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Section: Technologies of Geodesy and Cadastre

Designing issues of the geodetic vertical reference network of Lithuania

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Abstract

Activities of Lithuanian National Geodetic Vertical Reference Network (NGVRN) establishment are going on since 1998. The goal of NGVRN establishment is a creation of new Lithuanian height reference suitable for present period practical and scientific needs. The Lithuanian Geodetic Vertical First Order Network consists of five polygons. Perimeter of the network is ca. 1900 km. Its development was finished in 2006. Connections of the first order vertical network with the vertical networks of neighbouring countries were established. All this creates good preconditions for determination of relations between height systems and for introduction of a new Lithuanian geodetic vertical (height) system. But this network is not dense enough to transfer the geodetic vertical system to the all territory of Lithuania and to improve the geoid model. It is necessary to dense available First Order Geodetic Vertical Network by developing the Second Order Geodetic Vertical Network.
The territory of Lithuania is divided into five regions. Borders of the regions are First Order Network levelling lines and lines connecting Lithuanian national Vertical Network to the corresponding networks of the neighbouring countries. The regions are called: South, East, North, West and Centre. The design of the Second Order Geodetic Vertical Network is presented. The necessary density, accuracy of the geopotential numbers and ellipsoidal heights are discussed. Some results of the geodetic measurements are presented too.

Keywords: Geodetic Vertical Network; levelling; geopotential number; ellipsoidal height.

1. Introduction

Activities of Lithuanian National Geodetic Vertical Reference Network (NGVRN) establishment are going on since 1998 [1–8]. The goal of NGVRN establishment is a creation of new Lithuanian height reference suitable for present period practical and scientific needs. The Lithuanian Geodetic Vertical First Order Network consists of five polygons. Perimeter of the network is ca. 1900 km. Its development was finished in 2006. Connections of the first order vertical network with the vertical networks of neighbouring countries were established (one – with Polish vertical network, three – with Latvian vertical network) [9–11]. All this creates good preconditions for determination of relations between height systems and for introduction of a new Lithuanian geodetic vertical (height) system. But this network is not dense enough to transfer the geodetic vertical system to the all territory of Lithuania and to improve the geoid model. It is necessary to dense available First Order Geodetic Vertical Network by developing the Second Order Geodetic Vertical Network. The project of the Second order network was prepared in 2005–2006 [12], therefore its realisation was stopped by economic crisis. Nowadays the works to develop the Second Order Geodetic Vertical Network of Lithuania are going on.

2. Design of the Second Order Geodetic Vertical Network

The territory of Lithuania (65.3 th.sq.km) is divided in to five regions. Borders of the regions are First Order Network levelling lines and lines connecting Lithuanian national Vertical Network to the corresponding networks of the neighbouring countries. The regions are called: South, East, North, West and Centre. Fig. 1 represents a division scheme of Lithuania into regions.

