EVALUATION OF POSSIBILITIES TO APPLY LASER SCANNING FOR ASSESSMENT OF CONDITIONS OF CONCRETE

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ABSTRACT

Periodical surveys of concrete structures, performed within geodetic monitoring, may be implemented using laser scanners. Similarly to a tacheometer, the scanner determines spatial co-ordinates (X, Y, Z) of surveyed points, specifying the distance and angles. Besides the speed of operations, the parameter, which mostly differentiates the scanner from the tacheometer, is registration of the 4th co-ordinate – an intensity of reflectance of the returning light signal, emitted by the scanner. The analysis of recorded values of that additional, 4th co-ordinate may be applied in diagnosis of conditions of structures.
The paper presents evaluation of possibilities to utilize results of laser scanning for determination of conditions of outer surfaces of construction of a water dam – variations in porosity and resistance of concrete.

1. INTRODUCTION

The issue of damages caused by ageing of dams concerns the majority of water dams, considered in reports of the Centre for Technical Inspection of Dams. Among constructions, which have been investigated, more than 50% were exploited longer than 50 years and exploitation of more than 10% of constructions was longer than 25 years; due to the low quality of works, in Polish conditions it is equivalent to commencing intensive repairs and overhauls, resulting from ageing of the structures and their elements. It should be stressed that – apart from difficult conditions of implementation and utilisation of those types of structures, their conditions are usually important for safety of the surrounding areas, and that such structures have strong impacts on those areas. Therefore it is necessary to accurately and promptly recognise the conditions of the structure in relation with conditions and phenomena which occur within surrounding areas.

2. AGEING OF MASSIVE CONCRETE STRUCTURES

Concrete in big, massive hydrotechnical structures, is exposed to many factors, which may lead to accelerated wear. Those factors include, among others: plastic shrinkage, tensions resulting from diversification of moisture and temperature in hardening concrete mix and from changes of temperature and humidity of the surrounding space. In case of matured concrete those factors may include: tensions resulting from variations of temperature and shrinkage of concrete, uneven setting of the base, tectonic and seismic movements of the base, variations of the heights of water lifting, changes of parameters of the background soils and many reactions, which occur in the course of the structure exploitation, such as: chemical aggression of surface, underground or storm waters, movements of water, pressure of water, pressure of ice, pressure imposed by frozen water in capillaries of concrete masses, transport of masses inside materials, diffusion of CO_2 included in the air, variations of temperatures, thermal shock, humidity of the air, fog, rainfalls, factors resulting in abrasion and cavitation, micro-organisms, vegetation, animals, excessive or diversified load. The total impacts of mentioned factors usually result in occurrence of the first warnings of damages of materials or the structures within the several or dozen or so years. Those warnings may include scratches of concrete masses, increased filtration or leakages in the structure body, surface destruction of concrete, excessive deformations of the structure and other symptoms. [1].

3. METHODS OF INVESTIGATIONS OF CONDITIONS OF CONCRETE

Three following groups of methods of investigations of concrete may be distinguished:

Damaging methods, which, in general, consist of loading the concrete samples, which are specially prepared or acquired from a structure, in the form of cylindrical wells of various diameters and lengths,

Slightly damaging methods, which consist of determination of parameters of concrete basing on tests of peeling of an anchored or pasted concrete element from sub-surface layers of the structure,

Non-damaging methods, being a set of methods which allow for determination of the quality of the tested structure without decreasing its useful properties; those methods include, among others, sclerometric methods (e.g. using the Schmidt hammer), ultrasound and seismic methods (which utilise the hit as a factor which releases vibrations), radar methods, acoustic and radar tomography.

Non-damaging tests are justified by their high accuracy, but disadvantages, which occur in the course of sample acquisition, resulting from technical conditions, time consumption, the necessity to perform two stages of testing, and, first of all limitation connected with the possibility to unsafely lower the capacity of weakened elements [2], motivate to use other measuring methods, which are less accurate, but which require less time and which are more effective. Commonly applied non-damaging methods allow for marking the quality and resistance of concrete in a performed structure.

