PRECISE LEVELING IN VIDZEME

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Abstract
The paper analyzes National leveling network measurement errors along the leveling lines in Vidzeme region, forming the V, VI and VII polygon. Leveling along the lines performed in the time period from year 2001 to year 2009. For accuracy characterizing of the leveling lines, are determined random standard deviation η, systematic standard deviation σ and the station's average elevation determination standard deviation $\eta_{h.}$ There is analyzed measuring accuracy influencing external factors, as well as is concluded how to avoid them.
Key words: precise leveling, level, leveling line, standard deviation, polygon

Introduction

Precise leveling for leveling network renewal in the Republic of Latvia performed from year 2000 to year 2010 (Fig. 1). The height network linkage also completed with Lithuania network in three and with Estonia network in four line points. If necessary, like in international border surveying, is carried out the elaboration forerun of first order leveling linking with Belarus and Russia network (Takalo M., Kuznertsov Y., 2006). In process of carrying out measurements along the Latvian border, sea coast, leveling are performed with attraction to sea level observation stations. Currently in Latvia is used the Baltic 1977th normal height system. Renewable leveling network main tasks are:

– define the height system's output level in the country;

– determine the country height system's exit point;

– ensure and provide justification for the height data synchronization with the closest Baltic Sea region data models (height data models) (Celms A., Helfriča B., Kronbergs M., 2002);

– ensure and provide justification for the height data synchronization with the Amsterdam output level (Schmidt K., 2000);

– determine the ground's vertical movement speed with stationary (permanent) global positioning points, in common system (Celms A., Kronbergs M., 2008);

– specify geoid model with the Global Positioning System and gravimetrical measurements (Proceedings from Seminar ….., 2001.; Celms A., Kaminskis J., 2005.).

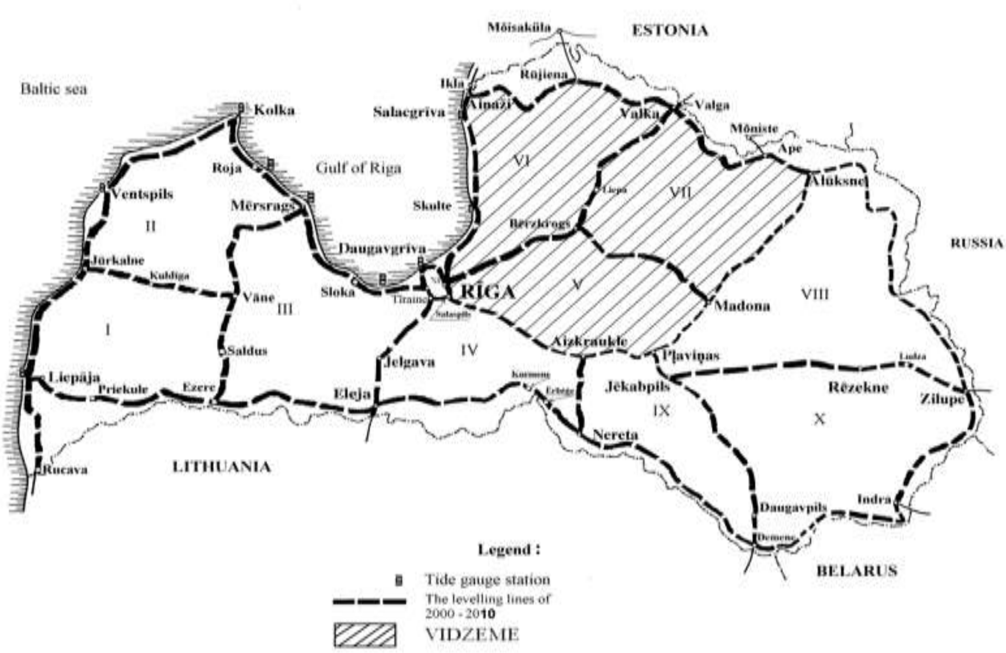


Figure 1. Scheme of first order leveling network

Leveling core network reconstruction in Latvia basically is based on the 1929 – 1939 years created and 1967 – 1974 years renewed leveling network. Only in two lines fulfilled leveling, where have not been previously done Class I and Class II leveling (Latvia SSR precise ….., 1941).
In relation with Latvia membership of the EU and NATO, as one of the priorities was determined the country east border arranging. For this reason, leveling core network reconstruction was also activated in this region.