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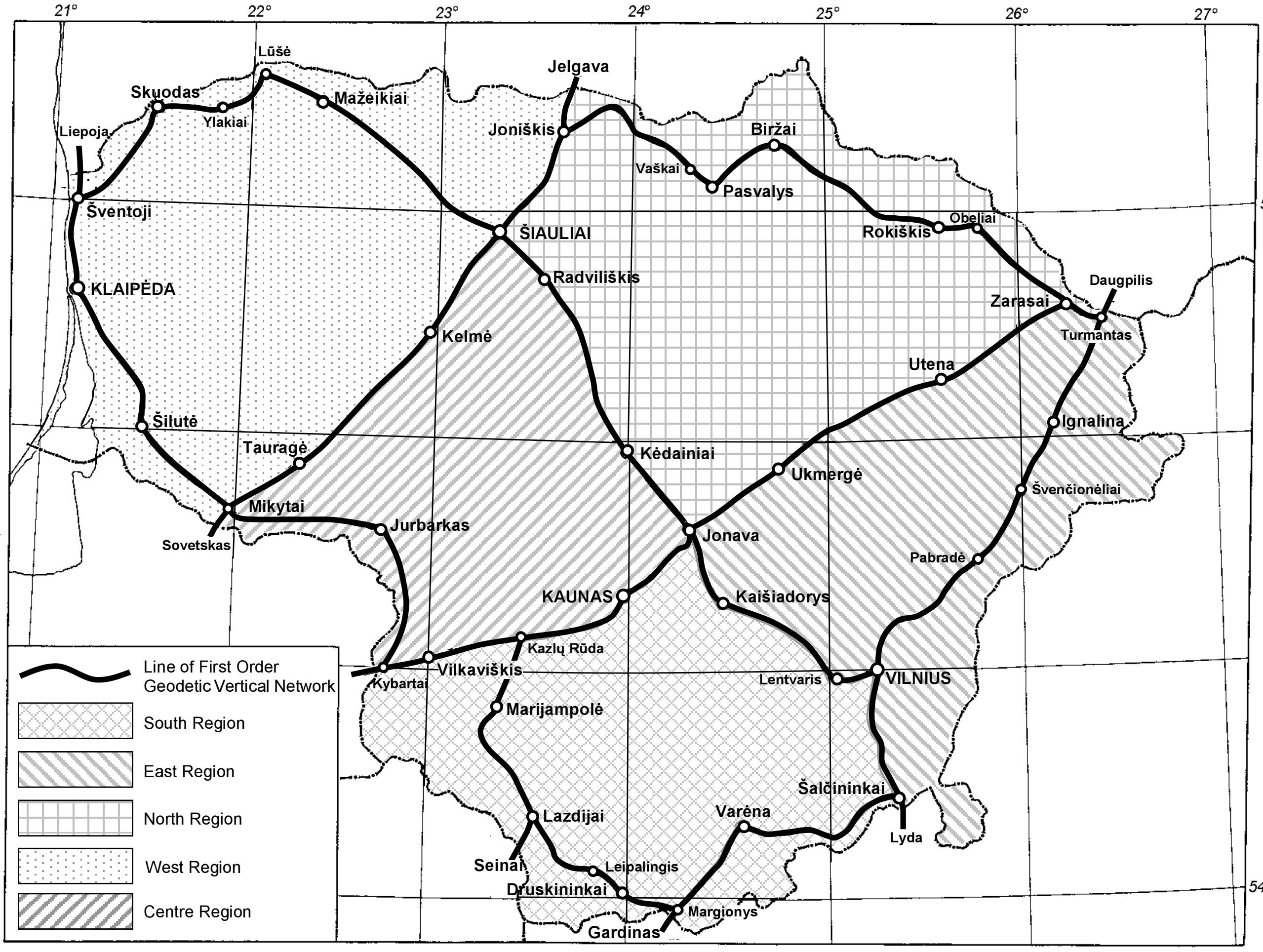

Fig. 1. Scheme of First Order Geodetic Vertical Network of Lithuania and division of the country's territory to the regions

Lines of Second Order Geodetic Vertical Network are arranged in such way that any point inside or outside the polygon will be in less than 30 km away from benchmarks of First and Second Order Network. Were possible levelling lines were projected through gravimetric points of first class, existing National levelling benchmarks and National GPS Network points (which are mounted in appropriate way).

The project of Second Order Network of each region was created individually, based on the benchmarks of First Order Network which are in territory of this region. Existing road network, relief and specific conditions of locality was taken into account. Former levelling lines were used for Network of Second Order project (Fig. 2).

Position of planned levelling lines are determined, length of each line and information about the existing levelling benchmarks was collected. Projected lines are marked by codes – numerical fractions (First Order Polygon number in numerator and Second Order line number in denominator).The project provides main necessary information to plan the reconnaissance of projected lines in the countryside and to locate existing old levelling benchmarks. Connections of the second order vertical network with the vertical networks of neighbouring countries (Latvia, Poland, Belarus and Russia) are foreseen.

About 2250 points, 1200 of them newly built should be included into the Second Order Network, following regulations, that the mean distance between benchmarks in the lines of Vertical Network should be less than 1.5 km.

