmidt rebound hammer have been recognized as dubious readings – these have been excluded from the total amount of measurements. The mean value of the velocity of ultrasonic pulse propagation V_m was 3342 m/s, and the same statistical parameter of the rebound hardness R_m was 26.4 MPa. It must be emphasized that rebound hardness (MPa) were calculated by using corresponding correlation curves provided by the manufacturers of Schmidt hammer.

The coefficient v characterizing variations of the measurement dispersion was correspondingly lower for the measurements performed by the ultrasonic tester – 10.7 %. Whereas, for measurements of the Schmidt rebound hammer, coefficient v was close to the maximally allowed limit – 14.7 %.

The obtained results show that rather similar results have been determined for internal walls at both construction volumes. Evaluating by practically all mean parameters, the lowest results have been fixed at the 2nd and 3rd floors. Thereto, by comparing the results at other floors of the construction volumes A and B, it has been concluded that these parameters have a similar tendency – they do not differ basically (see Table 1).

Table 1. The results obtained at the first object (by floors)

Floor	Volume A		Volume B	
	Ultrasonic pulse velocity, V_m (m/s)	Rebound hardness, R_m (MPa)	Ultrasonic pulse velocity, V_m (m/s)	Rebound hardness, R_m (MPa)
1st	3590	28.3	3648	28.4
2nd	3199	22.6	3392	25.1
3rd	2976	24.8	2941	21.7
4th	3303	29.7	3221	25.0
5th	3264	25.5	3332	25.8
6th	3434	26.8	3329	27.1
7th	3615	28.2	3185	26.0
8th	3227	24.6	3296	26.8
9th	3453	29.4	3531	29.6
10th	–	–	3518	26.5
1st–10th	3342	26.6	3341	26.2

The variation rows have been created for the performed measurements, to establish the distribution nature of the measurement groups. Drawing from the calculations, the mathematical expectation rating χ for both test methods (correspondingly 3344 m/s and 26.0 MPa) has turned out to be very close to the arithmetically calculated final mean indexes (see Table 1). Hence, the variation rows interval amount k and their average values x_m are concluded to be determined correctly. This, in its turn, has allowed evaluate the distribution way of the measurement groups.

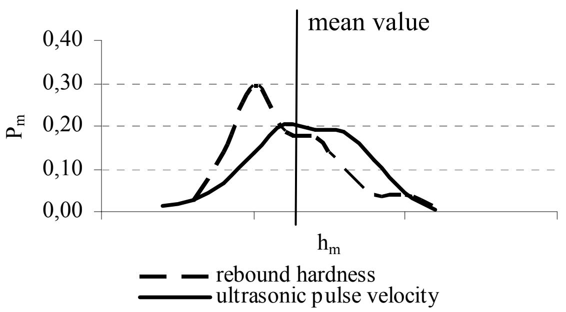

Fig 1. Distribution of the variation rows of the measurement results at the first building object

As seen from the Figure 1, in case of measuring the ultrasonic pulse propagation velocity, the characteristic distribution is cognate to the normal one. In its turn, distribution of the measurement group obtained with the help of the Schmidt rebound hammer at the performed sclerometric testing does not correspond to the normal distribution appearance. It should be added that similar tendencies are observed at sclerometric measurements, when inspecting other building objects too (see further explanation on possible reasons of such tendencies).

When loading at compression the concrete cores drilled from internal walls of the building object, the obtained results are of a wide range – f_c = 9.9 – 30.2 MPa (Table 2). Thereto, the amount of the drilled cores is not that large, in order to correctly evaluate the strength indicators of the concrete used in the walls at the entire construction.

