Management Systems in Production Engineering

2014, No 4 (16), pp 168-171

DOI 10.12914/MSPE-05-04-2014

ALGORITHMS VARIANTS OF ELABORATION OF THE PRECISE GNSS NETWORK ESTABLISHED FOR GEODETIC SERVICE OF BUILDING OF THE MINING FACILITY

Ryszard MIELIMĄKA
Silesian University of Technology
Zbigniew SIEJKA
University of Agriculture in Krakow

Abstract:
The article presents the problem of the usage of post-processing services of the ASG-EUPOS system on the example of GNSS network established for geodetic service of building of the inclined drift, to make coal deposit accessible, and also building associated objects. For the purpose of geodetic service of construction realization network was established outside the planned objects.

The network consists of six new ground points and four control points belonging to ASG-EUPOS network. Simultaneous, static measurements of the network were performed in three-hour observation session, using multi-frequency and multi-system satellite receivers – Trimble R8.

The paper presents three variants of post-processing of the observation results. Calculations were performed using POZGEO-D service and geodetic software package GEONET. The results of the calculation process revealed, that homogeneous vector networks should be adjusted on the ellipsoid or in the geocentric system. Model of adjustment of the vector network on the plane adopted in the GEONET software package should not be applied for elaboration of this type of network (long reference vectors more than 50km).

Key words: *GNSS, POZGEO-D, post-processing*

INTRODUCTION

Geodetic ground control is the fundamental link in the technological-geodetic chain, which has a decisive impact on the quality and relevance of final products of all geodetic elaborations [1].

Geodetic points realize in the country geodetic reference system and the system of heights [4]. The ground control is a basis for all measurements, cartographic elaborations and laying out, carried out by the surveyors.

Currently, according to the Regulation of Minister of Administration and Digitization of February 14, 2012, „in the case of geodetic, gravimetric and magnetic ground controls" and Regulation of the Minister of Internal Affairs and Administration of November 9, 2011, „in the case of technical standards of performing geodetic surveying and height measurements, also in the scope of elaboration and transfer of measurement results to the National *Geodetic* and *Cartographic* Resource" geodetic ground control is divided into:

- fundamental network,
- basic network,
- detailed network,
- survey network,
- realization network.

Measurements of: setting-out of building, geodetic service of construction and construction of buildings, displacements and deformations of buildings and also measurements of geodetic post-completion stocktaking of buildings or buildings elements are performed basing on geodetic survey ground control or realization ground control [4].

Realization ground control is being established when:

- it's impossible to set-out directly from the existing horizontal geodetic ground control and survey ground control,
- the accuracy of the existing geodetic horizontal and vertical ground controls is too low to meet the needs of investment,
- the existing geodetic horizontal and vertical ground controls may be destroyed during realization of investment.

Realization ground control is being referenced to horizontal and vertical geodetic ground control and adjust by the method of least squares with calculation of mean square errors of points location.

Realization ground control in terms of construction can be:

- a single-row network,
- a double-row network established for complex and large investments which are accomplished in stages.

THE INVESTIGATED OBJECT AND MEASUREMENT METHODOLOGY

In the newly raised mining facility the construction of inclined drift was started, to connect the surface with the existing excavations at 700 m level. Transport of the output will take place from the depths of the mine to the surface also by the drift.