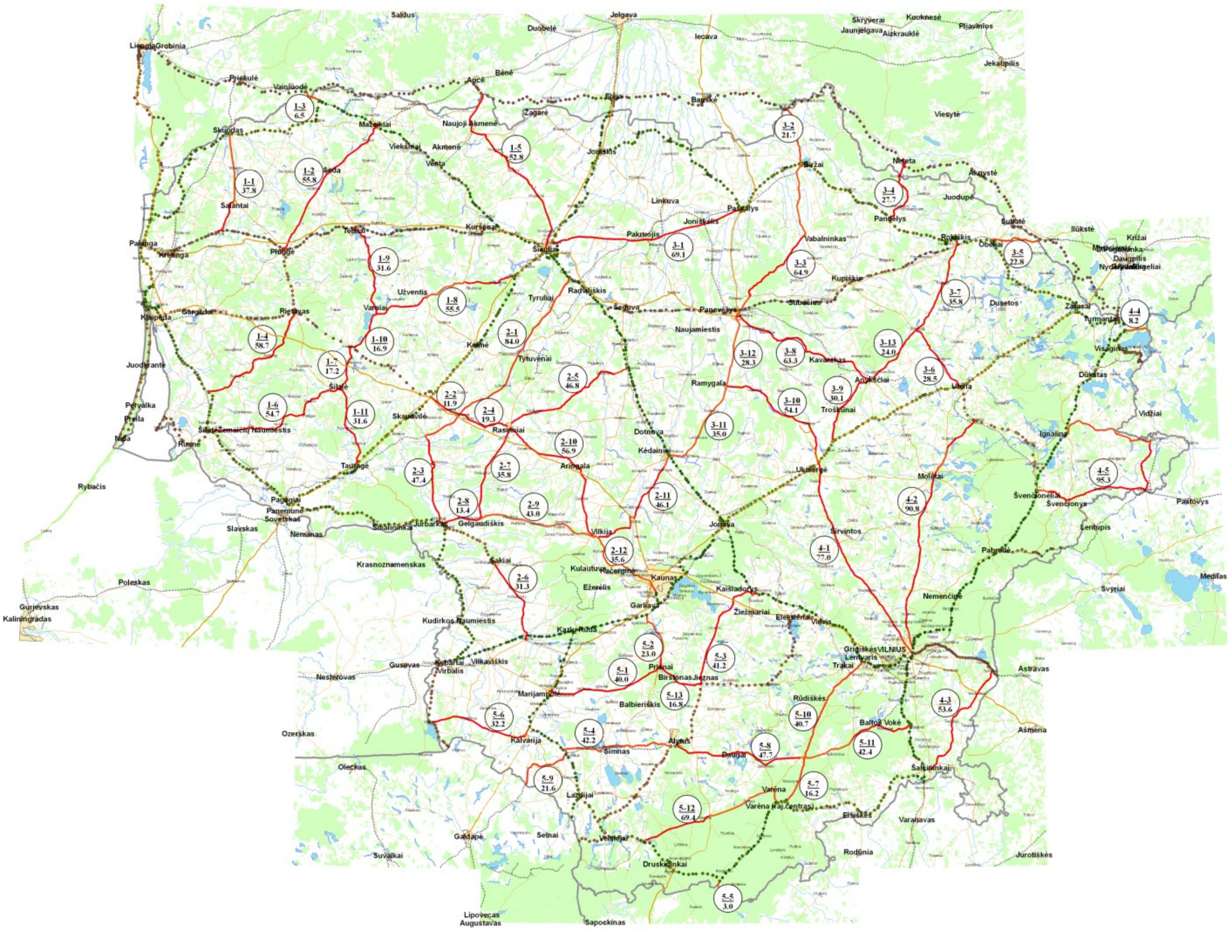

Fig. 2. Scheme of First Order Geodetic Vertical Network of Lithuania (lines in red colour, the line codes and projected lengths are presented in circles)

3. First experimental results

The first levelling works were executed in the period from 2007 till 2013. For example, lines of the centre region are shown in Fig. 3.

The two level's sets Trimble DiNi12 were used. They were researched, calibration of coded staffs was done, additional equipment was checked preparing to field expeditions. The field expeditions were organized to fulfil works of the precise levelling. In each expedition 6 employees of Institute of Geodesy (2 teams) were formed (levelling teams and preparing the levelling line team). Preparations of levelling line were done by additional levelling instrument N3K and steal cable – to keep distances equal. 35–50 cm length metal stakes were driven into soil or 5 cm length steal nails with spherical heads in case of asphalt cover.