The most popular classification method of parameters of performed concrete and reinforced concrete structures is the non-damaging method of testing the concrete quality using the Schmidt hammer. In the case of that method the resistance and homogeneity of concrete is determined by means of measurements by the value of reflectance (measurements of local surface hardness) and then by means of statistical analysis of results of measurements basing on empirical relations. For the Schmidt sclerometers it is the relation between the value of reflectance and the resistance to compression (fc-L) [3].

4. GEODETIC MONITORING PERFORMED USING SCANNING INSTRUMENTS

Geodetic monitoring of displacements – changes of geometry of structures, concerns all concrete dams of the I and II classes in Poland.

Periodical measurements may be performed within geodetic monitoring using modern surveying instruments, the so-called, scanning instruments, i.e. laser tacheometers and scanners, which allow for acquisition of point models (of quasi-continuous nature), which are easy for processing and analysis. Similarly to the tacheometer, the scanner determines spatial co-ordinates (X, Y, Z) of surveyed points, determining a distance and angles. Accuracies of measurements performed by the scanner are very close to those of results of conventional surveys. The parameter, which mostly differentiates scanning instruments from the tacheometer – besides the speed of operations – is the registration of the 4th co-ordinate – the intensity of reflectance of a returning light signal (intensity of reflectance) emitted by the scanner, by the scanned surface. This value is assigned to every measured point as the intensity and after interpolation onto a regular grid it produces an image of intensity. The image of intensity for a water dam, together with colour visualisation, is presented in Fig.1. Presented results of measurements were performed by the Chair of Engineering Geodesy and Topographic surveys of the Warsaw University of Technology and Leica Geosystems Polska on June 8-9, 2009. The Leica ScanStation2 laser scanner was used.

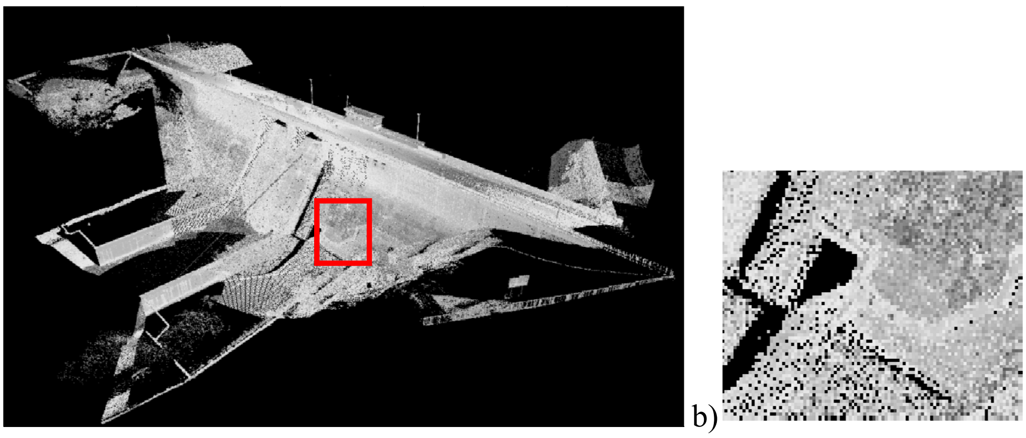
a)  b)

Fig.1. Besko Water Dam – colours of measuring points correspond to the registered value of the 4th co-ordinate – measurements were performed on June 8-9, 2009 a) view of the dam from the downstream face, b) closer look of the selected fragment [4].

The analysis of recorded values of that 4th additional co-ordinate may be applied to diagnose the conditions of the structure. Some cases are known when it was stated basing on such analysis that various elements of the structure were made of various materials. Attempts aiming at diagnosis of conditions of a structure, made of the same materials, which was ageing and undergoing variable loads, have not been performed yet. Basing on the performed first experimental measurements it seems that such technology might be successfully applied for estimation of humidity of outer layers of concrete and for estimation of conditions/resistance/hardness of outer concrete surfaces of a dam, mainly from the downstream face (bottom water).

