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ACCURACY ESTIMATION OF THE LATVIA FIRST ORDER LEVELING NETWORK

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Key words: precise leveling, leveling network, accuracy estimation.

Introduction

The study aim is to provide the accuracy assessment of the executed most topical first order leveling in Latvia. Acquired estimation of the accuracy will provide an opportunity to predict certainty with which the precise leveling is applicable in the national economy.

National leveling core network is height system developer and maintainer of a given territory. Established leveling core network accuracy give guarantees for other studies that the data from this network is high quality. As an example, studies on the Earth' s crust vertical movements, their speed and amplitude of values. To accurately determine the exact changes that occurred, the leveling must be executed with the best possible accuracy [1]. In case if precise leveling final results for some reason is not with the highest certainty, then it is very difficult for further data application in the national economy.

In Latvia territory during the last seventy years was performed three precise leveling campaigns. During the time period from the year 1929 to year 1939 in Latvia territory was set and surveyed overall first order leveling network. Leveling network reached total length of 4422 km and included the 1262 leveling signs.

During the period from year 1967 to year 1974 in the leveling network the precise leveling was carried out again. Almost all lines were leveled again. In the leveling lines where the measurements were not fulfilled, the elevation values between the unit points were taken from the previous epoch measurement data.

The most recent first order leveling in Latvian was performed during the period from year 2000 to year 2010. At the time period from year 2000 to year 2005 precise leveling works were organized and executed by the State Land Service. In the following period – from year 2006 to year 2010 these works were continued and successfully completed by the Latvian Geospatial Information Agency experts.

Leveling was performed by the existing lines including in previous campaigns leveled leveling signs which were preserved till the present day. In this epoch the single lines some sections were leveled by new sites.

The first comprehensive study of the executed leveling certainty carried out in the year 1941 [2]. The study determined that leveling that were executed in the time period from year 1929 to year 1939 accuracy rates were following – one kilometer average random standard deviation $\acute{\eta} = \pm\ 0{,}5$ mm/km, one kilometer average systematic standard deviation $\sigma = \pm\ 0.05$ mm/km. These results show that these leveling works were performed very accurate.

From year 1967 the executed precise leveling catalogs with point height values are published. Leveling did not form a separate system in Latvia territory, but became as a part of the overall leveling network in Eastern Europe. However, the data on a particular line leveling accuracy in Latvia is not available. This leveling accuracy partly can be determined after combining the individual lines in separate leveling network. In late nineties these data were entered into the United European Levelling Network (UELN) database. Leveling data accuracy was evaluated and standard deviation S=1.67 kgal▪mm was determined, which can be considered as that time leveling core network certainty [3].

Materials and Methods

In this study, the most recent leveling network data were used. The raw data were obtained from the Latvian Geospatial Information Agency. These data were arranged by lines, in the result from these lines were created polygons. For each line the leveling data was arranged in a specific sequence showing the leveling signs, elevation between them and the distance between the leveling signs. Elevation values between the leveling signs are given as average, taking into account the “forward” and “back” measurements. Elevation values are given with the calibration corrections and including coefficients for the transition to the normal height system.

In this study, there are not included leveling lines which form links with Lithuania and Estonia. As well as for precision calculations the separate leveling lines combined into a single line – forming the line from node point to node point. For leveling data analysis were examined 10 large polygons with a perimeter from 341.90 km to 501.09 km and one smaller polygon – polygon number IV with perimeter 118.92 km, which were made up of leveling lines covering the Riga city. Therefore leveling network consists of 30 leveling lines with a total length 2940.21 km and 20 node points (Fig. 1).

Then the elevation weight (P) for each line was calculated, which is required to compile the system of normal equations. (Table 2) Next for the whole leveling network normal equation system was constructed, which includes all line corrections, which can be seen in figure 2.

The correlates are obtained by solving the normal equation system. (Table 1)

Using the correction regulation equations, the line elevation corrections are calculated, which can be seen in table 2.

