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THE EFFECT OF STORAGE TIME ON SELECTED MECHANICAL PROPERTIES OF POTATOES

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Key words: test stand, shearing, impact bending, potatoes.

Abstract

This paper describes a the effect of storage time on selected mechanical properties of potatoes, method for determining the impact strength and dynamic shear strength of potatoes on a test stand designed by the authors. The results of preliminary tests examining the effect of storage time on the average impact bending strength and shear strength values of potatoes cv. Irga are also presented. The above parameters and changes in their values during storage time have to be determined to support the optimization of technological processes in the food processing industry, including the production of French fries and potato chips.

List of symbols:

L_u – breaking energy, J;
G_R – pendulum mass reduced to the center of impact, N;
β – angle of the pendulum after fracture, °;
α – angle of pendulum drop or angle of the maximum pendulum bounce, °;
K – dynamic impact energy, $J \cdot cm^{-2}$;
A – cross-sectional area , cm^2;
R_t – dynamic shear energy, $J \cdot cm^{-2}$;
R – radius of pendulum arm, cm.

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Introduction

Potatoes' resistance to mechanical damage and suitability for mechanical harvesting and processing are determined during laboratory tests (BUDYŃ 1993, MOHSENIN 1986, SOBOL 2002, JAKUBCZYK, UZIAK 2005). The mechanical properties of potato tubers have to be determined to minimize damage during harvest and preliminary treatment, and to control and optimize technological processes in the food industry, including during the production of French fries and potato chips. The above is a complex process which requires the identification of strictly correlated factors: plants, machines with specific structural features and machine operating parameters (MOHSENIN 1986). Physical and mechanical parameters are an important set of features that characterize plant materials. Those characteristics are measured and expressed quantitatively to describe the state of the analyzed samples (CIUPAK, GŁADYSZEWSKA 2010, DOBRZAŃSKI, RYBCZYŃSKI 2008, ŻABIŃSKI 2006). The accumulated data support the design of cultivation, harvest, processing and storage devices and computer modeling of those processes (GOŁACKI ROWIŃSKI 2006, STROPEK et al. 2009). The mechanical properties of farm products are affected by various factors, including variety, fertilization, cultivation site, moisture content, and they are characteristic of a given species.

For example, potato tubers density affects the oil content in potato chips and French fries, which suggests potato processing efficiency and quality of the final products (MOZOLEWSKI 2000). Excessive density of tubers causing significant changes in the quality of these products – chips and chips are becoming too hard and have a granular structure, surface texture of fries is too hard and the interior gives the impression of raw, losing the characteristic taste and fragrance of fried foods (LISIŃSKA 2006, RYTEL et al. 2006). The density of potato tubers is a fundamental feature of the distribution used in the separators used in machines to harvest and postharvest processing of potato tubers (MARKS 2004). Potato tuber density tests show the dependence of the characteristics of the variety, weather conditions during the growing season, time of storage. Potatoes belonging to the smaller size fractions and fertilized with mineral fertilizers have a higher density (SOBOL 2006).

Plant materials characterized by high variability require an individual approach to designing and modeling their properties.

The objective of this study was to determine the impact bending strength and shear strength of potatoes used in the production of French fries and chips.

Materials and Methods

The experiment was carried out in a prototype test stand designed and constructed in the Farm Product Separation Laboratory at the Department of Heavy Duty Machines and Research Methodology of the University of Warmia and Mazury in Olsztyn. The developed test stand supports:

– impact bending tests, biaxial shear tests and dynamic mechanical damage tests of root crops using variously shaped hammers at different impact energy values,

– determinations of the energy transferred to the analyzed sample by the hammer.

The experimental materials comprised potatoes cv. Irga with a diameter of 50 to 65 mm and tuber weight of 100 to 200 g. Dried and chilled potatoes were stored indoors at a temperature of 8 ± 1°C and air humidity of 90 ± 5%.

The measurements were performed every seven days over a period of 15 weeks.

Test stand

The developed test stand was a modified Charpy's hammer (Fig. 1). Two brackets were fixed to the main body of the device (*1*). The supports (*3*) were welded to the brackets at the base of the device.

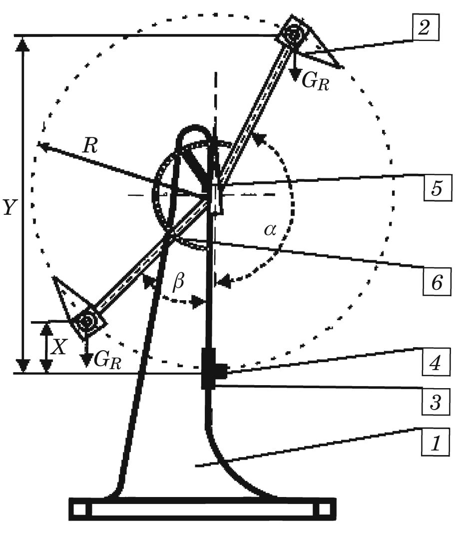

Fig. 1. Test stand: *1* – body, *2* – pendulum, *3* – supports, *4* – specimen, *5* – indicator, *6* – scale, G_R – pendulum mass reduced to the center of impact, Y (or h) – height between the highest and the lowest position of the pendulum, x – height of pendulum bounce after fracture, α – maximum angle of pendulum from the vertical axis, β – angle of pendulum after fracture, R – radius of pendulum arm

The specimen (*4*) subjected to impact bending tests or shear tests is placed between the supports. A pendulum with mounted bearings (*2*) is attached to the upper section of the brackets. Replaceable attachments are fixed at the end of the pendulum with the use of nuts (Fig. 2). A scale (*6*) with an indicator (*5*) is attached to one of the brackets for reading the angle of the pendulum after fracture (shear).

Fig. 2. Replaceable pendulum attachments: *a* – PVC cutting hammer, *b* – PVC flat hammer

The technical specification and structural description of the test stand was provided by (DUBER-SKWARSKA, GÓRKA 2012). The test stand measures the energy required to fracture (shear) the specimen with the accuracy of ± 0.5% of initial hammer impact energy, but not greater than 1 J.

Experimental procedure

Specimens were placed on the supports (Fig. 3) in the test device. The specimen's symmetry plane was located at the mid-distance between the supports where the impact took place.

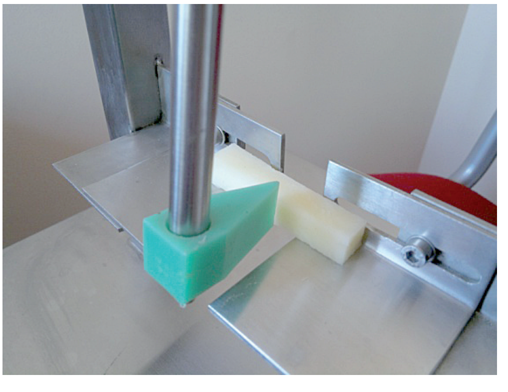

Fig. 3. Specimen positioned on supports during an impact bending test

Prior to the impact test, the specimen's cross-section along the symmetry plane was measured, and the cross-sectional area was determined with the accuracy of ± 0.2 mm. The pendulum moved along a vertical plane that intersected the mid-distance between the supports. The position of the cutting hammer relative to the supports and the distance between the supports were checked before every test series.

In an *impact bending test*, the specimen was fractured by a single impact of the pendulum hammer. The energy needed to fracture the specimen (measured in J) was determined based on the bounce of the pendulum shown on the measuring scale.

The angle of the pendulum hammer α (Fig. 1) without the specimen was read off the scaleto the nearest degree. The same method was used to determine the angle of the pendulum hammer β with the specimen. The impact energy needed to fracture the specimen L_u was calculated using the below formula (1).

$$L_u = G_R(\cos\beta - \cos\alpha) \tag{1}$$

Impact bending strength K was determined with the use of formula (2):

$$K = \frac{L_u}{A} \tag{2}$$

The impact bending test was carried out using a PVC cutting hammer (Fig. 2a) on rectangular specimens of 10 × 10 × 55 mm cut out from the experimental material at a temperature of 22°C. The distance between the supports was set at 26 mm. A pendulum swing test was performed without the specimen before the impact test. The indicator was set at 0, the pendulum was lifted to the angle of 90° and released. The result was read off the scale. The swing test was repeated three times, and the results were averaged. A potato sample was placed on the supports, and the above procedure was repeated.

In a *dynamic shear test* (Fig. 2), a specimen was sheared along two cross-sections transverse to the specimen's longitudinal axis. The result was read off the scale, impact energy L_u was calculated using formula (1), and shear strength Rt was determined based on formula (3).

$$R_t = \frac{L_u}{2A} \tag{2}$$

A dynamic shear test was carried out with the use of a flat hammer (Fig. 2b). The procedure was identical to that applied in the impact bending test. The distance between the supports was adjusted to the dimensions of the flat hammer, and it was 2 mm greater than hammer length. The results were subjected to analysis of variance (ANOVA) with post-hoc tests (LUSZNIEWICZ, SŁABY 2008), and they were processed with the use of STATISTICA PL v. 10 software. Duncan's test was applied to identify homogenous groups and to determine the significance of differences between means (STANISZ 2006). Differences were regarded as significant at 0.05. The following null hypothesis (H_0) was verified: the average impact bending (shear) strength values of potatoes cv. Irga do not differ significantly during the first 15 weeks of storage. Statistically processed impact strength values are given in Table 1 and are represented graphically in Figure 4.

Table 1

The results of statistical analyses investigating the effect of storage time on the average impact bending strength values of potatoes cv. Irga

Results of analysis of variance	
Value of F-statistics	$F = 6.5003$
Probability of exceeding F-statistics	$p = 0.0004$
Since p < level of significance, – the null hypothesis H_0 should be rejected in favor of alternative hypothesis H_1.	
Homogenous groups (Duncan's test)	
Group I	weeks of storage 8, 10, 11, 9, 13, 12, 14, 15
Group II	weeks of storage 6, 7, 8, 10, 11, 9, 12, 13
Group III	weeks of storage 5, 3, 2, 1, 4, 6, 7, 8, 10, 11, 9
Note: Homogeneous groups at a significance level 0.05	

Results

The results of statistical analyses and that the time of storage can be divided into three principal periods. The average impact bending strength in the first five weeks of storage was relatively stable at approximately 0.135 ($J \cdot cm^{-2}$). The lowest impact strength of 0.125 ($J \cdot cm^{-2}$) was noted on storage weeks of storage 3 and 5. Beginning from week 6, the impact bending strength of the analyzed material increased by approximately 0.015 ($J \cdot cm^{-2}$). Average impact bending strength of 0.15 ($J \cdot cm^{-2}$) was maintained until week 11. From week 12 (experimental day 84) until the last week of the experiment (day 105), the analyzed parameter increased steadily from 0.16 to approximately 0.20 ($J \cdot cm^{-2}$).

The results of statistical analyses of dynamic shear values are shown in Table 2 and are represented graphically in Figure 5.

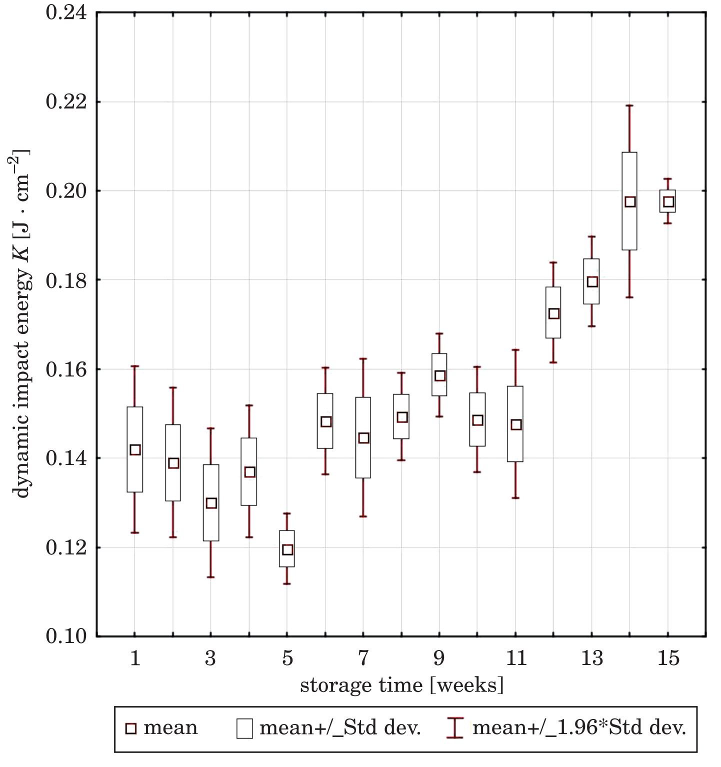

Fig. 4. The effect of storage time on the impact bending strength of potatoes cv. Irga

Table 2

The results of statistical analyses of the effect of storage time on the dynamic shear strength values of potatoes cv. Irga

Results of analysis of variance	
Value of F-statistics	F = 5.8822
Probability of exceeding F-statistics	p = 0.0008
Since p < level of significance, – the null hypothesis H_0 should be rejected in favor of alternative hypothesis H_1.	
Homogenous groups (Duncan's test)	
Group I	weeks of storage 5, 9, 3, 11, 4, 6, 8, 15, 13, 14, 12
Group II	weeks of storage 9, 3, 11, 4, 6, 8, 15, 13, 14
Group III	weeks of storage 3, 11, 4, 6, 8, 15, 13
Group IV	weeks of storage 1, 2, 7, 10, 5, 9, 3, 11, 4
Note: Homogeneous groups at a significance level 0.05	

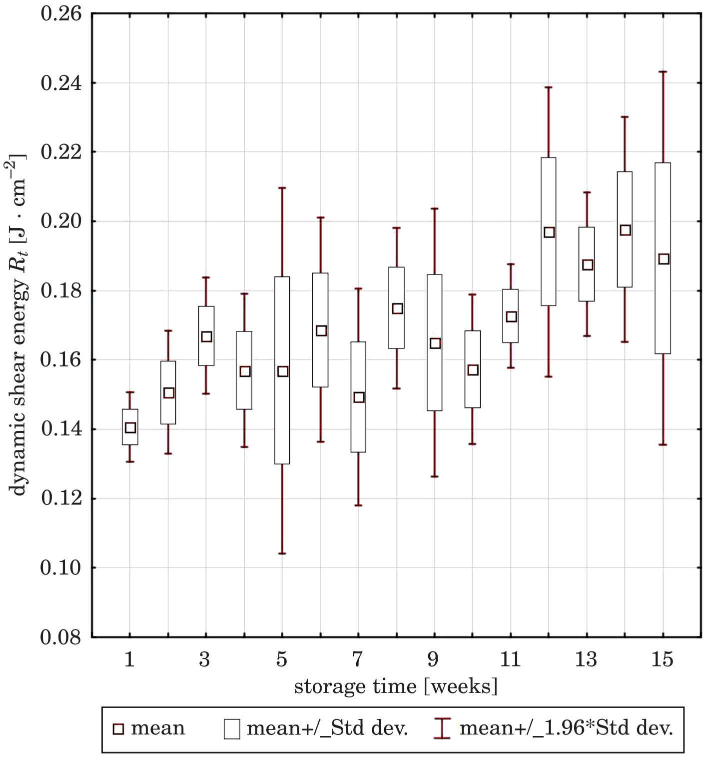

Fig. 5. The effect of storage time on the dynamic shear strength of potatoes cv. Irga

The results of statistical analyses and the observe correlations indicate that the average impact energy required for the dynamic shearing of tubers in the first 11 weeks of the experiment was not stable, with random variations in the estimated range of 0.14 to 0.17 (J · cm^{-2}). Between week 12 (day 84) until the end of the experiment (day 105), a clear increase in dynamic shear strength values was observed in the range of 0.19 ÷ 0.20 (J · cm^{-2}).

Conclusions

The designed test stand supports dynamic shear tests and impact bending tests of farm products in an environment which is similar to the conditions observed during the production of e.g. French fries and potato chips. The results of laboratory analyses performed on edible potatoes cv. Irga revealed fracturing of samples prepared from firm tubers (in the first weeks of the experiment) and deformations with damage of the stretched layer in older potatoes characterized by lower turgor pressure (in the last weeks of the experiment). The energy required to damage potato samples in impact bending tests and shear tests increased with a decrease in the turgor of potato tissue. The results of the analysis indicate that the developed test stand fulfilled experimental requirements. Further work is needed to investigate other farming products, such as root vegetables. The designed test stand should be modified to support calculations of dynamic mechanical damage values during harvest.

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GNSS MEASUREMENT TECHNIQUES APPLIED TO ESTABLISH A DETAILED CONTROL NETWORK BASED ON THE „TERMY WARMIŃSKIE" EXAMPLE OBJECT

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Key worlds: GPS measurement, terrain obstacles, POZGEO, POZGEO-D, control network.

Abstract

This paper covers the issue of the establishment of a detailed control network for the realization of a construction survey pursuant to existing legislation, in particular: *The Regulation of the Minister of Interior and Administration* of November 9, 2011 *on establishing technical standards of topographic surveys and processing of the results and submitting them to pzgik. (published in Polish: Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 9 listopada 2011 w sprawie standardów technicznych wykonywania geodezyjnych pomiarów sytuacyjnych i wysokościowych oraz opracowywania i przekazywania wyników tych pomiarów do pzgik).* Using the example of a detailed control network for the realization of the construction survey on the basis of the „Termy Warmińskie" object, various methods of GNSS observation processing were analysed and compared. The issue of the influence of some observation obstructions on the precision and accuracy of the results was also considered.

