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CRACK REPAIR ASSESSMENT BY ULTRASONIC METHOD

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ABSTRACT

Cast in-situ concrete structures are hardly ever built under ideal conditions so defects may occur as the concrete is being cast or very soon afterwards. In most cases the cause of defects is inadequate design and poor workmanship.
This paper describes the damage that occurred during the construction of a big shopping centre in Zagreb, Croatia. Very soon after the building construction was completed, large cracks appeared on the basement walls, and it was through those cracks that underground water permeated. Crack repair was done by injection of polymeric resins. During the wall repair a non-destructive quality control was done by ultrasonic method.
The ultrasonic pulse velocity method is a method that involves measuring the travel time of ultrasonic pulse over the known path length. It makes it possible to take a great number of samples or make structure examinations without structure destruction.
The assessment of repair successfulness is based on statistical analysis of the results of measurement results, that is to say, on Student's t-test. The results obtained showed that the ultrasonic method can be effectively used during the crack repair.

Keywords: Concrete structure, Crack repair, Injecting, Ultrasonic testing

1. Introduction

Cast in-situ concrete structures are rarely constructed under ideal conditions. This is the reason why defects, the causes of which are numerous, can occur as early as during construction or later in their use. In most cases, the causes of defects are: unsuitable materials selected; poor quality materials used; and inappropriate methods of construction employed. Bad solutions to structural details or unsuitable concrete composition can cause not only a whole lot of minor defects but also serious cracks and even the gravest consequences. [1]
At present, the assessment of the efficiency of concrete structure repair is carried out using, among other methods, a non-destructive method that involves measuring ultrasonic pulse travel time.
This paper describes the assessment of the efficiency of the crack repair in reinforced concrete walls of an underground garage built in Zagreb, Croatia. The building pit excavation, 16 m deep, was secured with combined systems of watertight reinforced concrete diaphragm wall with ground anchors and steel piles. The entire basement was constructed as watertight tub since ground water reached up to 4 m from the ground surface. The garage structure was installed

using the building system called 'a white tub' (Ger. weisse Wanne) in which traditional outside waterproofing is not placed. The diaphragm was supplemented with a reinforced concrete wall by means of only inside formwork.

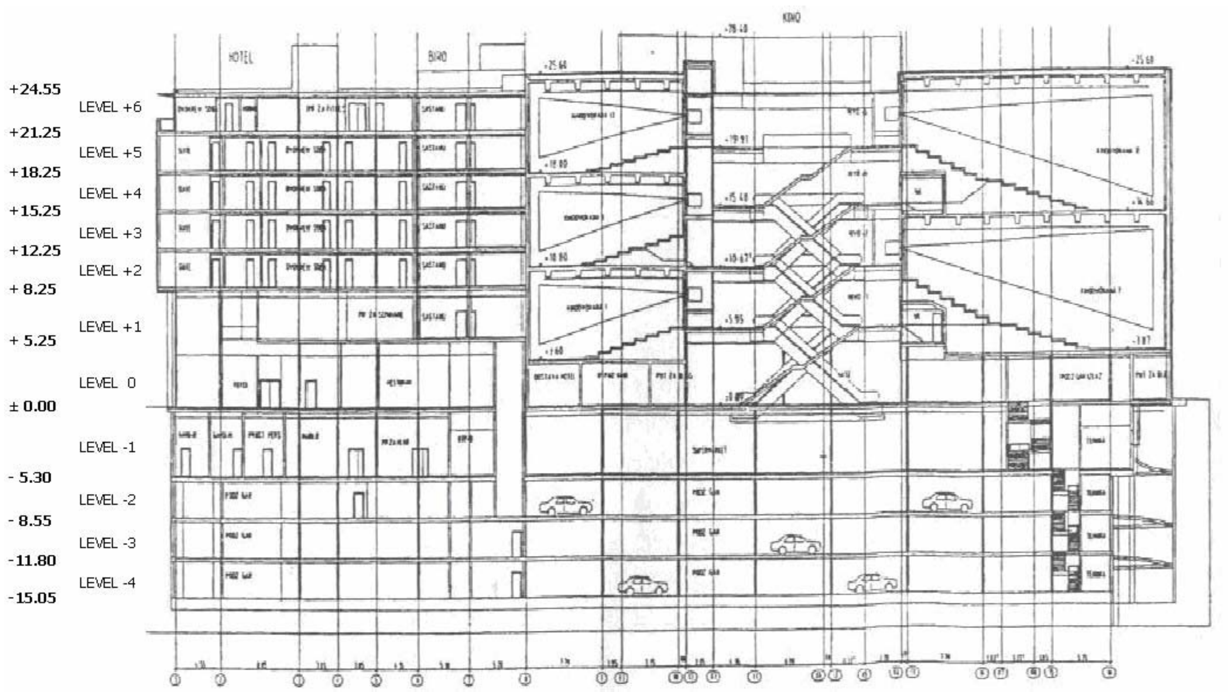

Fig. 1: Characteristic cross-section of the structure.