Materials and methodology of research
Considering the leveling instructions, in the last season before leveling, the lines were surveyed and condition of remaining ground and wall signs were assessed, the designed leveling lines were specified. Leveling lines included all marks, leveled in previous epochs. In places where the distance between existing marks were more than 2 km, were installed new wall and ground leveling marks. For example, in the fifth polygon where the perimeter is 371 km, additionally were installed 83 ground and 32 wall marks.
For leveling rod support were used 30 cm long and 3 cm thick steel pins. In urban areas into asphalt were driven steel nails with a spherical head. In some cases, for fragile soil were used screw pins. The length of sight was limited to 40 m. Distances between pins were measured with a thin labeled steel cable. The difference of the length of sight at the station was set no larger than 0.5 m.
Years when the leveling is fulfilled and applied precise leveler sets are showed in Table 2. Most notable is executed leveling in line Ainaži – Rīga. In the leveling performance year, into this line's section from Skulte to Salacrgīva were performed extensive road repairs according to Via Baltica program. Simultaneously in several places the carriageway widening works where performed, in which were used the excavators, trucks and other heavy machinery. In view of the circumstances invoked and analyzing the potential impact of external factors to the leveling process, it was decided in leveling use the ZEISS company optical level Ni 002.
Each leveling line section (interval between marks) was leveled "forward" and "backward" directions, each direction – in the morning and in the evening. In the measuring course had been observed so-called "Eight" principle, when, for example, leveling in one direction is performed in morning and leveled two sections, then the next two sections in the same direction is leveled in the day's other side. Measurements were started half an hour after sunrise and ended one hour before sunset. In every second station the air temperature was measured. Since the thermal impact on the used levelers were not studied, in sunny weather the sunshade was used to protect instruments from direct rays of sun. The maximum difference between the "forward" and "backward" directions measured elevations in section has been allowed 1.5 mm $\sqrt{L}$, where L – length of the section, km.
Leveling was performed from mid May to November. From May to July was the sunny weather, also the rainy weather with stormy winds. The best weather for leveling was observed from mid-September till the first half of November.
In all lines the leveling were carried by roads, mostly with asphalt cover. As an exception should be mentioned a separate section lines between Alūksne – Gulbene, where leveling were directed along the narrow gauge railway. Besides the already mentioned line Ainaži – Rīga, difficult leveling conditions were in leveling lines Pļaviņas – Salaspils and Bērzkrogs – Rīga, because there the leveling were performed along the highway with intense road traffic.
In the leveling lines also were carried out gravimetric measurements with SCINTREX company's gravity meter. Gravimetric measurements were used for calculating the elevation correction for the transition to the normal height system.
Ending the field measurements, after each season the leveling rods calibration was performed in the Finnish Institute of Geodesy.
In measured elevations the corrections were given by leveling rods meter length and temperature differences during the leveling and calibration.

Results
First order leveling lines in Vidzeme region with overall length of 959 km is forming 3 (V, VI, VII) closed polygons. Polygons description is given in Table 1.

Table 1

Leveling polygons description

Polygon No.	Polygon perimeter, km	Unbound in polygon, mm	Allowable unbound in polygon, mm
V	371	+24,2	38
VI	422	-2,3	41
VII	426	+9,9	41

As can be seen, the calculated unbound of the elevation sum in separate polygon is within acceptable limits. The largest unbound occurred in southern (V) polygon, which could be partly explained by the fact, that two of the polygon lines Rīga – Pļaviņas and Rīga – Bērzkrogs were leveled along highways with intensive road traffic, which adversely affects the accuracy of measurement. In addition, certain effects could also create the line orientation.

To describe the leveling quality, the kilometric elevation determination standard deviation was calculated by the forward and backward elevation differences in the sections (Zvonovs V., 1952):

$$s = \frac{1}{4n}\left[\frac{d^2}{r}\right], \text{ where} \qquad (1)$$

n – number of sections in the line;
d – difference of elevations in the section, mm;
r – length of section, km.
Similarly in all the lines, was determined "forward" and "backward" line average elevation kilometric random standard deviation η, excluded the systematic (formula 2). For this purpose for all leveling lines were constructed the height difference accumulation graphs (Figure 2) (Entin I., 1956).