The following experimental measurements were performed using specially prepared samples of concrete of diversified properties – hardness, granularity and porosity:

Initial measurements at the Laboratory of the Chair of Hydrological Constructions and Hydraulics of the Warsaw University of Technology, covering investigations of the number of reflectance (non-damaging method),

Experimental measurements at the Chair of Engineering Geodesy and Topographic Measurements, covering the scanning of samples using Leica C10 (Fig. 2) and Riegl VZ-400 scanners,

Experimental measurements performed in the field on the Besko Dam in Sieniawa, on the Wisłok River – scanning of the downstream face of the structure, using the above both instruments.

Mean values of the 4th co-ordinate, recorded for each sample of concrete, were compared with the results of tests of resistance, performed at the same time using the Schmidt sclerometer (hammer). 15 various samples were tested.

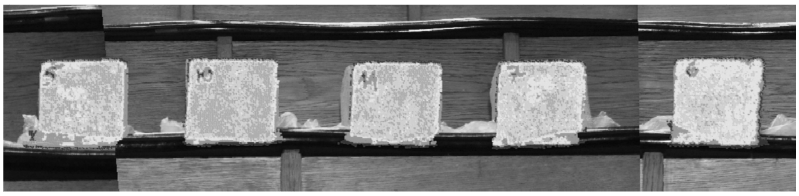


Fig. 2. Results of scanning surfaces of samples 5, 6, 7, 10, 11 using the Leica C10 scanner – colour visualisation of the I co-ordinates was imposed on the photograph of samples.

5. NUMERICAL PROCESSING OF RESULTS

Investigated samples were scanned using one instrument at the same time, in the same outside conditions.

Control fields – being circles of a given radius were distinguished on the scanned surface of each sample. Recorded values of the fourth co-ordinate I were divided into 14 intervals. For each field, the histogram presenting the number of I values, recorded in each interval, was developed. 15 samples of concrete of various properties, were tested.

The sample material feature was determined basing on the test of resistance, performer in laboratory conditions using the Schmidt sclerometer (hammer).

The list of results of scanning obtained with the use of Leica C10 instrument for the Sample no.6 is presented in Table 1. Appropriate diagrams are presented in Figures 4 and 5.

Table 1. Frequencies of occurrence of recorded I values for control fields of the Sample no. 6

Sample no.	Mean value of bounce number (sclerometer method)	Frequency of recorded I values							
6	36.9	Interval	Limit values	Field 1	Field 2	Field 3	Field 4	Field 5	Mean value
		3	-1100		4			2	1.2
		4	-1000	6	46		18	10	16
		5	-900	24	136	8	88	98	70.8
		6	-800	82	250	78	232	200	168.4
		7	-700	316	424	442	404	490	415.2
		8	-600	502	292	498	362	332	397.2
		9	-500	268	92	188	146	112	161.2
		10	-400	62	6	54	18	4	28.8
		11	-300	4		2	2	2	2

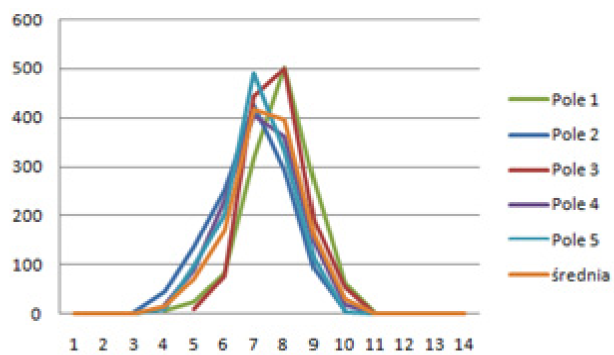


Fig. 4. Diagrams of the frequency of occurrence the I value in various fields for the Sample no.6 (Leica C10 scanner).

