The applicability of Sonreb method on damaged concrete

M. S. Akman

Dr. Ing., Professor in Faculty of Civil Engineering, Istanbul Technical University.

A. Güner

Ph. D., Assoc. Professor in Faculty of Civil Engineering, Istanbul Technical University.

In damaged structures, a knowledge of the value of the residual concrete strength is needed as a basis for the decision of reconstructing or repairing and for the design of the repair project. In this work, the limits of applicability of the Sonreb method, a combination of the ultrasonic pulse velocity and the Schmidt index measurement, in the detection of damage caused by high temperatures and chemical attack by ammonium nitrate and ammonium sulphate is discussed. It is concluded that the Sonreb method can be used in assessing the fire-damaged concretes after making a classification of the degree of damage, the duration and the temperature of exposure to fire. In the case of chemical attack, a knowledge is required as to the duration of exposure and the prevailing process of corrosion.

1. INTRODUCTION

The Sonreb method, which is a combination of the ultrasonic pulse velocity and the Schmidt rebound number, is widely employed in pratice due to its use in assessing the strength of concrete numerically and with sufficient reliability. This method, in addition to its use as an efficient quality control tool during production, gives reliable results on concrete structures with suspected strength and homogeneity when the composition of the concrete is known or when a limited number of cored specimens are available [1].

In deciding whether to reinforce or demolish and rebuild a structure, the problem is the determination of the residual strength [2]. The use of cored specimens, is usually quite limited. On the other hand, the fact that Sonreb is based partly on the rebound hammer results gives way to the conception of the opinion that the method cannot be useful for concretes whose structure of the outer layer is different from that of the inner mass. However, the expertise work and laboratory research carried out by the authors showed that the method is applicable for the detection of the damage due to fire or corrosion provided that the case is examined by a conscious way of approach and proper limitations are introduced.

2. RESIDUAL STRENGTH IN CONCRETES SUBJECTED TO HIGH TEMPERATURES

Considerable fire damage occurred in a number of reinforced concrete structures such as a 30,000 m^2 commercial building where synthetic textiles were stored in places, a tobacco processing store and a glass factory. Also damage due to exposure to temperature fluctuations in the chimneys of some industrial plants was encountered. The Sonreb method was utilized in the assessment of the damage in these structures. Laboratory research was also undertaken for the purpose of shedding light on the expertise work [3].

2.1. Investigations on the effect of high temperatures and temperature fluctuations

Exposure to high temperatures

Using the concrete aggregates and ordinary Portland cement available in the Istanbul region, 14 cm-cube specimens were produced. The aggregate comprised sea-dredged sand gravel of quartz and quartzite origin containing also mica and calcedony, and crushed limestone coarse aggregate. The water/cement ratios were 0.45, 0.55, 0.65 and 9 types of concrete in all were made with cement contents of 250, 350 and 450 kg/m^3.

0025-5432/84/03 195 06/$ 2.60/© BORDAS-GAUTHIER-VILLARS

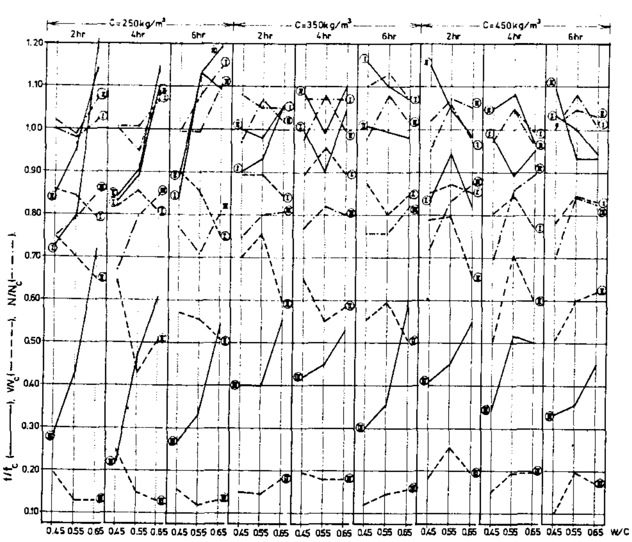

Fig. 1. — Variation of compressive strengths, pulse velocities and rebound numbers as a function of W/C ratio. I – 150°C, II – 300°C, III – 650°C.

