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New Research on Gravity Field in Lithuanian Territory

Petras Petroškevičius[1], Romuald Obuchovski[2], Rosita Birvydienė[3], Ričardas Kolosovskis[4], Raimundas Putrimas[5], Boleslovas Krikštaponis[6], Dovydas Macijauskas[7], Arvydas Musteikis[8], Gediminas Skuodis[9], Tautvydas Šorys[10], Simonas Valotka[11], Mantas Ringelevičius[12], Vytautas Puškorius[13]

[1–13]Institute of Geodesy, Environmental Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania
[2, 3, 4, 6]Department of Geodesy and Cadastre, Environmental Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania
E-mails: [1]petras.petroskevicius@vgtu.lt; [2]romuald.obuchovski@vgtu.lt (corresponding author); [3]rosita.birvydiene@vgtu.lt; [4]ricardas.kolosovskis@vgtu.lt; [5]raimundas.putrimas@vgtu.lt; [6]boleslovas.krikstaponis@vgtu.lt; [7]dovydas.macijauskas@vgtu.lt; [8]arvydas.musteikis@vgtu.lt; [9]gediminas.skuodis@vgtu.lt; [10]tautvydas.sorys@vgtu.lt; [11]simonas.valotka@vgtu.lt; [12]mantas.ringelevicius@vgtu.lt; [13]vytautas.puskorius@vgtu.lt

Abstract. New research of Lithuanian territory gravity field was started in 2016 with aim to improve accuracy of quasigeoid as well as accuracy of normal heights determined by methods of satellite geodesy. Obtained data could be used in the research of geophysics, geodynamics as well as in performing the precise navigation. Quartz automatic gravimeters Scintrex CG-5 are planned to be used for the survey consisting of 30000 points. Method of gravity measurements was worked out. RMS error of gravity determined with this method does not exceed 60 μGal. Coordinates and heights of measured points are determined with GNSS using LitPOS network and LIT15G quasigeoid model. RMS error of coordinate determination does not exceed 0,20 m, for normal heights – 0,15 m. Method of gravity anomalies determination and their accuracy estimation was prepared.

Keywords: gravity field, gravity anomalies, gravimeter, Bouguer anomalies.

Conference topic: Technologies of Geodesy and Cadastre.

Introduction

Geodetic observations are carried out in the Earth’s gravity field, therefore detailed information about this field is necessary for solution of geodetic tasks. It is become especially important when different geopotential height systems are used. For example in determination of normal heights with nowadays widely used GNSS is necessary to know exact surface of quasigeoid, which is defined by Earth’s gravity field. Gravity field data are also needed for solution of geophysical, geodynamical, navigation and other tasks. Information on global Earth’s gravity field can be taken from dynamic satellite geodesy methods, analysing orbits of Earth’s artificial satellites. But for detailed information about gravity field on the Earth’s surface are necessary to have overground gravimetric measurements.

Currently in Lithuania gravimetric map (scale 1:200 000) created from gravimetric survey in fifties of the last century (Petroškevičius 2004) is used to obtain detailed information of gravity field. Research performed shows that gravity value taken from above mentioned map can contain errors up to 3 mGal (Birvydienė *et al.* 2010). Such gravimetric substance does not meet requirements of nowadays, therefore is planned to perform new research of Lithuanian territory gravity field by measuring gravity at 30 000 points. By using modern automatic gravimeters the gravity should be determined with RMS error not exceeding 60 μGal. Accuracy of the gravity value and coordinates determined with GNSS should ensure suitability of the points for the future detailed gravity field research of Lithuanian territory.

In this publication the method of prospective gravimetric and geodetic observations, their data processing and gravity anomalies computing is presented. Results of accuracy estimation of first measurements are presented.

Lithuanian territory gravimetric reference

New modern gravimetric reference defined with absolute ballistic gravity measurements in Lithuania was created during last two decades. Absolute gravity measurements with ballistic gravimeter JILAg-5 were performed in three points: Vilnius, Klaipėda and Panevėžys (Petroškevičius 2004; Mäkinen, Petroškevičius 2003). RMS error of determined gravity value is 5 µGal. These points are composing Lithuanian zero order gravimetric network.

