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INVESTIGATIONS OF CONCRETE SURFACE ROUGHNESS BY MEANS OF 3D SCANNER*)

ABSTRACT *This paper presents investigations of the base concrete surface in concrete floors by means of a 3D scanner. Two base concrete surfaces, differing in their preparation, were investigated.*

Keywords: *concrete floor, optical method, Roughness, amplitude parameters, topography measurement.*

1. INTRODUCTION

The durability of concrete floors is to a large degree determined by the pull-off adhesion of the topping to the base concrete. It should be noted that adhesion at this interface significantly depends on proper base concrete surface preparation, described by surface roughness parameters.

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Roughness is a feature of a surface, representing its irregularities (convexities and concavities) whose height/depth is at least one order of magnitude smaller than the element's dimension. Surface roughness is analyzed in certain cross sections referred to as surface profiles.

Surface roughness is one of the properties describing the geometric structure of a surface. This structure comprises a set of surface irregularities, including shape deviations, waviness and roughness. Roughness is considered to be a major surface preparation indicator.

A surface profile is a line of the intersection of a surface by a plane. A nominal profile, a real profile, a cross profile, etc., are distinguished. A profile method and a surface method are used to measure concrete surface roughness.

2. LITERATURE SURVEY

The determination of the dependence between surface roughness and the pull-off strength of concrete was the subject of [1], where it was shown that there is a dependence between the parameters describing base concrete roughness and strength measured by the seminondestructive pull-off method [2].

The effect of base concrete roughness on the degree of bonding between the topping and the base concrete was studied in [3]. Parameter values determined by the profile method were used to describe base concrete surface roughness.

Paper [4] dealt with the dependence between base concrete roughness and parameters determined by the nondestructive impact-echo method [5].

The determination of the dependence between concrete surface roughness parameters and concrete pull-off strength versus compressive strength and the evaluation of the usefulness of standard and fractographic roughness parameters for the description of concrete surface topography were the subject of [6].

Also the dependence between the pull-off strength of concrete and protective coatings and the compressive strength of the concrete for different surface preparation methods, concrete moisture content and temperatures was investigated. Virtual 3D models of sandblasted and non-sandblasted concrete surfaces were made using a surface scanner and surface roughness parameters were calculated on their basis. It was shown that the greater the compressive strength of concrete, the greater the pull-off strength and the lower the values of the parameters defining the roughness of the sandblasted surface [7].

Because of its higher precision in determining concrete surface roughness a 3D optical scanner was employed in [6] to measure the point coordinates of elements (including concrete floors) from a few millimetres to a few tens of meters in size.

Considering the above, this paper presents investigations of concrete floor base surface roughness by means of a 3D scanner.

3. DESCRIPTION OF 3D SCANNER

In recent years two-dimensional analysis has come under criticism and new solutions have been proposed for describing concrete surface roughness. A single flat profile does not adequately characterize a 3D surface, such as the surface of concrete.

An optical method based on the measurement of light reflected or scattered from/by the surface of an examined object can be used for this purpose. There are several optical methods of measuring the coordinates of 3D objects and many ways of qualifying them, generally divided into active and passive. This division stems from the fact that passive measuring techniques work in uncontrolled natural light and so do not need any additional artificial light sources, whereas active methods engage additional light sources: incoherent (e.g. projectors) and coherent (lasers) light sources.

An advanced 3D scanner ATOS II represents the optical method, i.e. the digital light projection (DLP) method. The system consists of a projector and two digital cameras capable of supplying 1.4 million of measuring points per second. The measuring range is 175×140 – 2000×1600 [mm^2]. Thanks to the use of special lenses and a high-quality projector a very high resolution of the cloud of points is achieved whereby one can scan (measure point coordinates) elements from a few millimetres to a few tens of meters in size. The scanner works on the principle of triangulation, i.e. the two cameras observe the pattern of spectral lines on the detail being measured and for each camera pixel a coordinate point is calculated (fig. 3.1a). A dedicated scanner software makes possible a full measurement analysis, comprising dimensioning, plotting a colour map of deviations and producing inspection cross sections. The resolution in all the directions (x, y, z) is 20 μm.