On the 56th day the concretes were subjected to heat treatment at temperatures of 150, 300 and 650°C for durations of 2, 4 and 6 hours. No surcharges were applied to the specimens, and the rates of heating and cooling were 200 and 50°C/h respectively. After the heat treatment, the unit weight, pulse velocity, Schmidt index and compressive strength were determined. It was observed that the losses in weight did not exceed 9%, increasing with temperature and water/cement ratio, but the whole of the loss occurred during the two first hours. The changes in the Schmidt indices and the compressive strengths are shown in figure 1.

The relation of the $f_c = F(V, N)$ form between the compressive strength, the pulse velocity and the Schmidt index was established by multiple correlation method using a computer programme [4]. Also the relations $f_c = F(V)$ and $f_c = F(N)$ were statistically investigated. The results obtained from the 4-hour heat treatment are given in table I. In general, the combined approximation of the form $f_c = F(N, V)$ is better than either of the other two forms.

Some of the findings that are obtained from the laboratory investigation are as follows:

TABLE I

COMPARISON OF SINGLE AND MULTIPLE CORRELATIONS BETWEEN THE COMPRESSIVE STRENGTH, PULSE VELOCITY AND SCHMIDT INDEX (FOR 4-HOUR HEAT TREATMENT).

Relation	Coefficient of correlation			
	Control	150°C	300°C	650°C
$f_c = F(V)$	0.696	0.807	0.285	0.636
$f_c = F(N)$	0.844	0.876	0.741	0,694
$f_c = F(V, N)$	0.875	0.882	0.705	0.909

Relations are taken as the best fitting linear, power or exponential functions.

— Heat treatments at 150 and 300°C cause decreases in Schmidt indices and pulse velocities without inducing any significant change in the compressive strengths.

— For the heat treatment at 650°C, the decrease in the pulse velocity is very large and has no correlation with the decrease in the compressive strength. However, such concretes may exhibit some mechanical strength though it is incorrect to take it as "residual strength" due to the gross deterioration of the internal structure.

— For the leaner concretes the longer the duration of treatment the greater the decrease in compressive strengths. The Schmidt indices also follow the same trend. But, the change in the pulse velocity is independent of the cement content and the duration of heat treatment; it depends only on the temperature. Therefore, information on the duration of exposure to fire, the temperature reached during the fire and on the extent of damage on the internal structure of the concrete may be obtained not by the combined method but by evaluating the pulse velocity and the rebound number separately.

Exposure to temperature fluctuation

In chimneys of some industrial buildings, due to the protective insulating measures, the temperature remains below 250°C, but the temperature occasionally falls due to shut-downs, thus causing temperature cycles. In the laboratory experimental work, concrete specimens were subjected to 1, 3 and 5 temperature cycles between 25 and 250°C. The heating and cooling rates, on the average, were 70 and 30°C/h respectively, and the duration of treatment at constant temperature was 6 hours. Two different concretes of 350 kg/m³ cement content and 0.5 water/cement ratio were made [5]. The results obtained are given in table II.

Up to 3 temperature cycles, decreases in compressive strengths and pulse velocities (of 20 and 35% respectively) are observed, no significant change taking place in later cycles. The effect of temperature cycling on the pulse velocity is more pronounced. On the other hand, the Schmidt indices are almost unaffected. The cracks induced by temperature cycling are mostly of capillary type and are probably more concentrated in the aggregate-mortar interface, though partly hindered by the epitaxial behaviour of the limestone. It is also seen that the concrete that loses some strength becomes comparatively ductile due to the formation of microcracks.

2.2. The expertise work on structures subjected to high temperatures

Fire damage may not be of the same extent throughout the structure. Therefore, the regions of different degrees of damage were determined before starting the non-destructive tests. Undamaged concretes were also tested to obtain information vital for the evaluation and assessment of damage and the trends of the changes in the properties.

TABLE II
THE PROPERTIES OF CONCRETES SUBJECTED TO TEMPERATURE CYCLING (AS RATIOS OF THOSE OF CONTROL SPECIMENS).