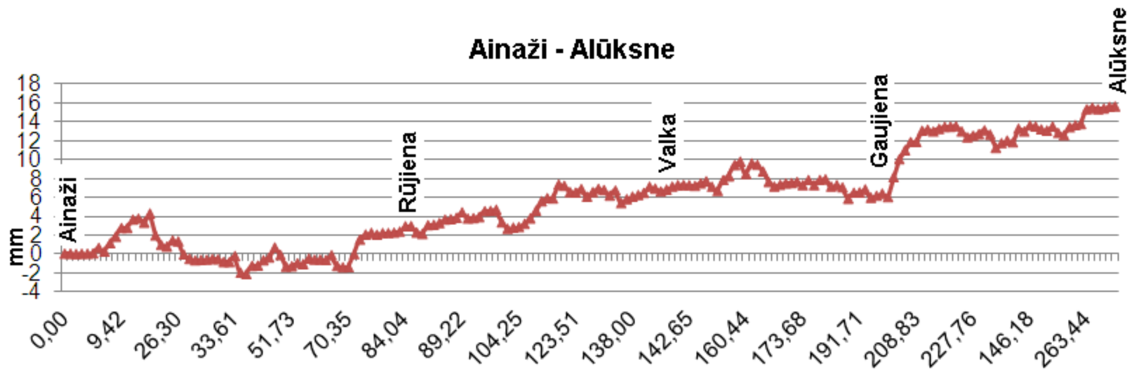
$$\eta^2 = \frac{1}{4(n - N)}\left\{\left[\frac{d^2}{r}\right] - \left[\frac{S^2}{L}\right]\right\}, \text{ where} \qquad (2)$$

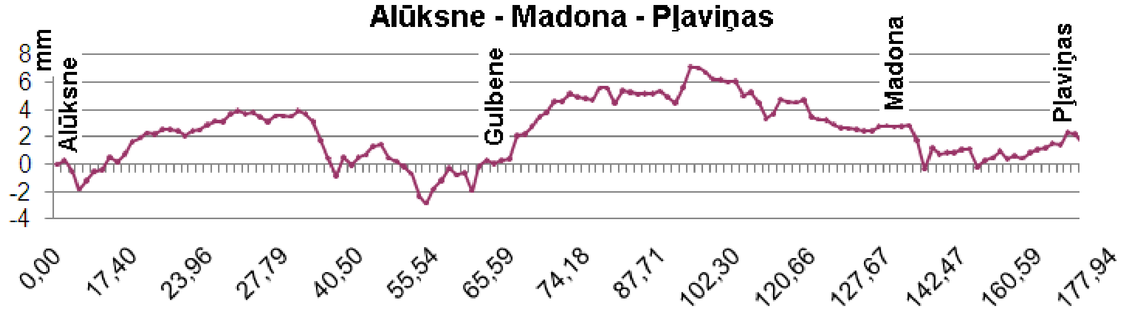
n – number of sections in the line;
N – number of span with same nature of systematic error accumulation;
d – difference of elevations in the section, determined in fore and back ways, mm;
r – length of section, km;
S – difference of extreme point ordinates of straight line drawn in the graph symmetrically against d symmetrical accumulation line in a traverse span, mm;
L – length of span with the accumulation of symmetric elevation differences, km.

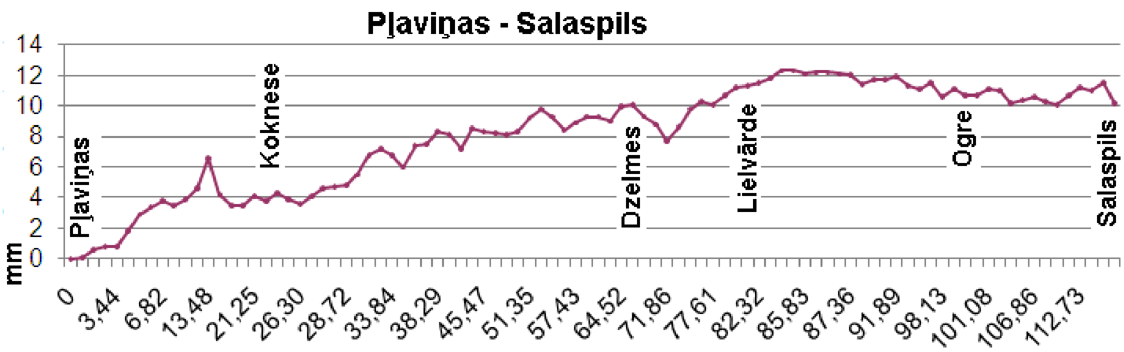
Kilometric systematic standard deviation, excluded random, were calculated by the formula:

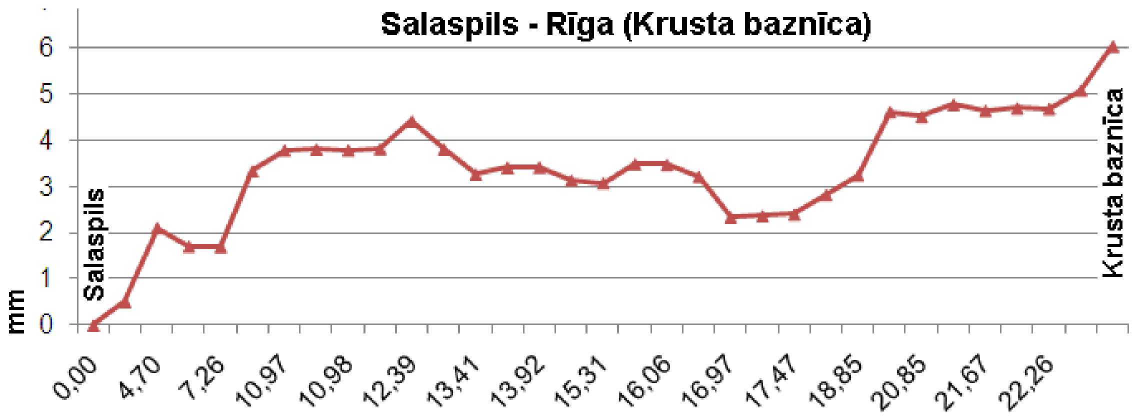
$$\sigma^2 = \frac{1}{L}\left\{\frac{1}{n}\left[\frac{S^2}{L}\right] - N \cdot \eta^2\right\}, \text{ where} \qquad (3)$$

L – length of span with the accumulation of symmetric elevation differences, km.
n – number of sections in the line;
S – difference of extreme point ordinates of straight line drawn in the graph symmetrically against d symmetrical accumulation line in a traverse span, mm;
N – number of span with same nature of systematic error accumulation;
η – elevation kilometric random standard deviation


Ainaži - Alūksne
mm
18
16
14
12
10
8
6
4
2
0
-2
-4
Ainaži
Rūjiena
Valka
Gaujiena
Alūksne
0,00
9,42
26,30
33,61
51,73
70,35
84,04
89,22
104,25
123,51
138,00
142,65
160,44
173,68
191,71
208,83
227,76
146,18
263,44


Alūksne - Madona - Pļaviņas
mm
8
6
4
2
0
-2
-4
Alūksne
Gulbene
Madona
Pļaviņas
0,00
17,40
23,96
27,79
40,50
55,54
65,59
74,18
87,71
102,30
120,66
127,67
142,47
160,59
177,94


Pļaviņas - Salaspils
mm
14
12
10
8
6
4
2
0
Pļaviņas
Koknese
Dzelmes
Lielvārde
Ogre
Salaspils
0
3,44
6,82
13,48
21,25
26,30
28,72
33,84
38,29
45,47
51,35
57,43
64,52
71,86
77,61
82,32
85,83
87,36
91,89
98,13
101,08
106,86
112,73


Salaspils - Rīga (Krusta baznīca)
mm
6
5
4
3
2
1
0
Salaspils
Krusta baznīca
0,00
4,70
7,26
10,97
10,98
12,39
13,41
13,92
15,31
16,06
16,97
17,47
18,85
20,85
21,67
22,26