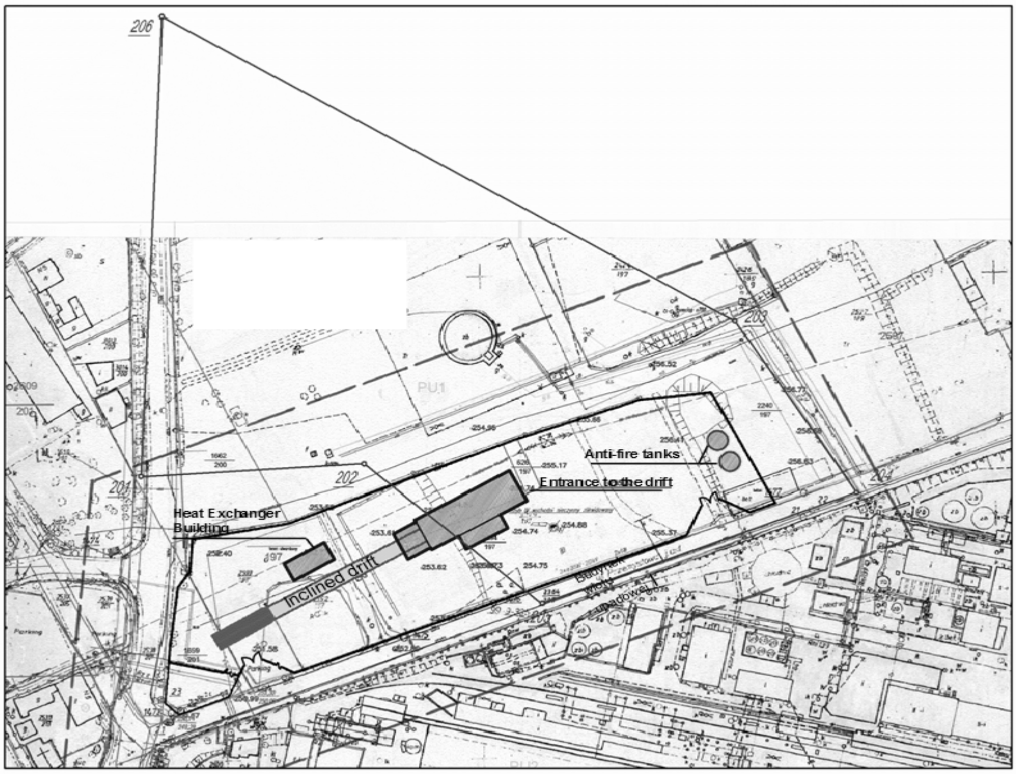

Fig. 1 Arrangement of determined points of the realization control for the geodetic service of building of the inclined drift and associated objects

Building area of the drift has approximately shape of a rectangle measuring about 230x62 m (Fig. 1). In this area, it is intended to build, in addition to the above-ground part of the inclined drift, main objects, like: building of the inclined drift inlet with dimensions of 42x14 m, heat exchanger building with dimensions of 18 x 8 meters, and two anti-fire tanks with a diameter of 8.6 m, and also it's planned to build infrastructure networks: water supply, heating, electricity, tele-technical, also sanitary and storm sewers.

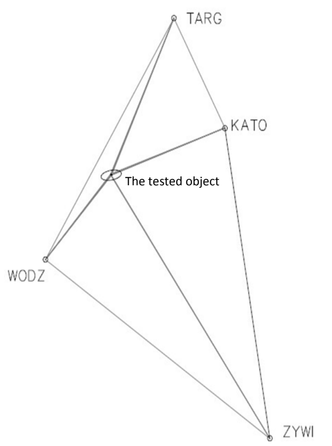

Fig. 2 Configuration of reference stations used in the measuremen

The drilled drift will be 10˚ inclined, it will be 6 m width and at the beginning – on a distance of about 92 meters it will be carried out directly in a trench, but at the end of the course approximately 25 meter long section will be covered. Next, the trench excavation method will be changed to mining methods.

In order to realization process of the drift building and its associated objects there was established a realization network composed of ten points. Six points were newly determined and located outside construction area (Fig. 1), while the rest four points were existing points belonging to the ASG-EUPOS system (Fig. 2).

Determination of the coordinates of the network points was made with usage of satellite techniques by applying the static method, in reference to four permanent and nearest reference stations of ASG-EUPOS system (KATO in Katowice, TARG in Tarnowskie Góry, ZYWI in Żywiec and WODZ in Wodzisław Śląski).

Newly created points were located in places ensuring their sustainability and stability during the whole construction period. Their location was chosen in such way, to:

- make it possible to reference realization measurements made by classical methods to the new geodetic network,
- make one of the sides of the network (side 205-206) as a basis for gyroscopic measurements, which are necessary on the stage of realization of the inclined drift and horizontal orientation of the mining extraction level.

Measurements at particular points have been planned in such way to ensure optimal conditions for observation of satellites, the same times of the observation on all points and correctness of the network geometry preserving high quality of additional observations and direct, optimum reference to superior class points.

Duration of the measurement session for the vectors between new points was assumed for 3 hours, with following measurement parameters:

- data logging interval from satellites was equal 1 second, the minimum number of satellites was set to 5,
- the opening angle of the horizon equal 10˚.

GPS antennas were leveled and centered using tripods, tripod heads and precise optical plummets, equipped with precise tubular levels.

The measurements of antennas heights were performed with accuracy of ±1 mm – inclined distances were measured (3 measurements on each point) between the center of ground mark and a reference point on the antenna (Antenna Reference Line). Applied solutions were aimed at minimizing operator errors.

ELABORATION OF VECTOR'S GPS NETWORK

Currently, in accordance to regulations, geodetic networks are being constructed using: static GNSS measurements, measurements performed with usage of ASG-EUPOS system and classical methods – traverse and resections measurements.

Realized network realized was a *„pure"* GPS vector network tied to reference stations of the ASG-EUPOS system (Fig. 2).

The proper alignment of the geodetic network has been preceded by the post-processing GNSS observations [3].

In the literature and in the practice there were distinguished generally three methods of strict adjustment of networks similar to presented in the article. They depend on the choice of the mathematical space, in which the adjustment process will be performed [2].