		Number of temperature cycles		
		1	3	5
Compressive strength	S	0.93	0.81	0.88
	L	0.85	0.76	0.75
Pulse velocity	S	0.86	0.65	0.65
	L	0.66	0.60	0.57
Rebound index	S	0.97	0.98	1.06
	L	0.98	0.98	0.95
Toughness	S	0.91	1.09	1.21
	L	1.10	1.05	1.04
Strain at maximum stress	S	1.01	1.45	1.47
	L	1.54	1.55	1.59
Coefficient of capillarity	S	2.20	4.40	4.89
	L	3.06	3.73	3.91
Water absorption	S	2.03	2.35	2.32
	L	1.15	1.34	1.66

S: indicates concretes made with siliceous rounded fine and coarse aggregate.
L: indicates concretes made with siliceous rounded fine and 50% crushed limestone coarse aggregate.

At the places where visual indications of the extent of damage such as reinforcement buckling, spalling, lime efflorescence and discolouration were observed, the corresponding values of pulse velocities and Schmidt indices were re-examined [6]. At the places where the pulse velocities were very low but the Schmidt indices remained at normal levels, the deterioration had probably remained superficial. This was proved by repeating the tests after removing the outer layers to various depths.

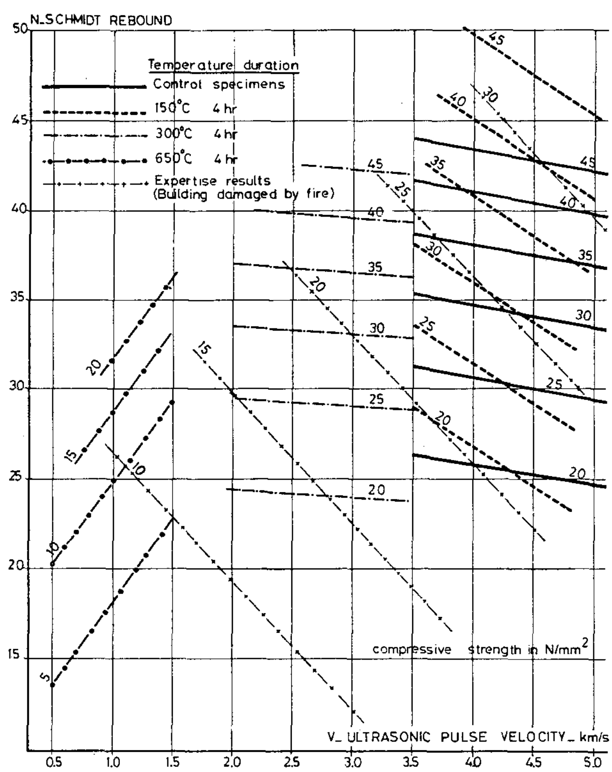

Fig. 2. — Nomograms for the evaluation of compressive strength from Schmidt rebound number and ultrasonic pulse velocity (concrete exposed to high temperatures).

There is seldom a decrease in the Schmidt index and an increase in the pulse velocity. Such trend may occur because of the high water contents due to the water used in the extinguishing operation. The results from the moist fire-damaged concretes were not included in the evaluation as they might be misleading ([7], [8]). No measurements were made at places where there were indications of excessive damage such as sagged floors, buckled or sheared columns. In general, the data from the points where the pulse velocities exhibited less than 50% and the Schmidt indices less than 10% decrease as ratios of that of the undamaged concrete were evaluated and nomograms were drawn by a statistical analysis of the results obtained on 30 cored specimens from these points. The coefficient of correlation for the population was found to be 0.74 and the standard error of estimate 2.60 N/mm^2 [9]. Figure 2 shows the results of the laboratory investigation and the *in situ* application. The decrease in the pulse velocities of the concretes subjected to 650°C temperature varies between 90 and 75%, indicating the formation of a material of totally different internal structure. In this case, the physical significance of the Sonreb nomograms are disputable. In fact, this region is considered to be practically outside the limits of applicability of the Sonreb method. However it can be used satisfactorily in the estimation of the residual strength in concretes subjected to temperature cycles below 300°C. Nevertheless, that the concrete has been converted to a material of higher deformability should be taken into consideration.