Introduction

Thanks to the rapid development of satellite measurement techniques and because the ASG-EUPOS system has been fully operational since June 2008, GNSS measurements techniques are now common, particularly in land survey measurements. GNSS measurement techniques are popular mainly because they are fast and inexpensive, can have a single operator and there is no need to maintain visibility between all points in the network. Furthermore, the ASG permanent reference stations network provides, at any location within Poland,

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access to a stable and uniform reference frame (Bosy 2010, Graszka 2007, Siejka 2009). This eliminates the need for direct access to classical control network points. In the case of static GNSS measurements, one of two post-processing services can be used: an automatic post-processing service (POZGEO), or a service which provides raw data from reference stations (POZGEO D). The declared estimated precision of the determination of coordinates in the POZGEO service depends on the measurement conditions and equals 0.01 to 0.10 meters (www.asgeupos.pl). An indisputable advantage of the POZGEO service is its ease of use and no need for special advanced software. It should be mentioned that each point processed by this service is processed separately, so in case of points in the network there is no possibility of adjusting the vectors in this network. In turn, when using the POZGEO D service, the user has to conduct post-processing, which involves advanced calculations and software, but also enables the user to set some additional calculation parameters and to adjust the entire measured network (Kadaj et. al. 2009).

This paper covers the issue of applying GNSS measurement techniques to establish a detailed control network for the realization of a construction survey pursuant to existing legislation. The technical standards of GNSS measurements for land survey purpose are regulated by: *Regulation of The Minister of Interior and Administration* of November 9, 2011 *establishing technical standards of topographic surveys and processing of the results and submitting them to pzgik (published in Polish: Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 9 listopada 2011 w sprawie standardów technicznych wykonywania geodezyjnych pomiarów sytuacyjnych i wysokościowych oraz opracowywania i przekazywania wyników tych pomiarów do pzgik)* and Technical Recommendations *Satellite GNSS measurements based on reference station system ASG-EUPOS* (*published in Polish: Zalecenia Techniczne Pomiary satelitarne GNSS oparte na systemie stacji referencyjnych ASG-EUPOS*). According to Article 8 of the Regulation of the Minister of Interior and Administration: topographic surveys can be performed using precise GNSS positioning methods if: 1) direct reception of satellite signals is assured, 2) signals broadcast by the satellites are not affected by the devices that emit electromagnetic waves, particularly radio and television transmitters, power lines, digital phone stations. The provision of direct satellite signal reception is essential because, otherwise, some obstructions can cause difficulties in ambiguity resolution and cause gross errors which are difficult to detect and mitigate, as has been often described in the literature (Bakuła et. al. 2011, Bakuła et. al. 2009, Bakuła et. al. 2008, Pelc-Mieczkowska 2012, Pirti et. al. 2010, Pirti 2008). Moreover, the Technical Recommendations require that over 10° above the horizon there has to be open sky. The above mentioned requirement applies to all geodetic measurements. In the Technical Recommendations there are also some specific provisions concerning the establishment of a detailed control network for the construction survey. For such a geodetic survey, it is recommended to use only static survey methods and the POZGEO D service for data post-processing. In the case of a minor horizontal control network, the use of the POZGEO service is allowed on condition that the observations of L1/L2 are at least 40 minutes. In addition, according to article 13, the calculated vectors should be adjusted together by the least squares method.

The study presented in this paper analyses the impact of the chosen GNSS data processing methods on the accuracy and reliability of the control network points. Since, due to the location of the test object, there were obstacles at some points higher than 10^{o} above the horizon, the impact of the limited access to the sky on the quality of the obtained solution was also examined. These considerations seem to be important, as in surveying practice there is often no possibility of avoiding obstacles at measuring points (HOSBAS et. al. 2009).

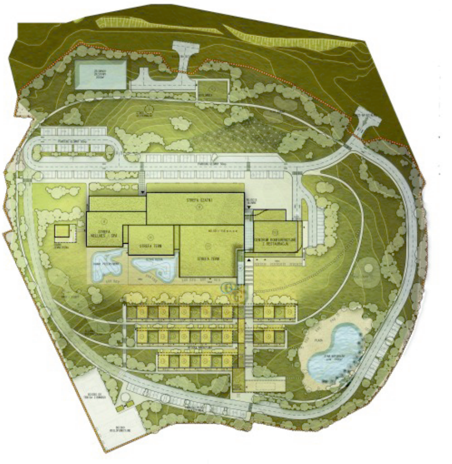
Object Characteristics

The object „Termy Warmińskie" on which the test measurements were taken is located in the vicinity of Lidzbark Warmiński. This project is realized by Lidzbark Warmiński District in partnership with Lidzbark Warmiński Municipality and is co-financed by European Regional Development Fund under The Regional Operational Programme Warmia and Mazury for the years 2007–2013. The entire complex covers an area of almost 60,000 m^2 and consists of a number of recreational, tourist and medical facilities.

In order to implement the investment process, six evenly-distributed control network points were marked (Fig. 1). The distances between the mentioned points were from about 55 m to about 250 m.

Although the possibility of using GNSS measurements was taken into consideration when designing the location of control points, the priority was to ensure the optimal shape of the network while bearing in mind the subsequent execution of the investment. Four of the control network points were situated under the so-called „open" sky. In the surroundings of the two remaining points (P001 and P002), there were some obstacles caused by tree canopy (Fig. 2). Point P001 was located within the network, on a hill, in a location convenient for performing classical survey measurements (no obstructions to sight for the whole area). However, the location of this point was inconvenient for GNSS measurements because of the trees on the east and west sides (the distance from the point to the obstacles equals several meters). In addition, point P002 was located about 15 m to the south of the forest area.

a



b

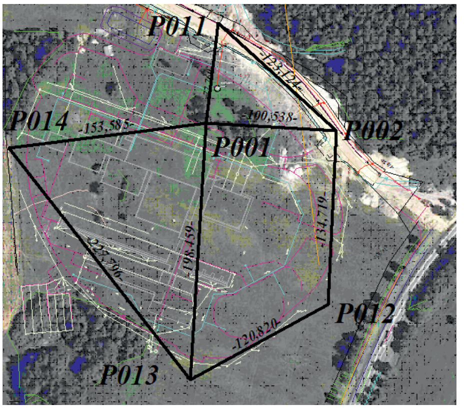
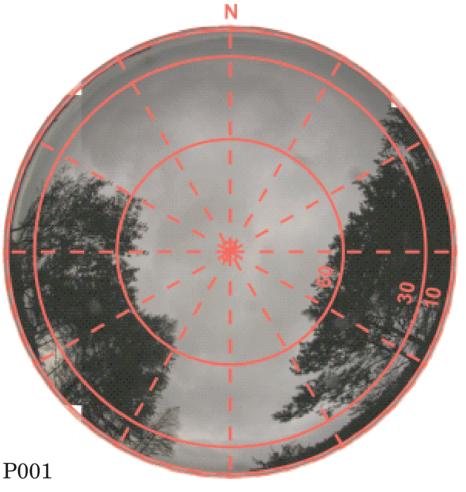


Fig. 1. The design of the complex (*a*) and the sketch of a designed control network (*b*)

a



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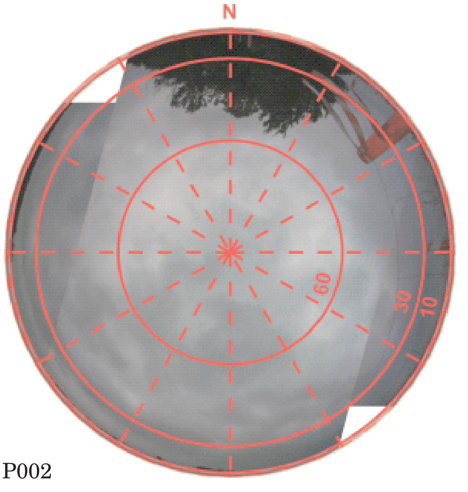

Fig. 2. Obstacles at points P001 (*a*) and P002 (*b*)

Field Measurements

Measurements were performed with the use of four Topcon Hier Pro geodetic, dual-frequency GNSS receivers. Two ninety-minute observation sessions were planned and executed (Fig. 3). There were two common points (P001 and P002) at which the measurements were conducted continuously during both observation sessions.

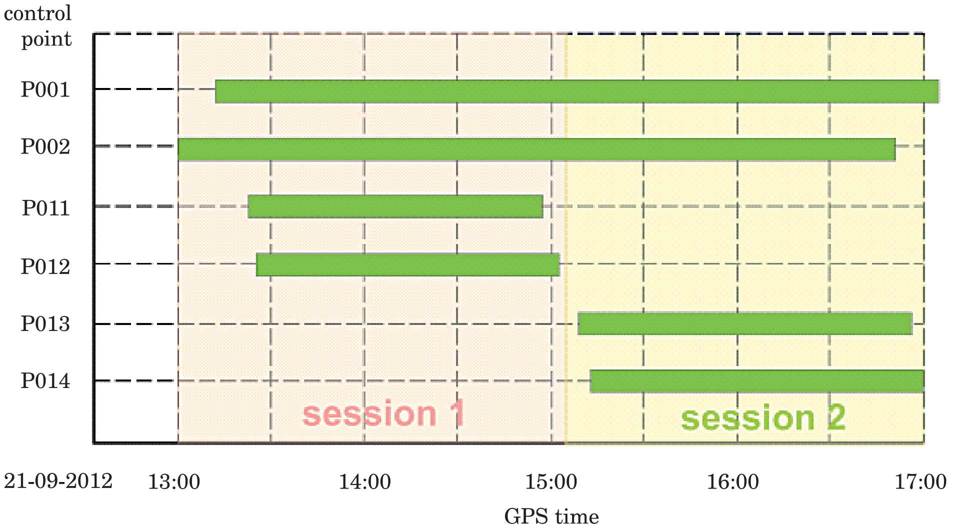

Fig. 3. Schedule of observation sessions

Measurements were made using the GPS system. The following GPS parameters were assumed for all measurements: 1 second interval and 10° elevation mask. The elevation mask was selected as the result of a compromise between the reduction of electromagnetic wave propagation delays and multi path error while maintaining adequate satellite geometry. Signals from high elevation satellites experience less ionospheric delays and multi path effects (KAPLAN et al. 2006) but a high elevation mask can degrade satellite geometry, which is critical for the appearance of terrain obstacles.

The entire network was also measured using a Leica Viva TS15 tacheometer. All directions and distances were measured at each control point for subsequent network adjustment. The direct levelling of control points was conducted as well. The adjusted base lengths and differences in height were treated as reference values for GNSS measurement validation.

Processing of results

In order to analyse and compare the quality of the solutions, four different data processing variants were conducted. In the first variant, the POZGEO service of the ASG-EUPOS system was applied. Observation data were uploaded in RINEX format. According to the POZGEO data processing methodology, observation data for each point were adjusted separately with reference to the six physical ASG-EPOS reference stations. For each point, the coordinates in the PL-2000 coordinate system were determined. Moreover, information on the employed reference stations and root-mean-square error of determined coordinates was available by an automatically-generated report (Tab. 1).

Table 1

The precision of coordinates determined by the POZGEO service

Point No	Reference stations	mx [m]	my [m]	mz [m]
P001	BART, LAMA, GIZY, ILAW, MYSZ, DZIA	0.003	0.002	0.015
P002	BART, LAMA, GIZY, ILAW, MYSZ, DZIA	0.002	0.002	0.016
P011	BART, LAMA, ELBL, GIZY, ILAW, MYSZ	0.009	0.008	0.016
P012	BART, LAMA, ELBL, GIZY, ILAW, MYSZ	0.011	0.011	0.018
P013	BART, LAMA, GIZY, ILAW, MYSZ, DZIA	0.004	0.004	0.016
P014	BART, LAMA, GIZY, ILAW, MYSZ, DZIA	0.003	0.004	0.016

In the second, third and fourth variants, data processing and adjustment were conducted using Topcon Tools v 8.0 software. The observation data from reference stations were downloaded by the POZGEO D service of the ASG-EUPOS system. In the second (3FRS) variant, the data were processed with reference to three physical reference stations (LAMA, KROL and BART), in the third variant (LAMA) the data were processed with reference to LAMA the nearest physical reference station and in the fourth variant (4VRS) with reference to four, virtual reference stations, evenly-distributed near the measured object. The length of the vectors to the LAMA, KROL and BART reference stations were 25 km, 41 km and 21 km respectively, and to the virtual reference stations they did not exceed 500 m (Fig. 4). For the post-processing of the second to fourth variants, the following strategy was assumed: absolute antenna models; broadcast ephemerides; L1/L2 mode for processing static vectors; all GPS observations were processed; constrained adjustment; confidence level for the adjustment process was 95%.

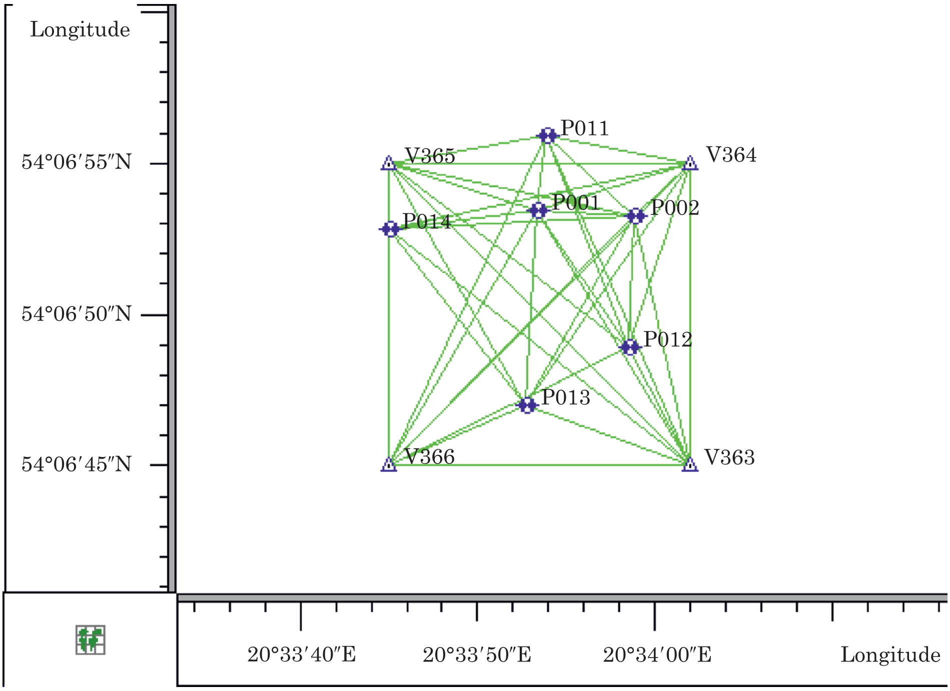

Fig. 4. Distribution of control points and virtual reference stations

After the coordinate transformation, PL-2000 coordinates and their mean-squared-errors were obtained (Tab. 2).

Table 2

Precision of coordinates determined at the second, third and fourth variants

Point No	Variant II (3FRS)			Variant III (LAMA)			Variant IV (4VRS)		
	mx [m]	my [m]	mz [m]	mx [m]	my [m]	mz [m]	mx [m]	my [m]	mz [m]
P001	0.004	0.003	0.008	0.006	0.005	0.013	0.001	0.001	0.001
P002	0.004	0.003	0.008	0.006	0.005	0.013	0.001	0.001	0.001
P011	0.004	0.003	0.009	0.006	0.005	0.014	0.001	0.001	0.001
P012	0.004	0.003	0.009	0.006	0.005	0.014	0.001	0.001	0.001
P013	0.004	0.003	0.009	0.006	0.005	0.014	0.001	0.001	0.001
P014	0.004	0.003	0.009	0.006	0.005	0.014	0.001	0.001	0.001

Analysis of results

The distribution of plane coordinates obtained in specific data processing variants varied from 1 centimetre for points P002 and P011 to 5 centimetres for points P001 and P013. Furthermore, for each considered point, the distribution of coordinates obtained in the second, third and fourth variants equalled approximately 1 centimetre, while for coordinates obtained in the first variant up to 5 centimetres deviations occurred and the directions of the displacement vectors differed (Fig. 5). The greatest coordinate differences in the first variant of data processing occurred because each point was adjusted separately in this variant while in other variants all networks were adjusted as a whole.

From the point of view of the user of a detailed control network for the realization of the construction survey it is very important to determine the internal accuracy of the network. For this purpose, baseline lengths and differences in height calculated from determined coordinates and their reference values from tacheometry (Fig. 6) and levelling (Fig. 7) were compared.

The accuracy of baseline lengths oscillated within the range of 2–14 millimetres in the second, third and fourth case and touched 6 centimetres for the POZGEO solution. Similarly, in the case of the differences in height, the greatest errors of up to 8 cm were obtained for the POZGEO solution while errors calculated for variants II, III and IV did not exceed 15 mm. It should be noted that the occurrence of some obstacles at the measuring points had no significant influence on the accuracy of the baseline length and differences of height determination.

In order to analyse the impact of the occurrence of obstacles on the determination of a position, data processing using a kinematic method was conducted. As a result of this analysis, a set of 13,000 positions was obtained for points P001 and P002, and about 6,000 positions for each of the remaining points (Fig. 8).