An innovative approach to measuring objects is the simultaneous use of two GOM systems: ATOS and TRITOP. Measurement is performed in two steps. First using the TRITOP's specialist photo camera one takes a series of photographs from different directions to determine the coordinates of the reference points stuck on the object and on this basis a precise system of coordinates is constructed on the part being measured (fig. 3.1b). In the next step the object is scanned by the ATOS system. In the course of a single measurement at least three reference points should be in the cameras' field of vision.

The 3D scanner is a promising tool enabling one to quickly obtain an accurate image of the examined surface of the concrete floor base in any measuring point.

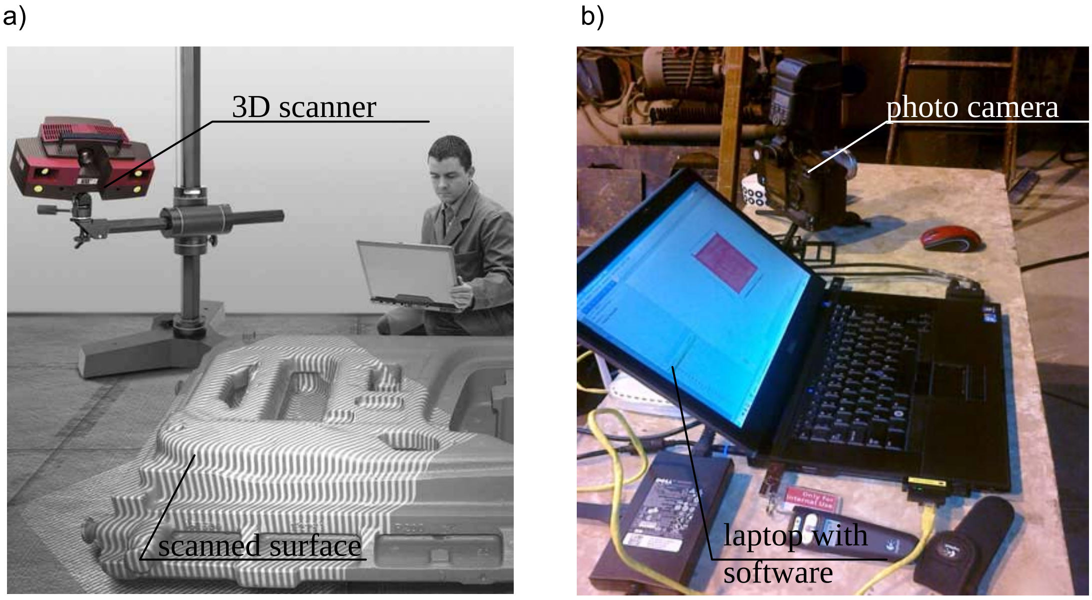

Fig. 3.1. 3D scanner:
a) surface scanning [8], b) laptop with installed dedicated software

4. INVESTIGATIVE METHODOLOGY

Two 125 mm thick 2500×2500 mm concrete slabs (specimens), constituting the concrete floor base, were investigated. The investigations were carried out prior to concreting a 30 mm thick topping. The floor base was made of class C30/37 concrete with consistency S3, w/c = 0.5 and a maximum aggregate grading of 8 mm. The base was laid on polyethylene sheeting and on a 100 mm thick layer of sand. In addition, six 150 × 150 mm specimens were made to study the physical properties of the concrete from which the concrete slabs were made. The studies were carried out after 90 days of concrete curing, except for compressive strength tests which were done after 28 days. The concrete slabs cured naturally in a laboratory hall at an air temperature of +18°C (±3°C) and a relative air humidity of 60%. For the first seven days they were stored under sheeting.

The following two ways of preparing the base concrete surface were used:

- surface I: mechanical grinding and dust removal,
- surface II: no surface preparation, i.e. after concreting the surface was left unchanged.

Figure 4.1 shows the ways of preparing the base concrete surfaces, the method of measuring surface roughness, and the measured roughness parameters.