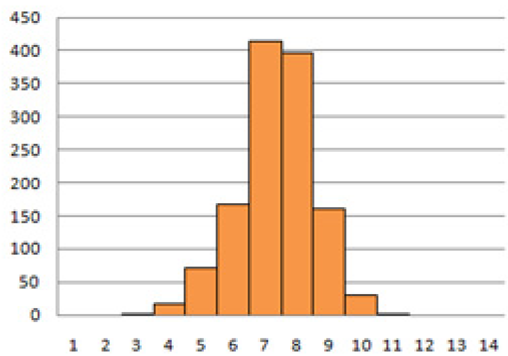
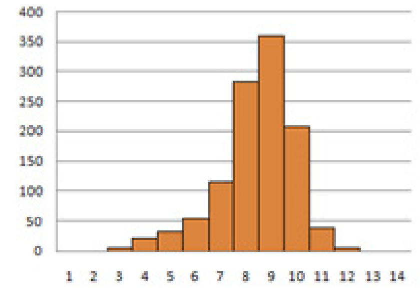
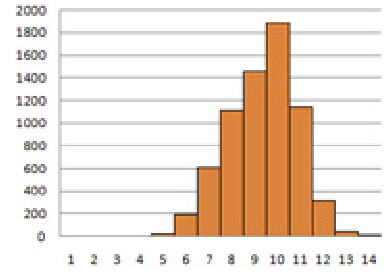
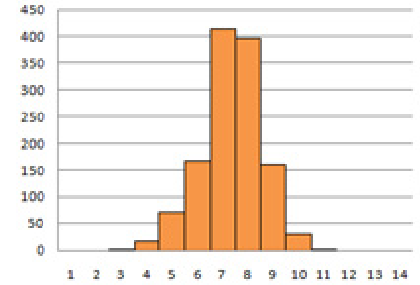
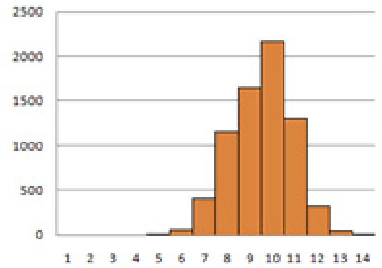
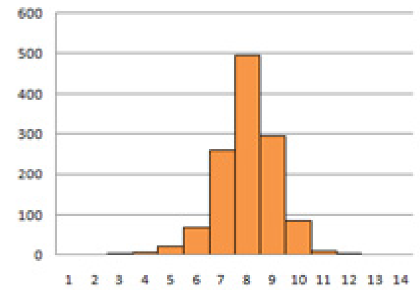
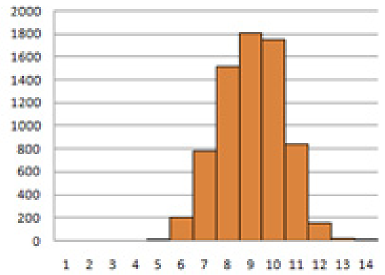
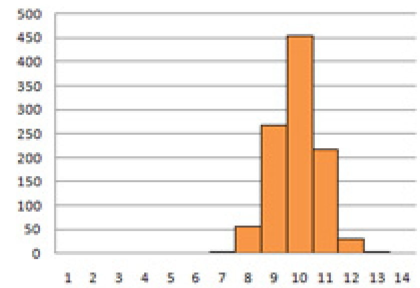
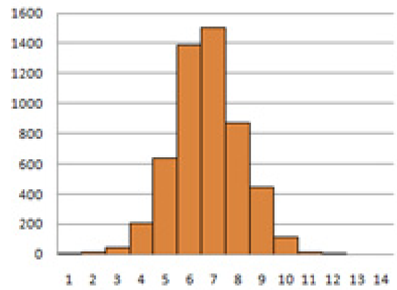


Fig. 5. Histogram of the mean frequency of occurrence of the I value for the Sample no.6(Leica C10 scanner)

Histograms of the mean frequency of occurrence of the I value for selected samples, prepared basing on measurements by means of two tested scanners, are presented in Table 2.

Table 2. Histograms of the mean frequency of occurrence of the I value for selected samples

Sample no.	Mean value of bounce number (sclerometer method)	Leica C10 scanner	Riegl VZ-400 scanner
3	**31,5**		
6	**36,9**		
7	**29,3**		
14	**43,1**		

It may be noticed that – for one scanner and a single sample – the consistency between the frequency of occurrence of the I value in various fields exists. Besides, for one scanner and various samples, diversification of histograms occurs, what allows to hope that utilisation of appropriate methods of analysis will enable to determine correlation between recorded values of the reflectance intensity and the properties of materials. This means, that data obtained from measurements performer by means of various scanners cannot be compared without further investigations and development of appropriate algorithms.

It may be expected that those differences result from various lengths of waves emitted by lasers applied in scanners produced by various manufacturers of surveying instruments.