For points P002, P011, P012 and P013, positions obtained from fixed solutions accounted for 100% of all obtained positions, while in the case of points P001 and P014 it was 36% and 18%, respectively. The low percentage of fixed solutions for point P001 was probably caused by difficult observation conditions at the measurement point. The influence of obstacles above the point P002 was, however, negligible. As shown in Figure 8, an unexpectedly poor kinematic solution occurs at point P014 and the point was unobstructed. This was probably due to poor satellite constellation during the second observation session. For geodetic purposes, only positions obtained from *fixed* solutions could be used. The standard deviation of *fixed* positions

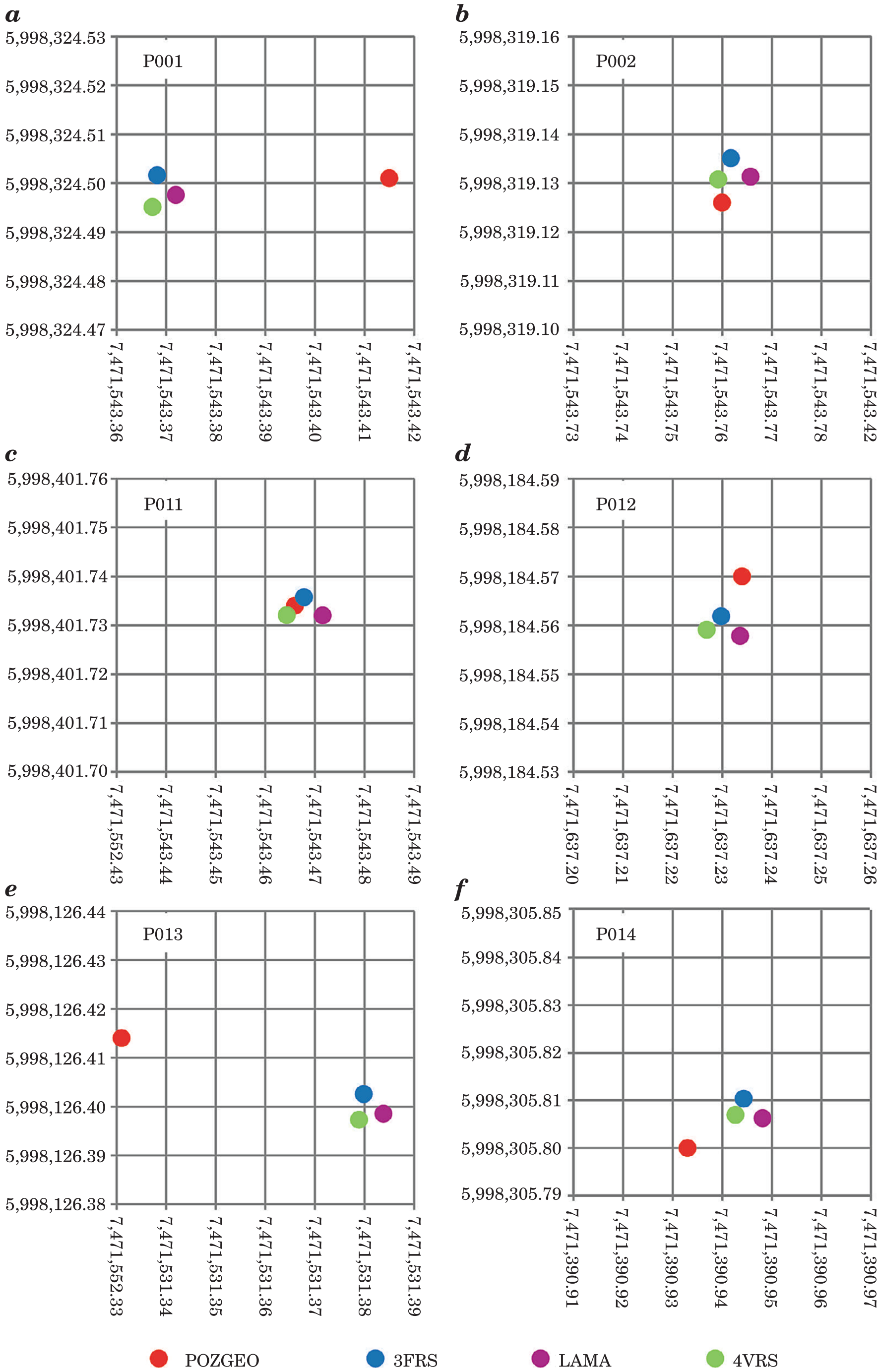

Fig. 5. The distribution of the plane coordinates obtained at each measurement point

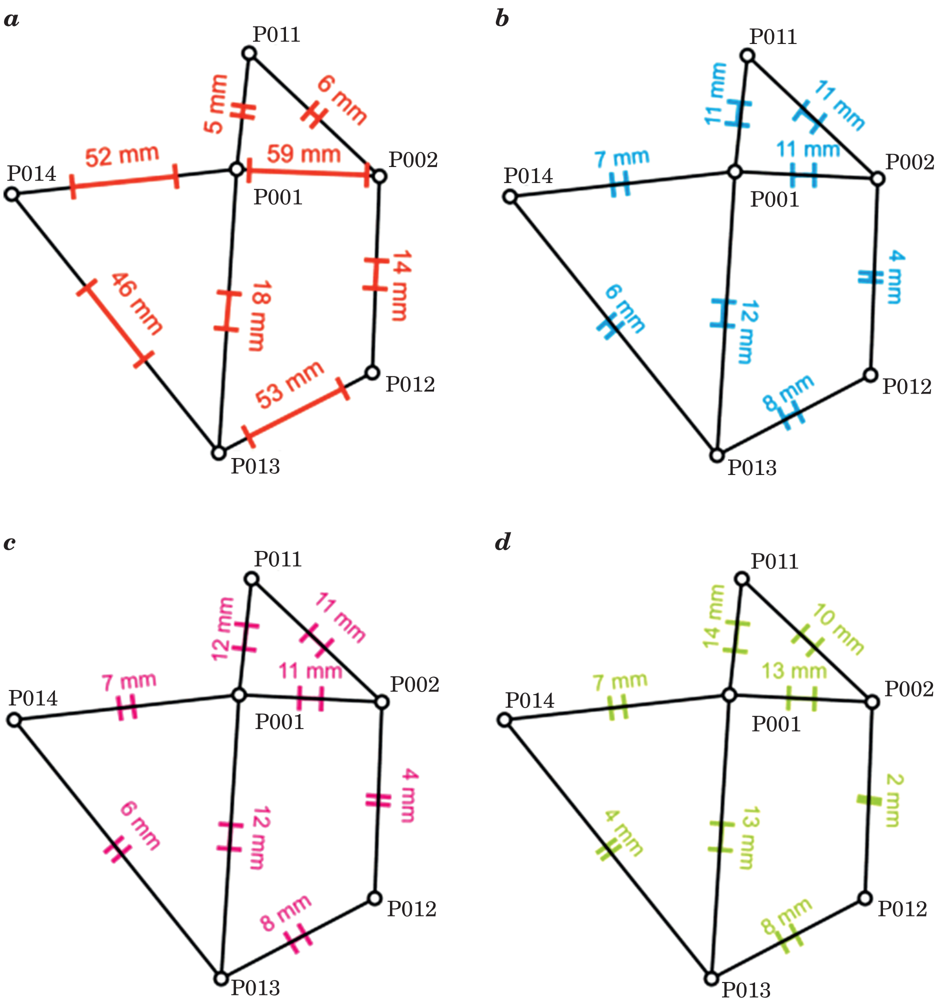

Fig. 6. Differences in baseline length between tachometry and GNSS solutions: *a* – POZGEO, *b* – 3FRS, *c* – LAMA, *d* – 4VRS

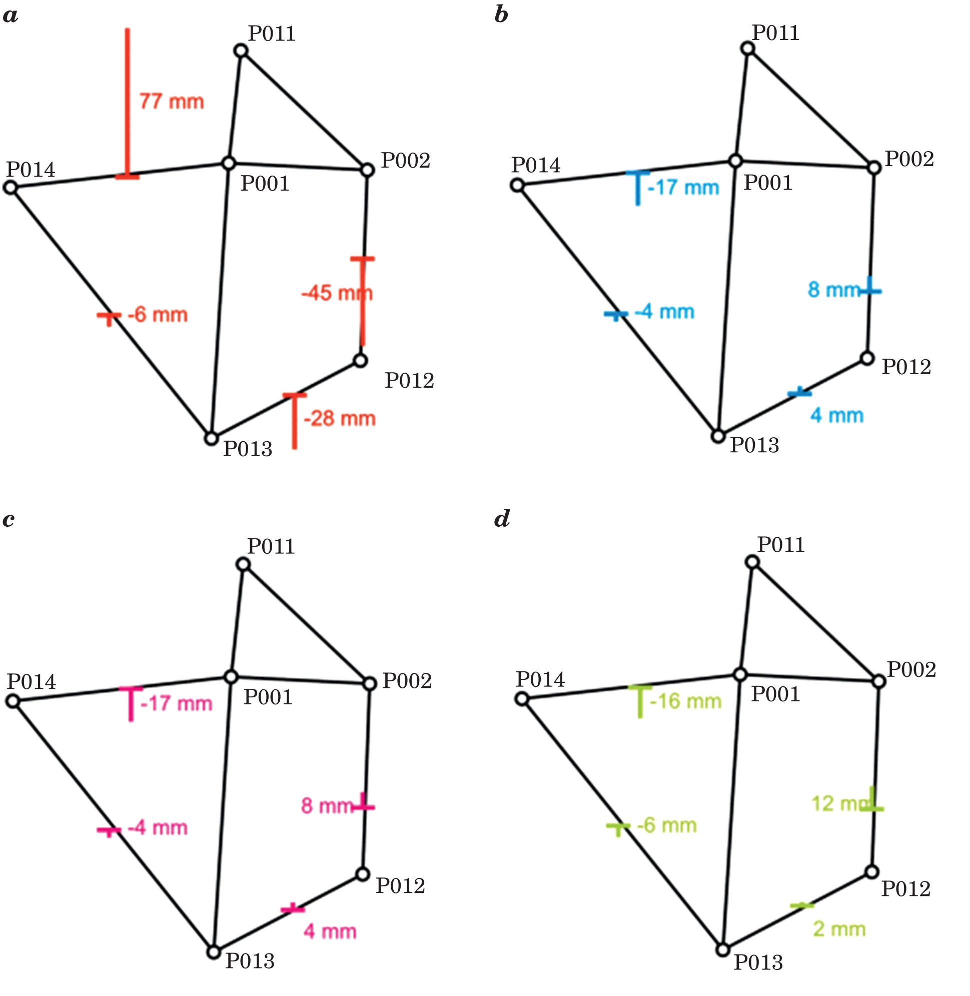

Fig. 7. Differences in height between leveling and GNSS solutions: *a* – POZGEO, *b* – 3FRS, *c* – LAMA, *d* – 4VRS

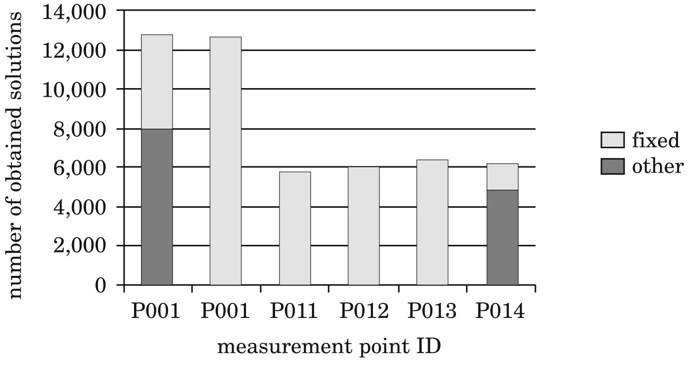

Fig. 8. The structure of solutions obtained from the kinematic method

ranged from 7–12 mm for plain coordinates and from 19–50 mm for height (Tab. 3). Considering the values of standard deviations, any decreases in precision at the obstructed points can be identified due to long observation sessions. In geodetical practice, kinematic solutions (especially RTK methods) are used for short or very short occupations at each point.

Table 3
Standard deviations of fixed kinematic solutions

Point No	Standard deviation		
	x [m]	*y* [m]	*h* [m]
P001	0.026	0.022	0.050
P002	0.019	0.014	0.034
P011	0.015	0.012	0.028
P012	0.012	0.009	0.019
P013	0.019	0.017	0.034
P014	0.012	0.007	0.026

In Fig. 9, the distribution of plane coordinates obtained from a kinematic solution is presented. Point (0,0) refers to the mean value of positions obtained in variants II to IV. The distribution of plane coordinates ranged from 2 centimetres at points P012 and P014 to 6 centimetres at point P002. It should be noted that, in this case, there is no clear relationship between the precision or accuracy of the determined position and the occurrence of a terrain obstacle. The coordinates of an unobstructed point P013 had a similar distribution of plane coordinates to point P002, on which there was some tree canopy.

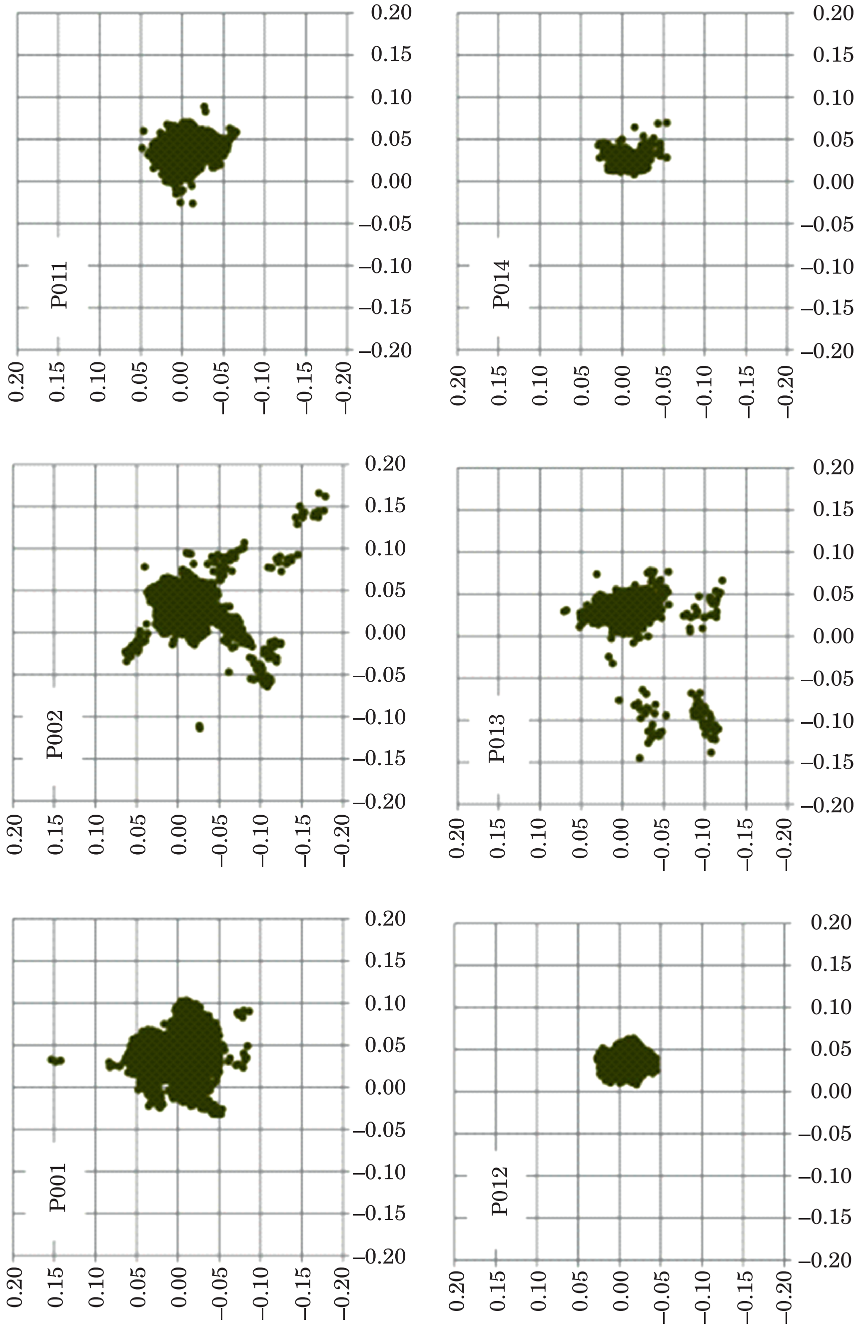

Fig. 9. The precision of plane coordinates obtained from a kinematic solution

Summary and conclusions

The foregoing paper presents four variants of GNSS data processing for the establishment of a detailed control network for the realization of the construction survey. The first variant assumed automatic data processing by the POZGEO service of ASG-EUPOS system and other three variants assumed manual observation data processing. The best results (the lowest baseline length errors and the lowest differences in height errors) were assured by manual processing of observation data. The number and type (FRS VRS) of employed reference stations, however, had no significant effect on the accuracy of the results. The great advantage of manual data processing is the flexibility of this solution, the possibility of setting up some parameters in various stages of post-processing and, what is most important, the possibility of adjustment of the whole network. The experiment confirmed that for control network establishment there is a need to use data processing methods which ensure the adjustment of the whole network.

The second issue considered was the impact of terrain obstacles on the quality of obtained coordinates. Despite the fact that in the experiment there was no significant effect of tree canopy on the position precision and accuracy, such an effect cannot be denied. The obtained results support the claim that the need to avoid obstacles over 10° above the horizon is too general and too restrictive requirement. The location of obstacles in relation to cardinal directions is as important as their height above horizon. Moreover, avoiding terrain obstacles above 10° in surveying practice is sometimes difficult or even impossible. The solution to this problem involves careful measurement planning, especially taking into account the shape, density and other features of obstacles.

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DERIVATION OF THE SCALING LAWS USED IN GEOTECHNICAL CENTRIFUGE MODELLING-APPLICATION OF DIMENSIONAL ANALYSIS AND BUCKINGHAM Π THEOREM

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Abstract

Geotechnical centrifuge modelling has been a world-wide used technology in physical tests. In this papers a derivation of scaling laws by dimensional analysis for the centrifugal modelling is presented. Basic principles of centrifuge modelling are described. Scaling laws for slow events like consolidation and fast events like dynamic loads are shown. The differences in scale factors for both processes are noticed. The aim of this paper is to introduce geotechnical centrifuge technology to a wider Polish audience.

Introduction

Geotechnical centrifuge modelling is a technique of testing $1/n$ scaled models subjected to gravitational field increased by a factor n. Similitude laws are a group of rules which links behaviour of a model to the prototype in the field. A set of scaling laws for static tests, dynamic tests, water flow and consolidation can be derived by dimensional analysis using assumption that stress level in prototype and centrifuge is the same (SCHOFIELD 1980, TAYLOR 1995, JOSEPH et al. 1988). They can be also derived by dimension analysis of equilibrium equation in continuum mechanics. However, only the results of this process were presented (CORTÉ 1989, FUGLSANG, OVESEN 1988). In this paper a full derivation using this method was shown. Consequently, the phenomena of centrifuge modelling based on scaling laws enables to maintain

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Fig. 1. Geotechnical beam centrifuge in Davis, University of California
Source: KUTTER (1998).