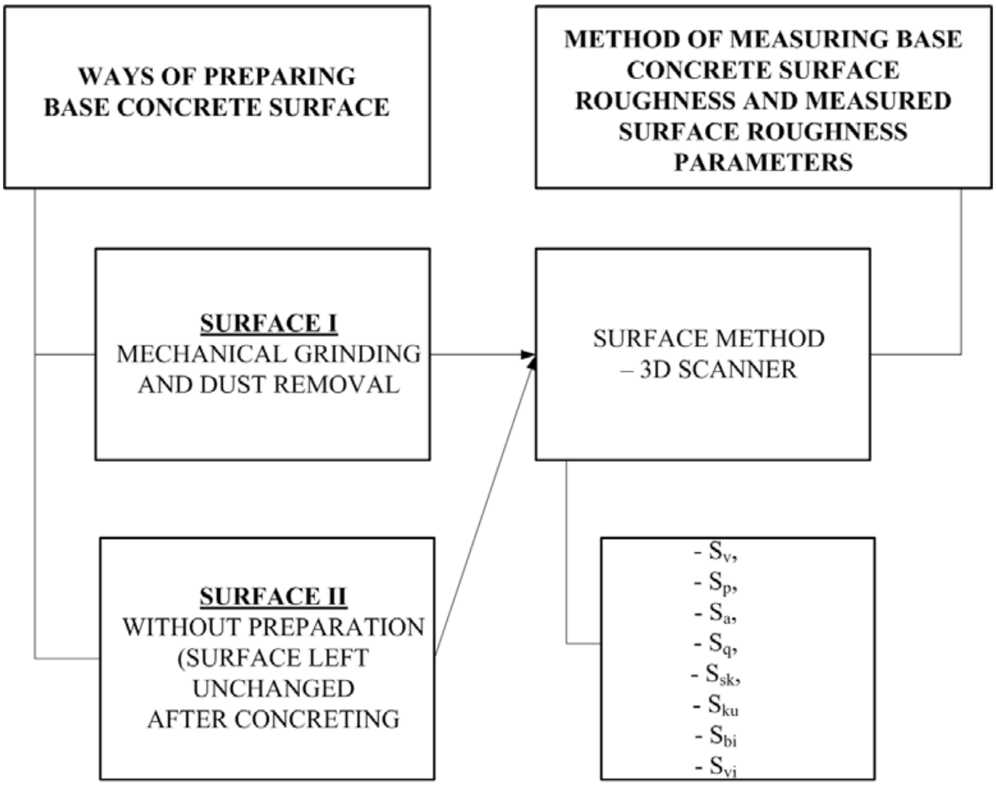

Fig. 4.1. Ways of preparing base concrete surface, methods of measuring its roughness, and measured surface roughness parameters

The parameters describing surface roughness can be divided into four groups:

- amplitude parameters,
- spatial parameters,
- hybrid parameters,
- functional parameters.

Amplitude and functional parameters are likely to be most useful for the evaluation of concrete surface roughness. In most cases it is enough to use eight parameters [9-12]. In order to distinguish the parameters acquired from the surface from the ones determined on the basis of a single profile, the former are denoted with the letter S.

Amplitude parameters:

S_q – a mean square deviation of the surface from the reference surface; the numerical formula for this parameter is as follows:

$$S_q = \sqrt{\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\eta^2(i,j)} . \tag{4.1}$$

S_{sk} – a surface asymmetry coefficient referred to as surface skewness

$$S_{sk} = \frac{1}{MNS_q^{\ 3}}\sum_{j=1}^{N}\sum_{i=1}^{M}\eta^3(i,j) . \tag{4.2}$$

S_{ku} – a measure of surface height probability density:

$$S_{ku} = \frac{1}{MNS_q^{\ 4}}\sum_{j=1}^{N}\sum_{i=1}^{M}\eta^4(i,j) . \tag{4.3}$$

S_p – the maximum surface convexity height:

$$S_p = \sup\ \{Z\ (i,j)\}. \tag{4.4}$$

S_v – the maximum surface concavity depth

$$S_{bi} = |inf\ \{Z(i,j)\}|. \tag{4.5}$$

Functional parameters:

S_{bi} – a surface load capacity index, being a ratio of surface roughness mean square deviation S_q to $\eta_{0.05}$, where $\eta_{0.05}$ is a level separating the peak surface irregularity from the core for a default value of 5%

$$S_{bi} = \frac{S_q}{\eta_{o.o5}} . \tag{4.6}$$

S_{ci} – an index of liquid holding by the core, defined as a ratio of the volume of voids in a unit sampling area between levels $h_{0.05}$ and $h_{0.08}$ to mean square surface deviation S_q

$$S_{ci} = \left(\frac{V_v(h_{0,05}) - V_v(h_{0,8})}{(M-1)(N-1)\Delta x \Delta y} \right) / S_q \tag{4.7}$$