Adjustment of the network in three-dimensional geocentric Cartesian coordinate XYZ system of the GRS80 (WGS-84) ellipsoid

In this method of adjustment, GPS (ΔX, ΔY, ΔZ) vectors are the observations directly adjusted, in the linear task of the least squares method.

System of normal equations in general notation has the form:

$$A^T \cdot P \cdot A \cdot X = A^T \cdot P \cdot L \qquad (1)$$

where:
X – vector of unknown coordinates of points,
A – matrix of coefficients of unknowns,
P – weight matrix,
L – vector of free terms.

Next, globally adjusted geocentric coordinates XYZ are being transformed to the horizontal coordinates of xy system.

$$XYZ(GRS80) \rightarrow BLH(GRS80) \rightarrow xy2000/18 \qquad (2)$$

Adjustment of the network on GRS80 (WGS-84) ellipsoid

In this method, before the final stage of adjustment, it is important to properly convert GPS vectors to the new mathematical space, in which functional model of the adjustment will be created.

In this method three-dimensional GPS (ΔX, ΔY, ΔZ) vectors, in the first stage of adjustment, are being converted to the given (WGS-84) ellipsoid into vectors of geodetic lines (s, A) and ellipsoidal heights differences (Δh) creating so called pseudo-measurements:

$$(\Delta X_{jk}, \Delta Y_{jk}, \Delta Z_{jk}) \rightarrow (s_{jk}, A_{jk}, \Delta h_{jk}) \qquad (3)$$

Next, pseudo-measurements are being finally adjusted on WGS-84 ellipsoid (determined are B, L coordinates for all points). At the end we transform the results to the cartographical coordinates system, e.g. „xy2000".

Adjustment of the network in map projection system

This procedure requires the preparation of pseudo measurements set, (plain of pseudo vectors) for adjustment on a proper projection plain, e.g. „xy2000".

It requires to complete the additional task involving the projection of the GNSS vector network to ellipsoidal network, and next to the network on the plane of projection:

$$(\Delta X_{jk}, \Delta Y_{jk}, \Delta Z_{jk}) \rightarrow (s_{jk}, A_{jk}, \Delta h_{jk}) \rightarrow (s'_{jk}, A'_{jk}) \qquad (4)$$

For practical reasons, (mostly to integrate satellite measurements with conventional ground-based observations) this procedure seems to be the most appropriate option of mathematical post-processing of integrated measurements.

However the key problem in this case is the correct post -processing of original GPS vectors to the pseudo measurements on the projection plain and this is a very complicated task.

RESULTS OF MEASUREMENTS AND CALCULATIONS

Adjustment of measured GNSS realization network in accordance to described variants was done with usage of POZGEO-D service and geodetic software package GEONET. This paper analyzes in details the results of plain coordinates "xy" adjustment. Global parameters of adjustment, that characterize the results of calculations, were shown in Tables 1, 2 and 3.

Table 1
Adjustment parameters in geocentric coordinates system XYZ (ETRF'89) – variant „W1"

Number of vectors	39
Mean horizontal error of antenna centering	0.0020 m
Mean error of antenna height measurement	0.0020 m
Number of all adjusted vectors (M)	39
Number of identified network points (LP)	10
Number of superior order points (3D)	4
Number of redundant elements (LU)	99
Mean squared error (Mo)	1.00
Average deviation of length vector vR(av)	0.0108
Maximum deviation of length vector vR(max)	0.0349

Table 2
Adjustment parameters on GRS-80 ellipsoid – variant „W2"

Number of all points in the network	10
Number of reference points of superior order	4
Number of points to be determined	6
Number of geodetic azimuths (GNSS)	39
Number of lengths GNSS	39
Number of unknown coordinates	12
The total number of observations	78
Redundancy of observations set	66
Global indicator of reliability: z [%]	84.6%
Average error of points position Mp(av)	0.0026 m
Maximum error of points position Mp(av)	0.0030 m
Mean squared error Mo	0.9858m
Partial estimates Mo for lengths	1.0845
Partial estimates Mo for azimuths	0.8756
Maximum deviation of geodetic line length	-0.0152 m
Average deviation of geodetic line length	0.0087 m

Table 3
Adjustment parameters on the plain of coordinates system xy2000 – variant „W3"

Number of all points in the network	10
Number of reference points of superior order	4
Number of points to be determined	6
Number of geodetic azimuths (GNSS)	39
Number of lengths GNSS	39
Number of unknown coordinates	12
The total number of observations	78
Redundancy of observations set	66
Global indicator of reliability: z [%]	84.6%
Average error of points position Mp(av)	0.0068 m
Maximum error of points position Mp(max)	0.0078 m
Mean squared error Mo	2.5495 m
Partial estimates Mo for lengths	1.0784
Partial estimates Mo for azimuths	3.4405
Maximum deviation of side length	-0.0130 m
Maximum deviation of azimuth	-10.9''

Distributions of mean squared errors of points locations obtained from the adjustments according to accepted variants were shown in the Fig. 3.