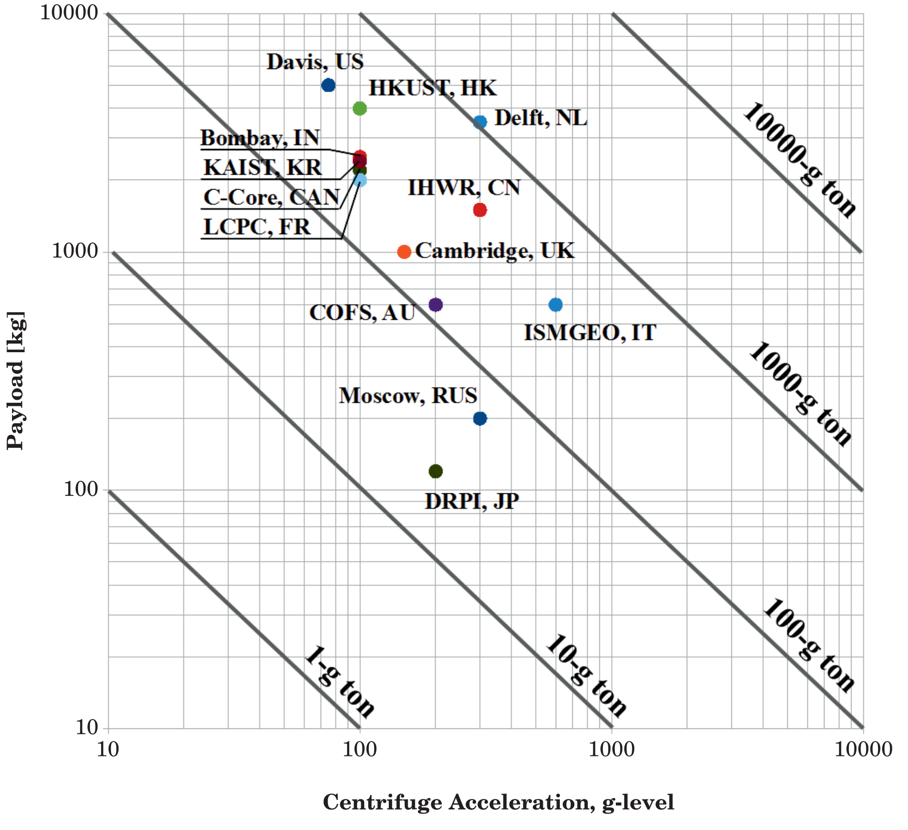

Fig. 2. Capacities of main geotechnical centrifuges around the world
Source: modified after NG et al. (2001) and KIM et al. (2013)

the same stress and strain levels in a model and the prototype. This is the main advantage of centrifuge tests. Catalogue of scaling laws and similitude questions in geotechnical centrifuge modelling was presented by TC2 committee of ISSMGE (GARNIER et al. 2007).

In figure 1 a view of typical centrifuge is shown. There are two types of geotechnical centrifuges. The first one is a drum centrifuge. Drum centrifuges enable to maintain high acceleration levels (up to 500 g), but require small models. Also, higher distortions in modelling occur for drum centrifuges with small radius than in a beam centrifuge. The second group is beam centrifuges. The radius of beam can reach up to 9 meters. They have lower acceleration levels, but they can carry a huge payload. For example, the Hong Kong centrifuge can carry 4.0 tons payload and its acceleration is up to 150 g (NG et al. 2001). Beam centrifuges enable to conduct more complicated tests like earthquake modelling and in-flight tests (MADABHUSHI, SCHOFIELD 1993). The capacities of centrifuges around the world are show in figure 2.

Scaling laws for dynamic events

A geotechnical model conducted under ng gravitational field, where g is acceleration due to earth gravity, and a prototype under one gravity have to be linked by some laws. Some requirements have to be fulfilled to achieve a strict similitude. These are geometric similarity, kinematic similarity and dynamic similarity (LANGHAAR 1951). Geometric similarity refers to the model and prototype with homologous physical dimensions. Kinematic similarity defines a model and prototype with homologous particle flow. Dynamic similarity means that net forces acting on model and prototype are homologous. It is often impossible to fulfil all these criteria during a model tests. Then partial similitude occurs and scale effects must be taken into account.

The relationship between model and prototype for centrifuge tests is generally derived through dimensional analysis. The dimensional analysis involves application of the Buckingham Π theorem. The Statement is: If there are n variables in a problem and these variables contain k primary dimensions the equation relating all the variables will have (n-k) dimensionless Π groups. Scaling relation may be resolved by equating Π terms in model and prototype.

Scaling laws for centrifuge tests may be derived form momentum conservation equation (CORTÉ 1989) using Buckingham theorem. Momentum conservation law is given by equation:

$$\operatorname{div}(\tilde{\sigma}) + \tilde{\rho} \cdot \left(\tilde{g} - \frac{\partial^2 \tilde{u}}{\partial t^2}\right) = 0 \tag{1}$$

Equation may be also rewritten using variables:

$$f(\sigma, \rho, g, u, t, x) = 0 \tag{2}$$

where:
σ – stress tensor [kg/(ms^2)],
ρ – density vector [kg/m^3],
g – gravitational acceleration vector [m/s^2],
u – displacement vector [m],
t – time [s],
x – position vector [m]

In this problem occurs 6 independent variables, so n=6. These variables contain 3 primary dimensions: length (l), mass (m) and time (t), making k=3. We can also use another variables, for example time (t), density (ρ) and position (x). By invoking the Buckingham theorem it can be shown that there are 3 non-dimensional Π terms:

$$n - k = 6 - 3 = 3 \tag{3}$$

Let us define the non-dimensional terms by grouping the variables into n-k groups. Each group contains 3 repeating variables and one non-repeating. This makes:

$$\Pi_1 = \sigma \cdot t^{p_1} \cdot x^{p_2} \cdot \rho^{p_3} \tag{4}$$

$$\Pi_2 = u \cdot t^{p_4} \cdot x^{p_5} \cdot \rho^{p_6} \tag{5}$$

$$\Pi_3 = g \cdot t^{p_7} \cdot x^{p_8} \cdot \rho^{p_9} \tag{6}$$

All variables may be expressed in terms of its dimensions, as shown in table 1.

Table 1
Variable's dimension

Variable	Dimension
σ	kg/(ms^2)
u	m
g	m/s^2
ρ	kg/m^3
t	s
x	m

By substituting these dimensions into eq. (4), eq. (5) and eq. (6) , we have:

$$\Pi_1 = \left[\frac{\text{kg}}{\text{m} \cdot \text{s}^2}\right] \cdot [\text{s}]^{p_1} \cdot [\text{m}]^{p_2} \cdot \left[\frac{\text{kg}}{\text{m}^3}\right]^{p_3} \tag{7}$$

$$\Pi_2 = [\text{m}] \cdot [\text{s}]^{p_4} \cdot [\text{m}]^{p_5} \cdot \left[\frac{\text{kg}}{\text{m}^3}\right]^{p_6} \tag{8}$$

$$\Pi_3 = \left[\frac{\text{m}}{\text{s}^2}\right] \cdot [\text{s}]^{p_7} \cdot [\text{m}]^{p_8} \cdot \left[\frac{\text{kg}}{\text{m}^3}\right]^{p_9} \tag{7}$$

The Π numbers are dimensionless ($\Pi_1 = \Pi_2 = \Pi_3 = 1$). Thus, by solving the eq. (7), (8) and (9) we have:

$$p_1 = 2, p_2 = -2, p_3 = -1 \tag{10}$$

$$p_4 = 0, p_5 = -1, p_6 = -0 \tag{11}$$

$$p_7 = 2, p_8 = -1, p_9 = -0 \tag{12}$$

Non-dimensional Π numbers become then:

$$\Pi_1 = \frac{\sigma \cdot t^2}{x^2 \cdot \rho} \tag{13}$$

$$\Pi_2 = \frac{u}{x} \tag{14}$$

$$\Pi_3 = \frac{g \cdot t^2}{x} \tag{15}$$

Variable $[g]$ may be expressed in dimensions of $[x]$ and $[t]$. Then Π_1 can be written as:

$$\Pi_1 = \frac{\sigma}{x \cdot g \cdot \rho} \tag{16}$$

Hence, momentum conservation equation in dimensionless form can be written as:

$$f\left(\frac{\sigma}{x \cdot g \cdot \rho}, \frac{u}{x}, \frac{g \cdot t^2}{x}\right) = 0 \tag{17}$$

Let us define a scale factors, which are described below:

$$\sigma^* = \frac{\sigma_m}{\sigma_p} \tag{18}$$

$$\rho^* = \frac{\rho_m}{\rho_p} \tag{19}$$

$$x^* = \frac{x_m}{x_p} \tag{20}$$

$$g^* = \frac{g_m}{g_p} \tag{21}$$

$$t^* = \frac{t_m}{t_p} \tag{22}$$

$$u^* = \frac{u_m}{u_p} \tag{23}$$

where suffix m indicates model and p prototype. Scale factors are non-dimensional numbers, so it may be written that:

$$f\left(\frac{\sigma^*}{x^* \cdot g^* \cdot \rho^*}, \frac{u^*}{x^*}, \frac{g \cdot t^{*2}}{x^*}\right) = 0 \tag{24}$$

$$\sigma^* = x^* \cdot g^* \cdot \rho^* \tag{25}$$

$$g^* \cdot t^{*2} = x^* \tag{26}$$

$$u^* = x^* \tag{27}$$

Equations from (25) to (27) are fundamental rules for derivation of scaling laws in physical modelling.

Understanding of centrifuge phenomenon can be explained by the comparison with traditional 1 g test ($g^* = 1$). Let us consider a $1/n$ scale model ($x^* = 1/n$). By using the same soil ($\rho^* = 1$) in a model and prototype, the scale factor for stresses following by eq. (25) will be described as:

$$\sigma^* = \frac{1}{n} \cdot 1 \cdot 1 = \frac{1}{n} \tag{28}$$

Consequently, deformation scale factor is given as:

$$u^* = \frac{1}{n} \tag{29}$$

Further, strain scale factor may be written as:

$$\varepsilon^* = \frac{\Delta u^*}{\Delta x^*} = \frac{\frac{1}{n}}{\frac{1}{n}} = 1 \tag{30}$$

Hence, the constitutive relations governed by equations (HEINBOCKEL 2001):

$$\sigma_{ij} = \frac{E}{1 + \upsilon}\left(\varepsilon_{ij} + \frac{\upsilon}{1 - 2\upsilon}\,\varepsilon_{kk}\,\delta_{ij}\right) \tag{31}$$

will be correct only for modified mechanical characteristics of material.

$$E_m = \frac{1}{n} E_p \tag{32}$$

where:
E_m – elastic modulus for model [Pa],
E_p – elastic modulus for prototype [Pa],
n – scale factor [–].

The choice of elastic moduli in soils described by eq. (32) may be problematic to solve. If small-scale models are tested, stress-strain relation is incorrect for full scale construction. The proper stiffness of the soil in the scale model can be achieved by using geotechnical centrifuge.

Now consider a $1/n$ scale model testing in a centrifuge ($g^* = n$). If the model is subjected to acceleration ng and the same materials for model and prototype are used ($\rho^* = 1$), the stress scale factor will be given as:

$$\sigma^* = \frac{1}{n} \cdot n \cdot 1 = 1 \tag{33}$$

Further, the deformation and strain scale factors will be described as:

$$u^* = \frac{1}{n} \tag{34}$$

$$\varepsilon^* = \frac{\Delta u^*}{\Delta x^*} = \frac{\frac{1}{n}}{\frac{1}{n}} = 1 \tag{35}$$

From above equations it can be seen, that stress and strain have a scaling factor of 1. This is one of the main advantages of centrifuge modelling. If the scale factors of g^* and x^* for centrifuge test are inserted into eq. (26), hence time scale factor for dynamic events becomes:

$$t^* = \frac{1}{n} \tag{36}$$

The list of scaling laws in geotechnical centrifuge modelling including dynamic events is presented in table 2. Presented scaling laws, not derived above in this paper, may be obtained from basic physical laws (KONKOL 2013).

Table 2

Scaling laws for centrifuge tests

Type of test	Parameter	Units	Notation	Scaling law model/prototype
Common	length	m	L^*	$1/n$
	area	m^2	A^*	$1/n^2$
	volume	m^3	V^*	$1/n^3$
	density	kg/m^3	ρ^*	1
	mass	kg	m^*	$1/n^3$
	gravitational acceleration	m/s^2	g^*	n
	unit weight	N/m^3	γ^*	n
	stress	N/m^2	σ^*	1
	strain	–	ε^*	1
	force (static)	N	F^*	$1/n^2$
	displacement	m	u^*	$1/n$
Dynamic	bending Moment energy	Nm J	M^* E^*	$1/n^3$ $1/n^3$
	time	s	t^*	$1/n$
	velocity	m/s	v^*	1
	acceleration	m/s^2	a^*	n
	frequency	s^{-1}	f^*	n

Scaling laws for consolidation

Derivation of scaling laws for dynamic events do not include water flow in centrifuge models. Diffusion events like consolidation are slow. Consolidation process is governed by the diffusion equation given as (WIŁUN 2010):

$$\frac{\partial u}{\partial t} = C_v \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \tag{37}$$

where:
u – excess pore pressure [Pa],
t – time [s],
C_v – coefficient of consolidation [m^2/s].

Coefficient of consolidation is linked to time by equation (WIŁUN 2010):

$$T_v = C_v \cdot \frac{t}{h^2} \tag{38}$$

where:
T_v – time factor [–],
h – drainage path [m].

Time factor T_v is non-dimensional term. Hence,

$$T_v{}^* = \frac{T_{v,w}}{T_{v,p}} = 1 \tag{39}$$

By expanding eq. (39) we will have:

$$T_v{}^* = \frac{T_{v,w}}{T_{v,p}} = \frac{C_{v,m} \cdot \dfrac{t_m}{h_m^2}}{C_{v,p} \cdot \dfrac{t_p}{h_p^2}} = 1 \tag{40}$$

When the same soil is used in the model and the prototype, coefficients of consolidation for the model and the prototype will also be the same ($C_{v,m} = C_{v,p}$). Consequently, in this case the following time factor t^* will be satisfied:

$$t^* = \frac{t_m}{t_p} = \left(\frac{h_m}{h_p}\right)^2 = \left(\frac{1}{n}\right) = \frac{1}{n^2} \tag{41}$$

Here an interesting feature in consolidation process appears. The time factor of $1/n^2$ enables modelling of settlements in short period of time. For example, let us consider a 3 m deep soft soil layer. It consolidates 15 months to reach 90% degree of consolidation. In geotechnical centrifuge, a 30 mm thick layer tested at 100g will reach the same degree of consolidation in a period of 1,1 h.

Now, let us analyse seepage velocity. Water flow velocity v_{fl} is governed by the Darcy's law and it can be written in two ways (THUSYANTHAN, MADABHUSHI 2003):

$$v_{ij} = k \cdot i \tag{42}$$

$$v_{ij} = -\frac{K}{\mu} \cdot \text{grad}(P) \tag{43}$$

where:
k – coefficient of permeability [m/s],
i – hydraulic gradient [–],
K – hydraulic conductivity (intrinsic permeability) [m^2],
μ – dynamic viscosity [Pa · s],
grad(P) – pore pressure gradient [Pa/m].