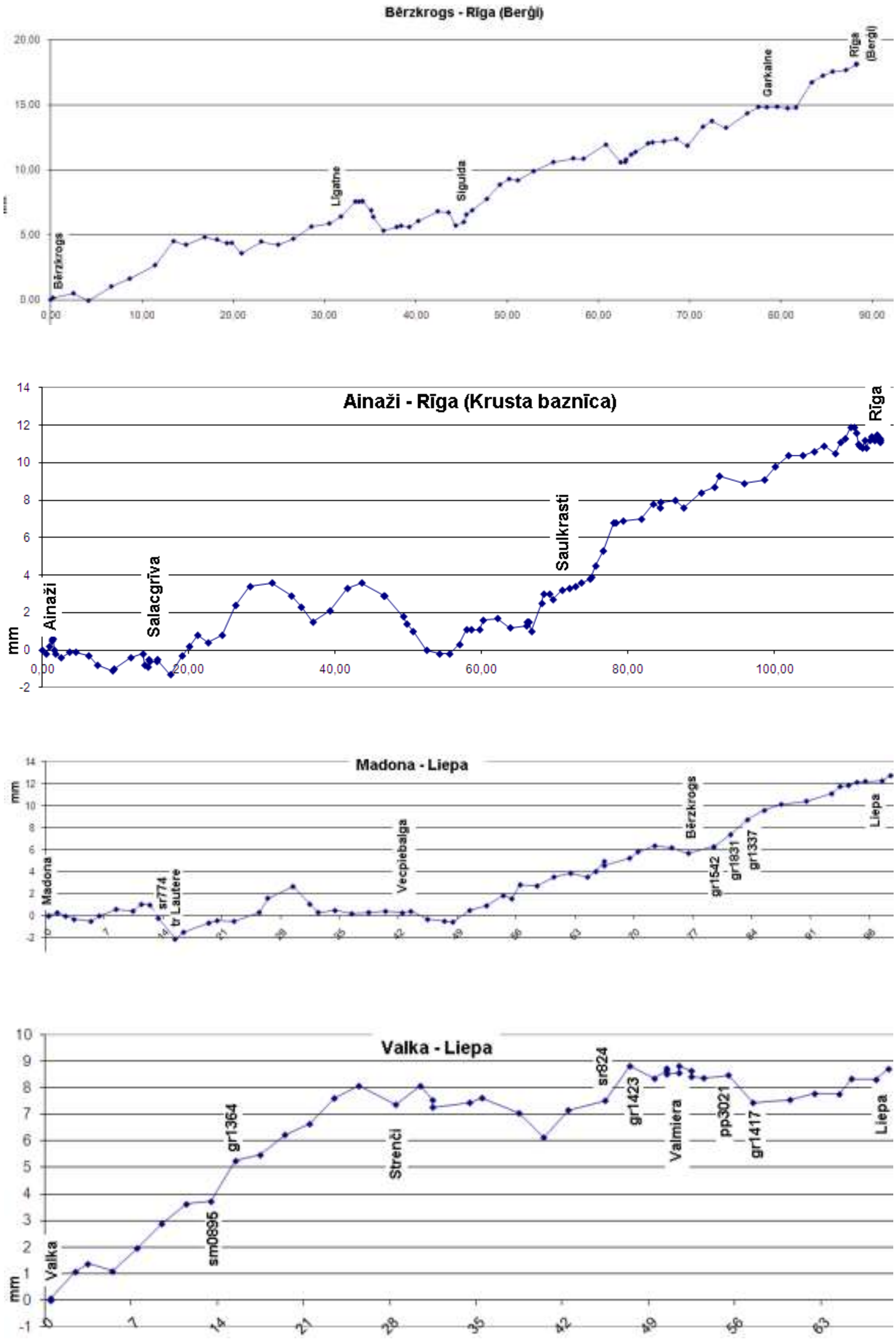


Figure 2. Graphs of accumulation of heights differences

Leveling accuracy also can be assessed by one-way travel elevation arithmetic mean systematic error – σa.

The accuracy indicators are given in the Table 2. These data indicate that the leveling performed with sufficiently high accuracy

Table 2

Leveling lines accuracy indicators

Leveling line	Leveling year	System of levels	Length of the line, km	Elevation kilometric standard deviation, mm			
				s	σ_a	η	σ
Ainaži – Rīga (Krusta baznīca)	2001	Ni 002	114	0,29	0,05	0,29	0,04
Alūksne – Pļaviņas	2003	DiNi 12	177	0,28	0,00	0,26	0,08
Pļaviņas – Salaspils	2004	DiNi 12	118	0,23	0,04	0,22	0,05
Ainaži – Valka – Alūksne	2007	DiNi 12	269	0,27	0,03	0,26	0,08
Madona – Bērzkrogs – Liepa	2008	DiNi 12	100	0,26	0,06	0,24	0,08
Valka – Liepa	2008	DiNi 0,3	68	0,22	0,06	0,18	0,09
Bērzkrogs – Rīga (Berģi)	2009	DiNi 0,3	88	0,28	0,10	0,26	0,09
Salaspils – Rīga (Krusta bazīca)	2009	DiNi 0,3	24	0,27	0,12	0,18	0,10

For characterization of the leveling quality, the leveling line sections were also divided by forward and backward line elevation difference values. These differences divided into 3 groups: ≤ 0.5mm$\sqrt{L}$, 0.6…1.0mm$\sqrt{L}$ and 1.1…1.5 mm$\sqrt{L}$ (Table 3)

