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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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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***

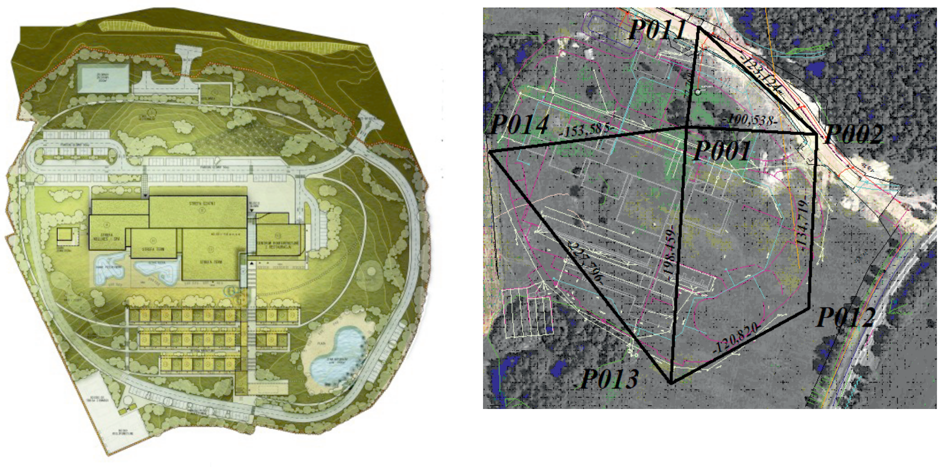
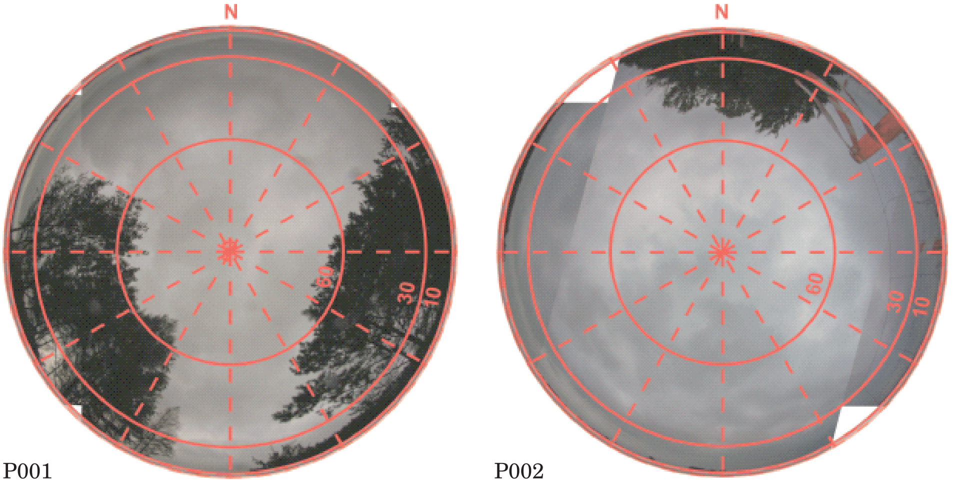


Fig. 1. The design of the complex (*a*) and the sketch of a designed control network (*b*)

a ***b***



P001 P002

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.

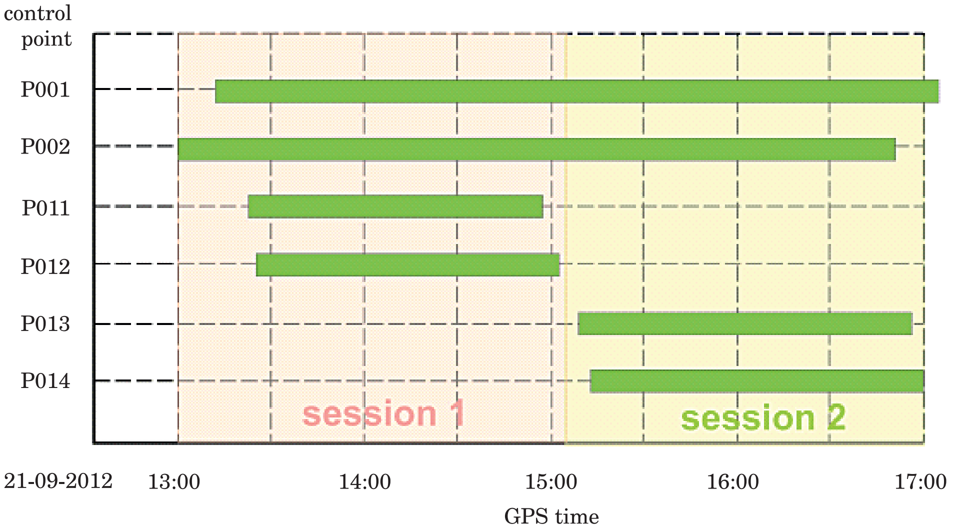


Fig. 3. Schedule of observation sessions

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%.