Table 2. Summary of the results obtained by the material destructive and nondestructive testing methods – the first object

Wall's designation (volume - floor - test point)	Destructive test	Nondestructive tests	
	Compressive strength, f_c (MPa)	Ultrasonic pulse velocity, V_m (m/s)	Rebound hardness, R_m (MPa)
A-1-1	27.6	3323	27.9
A-2-2	22.8	3282	23.8
A-2-3	14.7	2670	18.7
A-3-4	9.9	2917	20.8
A-4-5	27.2	3704	35.8
A-5-6	26.9	3194	23.7
A-6-7	24.3	3291	25.6
A-8-8	14.4	2863	19.2
B-1-9	30.2	3572	27.9
B-2-10	22.1	3152	23.7
B-3-11	14.4	2830	20.4
B-3-12	20.6	3278	25.1
B-4-13	11.4	2759	20.3
B-5-14	23.9	3555	24.6
B-7-15	18.0	3089	21.2
B-8-16	23.6	3414	29.1
Mean value:	20.8	3181	24.2
r*:	–	0.87	0.78

**Note*. The correlation coefficient r is calculated in relation to the results obtained during the destructive testing (then, by loading the drilled core, the concrete compressive strength is determined).

However, as there is the high correlation between the results obtained by destructive and nondestructive test methods (see values of the correlation coefficient r in Table 2: – 0.78 and 0.87), the following conclusions have been drawn. Considering that there is a lot of data obtained with the help of the ultrasonic tester and the Schmidt rebound hammer, by using the correlation relations, the wall concrete strength could be approximately determined with a very high precision. And namely, on the basis of the mean statistical parameters of the ultrasonic propagation velocity and sclerometry provided in Table 1, as well as by using the corresponding correlations seen on Figures 2 and 3 (regression curves equations), it has been determined that the average strength of the in situ reinforced wall concrete for both construction volumes is 22.7 – 23.5 MPa.

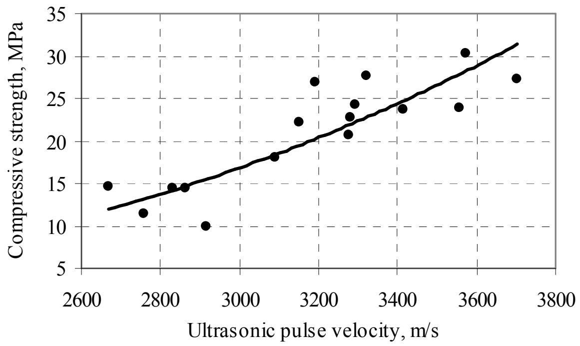

Fig 2. Correlation "ultrasonic pulse velocity – compressive strength" ($y = 9E\text{-}10x^{2.96}$)

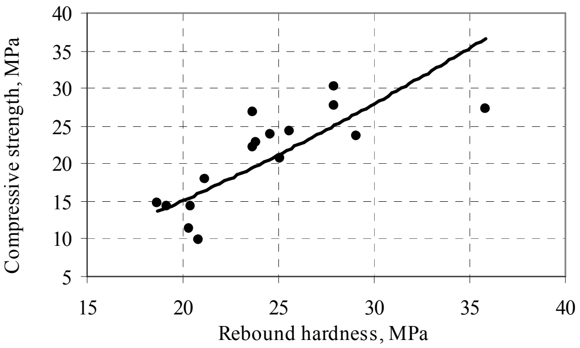

Fig 3. Correlation "rebound hardness – compressive strength" ($y = 0.157x^{1.52}$)

The approximate mean parameters of the concrete strength determined by the material nondestructive test methods are very close to the determined ultimate strength f_c average value of 20.8 MPa of the drilled core under loading (Table 2). As the indirectly obtained parameters of the concrete strength determined by both test methods are within a very small range, it has been concluded that the developed measurement plan for the in situ concrete walls of the building object has turned out to be successful with regards to its volume and methods. Thus, if both of the aforesaid material nondestructive test methods are applied simultaneously, the large amount of measurements (specifically – 2052) and the accurately planned regular distribution of measuring places in the building ensures both satisfactory accuracy and good effectiveness of the measurements.

