ANALIZA KAKOVOSTI NACIONALNE GRAVIMETRIČNE MREŽE V LITVI

THE QUALITY ANALYSIS OF THE NATIONAL GRAVIMETRIC NETWORK OF LITHUANIA

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IZVLEČEK

V prispevku je podan pregled gravimetričnih meritev, ki so se izvajale v Litvi v zadnjih dvajsetih letih. Prve absolutne balistične gravimetrične meritve so bile opravljene na treh točkah, izvedel jih je Jaakko Mäkinen (Finski geodetski inštitut), in sicer v letu 1994. Dosežena natančnost določitve težnega pospeška je bila 5 μGalov. Te meritve so podlaga za sprejetje gravimetričnega sistem IGSN71, ki v Litvi nadomešča predhodni Potsdamski gravimetrični sistem. Nacionalna gravimetrična mreža prvega reda v Litvi je bila vzpostavljena v obdobju 1998–2001. Sestavljena je iz 51 točk. Meritve so bile opravljene s tremi do šestimi gravimetri LaCoste & Romberg. V letih 2007–2009 je bila vzpostavljena gravimetrična mreža drugega reda. Sestavljena je iz 635 točk. Meritve so bile opravljene z dvema paroma gravimetrov Scintrex CG-5. Težni pospešek je bil izmerjen z natančnostjo pod 10 μGalov. Gravimetrična karta Bouguerjevih anomalij, ki temelji na gravimetrični izmeri iz obdobja 1954–1962, je bila ovrednotena glede na podatke gravimetrične mreže. Rezultati ovrednotenja kažejo, da je natančnost vrednosti težnih pospeškov, ki izhajajo iz gravimetrične karte, približno 0,7 mGaloov ter da je povprečna razlika med gravimetričnim sistemom IGSN71 in Potsdamskim gravimetričnim sistemom na ozemlju Litve približno 13,93 mGalov.

ABSTRACT

The paper reviews the gravimetric measurements carried out in Lithuania over the last twenty years. The first absolute ballistic gravimetric measurements were carried out at the three points by Jaakko Mäkinen (Finish Geodetic Institute) in 1994. The 5 μGal precision of the gravity acceleration was derived. These measurements allowed to adopt the IGSN71 gravity system in Lithuania instead of earlier used Potsdam gravity system. The national first order gravimetric network of Lithuania was developed during the period of 1998–2001. It consists of 51 points. The measurements were carried out by 3–6 LaCoste & Romberg gravimeters. In 2007–2009 the second order gravimetric network was developed. It consists of 635 points. The measurements were carried out by two pairs of the Scintrex CG-5 gravimeters. The gravity acceleration was measured with an accuracy better than 10 μGal.The gravimetric Bouguer anomaly map, based on gravimetric survey of the period 1954–1962, was evaluated against the gravimetric network data. The results of the evaluation show that the accuracy of the gravity acceleration value, derived from the gravimetric map, is about 0.7 mGal and that the average difference between the IGSN71 gravity system and Potsdam gravity system is about 13.93 mGal in Lithuania territory.

KLJUČNE BESEDE

gravimetrični sistem, gravimetrične meritve, gravimetrične karte

KEY WORDS

gravity system, gravimetric measurements, gravimetric map

1 INTRODUCTION

The gravimetric observations give valuable information on detail gravitational field. This information is necessary in solving various geodetic tasks of the high precision measurements (Mäkinen et al., 2006; Petroškevičius et al., 2008; Petroškevičius, 2004; Aleksejenko et al., 2012), performing investigations of a geoid (Denker et al., 2008; Krynski and Lyszkowicz, 2007; Kuhar et al., 2011) and geodynamic studies (Zakarevičius et al., 2011), executing the resources survey and in solving various geophysical, navigational and similar tasks.

In Lithuania new gravimetric measurements were carried out during last twenty years. With the help of Finish Geodetic Institute, absolute ballistic measurements of gravity acceleration (Mäkinen and Petroškevičius, 2003) were performed in three points in 1994 and this let to adopt new gravity system instead of early used Potsdam system. In cooperation with the specialists of Institute of Geodesy and Cartography of Poland and National Geospatial-Intelligence Agency of USA (NGA) the national first order gravimetric network of Lithuania consisting of 48 points was developed (Sas-Uhrynowski et al., 2002; Paršeliūnas and Petroškevičius, 2007). In 2007–2009 the first order gravimetric network was densified by the second order gravimetric network. The automatic gravimeters Scintrex CG-5 were used for the gravimetric measurements. At present the gravimetric network of Lithuania consists of 686 points (Birvydienė et al., 2009, Paršeliūnas et al., 2010), and this gravimetric basis could be used for further investigations of the gravity field.