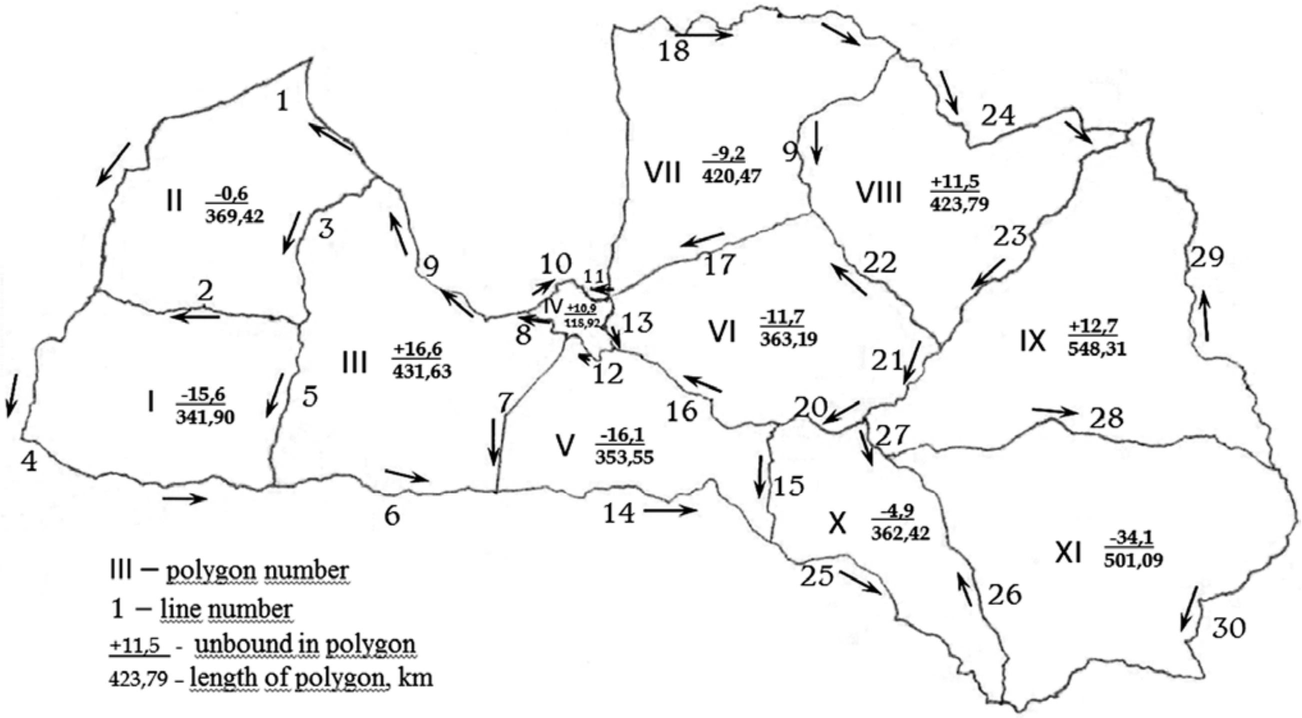

Fig. 1. Scheme of first order leveling network of Latvia

$$3.72k1 - 0.85k2 - 0.82k3 = 0.6$$
$$-0.85k1 + 3.42k2 - 0.72k3 = 15.6$$
$$-0.82k1 - 0.72k2 + 4.31k3 - 0.24k4 - 0.69k5 = -16.6$$
$$-0.24k3 + 1.19k4 - 0.27k5 - 0.25k6 = -10.9$$
$$-0.69k3 - 0.27k4 + 3.53k5 - 0.80k6 - 0.50k10 = 16.1$$
$$-0.25k4 - 0.80k5 + 3.63k6 - 0.88k7 - 0.80k8 - 0.49k9 - 0.38k10 = 11.7$$
$$-0.88k6 + 4.19k7 - 0.87k8 = 9.2$$
$$-0.80k6 - 0.87k7 + 4.23k8 - 1.28k9 = -11.5$$
$$-0.49k6 - 1.28k8 + 5.47k9 - 0.18k10 - 1.67k11 = -12.7$$
$$-0.50k5 - 0.38k6 - 0.18k9 + 3.62k10 - 1.23k11 = 4.9$$
$$-1.67k9 - 1.23k10 + 5.03k11 = 34.1$$

Fig. 2. Normal equation system.