The second object (the building in Riga) – the industrial administrative block

Inspection of the building was performed at the end of 2006 and in the beginning of 2007. Measurements with the ultrasonic tester and the Schmidt rebound hammer have been performed on sides of the precast reinforced concrete columns; thereto, 9 cores have been drilled out to determine the concrete actual compressive strength. In total, 18 reinforced concrete columns have been tested. Distribution of the amount of tested columns by floors is as follows: 3 on the 1st floor, 6 on the 2nd floor, 5 on the 3rd floor and 4 on the 4th floor (the distribution is chosen by considering area of the building floors). 6 measurements have been performed for each tested column with both measuring devices. In total, 108 measurements have been performed with each measuring device. The statistical processing results of the data obtained by the material nondestructive test measuring devices are provided in Table 3, whereas, the ultimate compressive strength of the column concrete specimens and the corresponding correlations can be found in Table 4. The first figure in the column designations is the floor; the second figure is the ordinal number of the tested column.

Table 3. The results obtained at the second object

Column's designation	Ultrasonic pulse velocity			Rebound hardness		
	V_m (m/s)	S (m/s)	v (%)	R_m (MPa)	S (m/s)	v (%)
1-1	4610	163	3.54	51.7	1.86	3.60
1-2	3830	88	2.30	43.7	2.42	5.55
1-3	4471	51	1.13	53.0	1.67	3.16
2-4	4337	100	2.31	53.7	2.88	5.36
2-5	4143	117	2.82	44.8	2.04	4.55
2-6	4227	149	3.52	54.8	3.43	6.26
2-7	4446	136	3.06	52.7	2.73	5.19
2-8	4049	66	1.63	48.2	3.66	7.59
2-9	4203	94	2.24	52.3	1.63	3.12
3-10	4106	109	2.66	52.3	3.39	6.47
3-11	4083	118	2.90	48.8	2.48	5.09
3-12	4102	139	3.39	53.3	2.16	4.05
3-13	4252	71	1.66	50.8	1.33	2.61
3-14	4238	74	1.74	53.8	1.83	3.41
4-15	4141	234	5.64	52.2	4.17	7.99
4-16	4464	196	4.40	51.7	4.68	9.05
4-17	4099	117	2.86	45.3	3.33	7.34
4-18	4196	133	3.17	53.0	2.45	4.62
Mean value	4222	–	–	50.9	–	–

Note. V_m and R_m – mean values; S – standard deviation; v – coefficient of variation.

The mean parameters of ultrasonic pulse velocity V_m and the rebound hardness R_m are accordingly – 4222 m/s and 50.9 MPa. Also for this object, when performing a test for one and the same construction by different methods, the comparatively less value of the variations coefficient v is 5.14 % for measurements with the ultrasonic tester (correspondingly 8.16 % for data obtained with the Schmidt rebound hammer).

Similarly to the building in Jelgava, variation rows have been formed for measurements carried out at the second building object as well, in order to establish the measurement group distribution nature. The mathematical expectation rating χ of the corresponding variation rows for the considered testing methods is 4228 m/s and 50.6 MPa.

The obtained distribution of the ultrasonic pulse velocity measurement results, comparing with the first building object, is basically qualified as even more congenial for the normal distribution (see Figures 1 and 4 for the comparison). Most probably, it is related to better homogeneity of the concrete structure of the precast reinforced concrete constructions. (It could be assured by regular observation of technological parameters of manufacturing the constructions at the factory conditions, for instance, similar ratio of binders and aggregates, similar circumstances of concrete manufacturing and curing etc. In the beginning of the 1990s, when manufacturing the in situ concrete constructions at the site, as it was at the first object, such conditions were mostly not observed.)