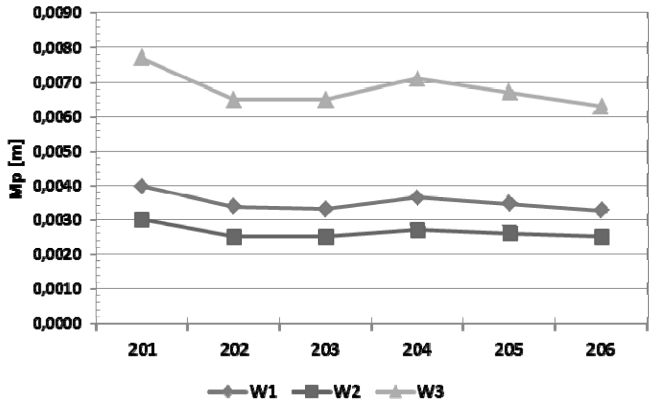

Fig. 3 Distributions of mean squared errors of points locations for the individual adjustment variants

CONCLUSIONS

Proper adjustment of observations, obtained during the measurement of the geodetic network, is fundamental to the quality of all works performed basing on determined control points. However, any properly made observation can raise the quality of the network elaboration. Very important issue related to the preparation of the correct sets of input data, is to bring the observations results to a common mathematical space, in which will be performed final network adjustment.

The experiments conducted in this study depended on that the same geodetic network, measured using the GNSS technique, static method, was aligned independently in three different mathematical spaces: in the geocentric coordinates system, on the GRS-80 ellipsoid, and on the projection plain in „2000/18” system.

Adjustment results showed, that adjustment of the network to ellipsoid after transformation of Cartesian vectors (ΔX, ΔY, ΔZ) in geodetic lines vectors (s_{jk}, A_{jk}) gave results that were the least affected by numeric errors:

- average error of points position $M_{p(av)}$ = 0.0026 m,
- maximum error of points position $M_{p(max)}$ = 0.0030 m.

Slightly worse results in terms of accuracy of numeric adjustment were obtained from the adjustment in three-dimensional geocentric coordinate system that seems to be the most natural way of adjustment of GNSS observations.

In this method were obtained:

- average error of points position $M_{p(av)}$ = 0.0035 m,
- maximum error of points position $M_{p(max)}$ = 0.0040 m.

The least accurate numerical alignment parameters were obtained by elaboration of the network on the plain of projection system „xy2000/18”.

In this case, were obtained:

- average error of points position $M_{p(av)}$ = 0.0068 m,
- maximum error of points position $M_{p(max)}$ = 0.0078 m.

These are the results more than twice worse than the results of adjustment on ellipsoid (GRS-80). However, obtained from the alignment the mean square error of average observation Mo = 2.5 (Table 3) disqualifies the solution as an numerically incorrect. adjustment

Comparison of the obtained results for performed adjustments of networks leads to the conclusion: that homogeneous vector networks should be adjusted on ellipsoid or in geocentric coordinates system. The adopted model of vector network adjustment on a plain can't be used for this type of network or requires corrections before it is used.

REFERENCES

[1] R. Kadaj. „Jak rachować pomiary GPS.” *Magazyn Geoinformacyjny Geodeta,* 1(19), pp. 10-13, 2009.

[2] J. Lamparski, K. Świątek. *GPS w praktyce geodezyjnej.* Katowice: Wydawnictwo Gall, 2007.

[3] Z. Siejka. „Propozycja metodyki opracowania obserwacji satelitarnych GNSS z wykorzystaniem serwisu POZGEO D do zakładania punktów osnowy pomiarowej.” *Infrastruktura i Ekologia Terenów Wiejskich*, no. 2/II, pp. 7-16. Kraków: PAN, 2012.

[4] Rozporządzenie Ministra Administracji i Cyfryzacji z dnia 14 lutego 2012 r. *w sprawie osnów geodezyjnych, grawimetrycznych i magnetycznych*. (Dz. U. z 2012.poz.352.).

Ryszard Mielimąka, Prof, PhD, DSc (Eng)
Silesian University of Technology
Faculty of Mining and Geology
ul. Akademicka 2A, 44-100 Gliwice, POLAND
email: Ryszard.Mielimaka@polsl.pl
Zbigniew Siejka, PhD
University of Agriculture in Krakow
Faculty of Environmental Engineering
and Land Surveying, POLAND
email: rmsiejka@cyf-kr.edu.pl