Coefficient of permeability is linked to unit weight γ, hydraulic conductivity K and dynamic viscosity μ by equation (MUSKAT 1937):

$$k = K \cdot \frac{\gamma}{\mu} \tag{44}$$

By using scaling factors given as:

$$v_{fl}^* = \frac{v_{fl,m}}{v_{fl,p}} \tag{45}$$

$$k^* = \frac{k_m}{k_p} \tag{46}$$

$$i^* = \frac{i_m}{i_p} \tag{47}$$

$$K^* = \frac{K_m}{K_p} \tag{48}$$

$$\mu^* = \frac{\mu_m}{\mu_p} \tag{49}$$

$$\mathrm{grad}(P^*) = \frac{\mathrm{grad}(P_m)}{\mathrm{grad}(P_p)} \tag{50}$$

The Darcy law can be written in dimensionless form as:

$$v_{fl}^* = k^* \cdot i^* \tag{51}$$

$$v_{fl}^* = -\frac{K^*}{\mu^*} \cdot \mathrm{grad}(P^*) \tag{52}$$

If the same soil ($K^* = 1$) and the same fluid ($\mu^* = 1$) are used in the model and the prototype, then the coefficient of permeability can be written as:

$$k^* = K^* \cdot \frac{\gamma^*}{\mu^*} = 1 \cdot \frac{n}{1} = n \tag{53}$$

Thus, because of non-dimensional value of hydraulic gradient ($i^*=1$), water flow velocity is given as:

$$v_{fl}^* = k^* \cdot i^* = n \cdot 1 = n \tag{54}$$

Notice that the time factor will be the same as for consolidation:

$$t^* = \frac{L^*}{v_{fl}^*} = \frac{\frac{1}{n}}{n} = \frac{1}{n^2} \tag{55}$$

Further, pressure gradient can be derived by eq. (52). By substituting $K^* = 1$, $\mu^*=1$ and $v_{fl} = n$ to eq. (52), we have

$$n = -\frac{1}{1} \cdot \mathrm{grad}(P^*) \tag{56}$$

$$\mathrm{grad}(P^*) = n \tag{57}$$

Now let us compare a scale factors for dynamic and consolidation events. In geotechnical modelling diffusion events often occur with dynamic events. As can be seen in table 3, excess pore water pressure in the model dissipate n time faster than in the prototype. For proper matching time, scaling factors for diffusion and dynamic events should be the same. This can be achieved in two different ways. Firstly, we may reduce the permeability of soil by decreasing soil grains in the model. This solution is not desirable because of strain-stress relation. Another approach is to increase viscosity of the fluid used in the model by a factor n. That is a better clue. In centrifuge modelling the fluids like silicone oil or methyl cellulose successfully are used (STEWART et al. 1998). In this case, viscosity scale factor μ^* is given as:

$$\mu^* = \frac{\mu_m}{\mu_p} = n \tag{58}$$

Because the permeability of soil and hydraulic gradient remains the same, the permeability factor will be described as:

$$k^* = K^* \cdot \frac{\gamma^*}{\mu^*} = 1 \cdot \frac{n}{n} = 1 \tag{59}$$

Consequently, the water flow velocity factor will be given as:

$$v_{fl}^* = k^* \cdot i^* = 1 \cdot 1 = 1 \tag{60}$$

Hence, the time factor may be written as:

$$t^* = \frac{L^*}{v_{fl}^*} = \frac{\frac{1}{n}}{1} = \frac{1}{n} \tag{61}$$

Notice that the pressure gradient factor remain unchanged:

$$v_{fl}^* = \frac{K^*}{\mu^*} \cdot \mathrm{grad}(P^*) = \frac{1}{n} \cdot \mathrm{grad}(P^*) = 1 \tag{62}$$

$$\operatorname{grad}(P^*) = n \tag{63}$$

By increasing the viscosity of the model's fluid we gain another profit. Reynolds number, which is given as:

$$\mathrm{Re}^* = \frac{v_{fl}^* \cdot d_e^* \cdot \rho^*}{\mu^*} \tag{64}$$

where:
v_{fl}^* – seepage velocity factor [–],
d_e – effective diameter of soil factor [–],
ρ^* – density of soil factor [–],
μ^* – dynamic viscosity factor [–]

When water in centrifuge model is used we have:

$$\mathrm{Re}^* = \frac{n \cdot 1 \cdot 1}{1} = n \tag{65}$$

But, when using alternative fluid such as silicone oil is used, we have:

$$\mathrm{Re}^* = \frac{1 \cdot 1 \cdot 1}{n} = \frac{1}{n} \tag{66}$$

Consequently, laminar flow in prototype will be always laminar in the model, but turbulent flow in prototype may also be laminar in the model.

Table 3

Different scaling laws for dynamics and consolidation

Parameter	Notation	Scaling law model/prototype	
		dynamics	consolidation
Seepage velocity	v_{fl}^*	1	n
Time	t^*	$1/n$	$1/n^2$

Conclusions

The derivation of scaling laws used in geotechnical centrifuge was show. The application of Buckingham Π theorem in dimensional analysis was presented. The dimensionless form of momentum conservation equation was obtained and the application of this equation in the derivation of scaling laws in physical modelling was featured. The differences in seepage velocity and time scale factors for consolidation and dynamic events were noticed. Currently used solutions of this problem were cited. The advantages of geotechnical centrifuge technology were described and finally, the basic principles of centrifuge modelling were featured.

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DETERMINANTS OF THE INNOVATION TRANSFER

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Abstract

The study is a result of research conducted in the environments of engineering and technical employees in industrial enterprises. The authors indicate the main dilemmas of modern entrepreneurship and innovation and present a development methodology based on a parallel increase in the adaptability of cultural and technological innovation. The authors have exposed a language and tool gap in the context of electronic communication and information processing technology, in particular, the effects of application of integrated computer systems CAD/CAM/CAE with a three-dimensional and animated option of electronic documents PDF and DOC.

Introduction

Three basic categories: matter, energy and information have a decisive significance while determining the epoch of the world's civilization development. In the industrial era it was the consumption of energy that determined the success. The era of information has come now and it became a decisive factor of running social-economic activities. The change of epoch became palpable with the mass popularization of the computer, universal software and worldwide network of informative sources, that is the Internet, in other words with very fast development and popularization of ICT technology (Information & Communication Technologies). Present epoch is called differently but undoubtedly it is an epoch of digital processing of information in which the importance of matter and energy decreased, but, of course, they are still indispensable.

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This work is based mainly on research conducted in industrial enterprises, which have to face many contingents of harsh competition not only on the home market but also on the European and the global one. The aim of the study is to identify the reasons for the low level of innovation and application of new technologies in the practice of Polish industrial enterprises and to present the methodology and tools that eliminate the identified causes. The identification of the causes was achieved mainly as a result of the synthesis of the conclusions of the research conducted in the years 2010–2012 (SALA, TAŃSKA 2010a, 2011), which have been verified in the study carried out in 2012. The research was conducted as a part of innovative project testing the international components called „The Way to Professional Excellence" realized within the Operating Program Human Capital, Priority VIII Regional economic human resources: Activity 8.2 The transfer of knowledge; Sub-activity 8.2.2. Regional Strategies of Innovation. The leader of the project is NSZZ Solidarność of Shipyard in Gdansk and the main partner is The Department of Ocean Technology and Shipbuilding at University of Technology in Gdansk.

Material and some methods – identifying the causes of collapse

Polish industrial enterprises experience essential helplessness of different advisory-training-research institutions which should support them. Industrial enterprises do not obtain essential support from the informative sources as far as innovative activity is concerned so they do not trust such entities, Central Statistical Office (GUS 2011) reveals a trace cooperation of innovatively active enterprises with: research center PAN (3.6%), research institutes (6.0%), foreign public research institutes (3.4%), schools of higher education (5.9%). The situation is similar with the usage of informative sources within a group: research-technical group, specialized group, professional societies and committees (4.9%). The market suppliers of innovative solutions are in the best position (GUS 2011). Various fields of science verify their methodological bases and paradigms as well as they experience reorganization and significant lack of subsidies in Polish institutional reality. The term paradigm is used in accordance with the interpretation by R.S. Covey'a, that is it involves „model, theory, perception, assumption and a reference point" (COVEY 2010). Such a situation takes place in humane and social sciences, economic and technical ones, as a result, they are less useful for the practitioners who look for support. At present a quite commonly applicable paradigm (SALA, TAŃSKA 2013a) involves innovation so it is sensible to focus on creating innovation as a part of innovative activity.

The concept of innovation is understood as implementing a new or significantly improved product (articles, services) or a process, new organizational method or new marketing method in economic practice, the organization of workplace or regarding the surrounding. In definition accepted in methodology, GUS adds that „A new or considerably improved product is implemented when it is introduced onto the market. New processes, organizational methods or marketing methods are implemented when the actual usage by the enterprise takes place" (GUS 2011).Various measurements and analyses concern the innovative activity which involves engaging the enterprises in different scientific, technical, organizational, financial and commercial undertakings leading to implementing innovation. Some of these activities have an innovative character whereas others are not new but necessary to implement innovation. It is accepted that an innovative activity includes research-development activity as well (R+D), which is not directly connected with creating a particular innovation.

There are many attempts of interdisciplinary „fusions of knowledge" to get to know and which support modern reality. Such an attempt is the idea of commercialization of scientific research results or combining the engineering with managing as well as the concept of instituting of the transfer of knowledge, technology and technical science. A some sort of attempt of motivating the enterprises to cooperation and, as a result, to innovation is the concept of creating an intelligent organization as well as academic entrepreneurship with its main trend of university spin enterprises so called spin-offs or spin-outs. Of course the dilemmas and contingents are similar (CHYBA 2011). The concept of transforming the research results to be used in practice as well as the methodology in a form of a guide for innovators undertakes the intention of „knowledge fusion" (JASIŃSKI 2011).

It seems that all undertakings lack some systematic coherence which would get to the nub of Polish technical, economic and social specification. A Polish role model can be an engineer Eugeniusz Kwiatkowski in II Republic of Poland, who impersonalizes the success of hitting the hot spot of innovative industrial activity. The American guru of proactivity at the turn of 20th and 21th century was S. R. Covey with his relations between the knowledge, skills, desire and habit as a cumulated value. The concept of mutual influence is presented on figure 1.

It is obvious the measurements of the innovativeness of enterprises are not enough, concrete activities supporting innovative activeness are necessary. The knowledge (what and why) as well as skills (how) are not enough. The will I desire-I want is necessary and at that point the condition of making a habit is fulfilled (COVEY 2010). In relation to this the process of transfer or transformation should not be treated as a sign of vertical transfer of technology „from

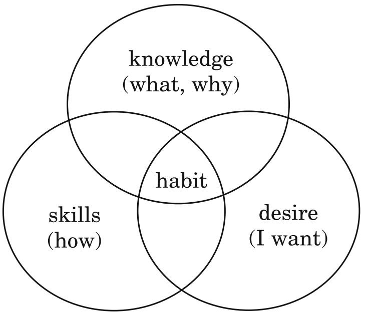


Fig. 1. Effective habits

Source: COVEY (2010).

top to bottom", that is the transfer of scientific-technical knowledge from research center to the enterprise. Unfortunately, too often in our country there is a scheme of such transfer which is interpreted as a traditional, one-directional, line transfer of technology. Many publications mention the modern approach as an interactive model of transfer but it seems all attempts of partner implementations have an incidental and local character.

On one hand we know much about industrial enterprises (in a collective as well as individual aspect), on the other side it is difficult to take responsibility for the way a particular production system should be as it is „designed with a purpose and organized as material, energetic and informative structure exploited by a human being and aimed at manufacturing certain products [...] to fulfill various needs of the consumers" (DURLIK 1993). In regard to the information provided above the issue of how to realize the concept of entrepreneurship and innovativeness in the area of technology is still open. Innovative process in its activity-related meaning is limited by a time range from the concept till the realization.

Working on the process of creating the innovative value the initial analysis of the enterprise's needs is more and more commonly limited to the identification of gaps (JASIŃSKI 2011). The professional literature offers few proposals of identification and measurement of the gaps but they all can be reduced to a generally defined informative gap (OLEŃSKI 2000). According to few interpretations, an informative gap has a multidimensional character. There are also interpretations focusing on indicated measurements, among others, motivational, emotional, competence, educational ones as well as technical, technological, effective or developmental ones.

As far as Polish conditions are concerned there are difficult institutional contingents (SALA, TAŃSKA 2013b) of identifying innovation so it is worth signaling the importance of the developmental gap understood as the difference between the potential of an activity (e.g. the culture of an organization, leadership skills, logistic skills, available resources, that is passive power) and the potential of the influence (e.g. the effectiveness and cultural aspirations, the structure of authority, the features of strategic leadership). The crucial barrier resulting from the experiences of Polish system transformation is a low level of trust which leads to a low level of cooperation. The consequence of such behavior in economic life is operating on a protective level of communication. These dependencies are presented on the diagram on fig. 2.

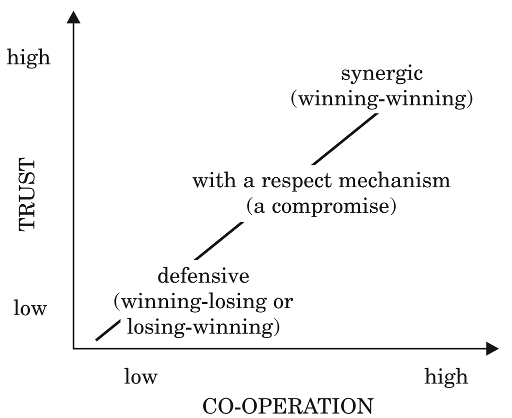


Fig. 2. Dependency of trust and co-operation

Source: COVEY (2010)

Defensive level of communication eliminates a synergetic effect resulting from high trust and cooperation. Crossing this barrier is not easy and a methodic proposal was prepared by S.R. Covey. According to the authors, it is a primer for proactive social-economic behavior in our country but this proposal is not enough.

Discussing the results

On the basis of conducted research the authors prepared methodology based on parallel increase of cultural adaptation and technological innovativeness in an industrial enterprise. In the context of communication the language gap was underlined which can be pragmatically called a tool gap because it focuses not on a natural language (mother tongue or a foreign one) but on an artificial language such as computer graphic tools. Traditionally a technical drawing was the main carrier of technical information and from such a form of presenting a technical project the development of integrated computer systems of CAD/CAM/CAE type started (NIKLAS, ŻRODOWSKI 2012). The present state of the most advanced solutions in processing digital graphics such as CATIA, NX, Pro-Engineer (producers: Dassault Systemes, Siemens PLM Software, Parametric Technology Corporation) offers complete environment to communicate in enterprise. It is not merely a tool to design but to integrate management of the product life cycle in an industrial enterprise regardless the branch and technical education (vocational, technical and engineering). Information gathered during initial research conducted on engineers and technicians supports this thesis.

Undoubtedly the image of a modern enterprise for over 40 years involves its attitude to using information as well as its level. The conceptual assumptions of proposed approach are presented on the figure 3.

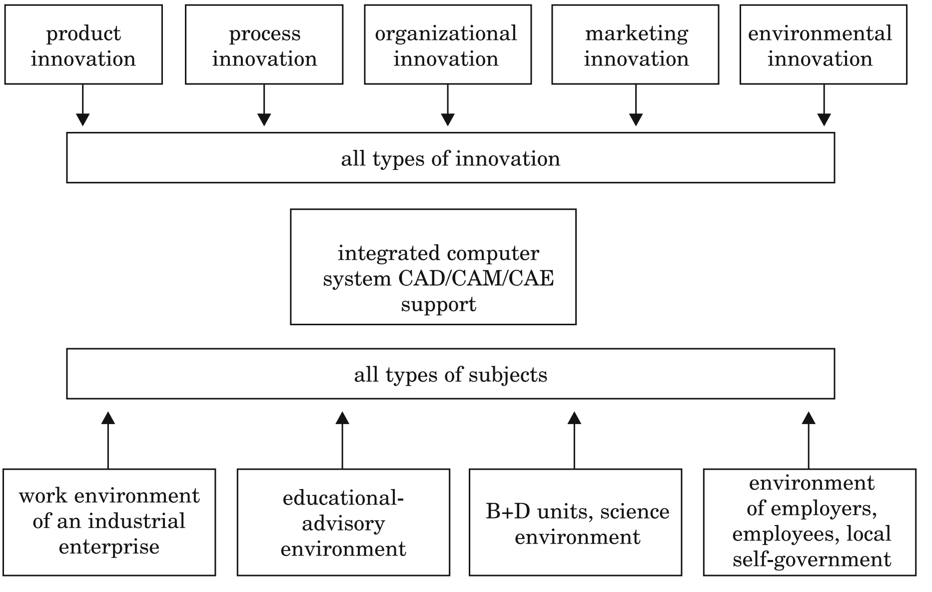


Fig. 3. Conceptual assumptions of tool approach to the transfer of knowledge

The assumptions of approach presented on figure 3 are very simple. All potential subjects of pro-innovative cooperation require mutual language as a platform to communicate. This language cannot, of course, be too difficult and should support all types of innovation. At the beginning of the research the authors, using the „top-down" approach, elaborated the positive verification of UML language (SALA, TAŃSKA 2010b), but unfortunately mainly on the level of organizational innovation. UML language is a tool of software engineering and in the context system, business and process diagrams constituate a useful graphic language of communication on the decisive level. Between the managers on all levels, during the conceptual cooperation as well as during implementation, exploitation and modernization in the IT system life cycle. Unfortunately UML turned out to be too abstract and not efficient enough for industrial enterprises, especially in reference to communication with the engineering-technical employees during the product innovation. In 11.4% of Polish industrial enterprises the product and process of innovation took place in percentages of all industrial enterprises between 2008–2010. In the developed countries belonging to UE this indicator shapes at the level of 20–30% of all industrial enterprises (GUS 2011).

As a result of „bottom-up" analysis of technicians and engineers it can be ensured, although the research hasn't been completed yet, that the proper platform of cooperation and communication is a graphic language integrated to a computer system of CAD/CAM/CAE type. The verification at workplace realized by the individuals with formal education on the level of a vocational school is planned for the season 2013/2014. The starting point was the diagnosis of gaps in engineers' competences with different areas of specialization in reference to the standard competence of a new profession „Product Engineer". Self-diagnosis was prepared and improved as a part of few research projects (SYMELA 2011). The analysis showed that a narrow atomization of technical specializations is a barrier for the flexibility, effectiveness and innovation in practice. The practitioners experienced by Polish conditions feel like „the prisoners" of traditional divisions and tools. The self-diagnosis and brief introduction to the potential of modern tools and the ways of team cooperation used by tool-advanced industrial enterprises stimulated the imagination and motivated to the development in this direction. Few tests on the level of an engineer were prepared for testing (42 hours), on the level of a technician (24 hours) and on the vocational level (18 hours). Unfortunately, the first stage of research verified only the conceptual assumption of the tool approach toward the transfer of knowledge. Strengthening this initial fascination of engineering-technical workers requires much more work-consuming and consequent method presented on figure 4.

The methodology assumes the realization on two methodic layers, usually weakly integrated in industrial enterprises casually called „soft" and „hard" (or clean and dirty, or white and blue collars or accountable for daily wages and task-piecework or administration and production). These are old divisions and antagonisms which Polish industrial enterprises did not manage to eliminate, even in the case of the most modern „high-tech" enterprises (and such enterprises were studied). On the diagram of methodology (fig. 4) the left side represents main „soft" contingents, and the right one – „hard" ones. In such a case one can think about an integrated pro-innovative effect in a Polish industrial enterprise if at the same time the increase of cultural adaptation is guaranteed (left side of the diagram) as well as the increase of technological innovation (right side of the diagram). The method of integrating two essential layers can be achieved as a result of realization of central process of team integration by the coordination of design works (workshop).