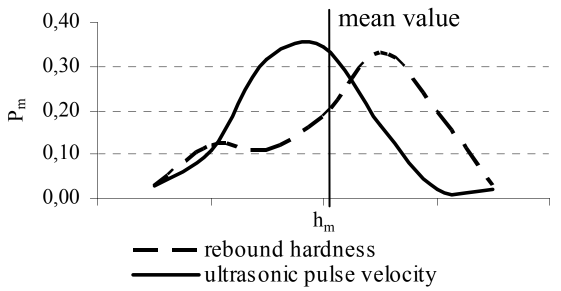

Fig 4. Distribution of the variation rows of the measurement results at the second building object

With sclerometric measurements determined by the Schmidt rebound hammer, the random nature distribution also for the second object is not considered to be congenial for the normal distribution (see Figure 4). Only this time, if proceeding from the mean parameter at analyzing, the largest amount of the measurement results is concentrated in the sector of the highest results.

Table 4. Summary of the results obtained by the material destructive and nondestructive testing methods – the second object

Test point's designation (building's floor – location)	Destructive test	Nondestructive tests	
	Compressive strength, f_c (MPa)	Ultrasonic pulse velocity, V_m (m/s)	Rebound hardness, R_m (MPa)
1 – I	65.9	4610	51.7
1 – II	31.9	3830	43.7
2 – III	52.1	4337	53.7
2 – IV	40.5	4143	44.8
2 – V	61.5	4227	54.8
3 – VI	49.2	4106	52.3
3 – VII	35.5	4083	48.8
4 – VIII	41.3	4141	52.2
4 – IX	46.3	4464	51.7
Mean value:	47.1	4216	50.4
r:	–	0.77	0.72

See *notes* under Table 2.

It is known, that might be much more correctly determine the construction concrete actual compressive strength, when a sufficient amount of cylindrical cores is drilled out of it and later compressed. Therefore, at the second object, cores have been drilled from different columns selectively: on the 1st, 3rd and 4th floor – two specimens each, and on the 2nd floor – three specimens. Prior to this, the ultrasonic pulse velocity and rebound hardness have been determined at corresponding places in the column concrete.

Also this time, when compressing the specimens, their concrete strength has turned out to be in a rather wide range – 31.9 – 65.9 MPa (on average 47.1 MPa). The mean parameters of ultrasonic pulse velocity and rebound hardness at the drilled core zones (see Table 4) are very close to corresponding mean arithmetic results of all measurements (see Table 3). Having comparing the obtained data by the destructive and nondestructive test methods, the achieved correlation coefficient *r* values are 0.72 and 0.77 (the corresponding results are summarized in Table 4).

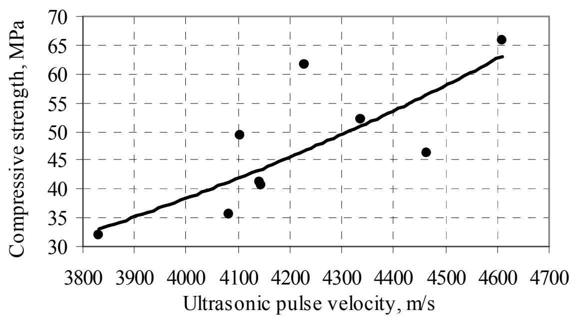

Fig 5. Correlation "ultrasonic pulse velocity – compressive strength" ($y = 1E\text{-}11x^{3.50}$)

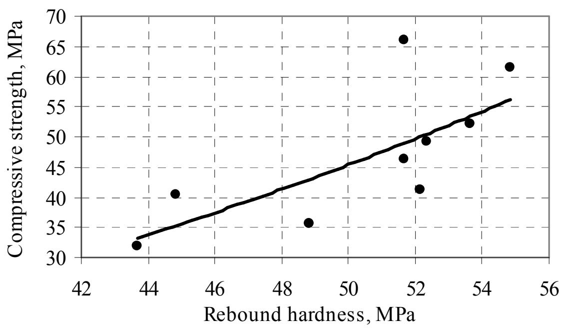

Fig 6. Correlation "rebound hardness – compressive strength" ($y = 0.0054x^{2.31}$)