New system of gravity was extended to the whole Lithuanian territory by creating first order gravimetric network which connects 51 point in total (Sas-Uhrynowski *et al.* 2002; Paršeliūnas, Petroškevičius 2007). Measurements were performed with gravity meters LaCoste & Romberg in 1998–2001. This network was densified in 2007–2009 by second order gravity network points. Measurements were made with automatic quartz gravimeters Scintrex CG-5 (Birvydienė *et al.* 2009; Paršeliūnas *et al.* 2010; Petroškevičius *et al.* 2014). Common adjustment of gravimetric network was performed, keeping absolute gravity points fixed. Lithuanian national gravimetric network now is composed of 686 points (Fig. 1). RMS error of the gravity value at these points does not exceed 10 µGal (Birvydienė *et al.* 2009). By Decree of the Government of Lithuanian Republic in 2014 the system LAS07 was accepted as Lithuanian Gravity System.

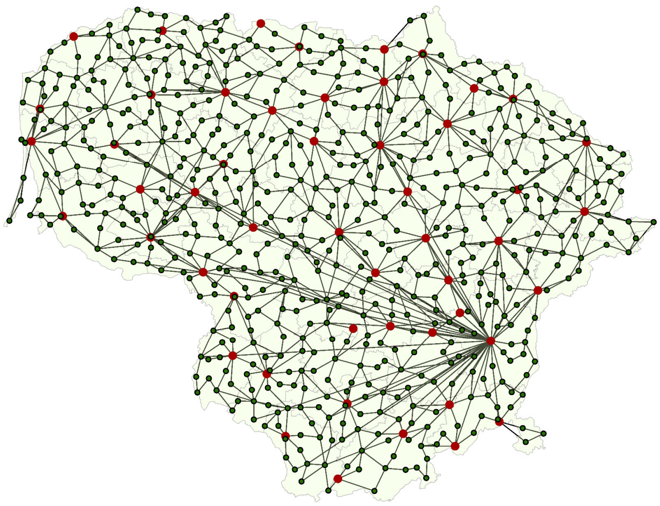

Fig. 1. Lithuanian national gravimetric network (zero and first order points – in red color, second order points – in green, lines mark the measured gravity acceleration differences)

More detailed research of Lithuanian territory gravity field could be performed using this gravimetric reference.

Program of gravity field research

In the new program of gravity field research in the Lithuanian territory it is planned to determine gravity value at the 30 000 points with RMS error not exceeding 60 µGal. According the program, the RMS error of point coordinates can not exceed 0,20 m, and normal heights 0,15 m. Gravity anomalies are computed using real density of 2,67 g/cm³ and 2,3 g/cm³ for intermediate layer. RMS error of Bouguer anomalies at gravimetric points can not exceed 0,080 mGal. Corrections for the terrain are also computed. RMS error of interpolated values of Bouguer anomalies can not exceed 1,00 mGal, therefore in the regions of intense change of gravity field densification of gravimetric points is planned. Gravimetric observations are made with gravimeters Scintrex CG-5, coordinates are determined in LKS 94 coordinate system, with GNSS using LITPOS, normal heights are determined in LAS07 height system, using quasigeoid LIT15G.

Selecting sites for gravimetric points

Positions for gravimetric points were designed with *QGIS* program on orthophoto map of Lithuania created in 2012. Selection of sites for gravimetric points was done in accordance with requirements that points should be positioned denser than 1 point per 2,4 km^2. Thus survey points were planned with distance from neighbouring points at 1,6 km. An auxiliary grid layer with squares of 1×1 km over Lithuanian territory was created for designing. The grid was used as auxiliary means for keeping requested density of points distribution. Lines of gravimetric measurements were projected between reference gravimetric network points, which were selected on sites easily accessible with car, close to the roads, forest quarter borders, artificial and other natural objects. 20–30 points were selected for every line. Selected point sites were chosen with open horizon for better GNSS positioning. Points were projected on larger lakes and marshes also. Gravimetric points were coded using six-digit code, in which first digit stands for the polygon number of Lithuania first class vertical network. Next three digits mean the line number, while the last two digits – the point number of the line. There are densification zones where distance between gravimetric points is around 1,0 km. Coordinates of the projected gravimetric points were taken, imported into the car navigation device and used to find these points on site. Fragment of projected gravimetric points in QGIS environment is shown in Figure 2.