Considering that the entire diaphragm is watertight, at the joint between the diaphragm and the internal wall no waterproofing was provided but only a layer of expanded polystyrene of a few centimetre in thickness. In the places where concrete placing was interrupted, strips for construction joints were installed. [2, 3] Immediately after the 'white tub' was constructed, cracks occurred. After some time the water penetrated under very high pressure through the cracks because of a high level of ground water in the location (Fig. 2).

Fig. 2: Penetration of water through reinforced concrete walls of the underground garage.

The cracks were repaired by injecting polyurethane foam and epoxy resin under high pressure (Fig. 3). Ultrasonic measurements and statistical analysis of data using Student's t-test showed that crack repair by injection was carried out successfully in seven out of eight reinforced concrete walls. This has proven that the use of ultrasonic measurement method can be used very successfully for a repair control.

Fig. 3: Crack repair by injection and a photo of repair position.

2. Assessment of crack repair successfulness by ultrasound

Ultrasonic testing can be used not only for concrete quality control but also for determining the presence of the cracks, in a very efficient and sufficiently accurate way, and for defining how deep they are. [4, 5, 6] The testing method is specified in the HRN EN 12504-4:2004 standard. There are three methods for measuring the speed of ultrasonic pulse through the concrete. They are the following:

- The method of direct ultrasonic pulse travel through the concrete (Fig. 4-a)
  The probes (a transmitter and a receiver) are placed so as to face each other, that is, on two opposite sides of the element on which measurements are performed.
- The method of semi-direct travel of the ultrasonic pulse through the concrete (Fig. 4-b)
  The probes are installed at an angle of 90° one in relation to the other.
- The method of surface travel of the ultrasonic pulse through concrete (Fig. 4-c)
  This method is used when only one surface of the element tested is accessible.

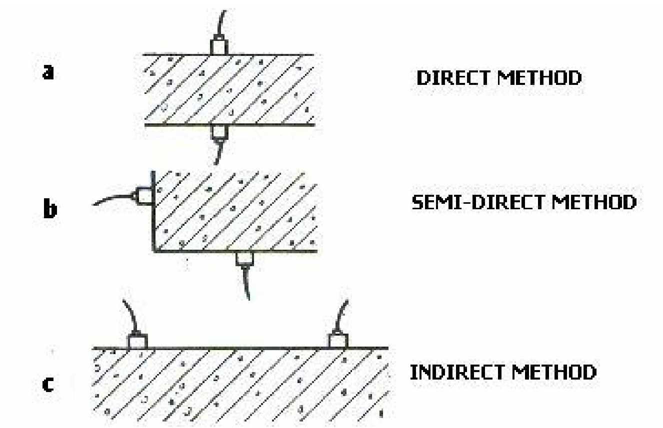

Fig. 4: Methods of measuring ultrasonic pulse velocity through the concrete [1, 5].

A pulse generator transmits through a transmitter a pulse of longitudinal oscillations to the concrete (Fig. 4). After the pulse has passed through the concrete having the length L, in the second probe of the receiver it is transformed into a pulse. The time interval from the moment

when the pulse leaves the transmitter to the moment when the pulse is received in the second probe, i.e. the receiver, is the pulse travel time (t).
Ultrasonic pulse velocity in concrete is closely related to its density, modulus of elasticity and strength. In the methods mentioned above the speed of pulse is calculated from the time required by the pulse to cover a certain distance. Ultrasonic velocity (v) is given by the following formula:

$$v = \frac{x}{t} \tag{1}$$

where:
v – Ultrasonic pulse velocity in the sound, crack-free concrete (m/s)
x – The space between the probes, i.e. the distance travelled by the ultrasonic pulse in the crack-free concrete (m)
t – The time required for the ultrasonic pulse to pass in the crack-free concrete (s).

If ultrasound is used to determine visible cracks or to assess the effect of crack repair, the method of surface ultrasonic pulse travel through concrete is employed (Fig. 5).