6. SUMMARY – THE POSSIBILITY TO APPLY VARIATIONS OF REFLECTANCE INTENSITY OF LASER BEAMS FOR ASSESSMENT OF CONDITIONS OF A CONCRETE STRUCTURE

The authors of the paper are focused on utilisation of results of measurements performed with the use of a laser scanner for estimation of conditions of outer layers of concrete of the dam, considering two aspects: evaluation of the humidity and assessment of the resistance/elasticity. It should be noticed that – due to the surface nature of laser scanning, only the thin, outer layer of concrete may be evaluated using the analysis of variations of the signal of light reflectance intensity.

Results of measurements of an individual point, performed with the use of a scanner, after appropriate numerical processing – connection, orientation of scans in a local system of a structure and filtration aiming at elimination of gross errors (scanning of incidental structures, such as flying birds, splattering water, elements located in front of a structure in the light beam) correspond to X,Y,Z co-ordinates and I (Intensity of reflectance – the amount of energy of a laser beam returned to the recording device).

The value of the „fourth" co-ordinate is mainly influenced by the following factors:
Physical properties and topography of the scanned surface,
The laser applied in the scanning instrument,
Atmospheric factors (energy of a source and its possible fluctuations may be neglected, if we consider individual scans, performed using the same instrument).

Works concerning preparation of an appropriate algorithm of evaluation of technical conditions of the water dam downstream face concern: selection of a surveying instrument (scanner, scanning tacheometer), development of a method of selection of control fields, methods of measurements, methods of measurements using the sclerometer, development of algorithms of filtration of results of measurements (detection of measuring errors, selection of points from a cloud of points measured using the scanner for a representative sample corresponding to the evaluated surface) and selection of methods of calculations and numerical analyses, interpretation of results – preparation of preliminary evaluation of the structure, specification of places for detailed inspection (works at heights on water dam sections, performed by contracted workers, trained to perform such tasks).

In case of diagnostic tests of exploited building structures the danger to make errors, which impacts can be hardly determined, concerning the estimation of properties of building materials.

Investigations of resistance using damaging methods may be performed with the use of the limited number of wells, collected from places of diversified homogeneity of concrete. In practice, non-damaging tests allow for inspection of the quality of concrete in the exploited structure without interference in the structure itself, i.e. without weakening of the structure.

The method of evaluation of conditions of concrete, which is under development, is a non-damaging method and may be simply utilised with the use of available surveying instruments. It seems that it will be sufficient to take one sample or to determine a control field on the structure in order to compare the conditions of control surfaces, determined on the structure's wall with the conditions of the surface of the control field. Simultaneous application of test using damaging and non-damaging methods (including laser scanning) will allow for increasing the accuracy and reliability of performed evaluation of the conditions of the structure.

REFERENCES

Kilian W.: Współczesne metody diagnostyki masywnych konstrukcji betonowych. *Contemporary methods of diagnostics of massive concrete structures.* Zeszyty Naukowe PAN "Infrastruktura i ekologia terenów wiejskich", Nr 4/2/2007.

Krentkowski J., Tribiłło R.: Badania wytrzymałości betonu w konstrukcjach inżynierskich z uwzględnieniem normatywów europejskich. *Testing the resistance of concrete in engineering structures with consideration of the European standards.* Przegląd Budowlany 12/2006.

Runkiewicz L.: Ocena wytrzymałości betonu w konstrukcji za pomocą sklerometrów Schmidta. *Estimation of resistance of concrete in a structure using the Schmidt sclerometers.* Prace Naukowe ITB, seria monografie, rok: XXXVIII. Warszawa, 1983.

Zaczek-Peplinska J.: Możliwości wykorzystania skanowania laserowego do pozyskiwania danych i weryfikacji geometrii modelu numerycznego zapory betonowej. *Possibilities to apply laser scanning for acquisition and verification of geometry of a numerical model of a water dam.* Materiały niepublikowane. Warszawa, 2009.

PN-EN 12504-2: 2002 Badania betonu w konstrukcjach – Część 2: Badania nieniszczące – oznaczanie liczby odbicia. *Investigation of concrete in structures – Part 2: Non-damaging tests – marking the bounce number.*