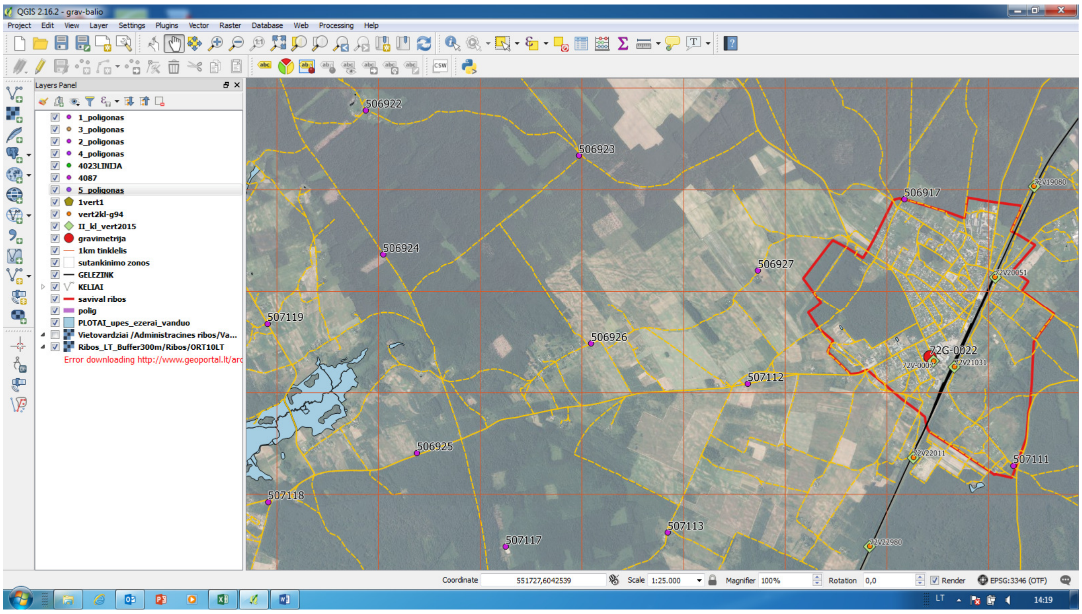

Fig. 2. Gravimetric points designed using *QGIS* program

Determining of coordinates of the gravimetric points

Gravimetric points on site are found using car navigator as well as the sketch of project of gravimetric points printed on paper. A stable place for gravimeter position normally was selected with open horizon suitable for GNSS observations.

The site of the gravimeter placement is coordinated with GNSS receiver by RTK method from LitPOS network of reference stations. *Trimble 5800*, *Hi Target V90 Plus*, *Leica GS15* and *GS08 GNSS* receivers were used. To increase accuracy of coordinates and height determination, two positionings were performed at every point. Coordinates and heights double difference variation determined at 460 survey points is shown in Figure 3.