Digital level DiNi12 and coded staffs LD13 guarantee 0.4 mm RMS error of double levelling run of one kilometre between reference points. Height differences between points of vertical network were measured forward and backward. Number of stations between neighbouring benchmarks was always even. Staffs were interchanged when direction of levelling was changed. Levelling instrument was levelled in every station when telescope was pointing to the first staff. For the mean reading from the staff about 5 readings with the accuracy of 0.01 mm were done. Height difference at station measured twice did not exceed 0.25 mm. Distances to the staffs were measured in every station with accuracy of 0.01 m. Length of sight did not exceed 50 m. Difference of sight length in the station was less than 0.5 m. Accumulation of such differences between neighbouring points was below 1.0 m.

Digital levels DiNi12 have opportunity to choose sequence of observations at station. Alternative program was used: in uneven stations – back, forward, forward, back (BFFB); at second station every even station of forward run and in odd stations on back levelling run – forward, back, back, forward (FBBF). Levelling in each station was started from first staff. To start forward levelling second staff was used (levelling staffs was changed). Because of that height differences of the same sign as on stations of forward levelling run were obtained on stations of backward levelling run. For measurements control field book was filled. Normal height of last benchmark, sums of distances between backward (DB) and forward (DF) levelling staffs was deducted after measurements in last station. Length of levelling run was calculated L = DB +DF. Computed discrepancy of levelling line height differences $d = \sum ht + \sum hd$ were compared with allowable ones. Temperature of invar bands was measured by contact electronic thermometers Ama-digit ad 30th with 0.1 °C accuracy. Staff invar band temperature was determined at the height 1.5 m.

Fig. 3. Levelling lines of Second Order Geodetic Vertical Network in the Centre Region of Lithuania (line No. 2 (red bold) observed in 2013)

The ground benchmarks of vertical network were positioned by 7 GPS receivers Trimble 5700 with Trimble Zephyr Geodetic antennas. LitPOS stations served as fiducial points. Inclined antenna height from three antenna sides was measured in meters and in inches for control. Data registration interval was 10 seconds and cut off angle was 5°. Depending on observation conditions and distances from the GPS stations, measurement sessions lasted for 2.5–4 hours. Baselines connecting National Geodetic Vertical and GPS networks were computed and adjusted by Trimble Total Control software package. Wall benchmarks were coordinated by GPS receiver Trimble 5800 from permanent GPS stations network. Measurements were performed using LitPOS VRS service [13]. Typical scheme of GPS measurements is presented in Fig. 4.

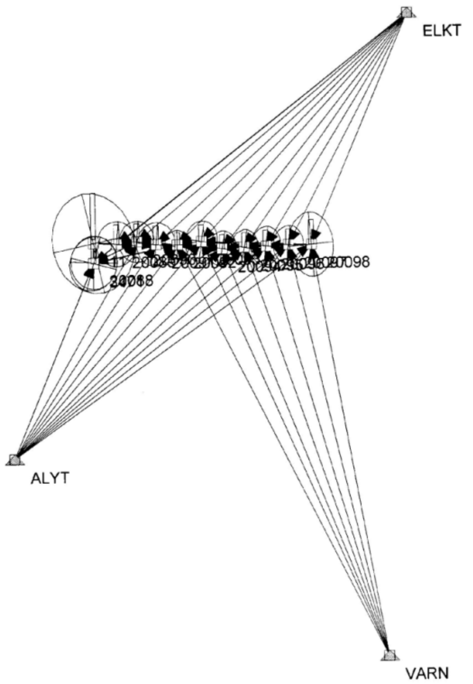

Fig. 4. Typical scheme of ground benchmarks positioning

The measurements of the gravity acceleration in each network point were performed by Scintrex CG-5 gravimeters. Gravimetric observations were tied with Lithuanian National Gravimetric Network points [14–16]. The example of gravimetric calculations is given below.

At the first step the analysis of daily gravimetric observations should be done [17, 18]. For example, the gravimetric observations were done by two Scintrex CG-5 gravimeters No.182 and No.185. Total number of readings at each point (total number of points in line is 15) is 10 by each gravimeter. The maximal differences d1max, d2max of the readings and the differences d1fl, d2fl of the first and the last reading should be calculated. At this moment the Moon and Sun corrections are not taken into account (Table 1).