3. RESIDUAL STRENGTH IN CONCRETES DAMAGED BY CHEMICAL ATTACK

Serious damage occurred in some factories where agricultural fertilizers are produced and in the related stores. The fertilizers involved were ammonium nitrate and ammonium sulphate. In the laboratory investigation magnesium sulphate was also included for the purpose of comparison.

3.1. Laboratory work on the effects of ammonium nitrate, ammonium sulphate and magnesium sulphate

In the first part of the work, the effects of NH_4NO_3, $(NH_4)_2SO_4$ and $MgSO_4$ solutions on mortars made with plain and partially blastfurnace slag substituted Portland cement were investigated [10]. Only the pulse velocities and resonant frequencies were measured. The effect of each chemical at the end of 28-day treatment may be cited as follows: $MgSO_4$ did not influence the compressive strength and the pulse velocity but caused an increase in the resonant frequency and the flexural strength, $(NH_4)_2SO_4$ did not influence the pulse velocity but caused a decrease in the resonant frequency and the compressive and flexural strengths, while NH_4NO_3 caused a small decrease in the pulse velocity but great decreases in the resonant frequency and the compressive and flexural strengths. The difference bet-

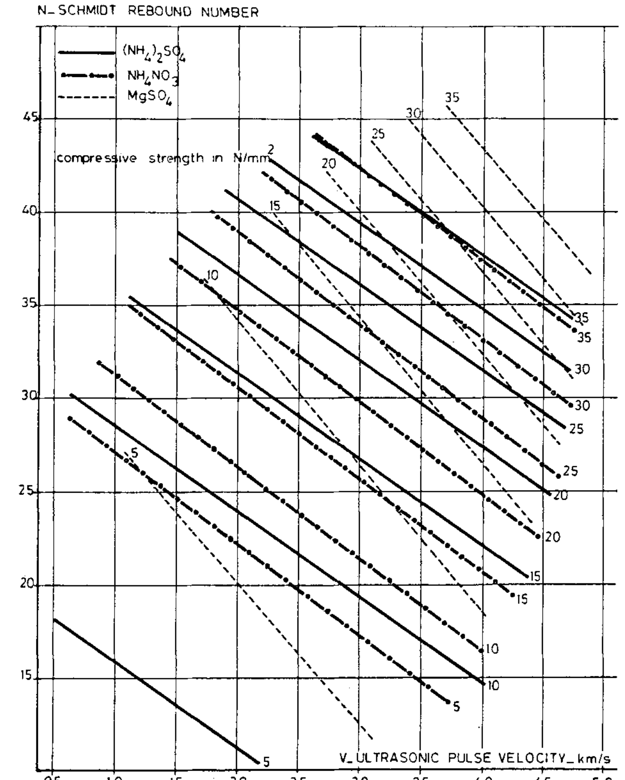

Fig. 3. — Nomograms for the evaluation of compressive strength from Schmidt rebound number and ultrasonic pulse velocity (concrete exposed to chemical attacks).

ween the effects of different chemicals may be attributed to the difference of processes involved ([12], [13], [17]). It should be noted that, in this work 4 × 4 × 16 cm mortar specimens were subjected to very severe chemical attack for 28 days in saturated solutions.

In the second part of the laboratory work, 14 cm cube specimens from 9 types of concrete were produced with water/cement ratios of 0.40, 0.55, 0.70 and cement contents of 250, 350 and 450 kg/m^3 using ordinary Portland cement, crushed limestone coarse aggregate (forming 45% of the total volume of aggregate) and sea-dredged siliceous sand as the fine fraction. The specimens were kept in water for 7 days after production and afterwards in 65% relative humidity and 20°C for 21 days and then under chemical attack for 28 days. During this last period, some of the control specimens were kept in air and the others in water, as the non-destructive measurements and strength tests had to be performed on moist specimens subjected to chemical attack in aqueous solutions. The corrosive solutions were renewed every three days and the concentrations were about 3.0 g/l; just above those classified as causing "very severe" attack in TGL 11 357 [12]. The compressive strengths of control specimens varied between 12.2 N/mm^2 and 51.7 N/mm^2. The results are summarized in table III.

As the period of exposure to corrosive media was too short for the damage to reach a significant magnitude, the comparison of the results was based on the data from wet cured control specimens and the values corresponding to 90% confidence level. The results are shown in the nomogram in figure 3.