Considering mean parameters of the ultrasonic pulse velocity measurements and the sclerometric data (Table 4), as well as the correspondingly obtained correlations (regression curves equations) – Figures 5 and 6, the average calculated result of the column concrete compressive strength has reached 47.5 – 48.4 MPa. It has been concluded that also in this case the approximated concrete strength mean parameters determined by the material nondestructive test methods are very close to the determined average ultimate strength f_c of the drilled cores at compressing of 47.1 MPa (see Table 4). Also in this case, when simultaneously applying both of the aforesaid material nondestructive test methods, the total amount of measurements (216) and the accurately planned distribution of measuring places in the building has assured both satisfactory accuracy and good effectiveness.

Concrete strength prediction accuracy by using equations with ultrasonic and sclerometric data

Various scientific articles propose formulas for concrete compressive strength calculation, and these mathematical expressions contain a data obtained during the nondestructive testing, ie., results of ultrasonic and sclerometry test methods simultaneously. These formulas are established on the basis of previous researches for parameters of concrete binders and other source materials as well as the concrete ages. In developing the equations, the factors affecting to the measurement accuracy are minimized as much as possible. Correlation between potential concrete compressive strength and combined data of ultrasonic and sclerometry test results most often are expressed in the form of the multi-regression equation – as exponential function with empirical coefficients:

$$S = b_0 + b_1 R + b_2 V^4, \qquad (1)$$

where
S – estimate in situ compressive strength (MPa);
b_0, b_1, b_2 – coefficients in regression equations;
R – Schmidt hammer rebound number;
V – ultrasonic pulse velocity (km/s).

In the paper (Samarin and Meynink 1981), equations are formulated by taking into account two factors – concrete age and aggregate type. It must be emphasized that the empirical coefficients are determined on the basis of the results of research in the laboratory. Manufactured concrete mixes were different between the aggregate and the nature of their chemical properties. Between the destructive and combined nondestructive tests were obtained in fairly high correlation coefficients – 0.92 – 0.97. Multi-regression equations applied to the most frequently used aggregates in concrete in our region are the following:

$$S = -25.9 + 1.32R + 0.057V^4 \text{ – crushed river gravel;} \qquad (2)$$
$$S = -23.4 + 1.20R + 0.051V^4 \text{ – dolomite.} \qquad (3)$$

It is obvious that the empirical coefficient differences are significant. Furthermore, it is to be noted that the researches were not carried out in particular building for testing the concrete in constructions. These researches have only been performed in the laboratory. In this paper (Samarin and Meynink 1981) correlation as well as distribution of various parameters for ultrasonic and sclerometric data is also separated individually. Australian scientists in their laboratory researches for relation "ultrasonic pulse velocity – concrete strength" have determined a lower correlation coefficient (similarly for the measurements standard deviation) in comparison with the same coefficient for relation "rebound hardness – concrete strength". However, this condition differs from our research results, when concretes were tested in building objects. In this paper (see below) are analyzed results of another previous research. It should be noted that also in this case concrete was manufactured and tested in laboratory (see (Nasser and Al-Manaseer 1987)), and there were similar correlation data to the results of before-mentioned research (Samarin and Meynink 1981). Obviously, in the laboratory Schmidt hammer measurements accuracy, depending on the sample surface roughness, is significantly less in comparison with measuring in building objects.

In both above described objects (see previous chapters) dominant aggregate in concrete was dolomite, as well as other sedimentary rocks. Therefore, our research results of nondestructive testing are placed in formula 2 and 3. It should be emphasized that rebound hardness is inserted in formulas as a rebound number and not as reading in MPa, as it was given in previous chapters. Concrete estimated or so-called theoretical strength S parameters were compared with the ultimate compressive strength f_c practically obtained in laboratory. Comparison of practically and theoretically obtained concrete strength has been calculated by equation (4) and expressed in percentage Δ.

$$\Delta = \frac{f_c - S}{f_c} \cdot 100\% \qquad (4)$$

The results achieved are summarized in Table 5. This comparison demonstrates the effectiveness of application of formula in particular cases.