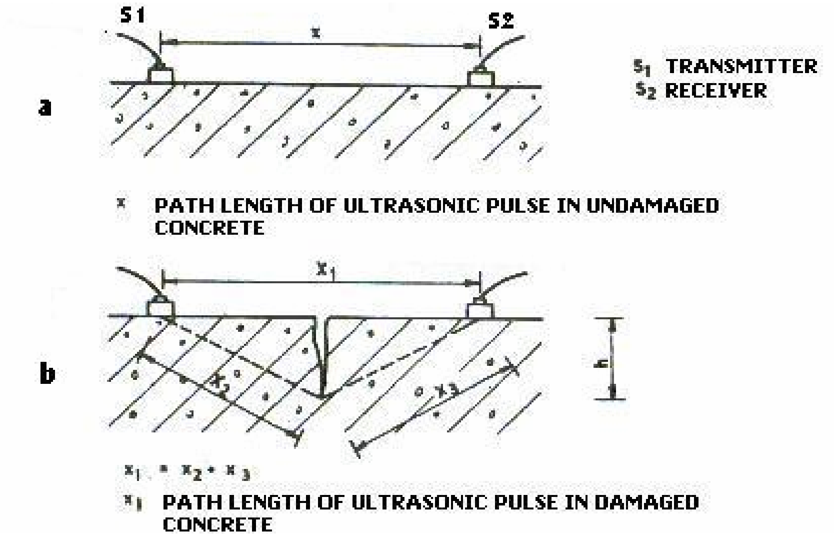

Fig. 5: Distance covered by ultrasonic pulse in crack-free concrete and cracked concrete [1, 5].

The technique involves the following:

- Measure the travel time of the ultrasonic pulse using the method of surface travel of the ultrasonic pulse through sound, crack-free concrete and damaged concrete before and after crack repair has been made by injection.
- From the measured values of time and distances between probes, calculate ultrasonic pulse velocity.

By an analysis of the results of measurement obtained and calculations done before and after the repair, an assessment of efficiency of the repair is made.
In the cracked concrete, the distance to be travelled by a pulse is longer and, consequently, the time required for the pulse travel is longer (Fig. 5-B). Then the pulse velocity is:

$$v_1 = \frac{x_1}{t_1} \tag{2}$$

where:
v_1 – ultrasonic pulse velocity in cracked concrete (m/s)

x_1 – the space between probes, i.e. the distance travelled by the ultrasonic pulse in the cracked concrete (m)
t_1 – time required for the travel of ultrasonic pulse in cracked concrete (s).

It is assumed that $x = x_1$, i.e. that the travel of pulse in crack-free and cracked concretes is equal. Since the times required for pulse travel in the cases of crack-free and cracked concrete are different, for the same travel, speeds are also different ($v \neq v_1$).
Also, by using the marks given in Figure 4-B and the equations given above, the crack depth can be calculated as follows:

$$h = \frac{x_1}{2}\sqrt{\frac{t_1^2}{t^2} - 1} \quad (3)$$

where:
h – crack depth (cm)

It should be noted that surfaces selected for measuring points should be smooth, clean and dry. If this is not possible, then they should be brushed and cleaned to satisfy the above condition. To provide a good contact between the probe and the concrete, the surface at the measuring point should be smeared with a thin layer of lubricant. If the surface is very rough and cannot be brushed, a good contact between the probe and the concrete is provided with an agent of higher density than that of a lubricator. The space between the probes and the time of ultrasonic pulse travel is measured with ± 1% precision. The ultrasonic pulse velocity is determined with ± 2% precision. Ultrasonic velocity at the measuring point is to be determined on at least three measurements. [7, 8]
The ultrasonic measurements have certain drawbacks. The pulse velocity can be influenced by:

- temperature
- travel length
- moisture content in the concrete
- presence of reinforcement