Table 1. Differences of readings, mGal

Nr.	d1max	d1fl	d2max	d2fl
1	16	–12	17	–17
2	9	–9	7	–4
3	5	–4	22	–4
4	3	2	8	–3
5	4	–1	18	–18
6	5	–1	9	2
7	9	–6	6	–6
8	4	–1	25	1
9	26	10	12	–9
10	13	–12	12	-12
11	9	–6	10	–8
12	98	0	73	–10
13	3	–2	14	–14
14	9	–9	17	–16
15	26	–26	15	–6

At the second step the correted readings due Moon and Sun are calculated and plotted (Fig. 5 and 6).

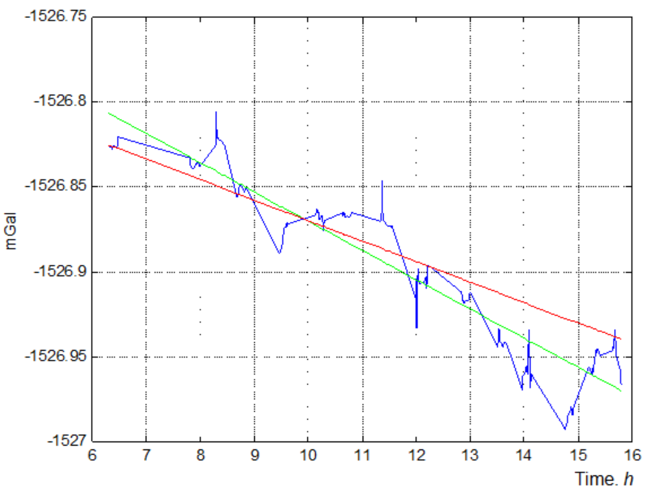

Fig. 5. Differences of corrected readings along a time

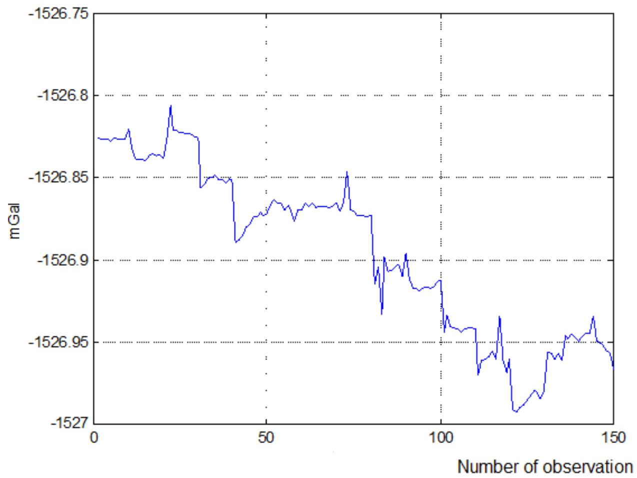

Fig. 6. Differences of corrected readings along a sequence of the observations

At the third step the values of gravity acceleration g2 and g5 and their estimations sd2 and sd5 are calculated. The differences (g2–g5) in µGal are calculated too, as well as average values of the gravity acceleration gv and its standard deviations mxv. Finally the average values of the gravity acceleration g25 observed by both gravimeters at the gravimeter heights H_g and their standard deviations sd25 are derived (Table 2 and Fig. 7).

Table 2. Gravity acceleration at points in levelling line, mGal

Point No.	g2	sd2	g5	sd5	g2–g5, μGal	gv	g25	sd25	gv–g25, μGal
1	981475.607	0.003	981475.587	0.003	20	981475.597	981475.597	0.004	0
3	981465.937	0.003	981465.926	0.003	11	981465.932	981465.932	0.003	0
1357	981489.384	0.003	981489.376	0.004	8	981489.380	981489.380	0.004	0
1605	981469.256	0.003	981469.273	0.003	–17	981469.264	981469.264	0.003	0
1901	981470.742	0.003	981470.766	0.003	–24	981470.754	981470.754	0.003	0
8853	981474.920	0.003	981474.914	0.003	6	981474.917	981474.917	0.003	0
20052	981466.046	0.003	981466.053	0.003	–7	981466.050	981466.049	0.004	1
20054	981460.666	0.003	981460.676	0.003	–10	981460.671	981460.671	0.004	0
25110	981463.347	0.003	981463.378	0.003	–31	981463.362	981463.362	0.004	0
25111	981470.582	0.003	981470.591	0.003	–9	981470.586	981470.586	0.003	0
25113	981471.554	0.003	981471.550	0.003	4	981471.552	981471.552	0.004	0
25114	981476.411	0.003	981476.376	0.003	35	981476.394	981476.394	0.004	0
25115	981483.032	0.003	981482.984	0.004	48	981483.008	981483.008	0.004	0