The most significant decrease in compressive strength was obtained in NH_4NO_3 solution, 17%; in the other solutions the decrease is 9%. The pulse velocities remain practically unchanged for $MgSO_4$ and NH_4NO_3 but a decrease of 10.4% is observed for $(NH_4)_2SO_4$. In the Schmidt indices, there is some increase (11.0%) in $MgSO_4$, and a significant decrease (21.1%) in NH_4NO_3 solution while there is no change for $(NH_4)_2SO_4$. It is worth noting here that the above results are relevant for the present stage of corrosion. As a matter of fact, decreases in pulse velocities and Schmidt indices of up to 30 and 31%, respectively, were observed in a prilling tower exposed to NH_4NO_3 attack for about 5-6 years. It was observed that, in deteriorations initiated by solvation (removal of hydration products, especially Ca^{++}, as soluble salts), the compressive strength decreased due to a decrease in the hardness of outer layers of concrete while the pulse velocity was not affected, for the crack formation had not yet started. On the other hand, in the initial stages of the corrosion damage due solely to the formation of expanding salts, the non-destructive tests are not sensitive to changes in compressive strength.

3.2. Expertise work on a structure exposed to ammonium nitrate attack

Pulse velocity and Schmidt surface hardness were measured *in situ*, and also cored specimens were taken from the prilling tower. The residual strength was estimated to be about 13,0 N/mm^2 at the places where the degree of destruction was high. The results are given in table IV.

TABLE III

THE MECHANICAL PROPERTIES OF CONCRETES KEPT IN VARIOUS MEDIA

Corrosive medium	P. velocity (km/s)	Schmidt index	Comp. str. (N/mm^2)
Air (control)	4.71 (4.24)	35.5 (27.5)	29.0 (11.5)
Water (control)	4.85 (4.20)	30.6 (20.4)	27.0 (10.0)
$MgSO_4$ solution	4.87 (4.22)	31.1 (22.3)	28.1 (9.1)
NH_4NO_3 solution	4.88 (4.28)	27.6 (16.1)	28.5 (8.3)
(NH_4SO_4 solution	4.76 (3.76)	29.7 (20.2)	28.9 (9.1)
The values correspond to "mean (90% confidence level)".			

TABLE IV

AVERAGE TEST RESULTS OBAINED ON THE CONCRETE OF THE PRILLING TOWER

Place	P. velocity, (km/s)	Schmidt index	Comp. str., (N/mm^2)
In situ	2.70	32.0	–
Cored specimens	3.68	30.0	16.7

It can be concluded that the Sonreb method can be extended to cover the problems involving damage caused by chemical attack. However, in this case also, to obtain reliable relations, firstly, the process or mechanism by which the corrosive agent attacks the concrete and the degree of damage should be determined. Such relations should be established separately for each corrosive medium taking into account also the stage of corrosion.

4. CONCLUSION

The Sonreb method, in essence, is based on evaluation with the coefficients of influence ([1], [14], [15]). It is impossible to apply this practically very useful method to damaged concretes. Moreover, it cannot be a reliable way of aproach to use an $f_c = F(N, V)$ nomogram developed for a certain case of damage in some other case by employing an experimental coefficient of influence. Neither the calculation of a characteristic strength for the damaged structure as a whole may be regarded as a permissible approach. In fact, even in normal undamaged low-quality concretes, the characteristic strength can be estimated from the non-destructive test results with an error of up to 50% [16]. The same amount of error of estimate may be made in the case of damaged concretes.

Reliable results can be obtained by estimating the residual strength using the combined non-destructive test method providing a correlation is developed for every specific case based on the data from test points where the degree of destruction is not high. In addition, the conflict between the trends of Schmidt index and pulse velocity provides valuable information for detecting the degree of damage and the regions of destruction.

6. REFERENCES

[1] *Rilem tentative recommendations for in-situ concrete strength determination by non-destructive combined methods.* Rilem 43 CND (2nd Draft), Athens, April 1981.

[2] JOHNSON S. M. — *Deterioration, maintenance and repair of concrete structures* McGraw-Hill, 1965.