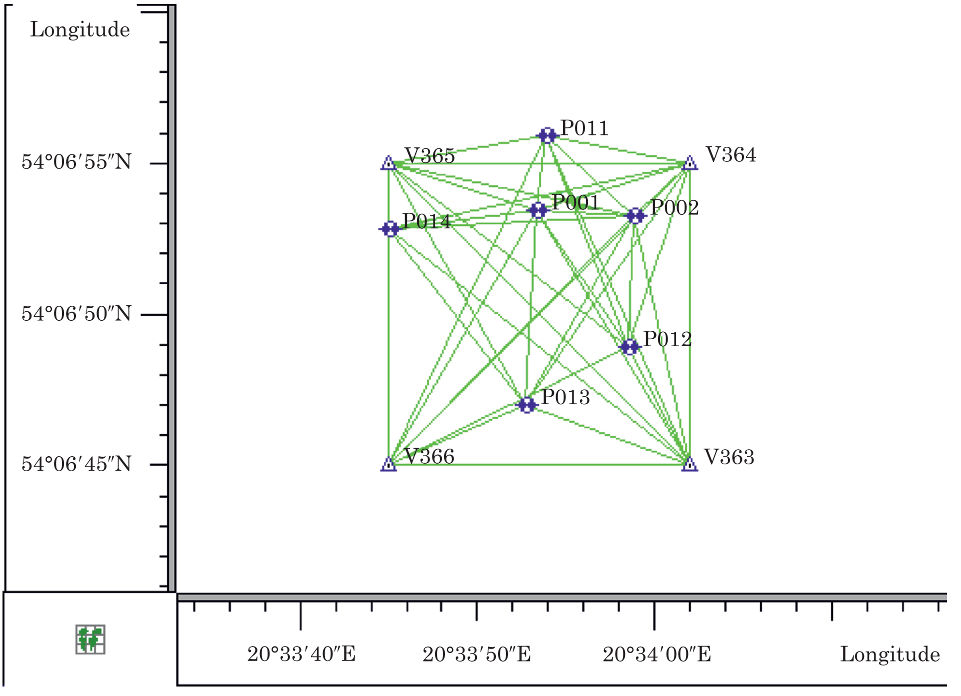


Fig. 4. Distribution of control points and virtual reference stations

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

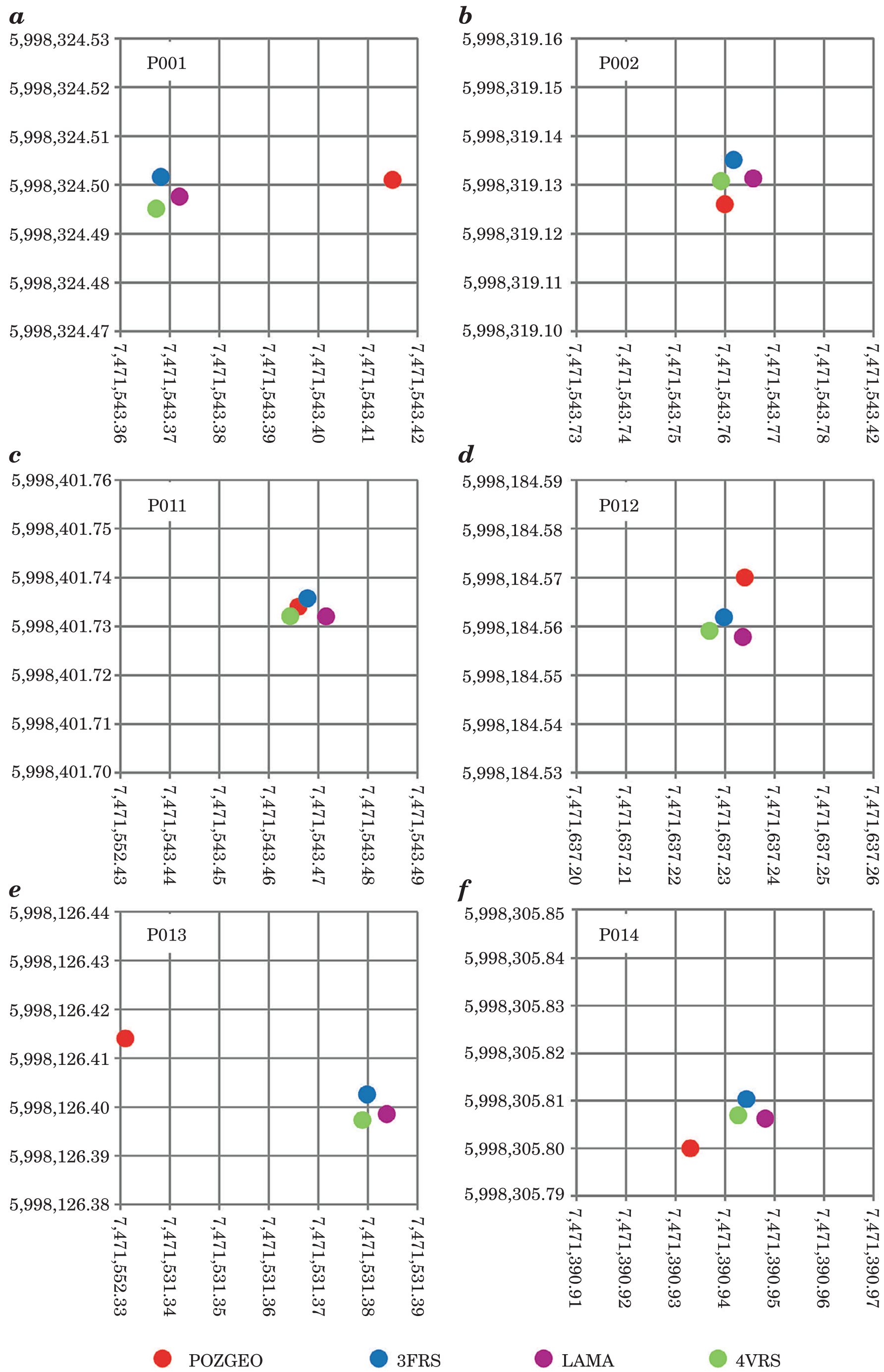


Fig. 5. The distribution of the plane coordinates obtained at each measurement point