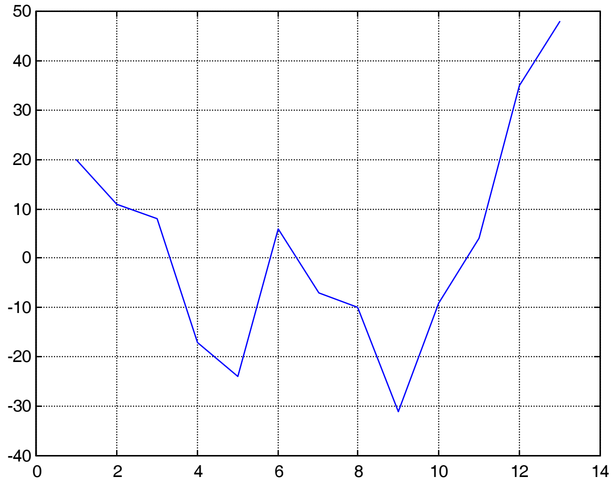

Fig. 7. Differences of gravity acceleration (g2–g5), μGal

At the fourth step the final calculations could be done [19–22]. The gravity acceleration g_z at Earth's surface height H_z can be obtained by using the formula

$$g = g_z + dg\,. \tag{1}$$

If $H_z > H$, than

$$dg = \Delta\gamma_{80}(h) - 2\Delta g_\delta(h)\,, \tag{2}$$

here $h = H_z - H$; H – height of gravimetric point, height correction $\Delta\gamma_{80}(h) = 0.3086h$ was calculated applying the average normal gravity acceleration vertical gradient; correction $\Delta g_\delta(h) = 2\pi G\delta h$; gravitational constant $G = 6.67259\cdot 10^{-11}$ m^{3}kg^{-1}s^{-2}; density of the Earth's crust $\delta = 2.67$ g·cm^{-3}.

If $H_z < H$, than

$$dg = -\Delta\gamma_{80}(h) \tag{3}$$

here $h = H - H_z$.

If gravity acceleration was measured above Earth's surface, than its value at the Earth's surface will be

$$g_z = g + \Delta\gamma_{80}(h)\,. \tag{4}$$

The Bouguer dgB80 and free air dglo anomalies at the height H_z are calculated also (Table 3 and Fig. 8).

Table 3. Gravity acceleration and anomalies

No.	Point code	H m	B °	H_g m	H_z m	g25, mGal	gz, mGal	dglo, mGal	dgB80, mGal	g, mGal
1	83V-1357	130.245	54.98506126	131.665	131.75	981489.380	981489.373	24.709	9.961	981489.500
2	83V25115	143.251	54.98034536	144.541	144.56	981483.008	981483.006	22.694	6.512	981483.117
3	83V-5958	147.487	54.97750000	148.091	148.09	981480.050	981480.050	21.069	4.492	981480.101
4	83V25114	154.090	54.98166667	155.730	155.74	981476.394	981476.393	19.416	1.982	981476.532
5	83V----1	142.370	54.98508510	142.110	142.11	981475.597	981475.597	14.126	–1.782	981475.517
6	83V-8853	148.052	54.97880556	148.582	148.64	981474.917	981474.912	15.989	–0.649	981474.962
7	83V25113	149.482	54.97447271	149.552	149.56	981471.552	981471.551	13.281	–3.460	981471.558
8	83S-1901	150.033	54.97576841	150.513	150.57	981470.754	981470.749	12.680	–4.174	981470.794
9	83V25111	146.749	54.97351389	146.969	146.97	981470.586	981470.586	11.599	–4.853	981470.605
10	83V-1605	147.234	54.96977778	147.574	147.61	981469.264	981469.261	10.790	–5.734	981469.293
11	83V-0003	153.135	54.96330556	153.135	153.14	981465.932	981465.932	9.717	–7.425	981465.932
12	83V20052	153.148	54.97879936	153.218	153.30	981466.049	981466.042	8.557	–8.604	981466.055
13	83V-6061	158.779	54.98444444	159.781	159.78	981465.461	981465.461	9.493	–8.393	981465.546
14	83V25110	162.257	54.98445000	161.697	161.74	981463.362	981463.358	7.994	–10.111	981463.199
15	83V20054	169.021	54.98768836	169.091	169.17	981460.671	981460.664	7.315	–11.622	981460.677