2 DATA AND METHODS

2.1 An adoption of new gravity system

The first measurements of gravity acceleration in Lithuania were carried out at the beginning of XIX century (Petroškevičius, 2004). The measurements were performed by Vilnius university professor J. Sniadeckis. At a later date, in 1865–1891, the director of Vilnius observatory P. Smyslovas performed measurements of gravity with the reverse Repsold pendulum. In 1930–1934, according to the common Baltic countries research programme, pendulum gravity measurements were carried out at 35 points. The relation with the Potsdam initial point was determined. In 1968 the second order gravimetric network consisting of 21 point was developed, the measurements were performed by relative quartz gravimeters, and the accuracy of gravity acceleration of 0.2 mGal was achieved.

In 1976–1983 the relative pendulum gravity measurements were performed at the first order gravimetric network points Vilnius and Klaipeda. The accuracy of gravity acceleration of 0.03 mGal was achieved.

Such a gravimetric basis with the Potsdam gravity system did not comply with the requirements for further investigations of gravity field. It was necessary to establish contemporary more precise gravimetric base with the new gravity system. Institute of Geodesy at Vilnius Gediminas technical university in coordination with National Geodesy and Cartography Service was responsible for solving this task.

With the help of Finish Geodetic Institute the absolute gravity acceleration measurements were carried out at three zero order gravity stations in VILNIUS, KLAIPEDA and PANEVEZYS in 1994 (Mäkinen and Petroškevičius 2003). The zero order gravimetric network points were mounted in the buildings in the ground floor rooms. Measurements were carried out by researcher Jaakko Mäkinen by ballistic gravimeter *JILA*g-5 (Figure 1).

Figure 1: The absolute gravity acceleration measurements at zero order gravity station in VILNIUS

The 5 μGal precision of the gravity acceleration was derived. The absolute gravity measurements were repeated in 2002. The differences of gravity acceleration values obtained from measurements performed in1994 and 2002 are: –10.7 μGal at station VILNIUS, –4.4 μGal at KLAIPEDA and –4.2 μGal at PANEVEZYS.

The absolute gravity measurements allowed to adopt the new gravity system of Lithuania instead of Potsdam gravity system practically.

2.2 New gravimetric network

First order gravimetric network consisting of 48 points was developed in order to expand the new gravity system to whole Lithuanian territory (Petroškevičius, 2004; Sas-Uhrynowski, 2002; Paršeliūnas and Petroškevičius, 2007). The gravimetric points are spread evenly over the territory of country. Mostly the major buildings and churches were chosen for establishment of the gravimetric points because of calm and stable places. The gravimetric points are signed with the marks fixed into concrete foundation or staircase. The normal height of the gravimetric points was determined by leveling from the nearest benchmarks. The coordinates of the points were determined in Lithuanian coordinate system LKS 94 which corresponds to the ETRS 89 system. The gravimetric measurements of the network were performed in 1998–2001 with the help of the specialists from Institute of Geodesy and Cartography (Warsaw, Poland) by 3–6 *LaCoste & Romberg* gravimeters. The gravimeters G-1012, G-1036, G-1078, G-1084 of Warsaw Institute of Geodesy and Cartography and gravimeters G-191, G-192, G-193 of NGA were used for measurements. The calibration of the gravimeters was performed between absolute gravity stations in Lithuania and Poland. Totally 117 gravity differences were observed. Every difference was measured three times by three to six gravimeters. According to closing errors of the closed figures the accuracy of single gravity difference (vector) of 6 μGal was achieved. The measurements of gravimetric network were adjusted using software package GRAVSOFT. The three absolute gravity stations in Lithuania were chosen as initial points. The errors of the initial points were taken into account. The accuracy of the adjusted values of gravity acceleration did not exceed 4 μGal. The r.m.s. of a single measurement was 14 μGal.

The second order gravimetric network consisting of 635 points was developed in 2007–2009 in order to densify the first order gravimetric network (Figure 2).