S_{vi} – an index of liquid holding by valleys, defined as the volume of voids in a unit sampling area below level $h_{0.08}$ to mean square surface deviation S_q

$$S_{vi} = \left(\frac{V_v(h_{0,8})}{(M-1)(N-1)\Delta x \Delta y} \right) / S_q \, . \tag{4.8}$$

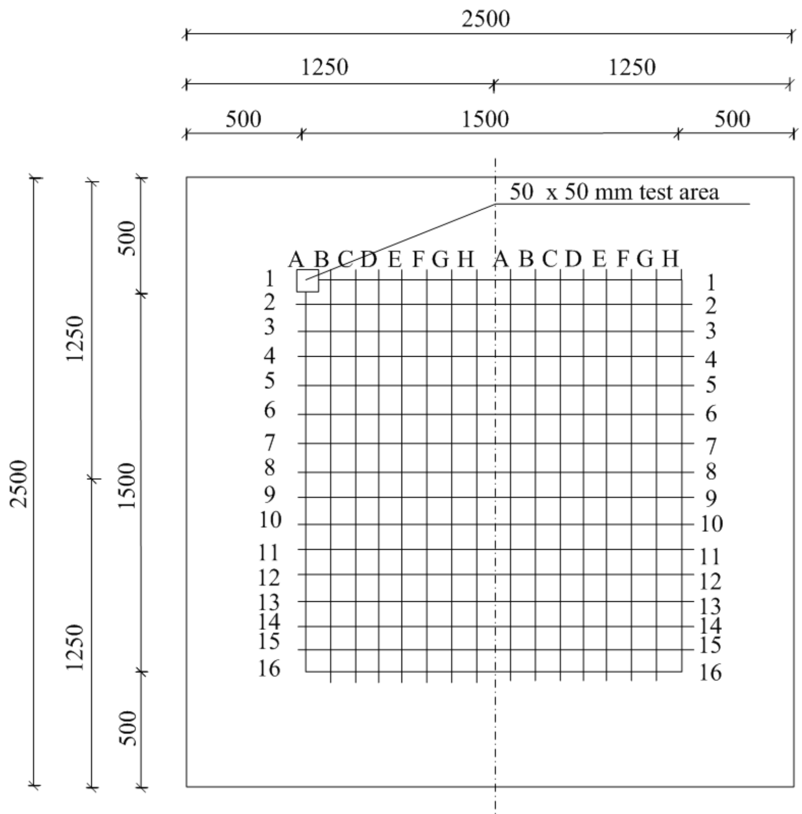

Fig. 4.2. Distribution of measuring points on investigated concrete slabs

After the concrete slabs were labelled a 1500×1500 mm test area was demarcated on each of them. A grid of points spaced at every 100 mm was marked on each of the slabs. The columns were denoted with letters from A to H and the rows were numbered from 1 to 16. In total, 256 measuring points were marked on each surface (fig. 4.2).

The ATOS system was calibrated prior to measurements. Calibration is automatic and consists in measuring and checking the parameters of the standard in its different angular positions and distances from the measuring cameras. Then the TRITOP system was used to take a series of photographs from different directions in order to determine the coordinates of the reference points stuck on the object. As a result a precise coordinate system was created. Through the reference points located on the measured object and in its vicinity the individual measurements are transformed to a single common coordinate system. The entire surface of the slab was scanned by means of the ATOS 3D scanner and then using the dedicated GOM INSPEKT V7 SR2 software a 3D image of the scanned surface was obtained. In order to determine the 3D parameters of the investigated concrete surfaces, it became necessary to develop an algorithm for processing the measured data (fig. 4.3).