The diagram of methodology (fig. 4) distinguishes three stages of time dynamics. The boundaries of vertical and horizontal divisions were not graphically presented on the fig.4, to avoid the deterioration of readability of the transfer of integrating relationships. Stage 1 involves the preparation to implement the methodology (in an actual cycle) by preparing few or few dozen leaders of team work, stage 2 is the research part of undertaken projects, stage 3 is a project and documentation part. Methodology has a cyclical character which means it should be repeated. The first cycle can be on the advantage of the theoretical solutions (acquired during trainings) over the practical solutions which serve more to credibility than their utility(similar to the process of creating academic papers but within a team, not in an individual way). Second and following cycles should have more practical character with keeping the correctness of used methods and techniques. More often advisors, consultants and scientists get to know the specific of an enterprise (the change of the direction of the transfer of knowledge). The necessary condition is the publication of the research results of every team, subjecting every work to the process of reviewing by scientists and practitioners as well as public presentations (at least to all teams and all cooperating specialists of the responsible advisory-training-research unit). Unfortunately, the implementation of methodology in 40 enterprises did not obtain the subsidy in a contest organized by PARP and its efficiency is presently studied in a selective way, not in a complex way. It seems that a complex realization of methodology in an industrial enterprise would cause the most spectacular effect in the period from 1 year to 2 years depending on the branch and the size of the enterprise.

Finally the time has come for the attempt of implementing methodology leveling the gaps requiring interactive but not one-directional transfer of innovation. Identification and enlightening of the most essential contingents of pro-innovativeness take places as a result of the verification. The barrier of outside cooperation between an industrial enterprise and symbolically presented advisory-training-research unit is crossed. The need of inner cooperation in an enterprise is stimulated and the ways, methods and techniques (almost approaching a habit) are acquired and strengthen. The communication language necessary to increase the effectiveness of cooperation between engineering-technical positions as well as with other participants of design, production and service processes, that is in all business processes, was accepted, adapted and verified.

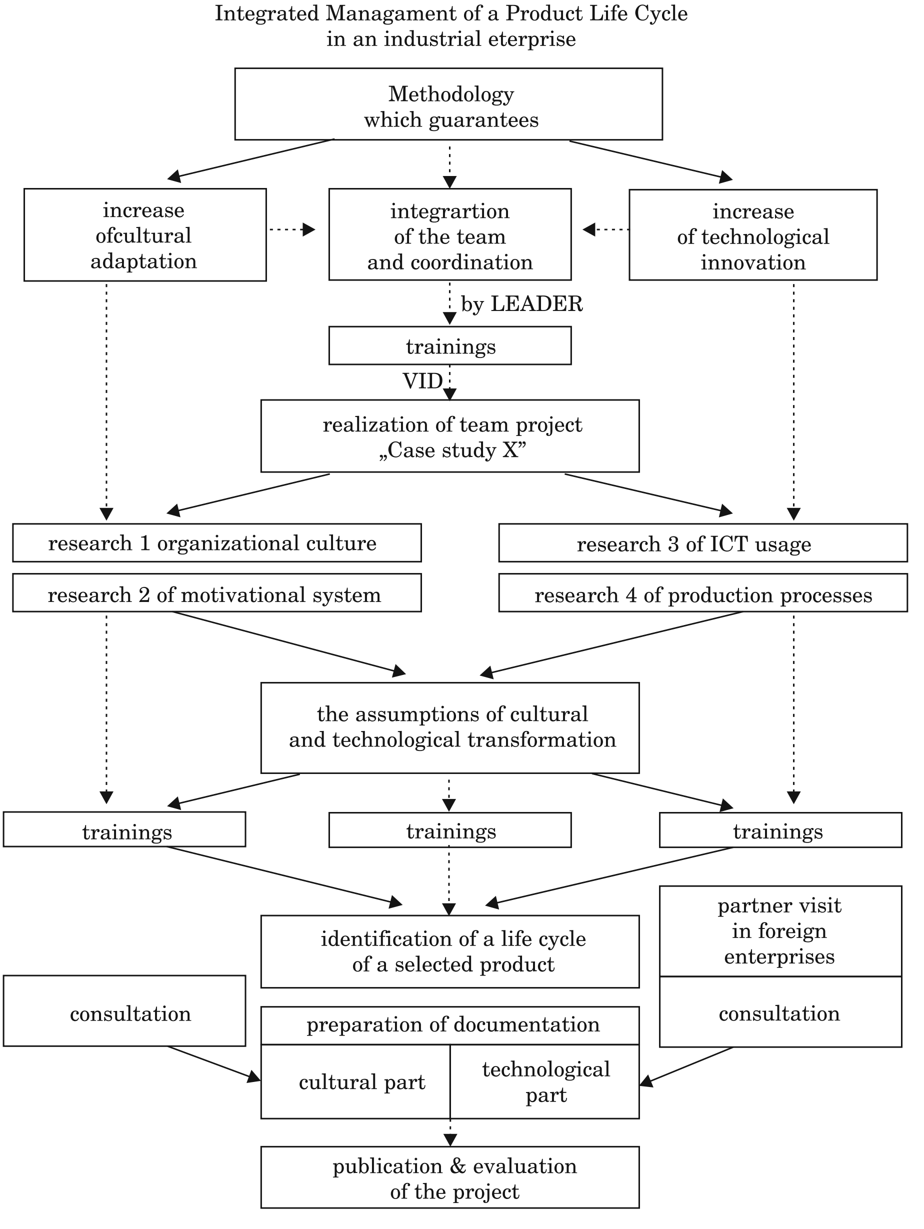
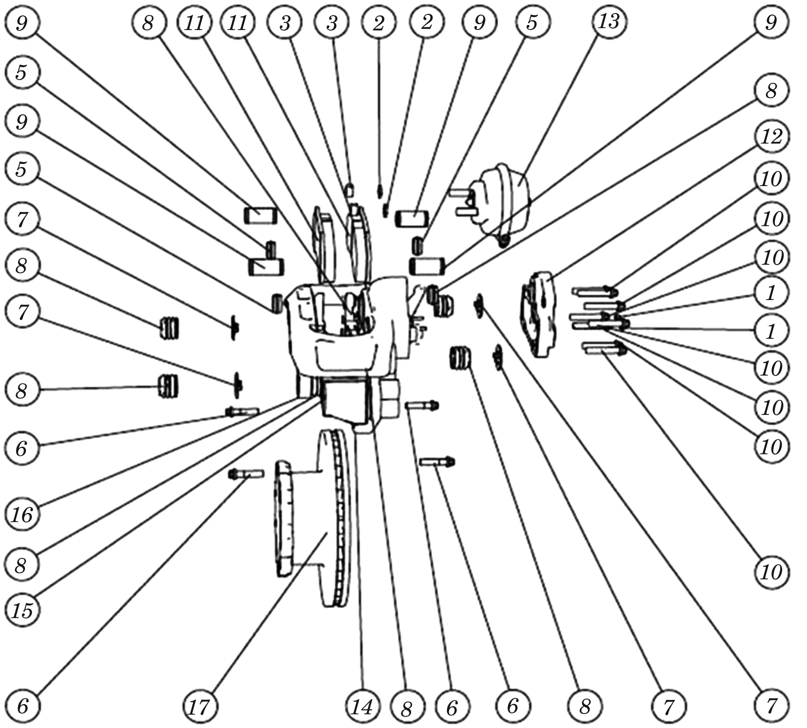


Fig. 4.The methodology of the increase of cultural adaptation and technological innovation in an industrial enterprise

Regarding the above, another task is to make the contingents for the technical information carriers more precise so the document would be useful for all and at the same time the cooperation would become too work-consuming and one-directional. An example of traditional documentation is presented on figure 5.



1	2	E3098150.PRT	*5*	4	E3088158.PRT.	*9*	4	E3088157.PRT.	*13*	1	975334A.PRT.	*17*	1	976030.PRT.
2	2	WASHER_625.PRT	*6*	4	E3088045.PRT.	*10*	8	E3088028.PRT.	*14*	1	6000415.PRT.			
3	2	NUT62.PRT	*7*	4	E3088165.PRT.	*11*	2	6000414.PRT.	*15*	1	E3088020.PRT.			
4	2	E3088037.PRT	*8*	9	E3088159.PRT.	*12*	1	E3088273.PRT.	*16*	1	E3088271.PRT.			

Fig. 5. Traditional documentation of component details and product installation
Source: NIKLAS, ŻRODOWSKI (2012)

Undoubtedly the knowledge on technical information carriers is very crucial and connected with precise contingents but simplifying it involves the necessity of introducing a three-dimensional and animated documents, an example of which is presented on fig. 6. Such a document can be read by using universal and free browsers (e.g. Adobe Viewer), to which, with the document itself, an additional tool stripe regarding animated operations is downloaded as well (fig. 7).

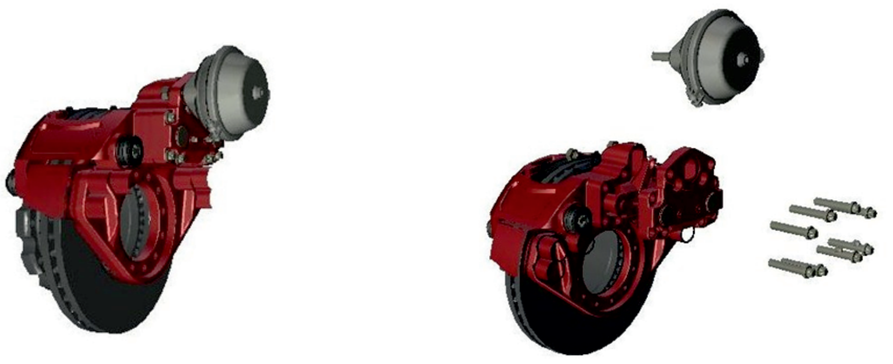


Fig. 6. Three-dimensional and animated operation of an electronic document of a product and its installation from fig. 5 (stages and component details) in a PDF format started
Source: NIKLAS, ŻRODOWSKI (2012).

Figure 7 presents the two toolbars – top bar applies animated PDF document and toolbars at the bottom of the drawing on an animated document in DOC/JT. Toolbars ensure that each 3D object (model, product) can be rotated and enlarged, it can be viewed by the structure (tree) model from different perspectives and with different types of light. In this way, anyone can read the information relevant to the professional activity and its role in the team or process (from design through production, operation, and visualization, promotion and sales).

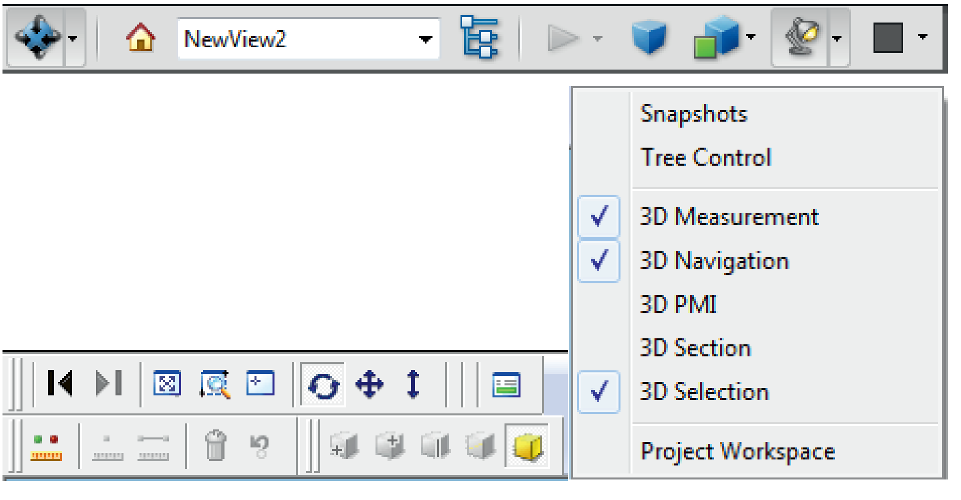


Fig. 7. Toolbars for animated electronic technical document in PDF format (top) and DOC/JT (bottom)

Of course, what is important and unique is the organization of the flow of documentation for individual files (such as PDFs in Figure 5–7) to the group of specific arrangements.

Conclusion

In the summary of reflections concerning authors' proposals for Polish industrial enterprises of the first decade of the 21st century it is worth underlining that an enterprise cannot be innovatively active or innovative among other things without: objective identification (self-reflection of the employees and employers), the state of activeness and, as a result, without credible and advanced ICT usage as well as using effective methods and the ability to cooperate.

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THE EFFECT OF GRINDING EXTENT ON NEAR INFRARED SPECTROMETRY (NIRS) ANALYSIS OF SOME ANIMAL FEEDS

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Key words: NIRS technique, feedingstuffs, prepare a sample, grinding.

Abstract

A study was performed aimed at evaluating the method of sample grinding and its effect on the results of the analysis using the method of near infrared spectrometry. The object of the analysis was feed materials commonly used in animal feed manufacturing, such as cereal grain, wheat bran and high-protein materials (soybean meal). We also tested feed mixtures for poultry and pigs. Laboratory samples were ground on three milling devices – with the sieve of 1.0 mm or 0.5 mm, and a disc mill with minimum working aperture. The content of nutrients was analyzed with the help of the InfraXact spectrophotometer scanning within the range of 770–2,500 nm. The analyses revealed that within the range applied the method is resistant to the diversified granulometric composition of the samples. However, excessive grinding of the research material should be avoided (a sieve of 0.5 mm) during analyzing water, due to potential overheating of the sample which could lead to partial evaporation of the component.

Introduction

The nutritional value of animal feeds may be determined by specifying their chemical composition. However, standard analytical methods are time consuming and may generate high costs. An alternative for accredited methods could be near infrared spectrometry (NIRS) which is one of physical analytical methods. It reduces both the time and the costs of the analyses. The results obtained with the use of this particular method are reliable, accurate and may be archived (ANDERSEN et al. 2013, BUHŁAK 2006, KOLBUSZEWSKI 2009).

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The method of measurements made with a spectrometer consists of exposing a sample to electromagnetic radiation in the range of 770 nm to 2,500 nm. Due to the fact that the radiation is of low-energy type, it does not cause any alternations. The absorption of the radiation induces vibrations of chemical bonds in the compounds. These vibrations modify the initial signal, so the signal reaching the detector carries the information on any chemical compounds present in the sample. Since each type of a bond has a different characteristic point, the software used by the apparatus enables the researcher to identify particular compounds and to assess their quantity. The spectrum of the analyzed sample is compared with the mathematical model created during calibration and this provides the basis for predicting the parameters of the sample (BLANCO, VILLARROYA 2002, DEMSKI 2010, WANG, PALIWAL 2007).

All issues related to the use of near infrared spectrometry for determining certain parameters of feeding stuffs can be found in EN ISO 12099:2010 International Standard on Animal feeding stuffs, cereals and milled cereal products – Guidelines for the application of near infrared spectrometry. Its translation into Polish, authorized by the Polish Committee for Standardization, was first published at the beginning of 2013. Item 4 of the quoted standard presents the guidelines concerning measurement facilities, including milling or fragmenting devices used to prepare a sample. A comment accompanying this item includes a statement concerning a possible effect of fragmenting on the results of NIR. The present work discusses the results of using InraXact spectrometer to analyze samples which were prepared on three milling devices of different milling degree (DORSZEWSKI et al. 2004, PODKÓWKA, KOWALISZYN 2010).

The aim of the study

The present study aimed at assessing the influence of the degree of sample grounding on the results of the analysis performed with the use of near infrared spectrometry.

Material and methods

The analyses were performed on typical feeding stuffs: wheat, barley, maize grains, wheat bran and extruded soybean meal, as well as on powdered complete diets: starter, grower for poultry and finisher for pigs for fattening. Laboratory samples (one sample for each feedingstuffs) weighing 100 g were ground in:

1. Ultra Centrifugal Mill Retsch ZM 200 with ø 1.0 mm sieve,
2. Lab Mill 3100 FOSS with ø 0.5 mm sieve,
3. Cemotec Mill 9010 FOSS with minimum aperture.

The measurement of the granulometric composition in the ground samples was performed by means of the optical analytical method with the use of IPS UA analyzer, a device for specifying the granulation of solid particles in the air. In the optical measuring instrument the stream of infrared radiation was scattered by passed particles. After measuring a set of particles was converted to class dimensional (KAMIŃSKI et al. 2008). Each sample weighing ca. 4 g was measured three times. The anticipated content of moisture, crude protein, crude fat and ash was measured with the help of InfraXact, near infrared analyzer from FOSS, scanning within the wavelength range of 570–1,850 nm. The apparatus contained calibration set developed by FOSS, which are updated by RINA network (Remote Internet Analysis). Each sample weighing 10 g was scanned ten times. The basic validation parameter was determined, namely laboratory repeatability or the absolute difference between individual results obtained by means of the same method, performed on identical materials, in the same laboratory and by the same operator using the same equipment during a short time span. The measure of repeatability is the coefficient of result variation calculated according to the formulae 1–3.

Calculation of the mean value for a component from a series of 10 measurements, following formula (1):

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} \tag{1}$$

x_i – value of each consecutive determination of the incremental sample,
$\bar{x}$ – the mean value of the determinations,
n – the number of determinations

and standard deviation, SD, from a series of 10 measurements, following formula (2):

$$\mathrm{SD} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{2}$$

SD – standard deviation.

Calculation of the coefficient of result variation, CV, following formula (3):

$$\mathrm{CV} = \frac{\mathrm{SD}}{\bar{x}} 100\% \tag{3}$$

CV – coefficient of variation.

Statistical analyses were performed with the use of Statistica package from StatSoft.

The results and the discussion

Sample results of analyzing the granulometric composition of the fragmented samples are presented in Figures 1–2 and in Table 1.