Figure 2: The scheme of the gravimetric points' displacements (zero order points – biggest dots, first order – average size, second order points – smallest dots; lines mark the measured gravity acceleration differences)

The most of the points are established near the churches and mounted like the points of the first order network, and 25 stations of the LitPOS (Lithuanian Positioning System) network (Paršeliūnas, 2008) were embraced to the gravimetric network. The coordinates of the gravimetric points were determined by GPS RTK method. Accuracy of positioning was 2 cm in horizontal and 3 cm in height. The normal heights of the points were calculated using quasigeoid model. The gravimetric measurements of the net were performed by four gravimeters Scintrex CG-5. The calibration of the gravimeters was carried out before and after every season of measurements. Two gravimeters were used to measure the gravity at the point. On 282 points the measurements were performed twice or more. The estimation of the results from double measurements showed that the accuracy of single measurement performed by two gravimeters is 6 μGal. The measurements were adjusted using software package GRAVSOFT.

The Lithuanian National Gravimetric Network was adjusted in two variants. In the first variant the reference points were all the points of the first order gravimetric network and three absolute gravity points, and in the second variant the initial points were only three absolute gravity points.

The adjustment procedure of the first variant gave the standard deviation of the single observation equal to 5 μGal, and standard deviation of gravity acceleration of the single points equal to 2 μGal. In the second variant the values of gravity acceleration changed in 4 μGal. The standard deviation of the single observation equal to 5 μGal, and standard deviation of gravity acceleration of the single points equal to 3 μGal were received. The obtained corrections to the initial points are: VILNIUS – –2 μGal, KLAIPEDA – +2 μGal, PANEVEZYS – 0 μGal. The corrections to the gravity acceleration values of the first order gravity points were from –14 μGal to 25 μGal. Results are shown in the Figure 3.

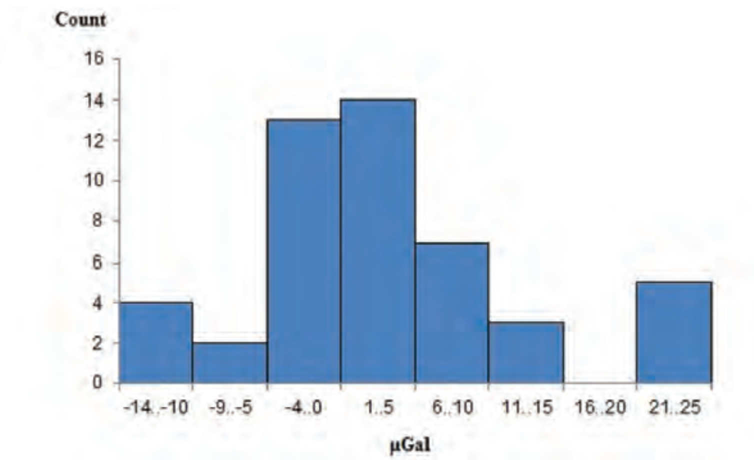

Figure 3: The corrections to the gravity acceleration values of the first order gravity points

Therefore new gravimetric network in Lithuania consist of 686 points in total.

2.3 Evaluation of the gravimetric map

The main source of the detailed gravity field in Lithuanian territory is the map of Bouguer anomaly of gravity field in scale 1:200,000 (Petroškevičius, 2004). The map was based on data from gravimetric survey made in period of 1954–1962. The third class gravimetric network consisting of 105 points where the standard deviation of the gravity acceleration does not exceed 0.35 mGal was used as base for the map. The coordinate system of 1942, the Krassovski ellipsoid and Baltic normal height system were used for mapping. The gravimetric Bouguer anomalies were presented at each point in the map and the number of points is more than 10,000. The Helmert's formula for the estimation of normal field and the density of the Earth's crust $\delta = 2.3 g/cm^3$ were used for calculations of the anomalies. Also the gravimetric field is presented by isolines at every 2 mGal. The data of the gravimetric network points were used to estimate the accuracy of gravimetric map. The Bouguer anomalies were calculated according to the equation:

$$(g_P - H)_\delta = g_{Pz} - \gamma_H^0 + 0.3086H_z - 0.0419\delta \cdot H_z, \qquad (1)$$

where there are g_{Pz} – Potsdam system gravity acceleration measured at the point on the Earth surface; γ_H^0 – the acceleration of Helmert normal gravity field on equipotential ellipsoid surface; H_z – Normal height at point on the Earth's surface, δ – density of the Earth's crust. The acceleration of Helmert normal gravity field on equipotential ellipsoid surface is calculated as:

$$\gamma_H^0 = 978030(1 + 0.005302\sin^2 B_{42} - 0.000007\sin^2 B_{42}), \qquad (2)$$

where B_{42} is latitude of 1942 year coordinate system. In order to derive the gravity acceleration from the map the following equation was used:

$$g_{Pz} = (g_P - \gamma_H)_\delta + \gamma_H^0 0.3086H_z - 0.0419\delta \cdot H_z. \qquad (3)$$