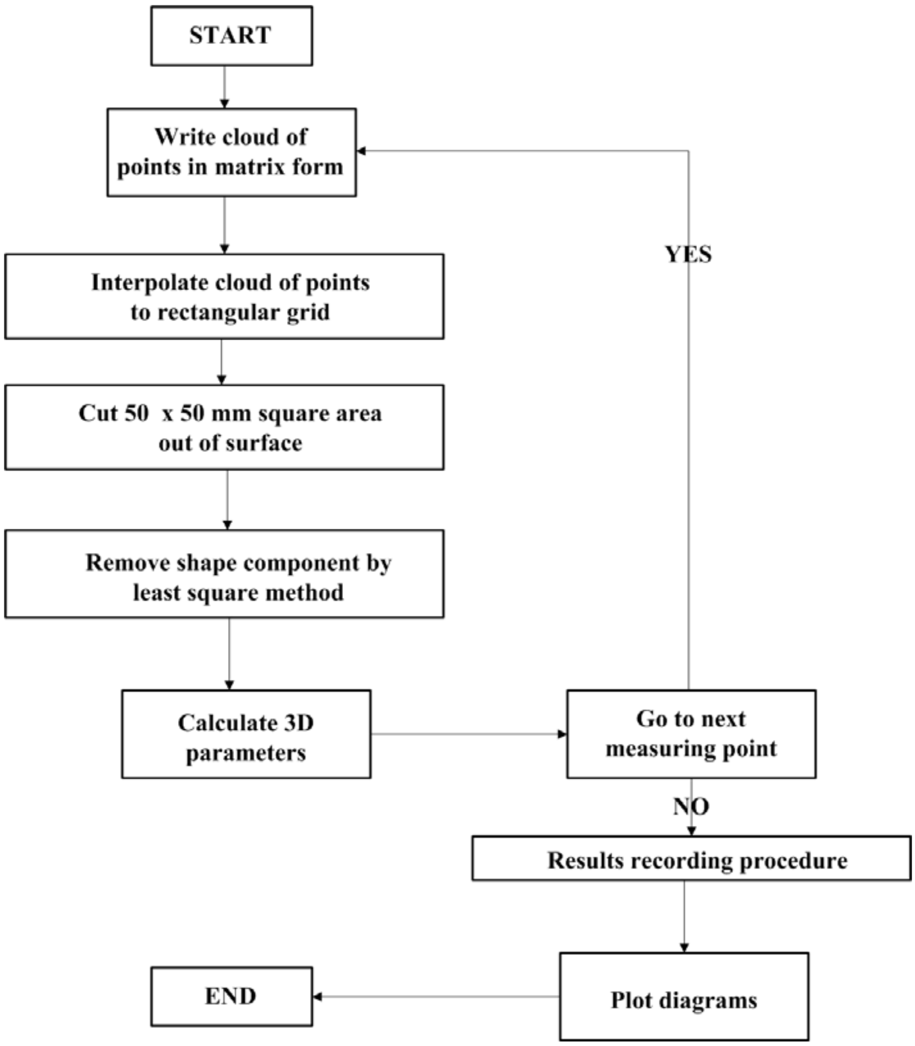

Fig. 4.3. Flow chart of algorithm for processing data acquired from measurements of surface roughness parameters

The application was created using the MATLAB software package which is highly suitable for numerical data analysis in both engineering and research calculations [13]. A 50 $\times$ 50 test area was demarcated around each measuring point and numerical values of the particular base concrete surface roughness parameters in this area were determined.

5. EXEMPLARY TEST RESULTS AND THEIR BRIEF ANALYSIS

Numerical values of the particular base concrete surface roughness parameters were determined in each measuring point. Test results for selected point A1 on surface I and II (figs 5.1 and 5.2) are presented below.

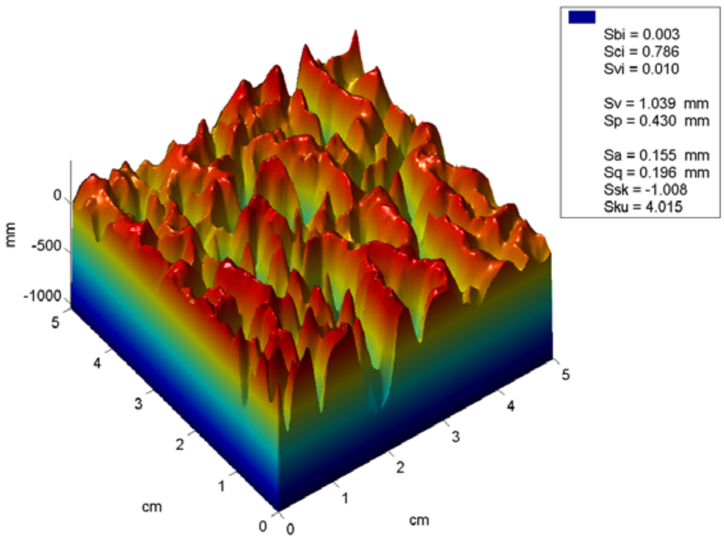

Fig. 5.1. 3D image of scanned surface and parameters determined for test area in point A 1 on surface I