Table 5. Practically (f_c) and theoretically (S) obtained concrete strength parameters in percentage comparison (Δ)

Object		the building in Jelgava		the building in Riga	
Construction		walls		columns	
N.o.R.*		16		9	
Equation**		(2)	(3)	(2)	(3)
Statistical parameters: mean value (range of results)	f_c	20.8 (9.9–30.2)		47.1 (31.9–65.9)	
	S	18.6 (11.3–32.3)	17.0 (10.4–29.4)	50.4 (39.8–59.0)	45.7 (36.2–53.4)
	Δ	6 (-48–32)	14 (-35–38)	–11 (-32–13)	0 (-20–21)
	V	3181 (2670–3704)		4216 (3830–4610)	
	R	29.3 (26.0–36.0)		44.2 (40.5–46.4)	

Note.
1. * – N.o.R. (Number of researches) – the number of tested areas, where measurements were carried out with ultrasonic tester and Schmidt hammer, and wherefrom cylinder cores were drilled out for compressive strength testing in the laboratory;
2. ** – form of multi-regression equation (see also (Samarin and Meynink 1981));
3. Designations:

f_c – ultimate compressive strength of constructions cylinder cores (MPa);
S – estimated compressive strength obtained from the multi-regression equation (MPa);
Δ – comparison of practically and theoretically obtained concrete strength (%);
V – ultrasonic pulse velocity (m/s);
R – Schmidt hammer rebound number.

The information summarized in Table 5 shows that between practically and theoretically obtained concrete strength – correspondingly f_c and S – there is an up to 20 % difference, but for each test area individually this parameter is in a very wide range – up to ~ 50 %. It is also noted that in case of practically acquired a relatively higher rate of strength the difference between parameters f_c and S decreases. Similarly, such relations are determined.

$f_c < S$, at $f_c < 35 – 40$ MPa;
$f_c > S$, at $f_c > 35 – 40$ MPa.

However, it must be emphasized that the above mentioned relations are considered as assumptions, and for their approval it is necessary to carry out further researches.

Using the correlation curves equations of destructive and nondestructive test methods, during this research work for concretes which were used in both building objects (for the buildings in Jelgava and Riga see accordingly equations (5) and (6)), multi-regression equations were determined.

$$S = -17.3 + 1.04R + 0.084V^4 \quad (5)$$

$$S = -31.6 + 1.13R + 0.092V^4 \quad (6)$$

Although for each building object practically f_c and theoretically S obtained concrete strength differs on average only about 5 %, looking at the tested areas separately, the results differ in a quite a large range – up to 30 %. So, to validate such expression of equation: 1) between the results of destructive and nondestructive tests must be very high correlation (supposedly, at least 0.85); 2) relations of such a strict definition only can be applied for concrete of one particular mix. Besides, application of similar equations for inspections of building objects is doubtful, if only before has not been done the calculation for particular concrete mix. It is also not determined how the accuracy of results may be affected by even minor deviations of ingredients proportions and their quality in concrete.

Statistical calculations show that for constructions in particular buildings such a calculation methodology is not acceptable. Our results demonstrate that: – with the help of using the destructive and nondestructive test methods, as well as determining the correlation curves, for the various building objects concrete obtained multi-regression equations have different empirical coefficients. Moreover, the estimated concrete strength measured by these equations can cause error as much as 30 %. This is largely because in drilling zones of concrete samples taken from the constructions destructive and nondestructive testing methods correlation coefficient is often only 0.75. Predicting the actual concrete strength, such a coefficient is acceptable only for drawing conclusions for each of nondestructive testing methods separately. However, if sufficient number of concrete samples were drilled out from the constructions, in the case of inspection error possibility is much lower than 30 %, and to a great extent it depends only on the correlation coefficient.