The gravity acceleration at the gravimetric point of height H can be obtained using the equations:

$$g_P = g_{Pz} + dg, \qquad (4)$$

$$dg = \Delta\gamma_H(h) - 2 \cdot 0.0419\delta \cdot h, \qquad (5)$$

when $H_z > H$, $h = H_z - H$,

Here

$$\Delta\gamma_H(h) = 0.30855\,(1 + 0.00071\cos 2B_{42})h - 0.0723 \cdot 10^{-6}h^2, \qquad (6)$$

– correction of the height;

$$dg = -\Delta\gamma_H(h), \qquad (7)$$

when $H_z < H$, $h = H_z - H$.

3 RESULTS AND DISCUSSION

The calculated differences of the gravity values derived from the gravimetric map and measured at the gravimetric points vary in the range of 10.74–17.76 mGal. The average value of the differences is 13.931 mGal. This value characterizes the difference between two systems used in Lithuania: the previously used Potsdam system and new gravity system of Lithuania based on absolute gravity survey. Using the obtained differences of gravity acceleration and taking into account the accuracy of gravity acceleration derived from measurements at gravimetric points, the accuracy of the gravity acceleration obtained from the gravity map is 0.7 mGal.

A digital gravity acceleration values correction model derived from the map was created. The model graphical representation is shown in Figure 4. The map corrections are presented using isolines for each 0.5 mGal.

By analysis of the data in Figure 3 we can note that there is a systematic error in some places in the map. The correction model could be used for revising gravity values derived from the map.

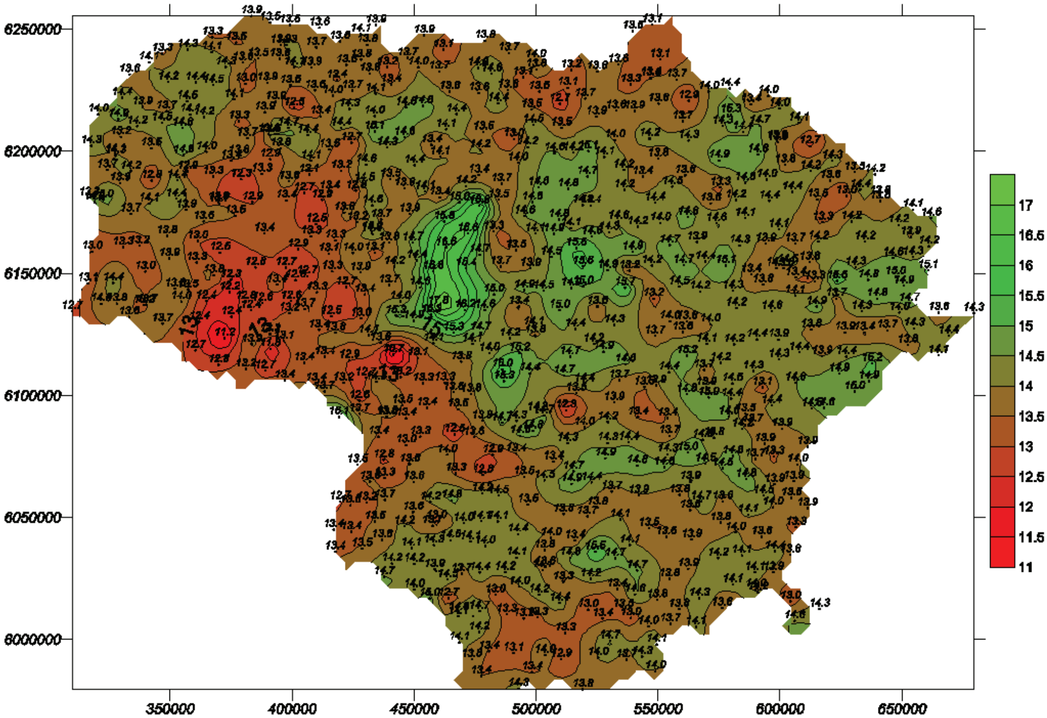

Figure 4: The graphical view of the model of the gravity anomalies corrections in mGal

Figure 5: The lines of the gravimetric measurements in 2010–2012

The accuracy of gravity values received from the map and correction model was estimated. For that aim the new gravity measurements data of 2010–2012 campaign at 228 geodetic vertical network points were used. The lines of the vertical network where the gravity measurements were carried out are shown in Figure 5.