Changes in temperature have no significant influence on the pulse velocity except in the cases of extremely high temperatures (micro-cracks appear in concrete) and very low temperatures (freezing of water inside concrete).
Because of heterogeneous concrete structure, the lengths of pulse travel shall not be too small. The HRN EN 12504-4:2004 standard recommends a minimum travel length of 100 mm for concrete with maximum aggregate size ranging between 20 mm and 40 mm.
Pulse velocity through water-saturated concrete may be up to 5% higher than through the same concrete under dry conditions. Such influence is less in concretes of high concrete strengths.
The influence of reinforcement is generally small if the direction of reinforcement bars is vertical to the direction of pulse spreading. This is because pulse travel through steel is relatively small in comparison with the total travel. When the direction of bars is parallel to the direction of pulse spreading, the influence increases since pulse velocity through the reinforcing steel is significantly higher (5.1-5.9 km/s) than through concrete (3.5-4.8 km/s). In order to avoid the influence of reinforcement, before using the ultrasonic method, the reinforcement should be located by means of a coveremeter. The covermeter can locate reinforcement in a non-destructive way with high accuracy; determine its diameter and the thickness of the concrete cover. Tests are carried out by means of a portable instrument based on measuring the changes in an electro-magnetic field caused by reinforcement installed in the concrete. If reinforcement laying in the direction that is parallel to the pulse spreading path cannot be avoided, correction factors should be used during measuring. [4, 5, 9]

The assessment of repair efficiency is made on the basis of Student's *t*-test according to the following formula:

$$t_{S-NN} = \frac{\bar{v}_{NN} - \bar{v}_S}{\bar{S}\sqrt{\frac{1}{n_{NN}} + \frac{1}{n_S}}} \tag{4}$$

where:

t_{S-NN} – variable of Student's t-distribution with the degrees of freedom $v = n_{NN} + n_S - 2$

$\bar{v}_{NN}, \bar{v}_S$ – mean values of ultrasonic velocity in crack-free concrete and repaired concrete (m/s)

n_{NN}, n_S – the number of elements in statistical samples of the crack-free and repaired concrete

$\bar{S}$ – common standard deviation for both statistical samples (m/s):

$$\bar{S} = \sqrt{\frac{(n_{NN} - 1)S_{NN}^2 + (n_S - 1)S_S^2}{n_{NN} + n_S - 1}} \tag{5}$$

(It is assumed that both basic sets have equal variances.)

S_{NN}, S_S – standard deviations of a particular statistical sample (crack-free and repaired concrete) (m/s)

A standard deviation is calculated from the following formula:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(v_i - \bar{v})^2}{(n - 1)}} \tag{6}$$

where:

S – standard deviation of the statistic sample (m/s)

$\bar{v}$ – mean ultrasonic pulse velocity (m/s)

v_i – ultrasonic pulse velocity for a particular sample (m/s)

n – the number of samples

The significance of the differences between mean values is tested with 95% reliability. Efficiency of the repair is assessed by comparing the values of the variable t_{S-NN} from Student's t-test for the repaired and sound concretes.

For the reliability selected and for the degree of freedom calculated, critical value ($t_{0.95}$) of Student's distribution is read from statistical tables and then compared with the calculated variable t_{S-NN} from Student's t-test. If $t_{S-NN} < t_{0.95}$, there is no significant difference between mean values v_S and v_{NN} (repair by injection was carried out properly). On the other hand, if $t_{S-NN} > t_{0.95}$, there is a significant difference (cracks have not been properly repaired – injection should be repeated). [7, 8, 10]

3. Results of measurement

In ultrasonic measurement of the times of pulse travel through the reinforced concrete walls of the underground garage, the method of surface pulse travel was used. Measurements were taken by ultrasonic instrument called PUNDIT. The speed of ultrasonic pulse travel was measured at 8

points on the wall structure in order to obtain the most reliable values of ultrasonic pulse velocity through sound, crack-free concrete.
Since the walls were reinforced with a fair amount of reinforcement, it was extremely difficult, without prior testing, to locate the portions without or with less reinforcement. By using tracker the location of the reinforcement was determined and thus its influence on the results of measurements reduced. The tracker used was PROFOMETER 3.
During measurements the efficiency of crack repairs was carried out on eight walls at the levels -3 and -4 of the underground garage (Fig. 1). The measurements were taken on the crack-free concrete in fifty repaired positions for comparison. In fifty measured positions, a total of 130.65 m’ cracks was repaired. Due to high moisture content, the measurements were not carried out on crack-free concrete before repair as the data obtained by measuring would not be reliable. However, they were made on the repaired surfaces that were most severely damaged and that posed the biggest problems for the contractors during repair. The number of measurements on each position varied from three to eight measurements depending on the position size, i.e. the length of the crack repaired. The total number of measurements made was 283.