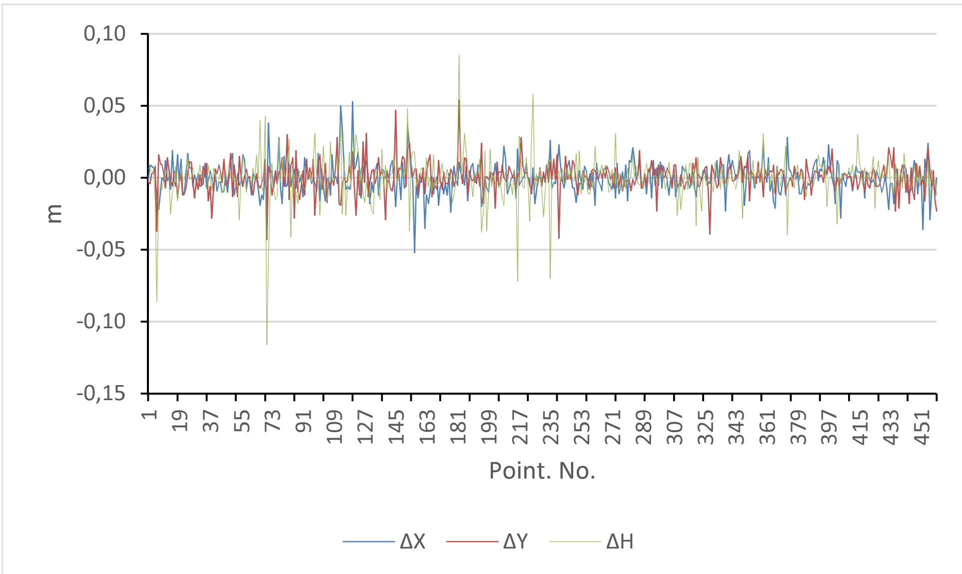

Fig. 3. Coordinate and height measurement double differences

The performed measurements indicate the RMS error of gravimetric points position 0,02 m, height 0,025 m. Taking into account the RMS error of quasigeoid LIT15G heights amounting to 0,03 m, we get RMS error of gravimetric point's normal heights below 0,04 m.

Calibration of gravimeters

For gravimetric measurements and data processing, it is very important to have precise values of gravimeters calibration coefficients. For this purpose, calibration of gravimeters was performed. Gravimeters in Lithuania are calibrated at the gravimetric baseline connecting gravimetric points EIŠIŠKĖS, VILNIUS, PANEVĖŽYS, SALOČIAI (Fig. 4).

Fig. 4. Scheme of gravimetric baseline

The baseline points VILNIUS and PANEVĖŽYS are located in cellars of buildings and are points of zero class gravity network, where absolute gravity value was determined with ballistic gravimeter JILAg-5 (Paršeliūnas *et al.* 2010). Another two points – EIŠIŠKĖS and SALOČIAI are established in the field. These are the points of the First Class Gravimetric Network. Measurements with gravimeters LaCoste & Romberg and Scintrex CG-5 were performed there. Gravimetric baseline points are situated along the meridian. The gravity value increase between bordering baseline points EIŠIŠKĖS and SALOČIAI is 201 mGal. The baseline length is 270 km. The baseline points have been established close to a good road, therefore are convenient to use for gravimetric measurements.

Two calibrations of 5 Scintrex CG-5 gravimeters were performed in 2016: first one in April, before the start of gravimetric measurements, the second one in November, to determine the change of calibration coefficients during the measurement season. Measurements at the points were performed in such sequence: VILNIUS, PANEVĖŽYS, SALOČIAI, PANEVĖŽYS, VILNIUS, EIŠIŠKĖS, VILNIUS. At every point, two measurements of ten cycles each were performed. Duration of each cycle – 55 seconds. Duration of one sequence is 12 hours. Results of the measurements were processed with GRAVSOFT program. Calibration coefficients of all the gravimeters are presented in Table 1. For the comparison, the results of calibration in 2015 are presented as well. Calibration date, RMS error m_k and change of calibration coefficients Δk between adjacent calibrations are presented here.

Table 1. Calibration coefficients of the gravimeters Scintrex CG-5 and their accuracy

Gravimeter No.	182	183	184	185	825
2015.03.31	1.012890	0.999010	1.000264	0.999710	0.999568
m_k	0.000059	0.000059	0.000058	0.000059	0.000058
2016.04.06	1.012877	0.999073	1.000163	0.999735	0.999474
m_k	0.000059	0.000059	0.000059	0.000058	0.000058
Δk	–0.000013	+0.000063	–0.000101	+0.000025	–0.000094
2016.11.04	1.012953	0.999135	1.000103	0.999688	0.999610
m_k	0.000060	0.000058	0.000060	0.000061	0.000058
Δk	+0.000076	+0.000062	–0.000060	–0.000047	+0.000136

RMS error of calibration coefficients were not exceeding 0,000061. The newest gravimeter Nr. 825 had largest calibration coefficient change during intense 2016 period of measurements. Change of gravimeters calibration coefficients is presented in Figure 5.