The measurements were carried out by two gravimeters Scintrex CG-5. The accuracy of gravity acceleration estimated from the double measurements does not exceed 14 µGal. The gravity acceleration values from the gravimetric Bouguer anomaly map were calculated at the measured points. These values were adjusted with the corrections from the model. Revised gravity values derived from the map differ from the measured values in the range from –2.39 till +1.28 mGal (Figure 6). The range of gravity values differences is shown in Figure 7.

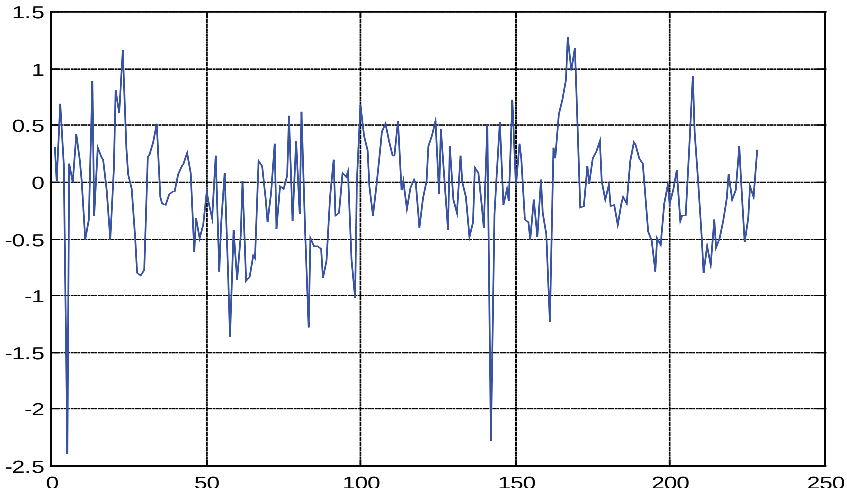

Figure 6: The differences of the gravity values in mGal

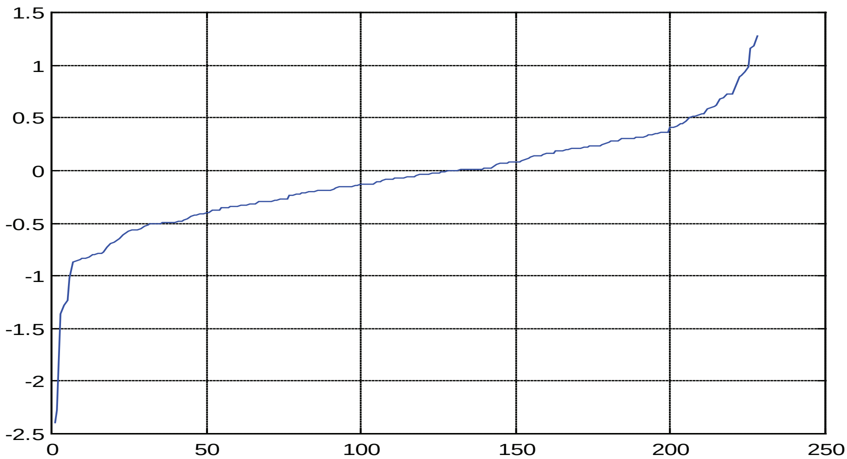

Figure 7: The distribution of the differences of the gravity values in mGal

The corrections let improve the standard deviations of the gravity acceleration values, obtained from the map, from 0.7 till 0.5 mGal.

4 CONCLUSIONS

The new gravity system of Lithuania was defined by absolute ballistic measurements performed at three points where the gravity acceleration was determined with the accuracy of 5 μGal. The accuracy of the gravity acceleration at Lithuanian gravimetric network consisting of 686 points, where the Scintrex CG-5 gravimeters were used for measurements, does not exceed 10 μGal. The mean square error of the gravity acceleration values obtained from the gravity map is 0.7 mGal. The error calculated comparing values obtained from gravity map and values from the measurements at the network points.

The gravity acceleration values correction model based on gravimetric measurements of the net was created for improving data obtained from the gravity map. The correction of the gravity acceleration values with this method improved the accuracy to 0.5 mGal. Based on the gravity map and new gravimetric measurements data the difference between the previously used Potsdam and new gravity systems was determined. The average difference value is 13.931 mGal.

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