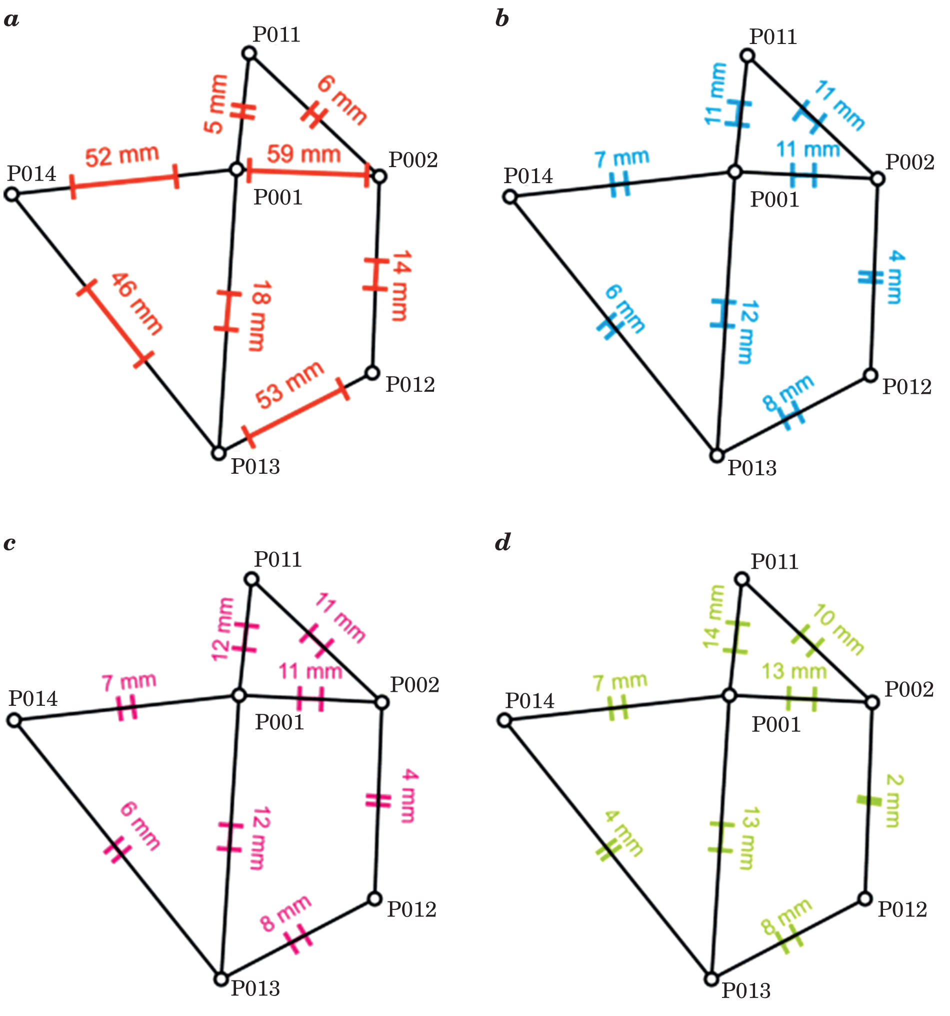


Fig. 6. Differences in baseline length between tachometry and GNSS solutions: *a* – POZGEO, *b* – 3FRS, *c* – LAMA, *d* – 4VRS