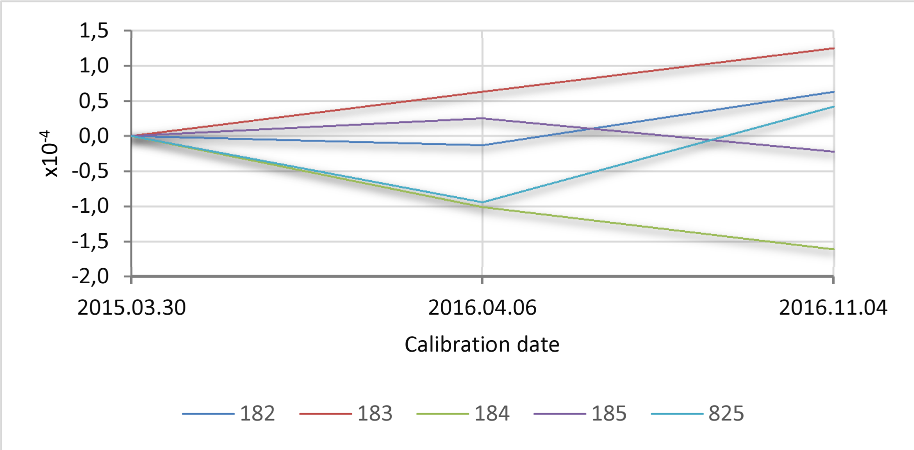

Fig. 5. The changes of the Scintrex CG5 gravimeters calibration coefficients from 2015

Method of gravimetric measurements

Measurements at the points were performed with gravimeters Scintrex CG-5 (Fig. 6). Day trip was started and ended at the points of gravimetric reference. During the day trip control measurements were performed at the points of gravimetric reference as well.

Fig. 6. Gravity meter Scintrex CG-5

At every point two cycles of measurements, 25 seconds duration each, were carried out. If gravimeter readings difference change was even but larger than 15 µGal, additional five cycles of observations were performed.

Adjustment of gravimetric measurements and accuracy estimation

The day trip measurement data were transferred from gravimeter to computer, while unnecessary measurement data were deleted. The data were sent to Institute of Geodesy for further adjustment. Coordinates file from GNSS receiver as well as the observer's notes on day observations were sent together.

Gravimetric measurement data were adjusted by applying GRAVSOFT software package procedures. Data were reduced by taking into account the gravimeter calibration coefficient values together with effects of the Moon and the Sun. Further the day trip data were adjusted by using two reference points and by determining errors in control points. If errors were allowable, then final adjustment was performed using control points as reference. Adjusted gravity values and their errors were obtained after the adjustment.

The accuracy of gravimetric measurements was estimated from differences of measured gravity values in control points. Figure 7 illustrates 298 control points gravity value differences after performed measurements at 5398 new points.