Considered with caution must be also in the scientific sources given relations, which propose to use the results of both previously described nondestructive test methods separately to determine the estimated concrete strength. For example, in the paper (Nasser and Al-Manaseer 1987) a number of nondestructive testing methods are compared (also the concrete specimens were manufactured in the laboratory in this case), and along with correlation relations are shown equations for concrete strength calculation. For sclerometric and ultrasonic methods these equations are accordingly (7) and (8):

$$C = -1380 + 214.13N \quad (7)$$

$$C = 0.00502V^{5.01} \quad (8)$$

where
C – the ultimate compressive strength (psi);
N – rebound number;
V – ultrasonic pulse velocity (ft/s · 10^3).

Similarly as above in the equations (2) and (3), also in the expressions (7) and (8) were inserted ultrasonic and sclerometric parameters of specifically inspected building constructions concrete. However, equations (7) and (8) do not provide the complex applicability of the nondestructive test methods. With both nondestructive testing methods obtained results are significantly different when they are compared separately with the practically determined concrete strength. The difference between the actual concrete compressive strength (for drilled specimens from constructions) and with the expression (7) obtained results on the average was 30 – 50 %, but for expression (8) the difference in results reached up to 60 – 80 %.

It should be noted that in other scientific articles (Evangelista *et al.* 2005, Arioglu *et al.* 2000) presented equations show an even greater difference between practically and theoretically determined strength parameters for previously described concrete in structures.

Aforesaid obviously shows that application of even separately determined empirical equation for concrete strength calculation is rather doubtful. If for concrete compressive strength determination used Schmidt hammer, and the specimens obtaining from the concrete constructions is not possible, for this purpose it is recommended to use the correlation curves which are compiled by the specific device manufacturers. In this case, the theoretical strength is determined by taking into account the rebound number and the direction of impact. However, if for such purpose is used only an ultrasonic method, calculation of concrete compressive strength without a real specimens obtaining from a specific concrete (and following strength tests) can not give the correct result.

Conclusions

1. Comparing the results of ultrasonic longitudinal waves velocity with rebound hardness for the concrete in structures, ultrasonic method gives more accurate results. And namely, the dispersion parameters of the measurement data and compliance to the normal distribution for ultrasonic method in most cases are higher. The rebound hardness can be affected both by presence of gravels in the construction surface zone (increasing the results) and by the surface roughness (correspondingly reducing the results).

2. For concrete in structures correlations between the results of the concrete nondestructive and destructive test methods are satisfactory only if the total amount of measurements is sufficiently large and comprises the inspected structure (location of testing places are regularly distributed by the structure). This ensures both satisfactory accuracy and good effectiveness.

3. Larger amount of the nondestructive measurements and data of the ultimate compressive strength of control specimens, allows approximately evaluating the situation in general, even there is a dispersion obtained between the ultimate strength results of the taken specimens.

4. Some laboratory researches realized by other scientists for relation "ultrasonic pulse velocity – concrete strength" are obtained a lower correlation coefficient in comparison with relation "rebound hardness – concrete strength". However, this result differs from our research results – for concrete in structures ultrasonic longitudinal waves pulse velocity correlation with the concrete strength is comparatively higher. Most likely, this is explained by the greater dispersion of the rebound hardness measurements, since their accuracy is highly dependent on the smoothness of testing concrete surface.

5. Determination of concrete strength by using ultrasonic and rebound hardness data in the multi-regression equations are applicable only for definite concrete mix, which has previously tested. Furthermore, the correlation between destructive and nondestructive test methods should be sufficiently high (supposedly, the correlation coefficient r must be at least 0.85). The application of specific empirical equation for concrete strength determination without a previous loading of control specimens is questionable.

6. In determining the concrete strength of previously untested structures without specimens destructive tests should be applied the correlation curves compiled by manufacturers of specific Schmidt hammer. Calculation of concrete compressive strength, by using ultrasonic method only, obviously will not give correct results. In this case it is necessary to use several methods of testing.

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