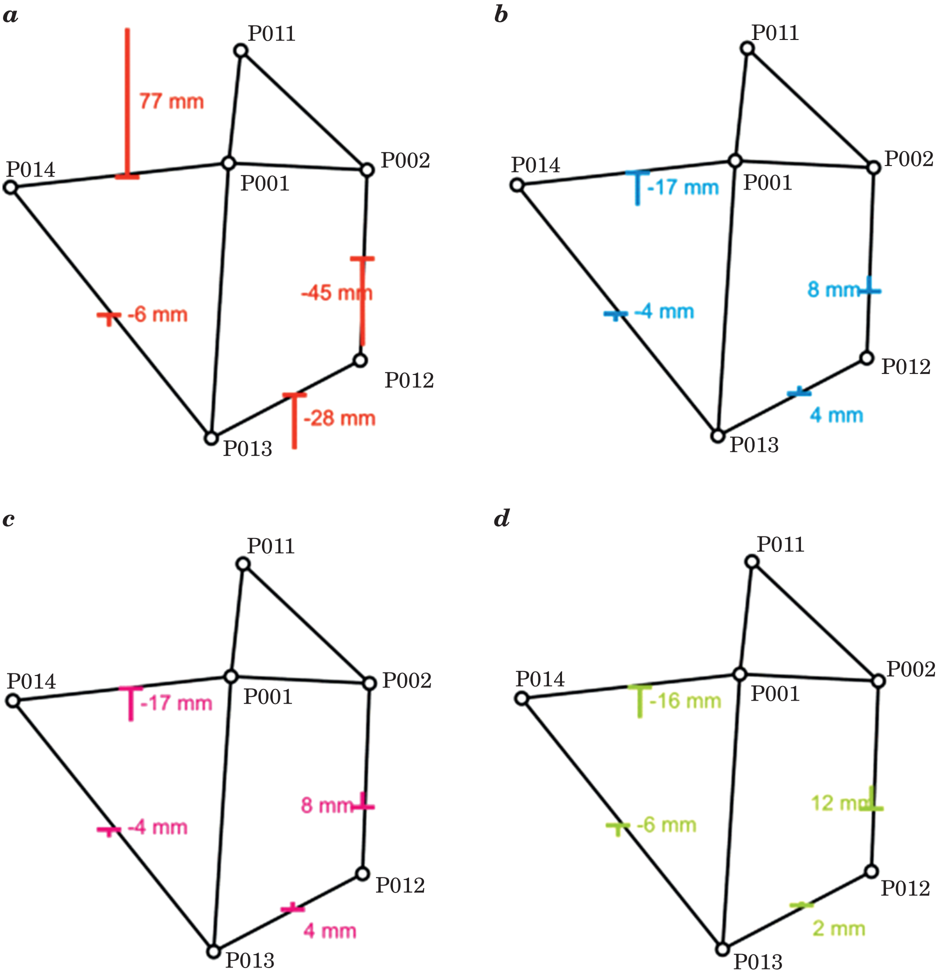


Fig. 7. Differences in height between leveling and GNSS solutions: *a* – POZGEO, *b* – 3FRS, *c* – LAMA, *d* – 4VRS