[3] AKMAN M. S., GÜNER A. — *The application of combined non-destructive testing with Schmidt rebound number and pulse velocity to concretes subjected to elevated temperatures.* Meeting of Rilem 43 CND, Sinaia, 1980.

[4] AKMAN M. S. — *Relation between concrete compressive strength and combined non-destructive test results-computer programmes as a solution.* Meeting of the Rilem Committee 43 CND, Stockholm, June 1979.

[5] The Institution of structural Engineers-*Fire resistance of concrete structures.* Report of a Joint Committee, London. August 1975.

[6] TANIGAWA Y., YAMADA K., KASAKA Y. — *Combined non-destructive testing method of concrete*-Trans. Japan Concrete Inst., II-2, 1976, pp. 79-86.

[7] AKMAN M. S., SEVIM I. — *Factors in determination of concrete strength by combined non-destructive testing.* VII. National Conference of Sc. of TÜBITAK, Izmir 1981 (in Turkish).

[8] GÖKÇEK M. — *The effect of temperature cycling on the properties of concrete.* B. Sc. Thesis, Faculty of Civ. Engng. Istanbul Technical University, 1980 (in Turkish).

[9] SEVIM I. — *A research on the quality control of concrete by combined non destructive testing.* M. Sc. Thesis-Faculty of Civ. Engng, Istanbul Technical University, 1979 (in Turkish).

[10] GÜNER A. — *The influence of addition of blastfurnace slag on the resistance of Portland cement against the corrosion of fertilizers.* Habilitation Thesis, Istanbul Technical University, 1982 (in Turkish).

[11] SCHRÖDER F. — *Blastfurnace slags and slag cements.* Proc. of the 5th Int. Symp. on the Chemistry of Cement-Part IV: Tokyo, 1968, p. 149-199.

[12] BICZÓK I. — *Betonkorrosion Betonschutz.* Bauverlag GmbH-Wiesbaden 1968.

[13] VAN AARD J. H. P. — *Deterioration of cement products in aggressive media.* Proc. 4th Int. Symp. on the Chemistry of Cement, Vol. II, Washington D.C., 1960, pp. 835-869.

[14] FACAOARU I. *et al.* — *Quality control of concrete in prestressed-clements by non-destructive testing methods.* Incerc, Bucharest 1970.

[15] CIANFRONE F., FACAOARU I. — *Study on the introduction into Italy, of the combined non-destructive method, for the determination of* in situ *concrete strength-Materials and structures,* Vol. 12, No. 71, 1979, pp. 413-429.

[16] AKMAN M. S., IPEK M. — *Estimation of characteristic strength of concrete by means of combined non-destructive testing.* Meeting, Rilem Com. 43 CND, Athens, April 1981.

[17] REGOURD M. — 32 *RCA : Resistance of concrete to chemical attacks.* Materials and Structures, Vol. 14, No. 80, pp. 130-137.

RÉSUMÉ

La méthode Sonreb et le béton endommagé. — *Dans le cas d'ouvrages endommagés par l'incendie, par les agents chimiques ou par des secousses sismiques il se pose souvent le problème d'évaluer la réserve de résistance mécanique du béton. La méthode Sonreb élaborée en grande partie pour le contrôle de qualité du béton au cours des travaux, et qui consiste à combiner les résultats des mesures des vitesses ultrasoniques et des mesures sclérométriques de Schmidt peut-elle être appliquée à ces bétons endommagés? Cette étude s'efforce de répondre à cette question. Les limites d'application de la méthode Sonreb sont discutées pour les bétons soumis à de hautes températures et aux effets des engrais artificiels tels que le nitrate d'ammonium et le sulfate d'ammonium. L'application de la méthode paraît être possible à condition qu'une étude préalable nous renseigne sur la durée et la température maximale atteinte par l'incendie et nous permette de classifier les niveaux des dommages par secteur. Les valeurs contradictoires des vitesses du son et des indices sclérométriques en un même lieu donnent des indications précieuses et en déterminant la profondeur de béton détérioré on peut arriver à des résultats sûrs avec Sonreb. Dans le cas des bétons corrodés, il est nécessaire de savoir si la corrosion est due à la dissolution de la matière ou à l'expansion des sels formés et si ces deux processus sont simultanés ou consécutifs, et de connaître la durée de l'exposition.*