Table 3

Leveling line section dividing by elevation differences in sections

Leveling line	Leveling year	Length, km	Number of sections	Section dividing by elevation differences					
				0.5$\sqrt{L}$	%	0.5… 1.0$\sqrt{L}$	%	1.1… 1.5$\sqrt{L}$	%
Ainaži – Rīga (Krusta baznīca)	2001	114	107	76	71	26	24	5	5
Alūksne – Pļaviņas	2003	177	139	89	64	35	25	15	11
Pļaviņas – Salaspils	2004	118	94	60	64	26	28	8	8
Ainaži – Valka – Alūksne	2007	269	186	120	64	57	30	9	6
Madona – Bērzkrogs – Liepa	2008	100	61	41	67	15	24	5	9
Valka – Liepa	2008	68	43	30	69	12	28	1	3
Bērzkrogs – Rīga (Berģi)	2009	88	70	45	64	18	25	7	11
Salaspils – Rīga (Krusta bazīca)	2009	24	30	20	66	6	20	4	14

The table data shows that average 66% the section elevation difference is less than 0.5$\sqrt{L}$, 26% – is in the range from 0.5 to 1.0$\sqrt{L}$, but only 8% section differences is larger than 1.0$\sqrt{L}$.

To analyze the measurement conditions on the obtained elevation difference in a section, were evaluated measurement accuracy in station. For analysis were chosen three separate sections on lines Madona – Liepa and Valka – Liepa, where forward and backward measured elevation difference was close to allowable. By the two elevations value difference were calculated the average elevation determination standard deviation in the section's station, by the formula:

$$s_s = \frac{1}{2}\sqrt{\frac{d_s^2}{n_s}}, \text{ where} \quad (4)$$

d_s – difference between the two elevations values in station, mm
n_s – number of stations in section

The calculated elevation standard deviations are given in the Table 4.
As can be seen by the results of the measurements in sections (Table 4), the mean elevation error in the station are small, and it is not a conclusive source of error in leveling.

Table 4

Elevation standard deviation in the section's station

Valka – Liepa	**sm 0895 – gr1364**	**gr1364 – sm0895**	**sr 824 – gr1423**	**gr1423 – sr824**	**pp3021 – gr1417**	**gr 1417 – pp3021**
s_s (mm)	0,039	0,044	0,029	0,036	0,049	0,052
Madona – Liepa	**sr 774 – trLautere**	**trLautere – sr774**	**gr1542 – gr1831**	**gr 1831 – gr1542**	**gr 1831 – gr1337**	**gr1337 – gr1831**
s_s (mm)	0,046	0,027	0,013	0,018	0,024	0,030

Conclusions

Assessing the results of precise leveling in Vidzeme region, the following conclusions can be given:

– the unbound of measured elevation sums in all three polygons are within acceptable limits, although in the southern polygon, which forming lines are leveled along highways with intensive road traffic, unbound is significantly higher;

– elevation determination kilometric random standard deviation in the leveling lines are close to used instruments precision;

– elevated systematic standard deviations is directly related to the line's leveling external conditions;

– whereas, the leveling rod's reading error is excluded in leveling with digital levelers, elevation determination accuracy in station depends only on the line of sight position changes in external conditions impact;

– in forward and backward walk measured elevation difference accumulation graphs show that generally through all leveling lines the differences builds up with a plus sign, which would be explained by the pins vertical movement – sinking during measurement. However, in order to determine these systematic effect real sources, there should be studied leveling rod reading changes in separate leveling line stations, in relation with external circumstances.

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Summary *(in Russian)*
АРМАНДС ЦЕЛМС, МАЙГОНИС КРОНБЕРГС, ВИТА ЦИНТИНЯ ВЫСОКОТОЧНЫЕ НИВЕЛИРОВКИ В ВИДЗЕМЕ
В статье анализированы ошибки нивелирования государственной основной нивелирной сети по линиям, образующих 3 полигона в Видземском регионе. Нивелировки выполнены в периоде времени с 2001 по 2009 год.
Для оценки точности нивелирования определены случайные и систематические стандартные отклонения на 1 км двойного хода и стандартное отклонение средного превышения, определенного на отдельной станции.
Сделан вывод, что причиной повышенных значений систематических стандартных отклонений является неблагоприятные внешние условия нивелирования. Высказано также предположение, что положительное накопление разностей прямого и обратного ходов является следствием оседаний костылей.

Key words *(in Russian)*
высокоточное нивелирование, линия нивелирования, нивелир, стандартное отклонение, станция, полигон

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