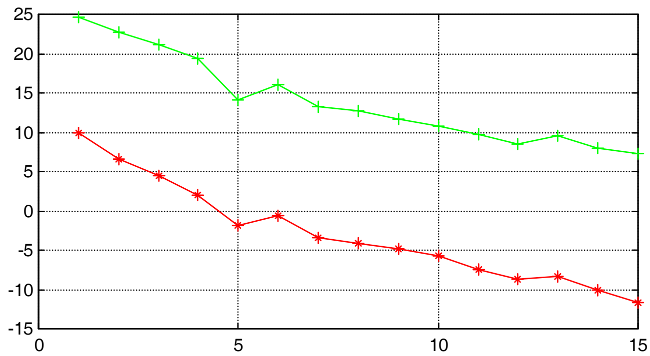

Fig. 8. Changes of gravity anomalies along the levelling line, mGal (dglo – -+-, dgB80 – -*-.

4. Quality evaluation of the precise levelling

Quality of the precise levelling of the Geodetic Vertical Second Order Network is controlled according to height difference tolerances computed for the levelling run. All discrepancies of height difference mentioned above should do not exceed:

$$d = 3.0mm\sqrt{L}\ , \tag{5}$$

where L – length of levelling line in km.

After finishing the precise levelling of few levelling lines based on double (forward and backward) run levelling discrepancies distributions should be estimated. Levelling results are correct if they satisfy formula (5). In the period from 2006 till 2013 the length of the precise levelling lines is 908 km (total 705 runs). The discrepancies of formulae (5) were distributed into intervals from 0 increasing every ±0.5 mm: $|0-0.5|mm\sqrt{L}$, $|0.5-1.0|mm\sqrt{L}$, $|1{,}0-1{,}5|mm\sqrt{L}$, $|1.5-2.0|mm\sqrt{L}$ and $\geq|2.0|mm\sqrt{L}$. Calculations are presented in Table 4 and Figure 9.

Levelling run weight unit (one kilometre) RMS error was computed fromwell known formula

$$\mu = \sqrt{\frac{\left[pd^2\right]}{2n}}\ , \tag{6}$$

where $p = 1/L$ – weight of height difference, L – distance between benchmarks in kilometres, d – double run levelling height differences discrepancy, n – number of discrepancies.

Table 4. Precise levelling quality evaluation basing on double run levelling discrepancies