Table 1

Corelates

K1	K2	K3	K4	K5	K6
+0,53631	+4,14772	-2,59814	-7,37626	+5,42923	+5,11964
K7	K8	K9	K10	K11	
+3,07983	-0,92046	+0,64944	+5,50754	+8,34172	

Results and Discussion

In general, performed leveling will give the opportunity to use the calculated elevation values for the existing height system update and successful inclusion in the European Vertical Reference System.

As well as given leveling product – elevation values are useable as support for various public sector research and development. For example, by the Earth' s crust vertical movement studies, updating the cartographic material components of height and other [5].

As a result of alignment the line elevations and corrected elevations are given in table 2.

The resulting leveling kilometric standard deviation in this leveling network is S = 0.785 mm /km. Based on elevation sum unbound in polygons, which in some polygons are close to the limit, significantly contribute to the overall leveling network accuracy. As well as the elevation sum unbound in polygons directly affect the correction values of the calculated leveling lines.

As one of the possible reasons, why XI polygon (in scheme 1) elevation unbound is close to the maximum permissible, it may be used leveler. Allowable unbound in polygon XI (by the instruction) are 44.7 mm, which acquired by formula 2, where L – length of the polygon, km. [6;7]. The polygon XI measurements were performed with leveler WILD NA 3003. This leveler was the first instrument which was used for leveling rod digital readings [8]. This instrument elevation determination accuracy which is characterized by leveling standard deviation on 1 km is 0.4 mm/km. This means that the maximum instrument accuracy is very close to the determined leveling kilometric standard deviation which is determined 0.5 mm/km.