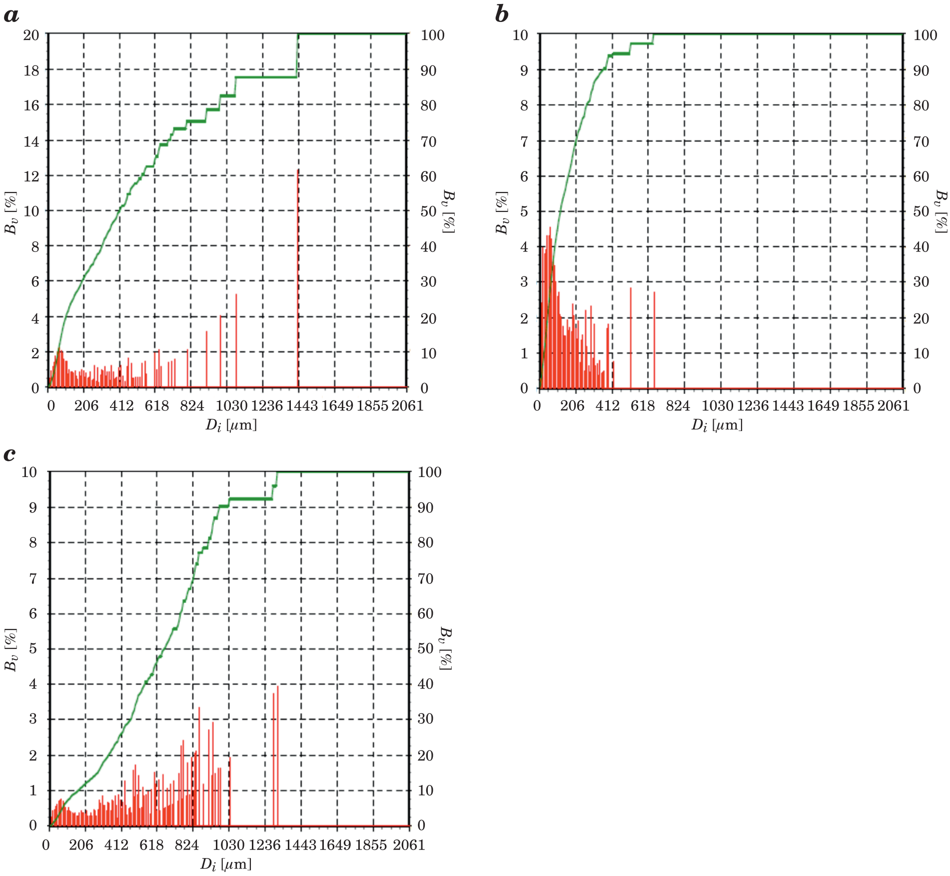

Fig. 1. Particle distribution in the samples of ground wheat: *a* – 1.0 mm sieve, *b* – 0.5 mm sieve, *c* – min. aperture

The smaller the sieve mesh in the grinder, the higher was the percentage content of fine particles in the milled feeding stuffs (Fig. 1, 2). The number of particles up to 200 μm ranged:

- for 1.0 mm sieve from 17.2% (grower diet for pigs) to 29.7% (wheat),
- for 0.5 mm sieve from 52.5% (grower diet for pigs) to 67.6% (wheat),
- for min. aperture from 11.5% (wheat) to 12.9% (grower diet for poultry).

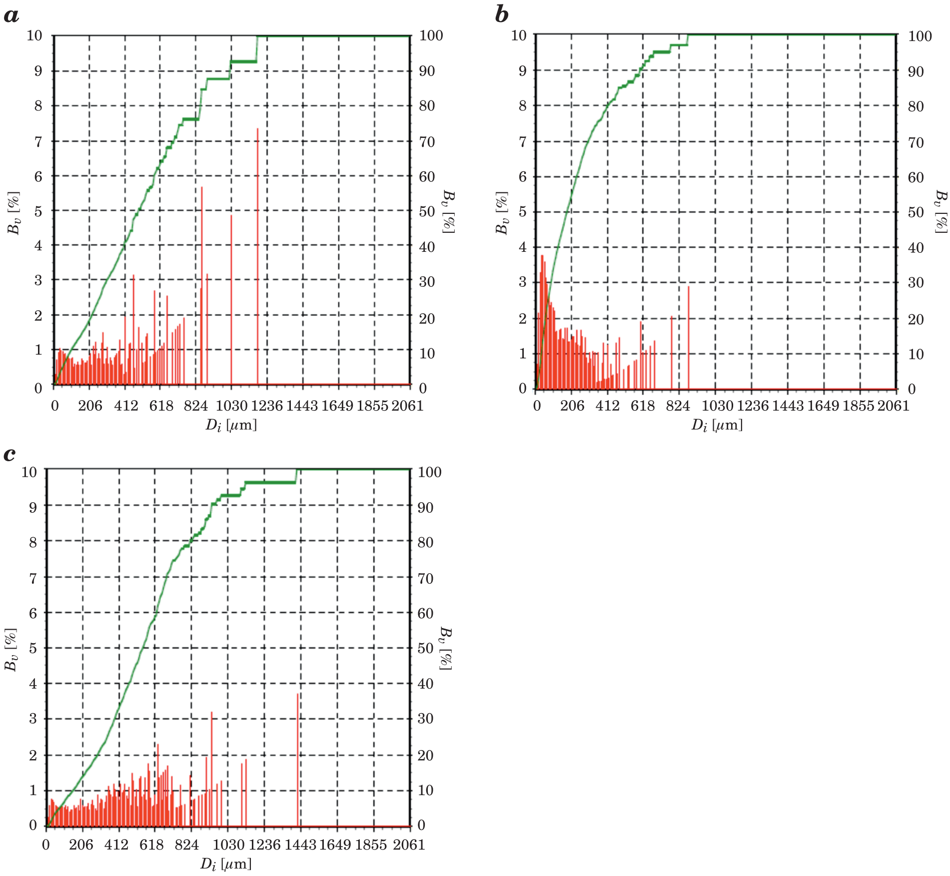

Fig. 2. Particle distribution in the samples of ground grower diet for pigs for fattening: *a* – 1.0 mm sieve, *b* – 0.5 mm sieve, *c* – min. aperture

The software used in the IPS UA analyzer let us calculate some characterizing parameters, such as the mean size of particles in the volume distribution, D_v, the diameter of particles marking exactly 50% of of the quantitative distribution, $D_{\mathrm{mod.}}$ The obtained values were the lowest in case of using a ø 0.5 mm sieve, and a ø 1,0 mm sieve. The highest values of the analyzed parameters were observed in case of using a grinder with the minimum aperture (Table 1).

The analysis of the content of nutrients in relation to the degree of grinding in the samples of the evaluated feed materials (Table 2) and diets did not reveal any unambiguous influence of the sample size in the studied range on the analyzed parameters: moisture, protein, fat, crude fiber and crude ash (Fig. 3). However, we observed a decrease in the content of water in the samples ground

Table 1

Selected characteristics of ground feeding stuffs

Material/Sieve [mm]	D_n [μm]	D_v [μm]	D_{mod} [μm]
Wheat			
1.0	21.2	56.3	420.1
0.5	16.7	34.5	121.5
Min. aperture	19.3	71.4	661.8
Starter diet for poultry			
1.0	34.0	81.9	424.9
0.5	31.0	55.2	152.5
Min. aperture	38.4	104.3	597.0
Grower diet for pigs			
1.0	23.2	68.8	459.8
0.5	24.8	48.7	185.3
Min. aperture	22.3	72.9	551.1

D_n – average particle size in a quantitative distribution, D_v – average particle size in a volume distribution, D_{mod} – mean value of the particles determining exactly 50% of the quantitative distribution

Table 2

The analysis of the content of nutrients in relation to the degree of sample grinding – feed materials (mean values)

Grinding/ sieve	Component	Wheat	Maize	Barley	Wheat bran	Soybean meal
1.0 mm	protein [%]	14.67^{a}	8.11^{a}	10.36^{ab}	17.22^{a}	48.04^{a}
0.5 mm	protein [%]	14.67^{a}	8.72^{b}	10.19^{b}	16.98^{b}	47.18^{b}
min. aperture	protein [%]	14.76^{a}	8.30^{c}	10.50^{a}	17.35^{a}	47.80*c*
1.0 mm	moisture [%]	11.60^{a}	12.11^{a}	11.75^{a}	13.55^{a}	10.69*a*
0.5 mm	moisture [%]	11.44^{b}	12.06^{a}	11.46^{b}	12.52^{b}	10.29*b*
min. aperture	moisture [%]	11.62^{a}	12.15^{a}	11.89^{a}	13.97^{c}	10.96^{c}
1.0 mm	fat [%]	1.58^{a}	4.01^{a}	1.97^{a}	3.93^{a}	1.18^{a}
0.5 mm	fat [%]	1.49^{b}	3.68^{b}	1.85^{b}	4.11^{b}	0.88^{b}
min. aperture	fat [%]	1.45^{b}	3.90^{a}	1.32^{c}	3.78^{c}	1.17^{a}
1.0 mm	fiber [%]	3.38^{a}	2.51^{a}	4.00^{a}	8.48^{a}	3.33^{a}
0.5 mm	fiber [%]	3.19^{b}	2.24^{b}	3.49^{b}	8.71^{b}	3.45^{b}
min. aperture	fiber [%]	2.95^{c}	1.97^{c}	3.42^{b}	8.39^{a}	3.19^{c}
1.0 mm	Ash [%]	1.72^{a}	1.28^{a}	2.00^{a}	4.41^{a}	6.53^{a}
0.5 mm	Ash [%]	1.62^{b}	1.24^{b}	2.04^{a}	4.50^{a}	6.56^{b}
min. aperture	Ash [%]	1.60^{b}	1.19^{c}	1.83^{b}	4.07^{b}	6.47^{c}

a, b, c – significant differences, with $p < 0.05$, within component and feed material

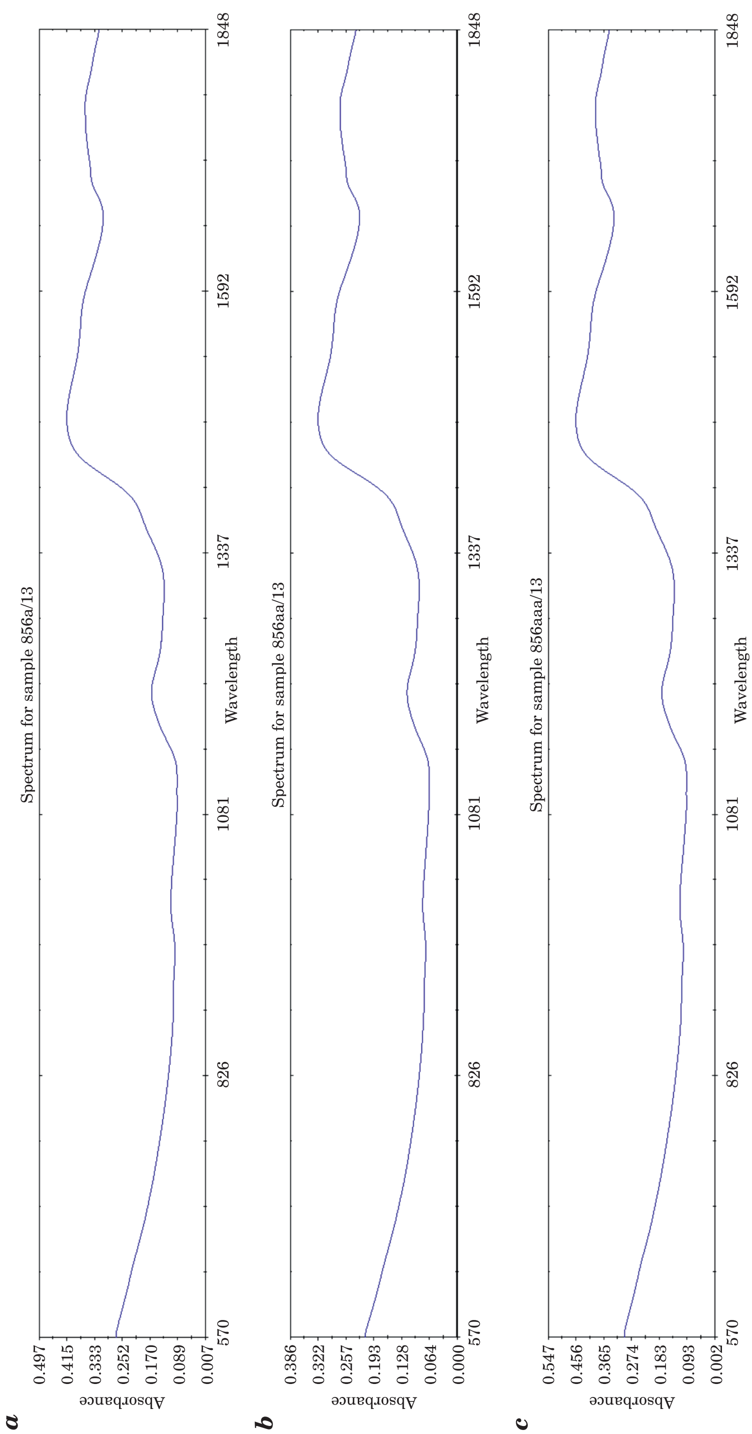

Fig. 3. Absorbance spectra for wheat ground: *a* – wheat – 1 mm sieve in grinder, *b* – wheat – 0,5 mm sieve in grinder, *c* – wheat – min. aperture in grinder

Table 3

Laboratory repeatability in relation to the degree of sample grinding – feed materials

Material	Parameter/Value determined [%]	Repeatability [%] grinding 1.0 mm	0.5 mm	min. aperture
Wheat	protein – 14.7	1.10	0.64	0.92
Maize	protein – 8.38	1.97	1.05	1.23
Barley	protein – 10.35	1.98	2.41	1.50
Wheat bran	protein – 17.18	0.93	0.78	0.88
Soybean meal	protein – 47.67	0.27	0.27	0.42
	Mean value	**1.25**	**1.03**	**0.99**
Wheat	moisture – 11.55	0.82	1.13	0.88
Maize	moisture – 12.11	1.09	0.95	1.48
Barley	moisture – 11.17	0.62	1.73	1.58
Wheat bran	moisture – 13.45	0.91	2.15	1.80
Soybean meal	moisture – 10.65	2.22	0.56	0.94
	Mean value	**1.13**	**1.30**	**1.34**
Wheat	fat – 1.57	3.89	4.63	5.02
Maize	fat – 3.83	2.94	1.13	7.37
Barley	fat – 1.71	6.12	3.06	7.50
Wheat bran	fat – 3.94	2.25	2.77	1.65
Soybean meal	fat – 1.08	5.20	7.34	4.46
	Mean value	**4.08**	**3.79**	**5.20**
Wheat	fiber – 3.27	3.64	4.63	5.02
Maize	fiber – 2.24	2.85	4.65	7.51
Barley	fiber – 3.64	4.12	3.61	4.60
Wheat bran	fiber – 8.53	1.92	1.36	1.75
Soybean meal	fiber – 3.32	2.60	2.54	2.05
	Mean value	3.03	3.36	4.19
Wheat	ash – 1.65	2.87	1.35	1.85
Maize	ash – 0.90	0.78	1.83	3.33
Barley	ash – 1.96	2.25	2.81	1.33
Wheat bran	ash – 4.32	4.14	3.32	7.57
Soybean meal	ash – 6.52	0.36	0.55	0.32
	Mean value	**2.08**	**1.97**	**2.88**

with the use of the ø 0.5 mm sieve, as compared to the other methods of milling. During processing the sample was heated, so some of the water could have evaporated. The content of fiber and crude ash was lower in the samples ground on the disc mill. However, the differences were not statistically significant in some cases.

Table 3 presents a comparison of the values calculated for laboratory repeatability, depending on the degree of sample grinding for feed materials. Similar results were obtained for feed diets. The values in particular groups did not differ significantly. Average laboratory repeatability for feed materials and the sieve used were, respectively, 1.0 mm sieve – 2.31%, 0.5 mm sieve – 2.29%, min. aperture – 2.92%. This parameter was comparable with the data obtained in validation examinations performed in the National Feed Laboratory in Lublin (Table 4).

Table 4

Laboratory repeatability in validation examinations in the National Feed Laboratory, following the Commission Regulation No 152/2009 of 27 Jan. 2009

Analysis	Laboratory repeatability [%]
Protein	1.0
Moisture	1.1 – 1.4
Fat	1.4 – 1.5
Fiber	2.8 – 4.25
Ash	1.3 – 2.0

Summary

1. Within the range of the studied degree of grinding the method of analyzing the content of nutrients with the use of the InfraXact apparatus is low sensitive to the diversified granulometric composition of the samples.

2. However, while determining humidity excessive degree of sample grinding should be avoided (0.5 mm sieve), since the material may become overheated and some water could evaporate.

3. Laboratory repeatability for the results obtained by means of the NIRS method is comparable with repeatability of the accredited methods following Commission Regulation (EEC) No 152/2009.

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EFFECT OF TEMPERATURE AND CONCENTRATION ON RHEOLOGICAL PROPERTIES OF BEETROOT JUICE

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Key words: beetroot juice, rheological properties, viscosity.

Abstract

The rheological behaviour of beetroot juice as a function of soluble solid content (from 10°Bx to 50°Bx) at a wide range of temperatures (from 10°C to 60°C) was studied. The measurements were made using rotational rheometer (Brookfield Engineering Laboratories: model LVDV-II + PRO). The investigation showed that the beetroot juice was Newtonian in behaviour and the viscosity was changed from 0.77 mPa s to 28.4 mPa s. The Arrhenius-Guzman equation was used to calculate the values of flow activation energy. In order to evaluate the influence of soluble solid content two models were applied: the power law and exponential equation. A new equation was proposed to express the combined effect of temperature and concentration on beetroot juice viscosity.

Introduction

Beetroot juice is one of the richest sources of antioxidants (WOOTTON-BEARD et. al. 2011) and naturally occurring nitrates. It also contains many other promoting compounds such as magnesium, potassium, iron, zinc, calcium, phosphorus, sodium, niacin, biotin, soluble fibre and vitamins A, B and C (WOOTTON-BEARD, RYAN 2011). Additionally beetroot juice provides a number of polyphenolic compounds (KAUR, KAPOOR 2002) as well pigments such as carotenoids (DIAS et al. 2009) and betalains (PITALUA et al. 2010).