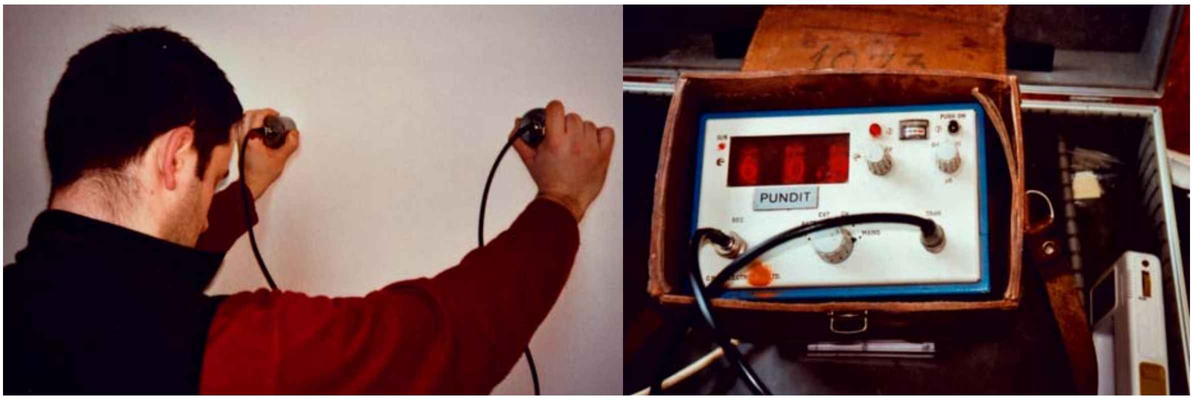

Fig. 6: Position of probes in measuring the time of ultrasonic pulse travel and a photo of the PUNDIT ultrasonic instrument.

The data obtained by ultrasonic measuring after repair and their subsequent statistical analysis served the purpose of making assessment of efficiency of repair (Tables 1, 2). A separate assessment was made for every wall.

Table 1: Analysed results of measurements of crack-free concrete.

Wall	CRACK-FREE CONCRETE
$\bar{t}_{NN}$ (µs)	82,4
$\bar{v}_{NN}$ (m/s)	3639
S_{NN} (m/s)	248

Ultrasonic testing on the underground garage structure and assessment of repair using statistical analysis of the measured data by Student’s t-test showed that the crack repair by injection was efficient on 7 out of 8 reinforced concrete walls. The T-test showed that the repair was not successful on the wall -3A, which makes 0.70 m’ of repaired cracks. This means that about 99.5% of wall surfaces with cracks were repaired successfully. Although the wall -3A did not demonstrate moisture actions, it is safe to say that injection was not carried out properly enough, and that it is very likely that permeation will occur again in the future. For this reason it is advisable to repeat injection on this wall. On three out of eight walls the measurements showed that the repaired concrete exhibits better quality and has less cracks than the crack-free concrete.

This can be explained by the fact that injection material filled all the cracks and concrete pores, thus making it possible for the ultrasonic pulse to quicker travel between the probes; this travel was even quicker than that in the sound concrete that still contains fine cracks.

Table 2: Analysed results of measurements of repaired concrete.

Wall	**-3A**	**-3B**	**-3C**	**-3D**	**-4A**	**-4B**	**-4C**	**-4D**
No. of measuring pts.	2	11	4	2	8	16	3	4
No. of measurements	6	55	27	9	46	102	13	25
$\overline{t_S}$ (μs)	88.8	85.0	80.3	79.6	84.0	83.9	84.5	80.3
$\overline{v_S}$ (m/s)	3378	3528	3737	3771	3571	3576	3550	3737
S_S (m/s)	262	473	310	593	390	312	352	299
$\overline{h_S}$ (cm)	5.2	3.1	1.8	2.7	3.6	3.2	2.8	1.5
$\overline{S}$ (m/s)	244	449	294	450	370	307	310	284
$t_{S\text{-}NN}$	1.979	0.655	-0.832	-0.604	0.481	0.559	0.640	-0.850
N	12	61	33	15	52	108	19	31
$t_{v;\,0.95}$	1.872	1.671	1.694	1.753	1.676	1.661	1.729	1.697
Assessment	Not satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory

4. Conclusions

This paper describes the ultrasonic measuring method as a non-destructive testing method for assessment of efficiency of concrete structure repair.
The ultrasonic measuring method proved to be a very suitable method for checks of repair because it can enable not only the comparison of cracked and repaired concretes with sound concrete through measuring ultrasonic pulse velocity, but also the determination of the depth of the cracks developed. The use of ultrasonic pulse is very simple, and the success of repair can be checked quickly and in an efficient way.

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