Levelling lines	Number of levelling runs / Distances, km	$\lvert 0-0.5\rvert mm\sqrt{L}$	$\lvert 0.5-1.0\rvert mm\sqrt{L}$	$\lvert 1.0-1.5\rvert mm\sqrt{L}$	$\lvert 1.5-2.0\rvert mm\sqrt{L}$	$\geq \lvert 2.0\rvert mm\sqrt{L}$
Palanga – Kretinga	12	6	5	1	–	–
	13.15	6.06	6.47	0.62	–	–
Kužiai – Telšiai	45	25	13	4	3	–
	58.12	31.70	18.43	5.09	2.90	–
Šeduva – Panevėžys	33	19	7	6	1	–
	48.91	25.49	12.93	9.97	0.52	–
Kiduliai – Šakiai	21	15	2	4	–	–
	24.86	18.35	2.51	4.00	–	–
Klaipėda – Rietavas	37	16	13	6	2	–
	52.54	23.48	17.40	7.23	4.43	–
Gudeliai – Alytus	32	17	9	5	1	–
	44.03	23.02	11.59	8.92	0.50	–
Vievis – Elektrėnai	10	7	2	1	–	–
	12.02	7.62	3.02	1.38	–	–
Rokiškis – Panevėžys	82	40	24	12	4	2
	84.43	43.42	23.40	11.22	4.15	2.24
Telšiai – Plungė – Kretinga	98	47	37	12	2	–
	74.28	35.25	29.02	8.01	2.00	–
Šilutė – Nida – Klaipėda	68	36	22	7	2	1
	102.80	46.02	40.65	11.18	1.94	3.01
Alytus – Elektrėnai	48	25	12	10	1	–
	80.57	41.43	19.94	17.51	1.69	–
Vilnius – Šumskas	43	24	11	6	1	1
	36.37	21.00	9.62	4.67	0.13	0.95
Pabradė – Gelednė	14	7	2	4	1	–
	25.17	11.95	4.59	7.51	1.32	–
Utena – Švenčionėliai	23	9	12	2	–	–
	49.18	18.68	26.98	3.52	–	–
Visaginas – Varniškiai	22	10	3	7	2	–
	21.70	7.74	3.00	7.63	3.33	–
Plungė – Rietavas – Stulgiai	47	26	12	5	3	1
	85.83	48.63	20.45	7.86	6.66	2.23
Kaunas – Vilkija	26	15	9	–	2	–
	34.26	19.81	12.47	–	1.98	–
Vilkija – Šilinė	32	17	11	3	1	–
	43.20	24.31	13.01	4.81	1.07	–
Šilinė – Jurbarkas	12	10	1	1	–	–
	16.40	13.57	1.01	1.82	–	–
$\sum$	705 (100%)	371 (52.6%)	207 (29.4%)	96 (3.6%)	26 (3.7%)	5 (0.7%)
	908 (100%)	467(51.5%)	276 (30.5%)	122 (13.5%)	32 (3.6%)	8 (0.9%)

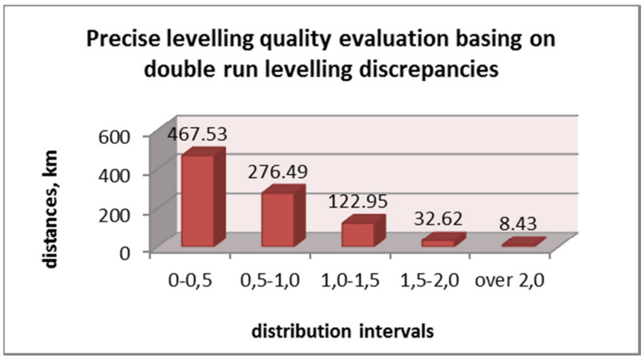

Fig. 9. Results of quality evaluation of precise levelling

Double run levelling one km length RMS error was computed:

$$m_{km} = \frac{\mu}{\sqrt{2}}. \tag{7}$$

The accuracy characteristics of every levelling line are presented in Table 5.

Table 5. The accuracy characteristics

No.	Levelling line	m_{km}, mm
1	Palanga – Kretinga	0.31
2	Kužiai – Telšiai	0.32
3	Šeduva – Panevėžys	0.35
4	Kiduliai – Šakiai	0.31
5	Klaipėda – Rietavas	0.46
6	Gudeliai – Alytus	0.35
7	Vievis – Elektrėnai	0.25
8	Šilutė – Nida – Klaipėda	0.12
9	Rokiškis – Panevėžys	0.38
10	Telšiai – Plungė – Kretinga	0.36
11	Alytus – Elektrėnai	0.37
12	Vilnius – Šumskas	0.36
13	Pabradė – Gelednė	0.43
14	Utena – Švenčionėliai	0.35
15	Visaginas – Varniškiai	0.47
16	Plungė – Rietavas – Stulgiai	0.37
17	Kaunas – Vilkija	0.12
18	Vilkija – Šilinė	0.35
19	Šilinė – Jurbarkas	0.47

Based on Table 5 data it is clear that the double run one kilometre levelling RMS error does not exceeds 0.5 mm. We could conclude that the levellings carried out so far is characterized by high precision.

5. Conclusions

1. The project of National Second Order Geodetic Vertical Network was prepared. The network is not so dense as it was initially designed. The network is composed of 70 lines, which total length is about 3000 km. Old levelling lines are selected for most of the projected lines. About 2250 benchmarks, 1200 of them newly built should be included into the Second Order Network.
2. Lithuanian digital geoid model will be improved after completing the First and Second Order of Geodetic Vertical Network. This will enable to derive normal height from ellipsoidal heights determined by GPS and replace traditional levelling of lower orders.

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