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Therefore, drinking beetroot juice could help to protect against heart disease and certain types of cancer, particularly lung and skin cancer (KAPADIA et al. 1996).

Processing beetroots needs knowledging of rheological properties. The rheological properties of juices is an important property, which has several application in developing food process, processing equipment, quality evaluation and structural understanding of food and raw material (MANJUNATHA, RAJU 2013). They are required to determine the power requirements for unit operation such as: pumping, sizing of pipes, pasteurization, filling, mixing, evaporation etc. They are also important in the calculation of heat, mass and momentum transfer phenomena (TELIS-ROMERO et al. 1999). Vegetable and fruit juice were subjected to different temperatures and concentration levels during processing, storage and transportation, where the rheological properties can be changed dramatically. Typical properties of the data for beetroot juice are rather limited. The aim of the paper was to study rheological behavior of beetroot juice as a function of temperature and solid concentration.

Material and methods

A sample of commercial beetroot juice was purchased from local market. The raw juice with approximately 10°Bx was concentrated to different concentration levels at 20, 30, 40 and 50°Bx by vacuum evaporation technique using laboratory rotary vacuum evaporator (Model; Buchi Rotavapor R-205) at 60°C with reduced pressure. The rotational speed of a flask was fixed at 60 rpm. The content of extract in juice was determined with the help of the refractometer Atago model Pal-1.

Rheological properties were measured using Brookfield viscometer (Brookfield Engineering Laboratories: model LVDV-II + PRO). A 500 ml sample of beetroot juice was used in a glass baker for all experiments. The temperature of sample was changed from 10 to 60°C and kept at constant value using water bath (Brookfield TC-502P). The flow curves at different temperatures were obtained in the range of shear rate of 12-130 s^{-1} using specific spindle S-61. The computer software (Rheolac 3.1) was applied to control viscometer and data acquisition. All experiments were carried out in three replications.

Results

The experimental flow curves obtained for the concentrated beetroot juice at different temperatures were shown in Figures 1–5. The rheograms of beetroot juice showed that there was linear increase in shear stress with respect to increase in shear rate. These results indicate the Newtonian behavior of concentrated beetroot juice.

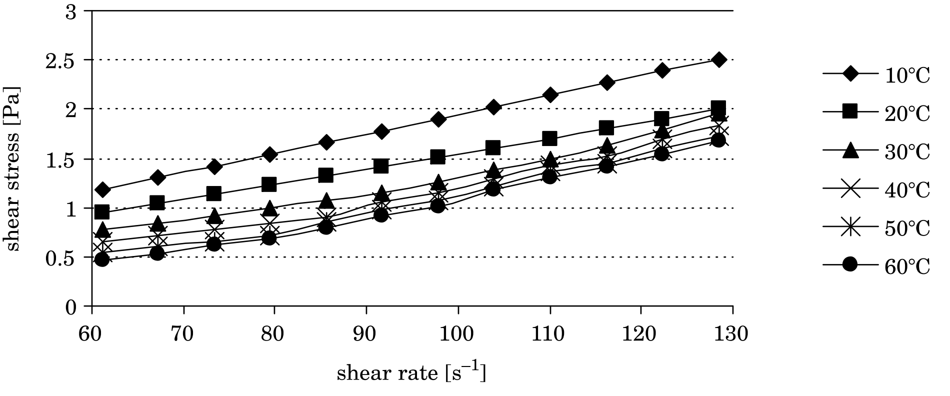

Fig. 1. Flow curves of concentrated beetroot juice (10°Bx) at different temperatures

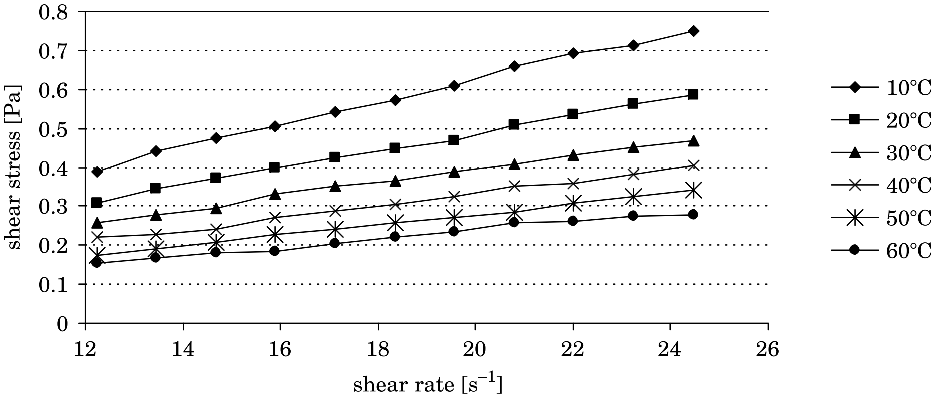

Fig. 2. Flow curves of concentrated beetroot juice (20°Bx) at different temperatures

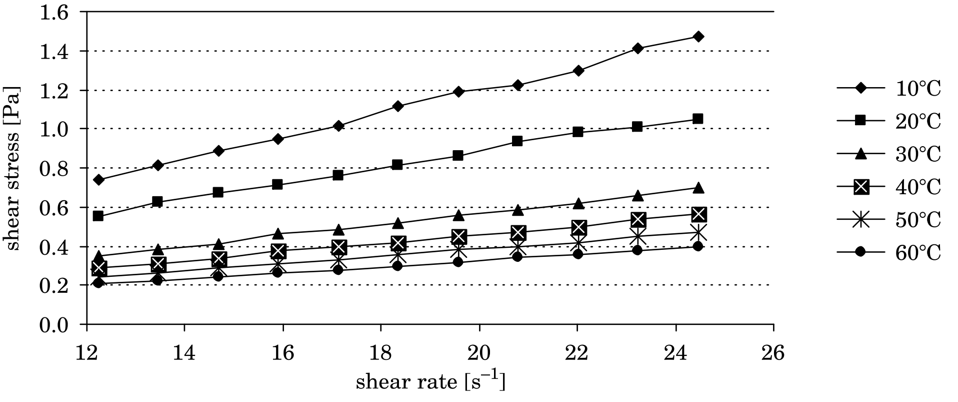

Fig. 3. Flow curves of concentrated beetroot juice (30°Bx) at different temperatures

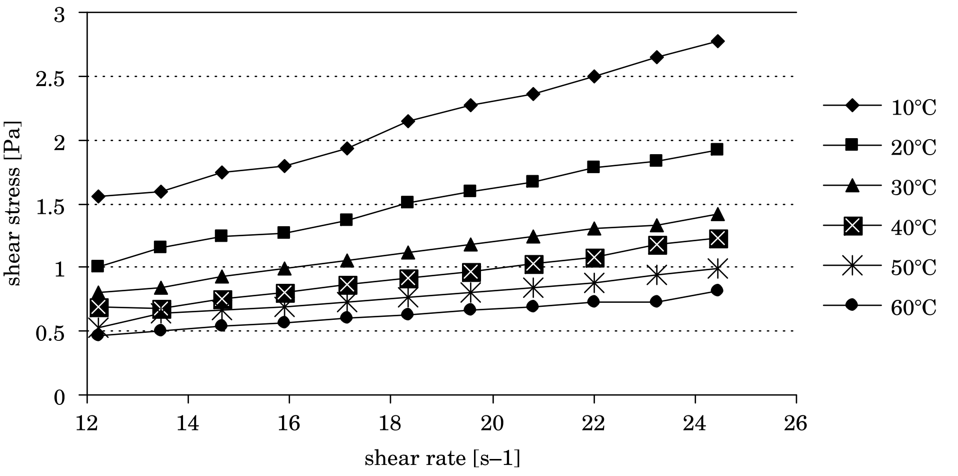

Fig. 4. Flow curves of concentrated beetroot juice (40°Bx) at different temperatures

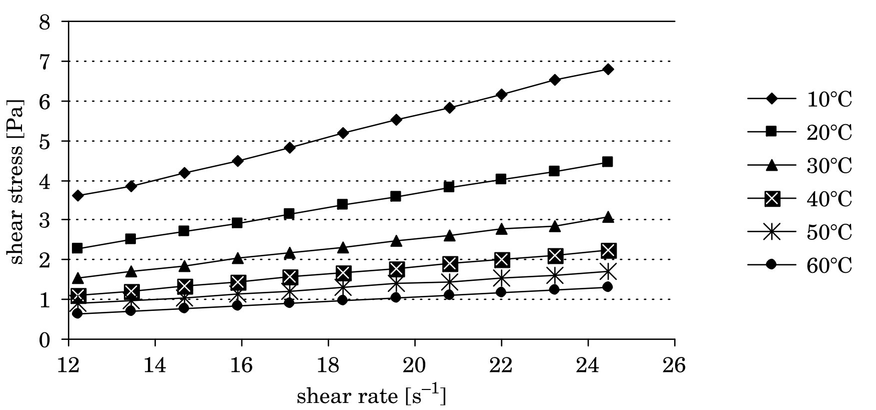

Fig. 5. Flow curves of concentrated beetroot juice (50°Bx) at different temperatures

Figure 6 shows the influence of temperature and soluble solid content on viscosity of beetroot juice.

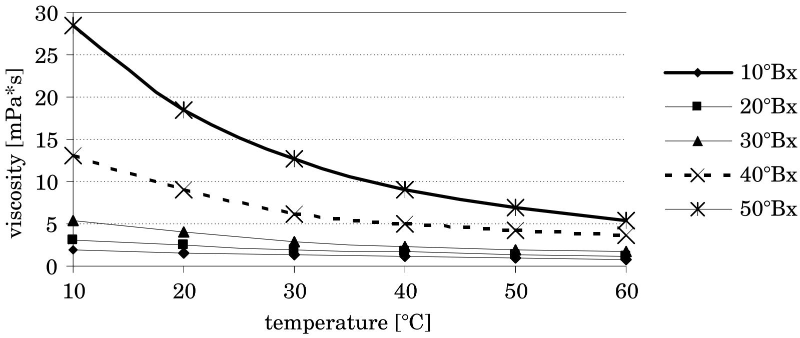

Fig. 6. The effect of temperature and the content of soluble solids on the viscosity of beetroot juice

Both the temperature and the soluble solid content had a significant effect on the viscosity of beetroot juice. The increase in temperature of fluid leads to increase in mobility of the molecules and increase in intermolecular spacing, which decreases the flow resistance. The viscosity of beetroot juice decreased markedly with increase in temperature. The variation in viscosity of beetroot juice with temperature was significantly high at a higher soluble solid content. The concentration of the soluble solids had a strong effect on viscosity of the Newtonian liquids. The increase in soluble solid content leads to change in degree of hydration of solute molecules, increase in hydrogen bonding with hydroxyl groups of solute and decrease in intermolecular spacing, which increases the flow resistance. The viscosity of beetroot juice increased rapidly with increase in soluble solid content.

The variation of viscosity with soluble solid content at particular temperature could be described by an exponential equation (IBARZ et al. 2009, PEROŃ et al. 2010]:

$$\eta = \eta_1 \exp(bC) \tag{1}$$

where:

η – is the viscosity [Pa · s],
η_1 – is the viscosity when the soluble solids content is 0°Brix [Pa · s],
b – is a constant [°Bx^{-1}],
C – is the concentration [°Bx].

Table 1 shows the values of the parameters, the determination coefficients and RMS for each temperature tested.

Table 1

Effect of soluble solids content on viscosity

Temperature	η_1	b	R^2	RMS
10	0.849	0.068	0.98	0.12
20	0.745	0.062	0.98	0.11
30	0.625	0.057	0.97	0.13
40	0.566	0.054	0.97	0.13
50	0.504	0.051	0.98	0.11
60	0.448	0.049	0.98	0.10

The parameter b decreases with the increase of temperature. The increase of viscosity at high temperature is smaller with the rise of concentration. Similar trends have been observed in other studies (RAO et al. 1984, IBARZ et al. 1992, 1994).

From the engineering viewpoint, it is useful to obtain a single equation that describes the combined effect of temperature and soluble solids contents on the viscosity of the beetroot juice. The parameters η_1 and b in equation 2 and 3 are dependent on juice temperature. Figure 7 shows the influence of temperature on values of constant η_1 and b.

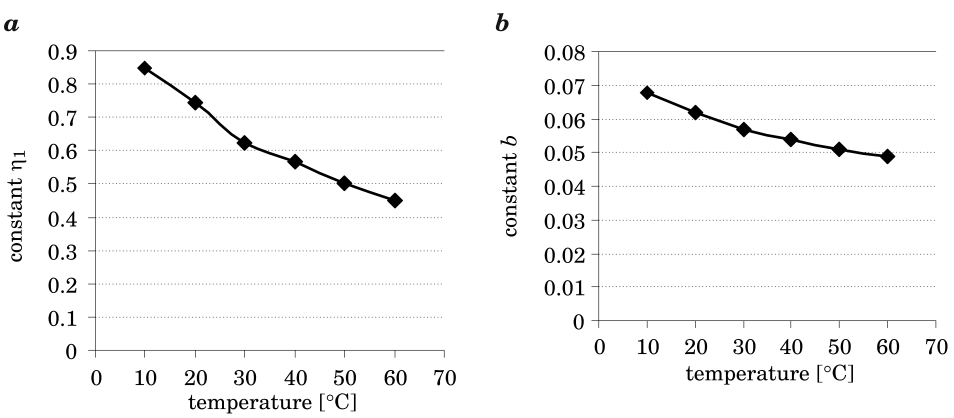

Fig. 7. Influence of temperature on values of constant η_1 (*a*) and b (*b*)

The relationship between temperature and constants η_1 and b could be written by linear equations:

$$\eta_1 = k_1 t + k_2 \tag{2}$$

and

$$b = k_3 t + k_4 \tag{3}$$

where:
k_1 – constant [$^{o}C^{-1} \cdot Pa \cdot s$],
k_2 – constant [$Pa \cdot s$],
k_3 – constant [$^{o}C^{-1} \cdot {}^{o}Bx^{-1}$],
k_4 – constant [$^{o}Bx^{-1}$],
t – temperature [^{o}C].

The final equation which represents combined effect of temperature and total soluble solid content on viscosity beetroot juice was given by:

$$\eta = (k_1 t + k_2)\exp[C(k_3 t + k_4)] \quad (4)$$

The parameters of the equation 4, the determination coefficient and RMS were reported in Table 2.

Table 2
The equation describing the dependency of viscosity against the temperature and the content of soluble solids

Equation	R^2	RMS
$\eta = (-0.008t + 0.915)\exp[C(-0.0005t + 0.0745)]$	0.99	0.16

The values of flow activation energy were calculated using Arrhenius-Guzman equation:

$$\eta = A_0 \exp\left(\frac{E_a}{RT}\right) \quad (5)$$

where:
η – viscosity [$Pa \cdot s$],
A_0 – material constant/pre-exponential coefficient/frequency factor [$Pa \cdot s$],
E_a – flow activation energy [$kJ \cdot mol^{-1} K^{-1}$],
R – gas constant [$kJ \cdot mol^{-1} K^{-1}$],
T – temperature [K].

Table 3 shows the values of the material constant and the flow activation energy for different soluble solid content.

Table 3

The Arrhenius equation parameters of beetroot juice

Soluble solid content [°Bx]	Material constant [mPa · s]	Flow activation energy [kJ · mol^{-1} K^{-1}]
10	0.0043	14.2
20	0.0063	14.6
30	0.0028	17.6
40	0.0023	20.2
50	0.0004	26.2

The flow activation energy is defined as minimum energy required which overcomes the energy barrier before the elementary flow can occur. The higher activation energy the greater influence of temperature on the viscosity.

The activation energy of beetroot juice rises with increase in soluble solid content. The values of flow activation energy of beetroot juice changed from 14.2 kJ · mol^{-1} K^{-1} for solid concentration of 10°Bx to 26.2 kJ · mol^{-1} K^{-1} for solid concentration of 50°Bx. A comparison of the results with literature data indicates that they were in conforming to values reported for other juice exhibiting Newtonian behavior (JUSZCZAK, FORTUNA 2004, IBARZ et al. 2009).

The variation of activation energy with solid soluble content could by described by two different models: the power law and exponential equation:

$$E_2 = a_1 C^{b_1} \tag{6}$$

$$E_a = a_2 \exp(b_2 C) \tag{7}$$

where:

C – total soluble solid content [°Bx],

a_1 – empirical constant [kJ · mol^{-1} · K^{-1} · °Bx^{-1}],

a_2 – empirical constants [kJ · mol^{-1} · K^{-1}],

b_1 – empirical constant [–],

b_2 – empirical constant [°Bx^{-1}].

The models were used to fit the values of flow activation energy with soluble solid content. The magnitudes of the parameters and determination coefficient and RMS were reported in Table 4. The results indicated that exponential model was more effective to describe the influence of total soluble solid content on flow activation energy of beetroot juice.

Table 3
The power law and exponential equation describing the dependency of flow energy activation against the content of soluble solids

Model	Equation	R^2	RMS
Power law	$E_a = 4.44C^{0.429}$	0.82	0.11
Exponential equation	$E_a = 10.88\exp(0.0168C)$	0.95	0.06

Conclusions

The rheological behaviour of beetroot juice was studied as a function of soluble solid content (from 10°Bx to 50°Bx) and temperature (from 10°C to 60°C). The results indicated that beetroot juice exhibits Newtonian behavior. The value of viscosity was strongly influenced by temperature and concentration of juice and changed in the range from 0.77 mPa · s to 28.4 mPa · s. The Arrhenius-Guzman equation was used to calculate the values of flow activation energy which ranged from 14.2 kJ · mol^{-1} K^{-1} for solid concentration at 10°Bx to 26.2 kJ · mol^{-1} K^{-1} for solid concentration at 50°Bx. The effect of soluble solids content on flow activation energy was described by exponential equation and the power law, but a better fit was obtained for the exponential function. A new equation was proposed to express the combined effect of temperature and concentration on viscosity beetroot juice.

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