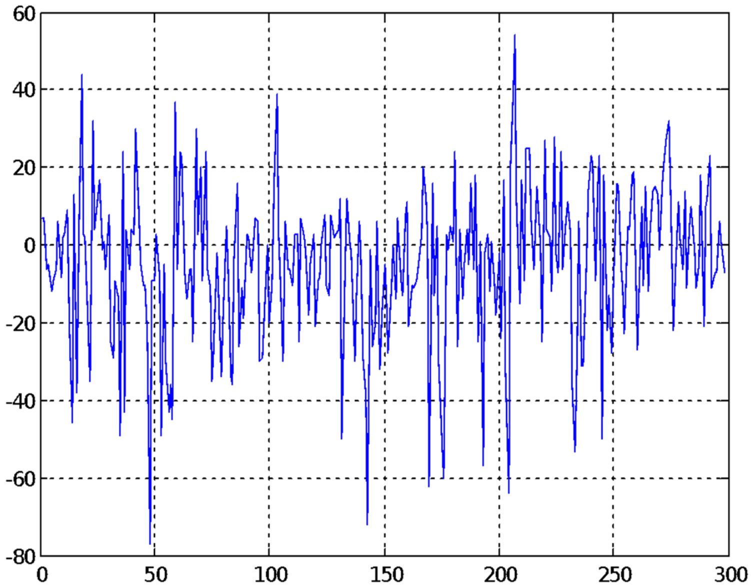

Fig. 7. Gravity value differences in control points in μGal

RMS error of gravity value was computed from gravity value differences in control points and is 20,7 μGal. RMS error of single measurement with gravimeter is 18,2 μGal.

Determination of gravity anomalies

Mixed anomaly in free air at the Earth's surface point with normal height H (*H>0*) after measurement of gravity value was computed from formula (Petroškevičius 2004):

$$(g-\gamma_{80}) = g_z - \gamma_{80}^0 + \Delta\gamma_{80}(H) + \Delta g_a(H), \tag{1}$$

where γ_{80}^0 – is acceleration of normal field GRS 80:

$$\gamma_{80}^0 = \gamma_{80e}^0 \frac{1+k_{80}\sin^2 B_{94}}{\sqrt{1-e_{80}^2 \sin^2 B_{94}}}, \tag{2}$$

where γ_{80e}^0, e_{80}, k_{80}– normal field GRS 80 parameters; $\gamma_{80e}^0 = 978032{,}67715$ mGal; $e_{80}^2 = 0{,}00669438002290$, $k_{80} = 0{,}001931851353$; B_{94} – geodetic latitude in LKS 94 system;

$$\Delta\gamma_{80}(H) = 0.30877(1-0.00142\sin^2 B_{94})H - 0.75\cdot 10^{-7} H^2; \tag{3}$$

– height correction in the GRS80 normal field, mGal (H in meters);

$$\Delta g_a(H) = 0.874 - 0.99\cdot 10^{-4} H + 0.356\cdot 10^{-8} H^2; \tag{4}$$

– atmospheric attraction correction, mGal.

Bouguer anomalies were determined by formula:

$$(g-\gamma_{80})_\delta = (g-\gamma_{80}) - \Delta g_\delta(H) + \Delta g_r, \tag{5}$$

where endless interim layer correction

$$\Delta g_\delta(H) = 2\pi G\delta H, \tag{6}$$

where δ – Earth crust density; Δg_r – correction for terrain; constant of gravity $G = 6.67259\cdot 10^{-11}$ $m^3kg^{-1}s^{-2}$.

After measurement of gravity value g at depth *h*, gravity at the Earth's surface will be:

$$g_z = g - \Delta\gamma_{80}(h) + 2\Delta g_{\delta}(h)\ . \tag{7}$$

After measurement of gravity value g at height h, gravity at the Earth's surface will be:

$$g_z = g + \Delta\gamma_{80}(h). \tag{8}$$

From results of measurements at gravimetric points the RMS error of determined Bouguer anomalies is 0,022 mGal.

Conclusions

1. RMS error of the gravimetric point coordinates determined using GNNS receivers and RTK method from the reference LitPOS stations with receivers *Trimble 5800*, *Hi Target V90 Plus*, *Leica GS15* and *GS08* was below 0,02 m. RMS error for normal heights determined in the same way and using LIT15G quazigeoid was 0,04 m.
2. RMS error of calibration coefficient of gravimeters Scintrex CG-5 was below 0,000061. The largest calibration coefficient change of gravimeter during measurements period reached 0,000136.
3. RMS error of gravity value determined at gravimetric points and computed from gravity value differences at control points was 21 μGal. RMS error of single measurement with gravimeter was 18,2 μGal.
4. RMS error of Bouguer anomalies determined at gravimetric points was 0,022 mGal.

Acknowledgements

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