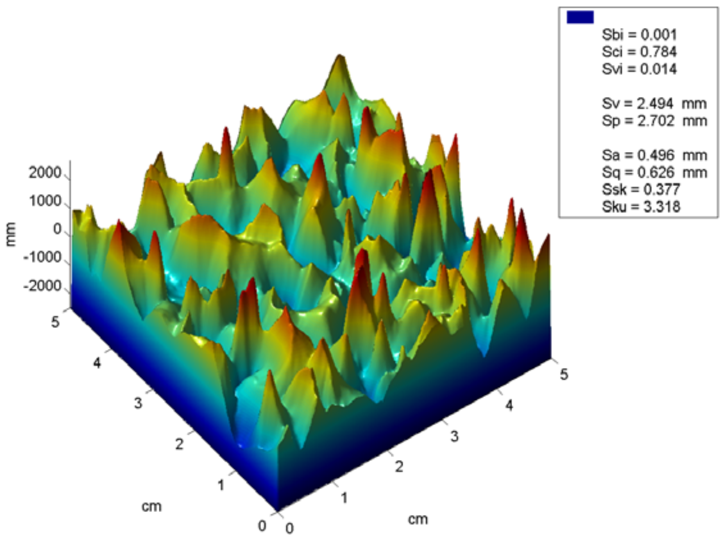

Fig. 5.2. 3D image of scanned surface and parameters determined for test area in point A1 on surface II

It appears from the 3D images of the scanned surfaces I and II that there are differences in the values of the surface roughness parameters. Surface load capacity index S_{bi} is three times higher for surface I than for surface II. This indicates that greater adhesion at the interface will be obtained for the ground surface. Whereas parameter S_v defining the maximum surface concavity depth and parameter S_p defining the maximum surface convexity height are twice higher for surface II than for surface I, which is evidence of greater roughness of the unprepared concrete surface. It should be noted that parameter S_q defining the mean square deviation of the surface from the reference surface is also higher for the surface left unchanged after concreting. It seems that parameters S_{ci} and S_{vi} will be less useful for the analysis of concrete floor roughness due to the fact that there is no difference between the parameter values for surface I and those obtained for surface II. It should be noted that surface skewness coefficient S_{sk} and coefficient S_{ku} are higher for the ground surface.

6. CONCLUSION

Investigations of floor base concrete surface roughness by means of a 3D scanner have been presented. Two concrete surfaces, differing in the preparation of the concrete base, were investigated. The following parameters: surface load capacity index S_{bi}, maximum surface concavity depth S_v, maximum surface convexity height S_p, the mean square deviation of the surface from the reference surface (S_q), surface skewness coefficient S_{sk} and surface height probability density measure S_{ku} were found to be particularly useful for the evaluation of the roughness of the investigated concrete surfaces. Whereas the parameters: the index of liquid holding by the core (S_{ci}) and the index of liquid holding by valleys (S_{vi}) were found to be less useful.

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BADANIA CHROPOWATOŚCI POWIERZCHNI BETONOWYCH Z WYKORZYSTANIEM SKANERA TRÓJWYMIAROWEGO

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STRESZCZENIE *W niniejszym artykule przedstawiono badania topografii (chropowatości 3D) powierzchni warstwy konstrukcyjnej podłóg betonowych za pomocą metody powierzchniowej. W tym celu wykorzystano optyczny skaner współrzędnościowy oraz opracowane oprogramowanie do analizy wyników pomiarów. Badaniom poddano dwie warstwy konstrukcyjne ze zróżnicowanym sposobem przygotowania warstwy konstrukcyjnej. W algorytmach obliczeniowych wykorzystano obowiązujące zależności dla wyznaczania poszczególnych parametrów 3D opisujących charakter badanych powierzchni.*

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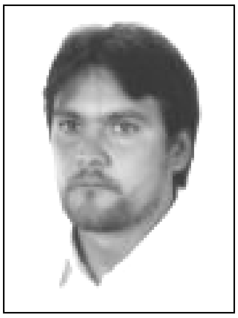

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