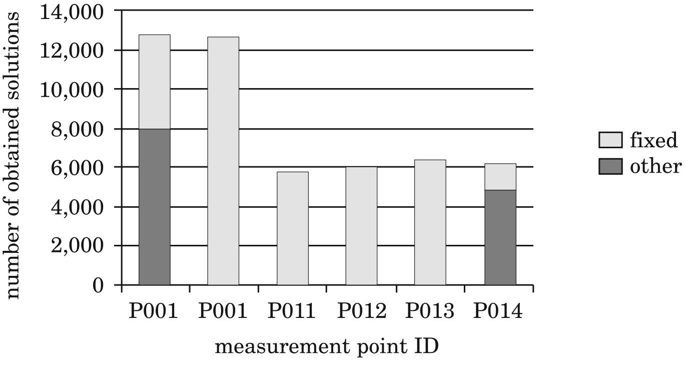


Fig. 8. The structure of solutions obtained from the kinematic method

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.

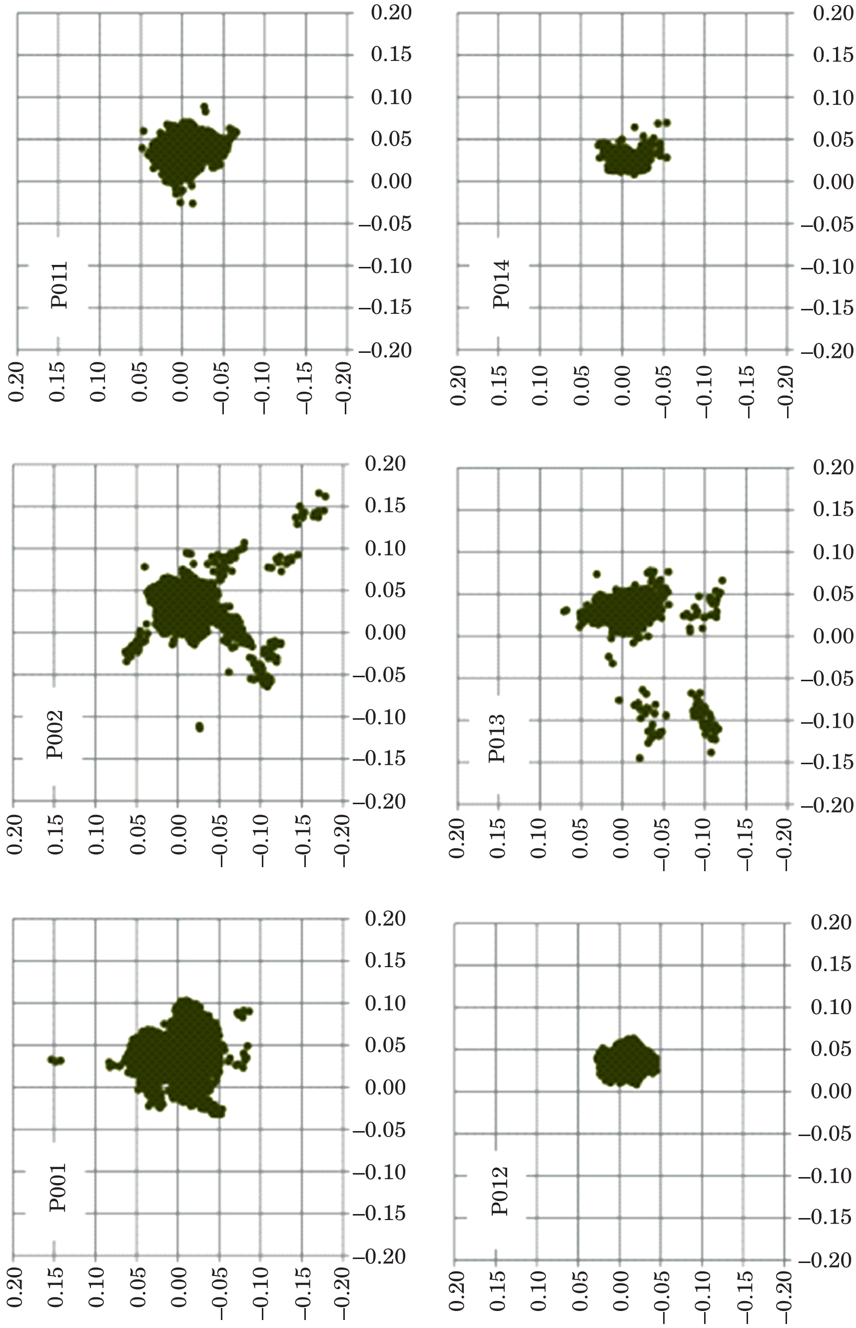


Fig. 9. The precision of plane coordinates obtained from a kinematic solution

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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