Table 2

Estimation of the leveling accuracy

Polygon Nr.	Line Nr.	Length of line (km)	Weight P	Measured elevation (m)	Correction v (mm)	Corrected elevation (m)
I	2	85,64	0,0117	74,0977	3,1	74,1008
	4	183,57	0,0054	-59,3844	7,6	-59,3768
	5	72,69	0,0138	-14,7289	4,9	-14,7240
		341,90		**-0,0156**	**15,6**	**0,0000**
II	1	202,05	0,0049	-0,7561	1,1	-0,7550
	2	85,64	0,0117	-74,0977	-3,1	-74,1008
	3	81,73	0,0122	74,8532	2,6	74,8558
		369,42		**-0,0006**	**0,6**	**0,0000**
III	9	92,24	0,0108	-9,6814	-2,3	-9,6837
	3	81,73	0,0122	-74,8532	-2,6	-74,8558
	5	72,69	0,0138	14,7289	-4,9	14,7240
	6	91,26	0,0110	39,2228	-2,4	39,2204
	7	69,46	0,0144	21,2669	-5,6	21,2613
	8	24,25	0,0412	9,3326	1,2	9,3338
		431,63		**0,0166**	**-16,6**	**0,0000**
IV	10	42,91	0,0233	10,3614	-3,2	10,3582
	13	25,01	0,0400	4,5268	-3,1	4,5237
	12	26,75	0,0374	-5,5447	-3,4	-5,5481
	8	24,25	0,0412	-9,3326	-1,2	-9,3338
		118,92		**0,0109**	**-10,9**	**0,0000**
V	14	127,22	0,0079	-46,6622	6,9	-46,6553
	7	69,46	0,0144	-21,2669	5,6	-21,2613
	12	26,75	0,0374	5,5447	3,4	5,5481
	16	79,76	0,0125	77,3842	0,2	77,3844
	15	50,36	0,0199	-15,0159	0	-15,0159
		353,55		**-0,0161**	**16,1**	**0,0000**
VI	11	2,88	0,3472	-2,8875	0,1	-2,8874
	13	25,01	0,0400	-4,5268	3,1	-4,5237
	16	79,76	0,0125	-77,3842	-0,2	-77,3844
	20	38,25	0,0261	10,6594	-0,1	10,6593
	21	49,28	0,0203	-56,5768	2,2	-56,5746
	22	79,76	0,0125	-38,0138	4,8	-38,0090
	17	88,25	0,0113	168,7180	1,8	168,7198
		363,19		**-0,0117**	**11,7**	**0,0000**
VII	18	245,48	0,0041	39,2487	7,5	39,2562
	19	86,74	0,0115	129,4601	3,5	129,4636
	17	88,25	0,0113	-168,7180	-1,8	-168,7198
		420,47		**-0,0092**	**9,2**	**0,0000**
VIII	24	128,61	0,0078	106,9424	-1,2	106,9412
	23	128,68	0,0078	-15,4846	-2	-15,4866
	22	79,76	0,0125	38,0138	-4,8	38,0090
	19	86,74	0,0115	-129,4601	-3,5	-129,4636
		423,79		**0,0115**	**-11,5**	**0,0000**
IX	29	185,4	0,0054	-26,2698	1,2	-26,2686
	23	128,68	0,0078	15,4846	2	15,4866
	21	49,28	0,0203	56,5768	-2,2	56,5746
	27	17,75	0,0563	-6,7887	-0,9	-6,7896
	28	167,2	0,0060	-38,9902	-12,8	-39,0030
		548,31		**0,0127**	**-12,7**	**0,0000**
X	25	133,14	0,0075	-51,9249	7,4	-51,9175
	15	50,36	0,0199	15,0159	0	15,0159
	20	38,25	0,0261	-10,6594	0,1	-10,6593
	27	17,75	0,0563	6,7887	0,9	6,7896
	26	122,92	0,0081	40,7748	-3,5	40,7713
		362,42		**-0,0049**	**4,9**	**0,0000**
XI	30	210,97	0,0047	1,7505	17,8	1,7683
	26	122,92	0,0081	-40,7748	3,5	-40,7713
	28	167,2	0,0060	38,9902	12,8	39,0030
		501,09		**-0,0341**	**34,1**	**0,0000**

Studies on the performed leveling and technical precision must be continued deepening the focus on impact of various error sources therefore improving the methodology of first order leveling.

Conclusions

1. The result of third full-scale leveling campaign realization is topical elevation data with a very wide range of economic and scientific applications.
2. Significant unbound in polygons I;III;V and XI points to the impact of increased systematic errors in the precise leveling.
3. To identify the sources of systematic errors, the leveling field data analysis by elevation difference accumulation, acquired from "forward" and "back" measurements, is required.
4. For studies necessary to use information from the leveler data storage register, separately dividing the random and systematic errors in measurement, as well as leveling field journals for external impact assessment.

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Оцінка точності нівелірної мережі першого класу Латвії

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Проведене дослідження дає оцінку точності робіт з нівелювання 1-го класу в 2000–2010 рр. Для новоствореної мережі нівелювання складено систему нормальних рівнянь, в яку увійдуть всі поправки по ходах нівелювання. За результатами розв'язання системи нормальних рівнянь отримано коефіцієнти поправок (корелати). За правилами урівнювання поправок отримано перевищення окремих ходів нівелювання. З метою загальної оцінки точності нівелювання обчислено середню квадратичну помилку на кілометр ходу S = 0,785 мм/км. Оцінені чинники впливають на величини отриманої точності та визначено завдання для розвитку подальших досліджень. Загалом проведене нівелювання дає можливість використовувати отримані значення перевищень для поліпшення характеристик наявної системи висот і успішного включення її до Європейської висотної системи (European Vertical Reference System).

Оценка точности нивелирной сети первого класса Латвии

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Иследование даёт оценку точности произведенных работ по нивелированию 1 класса в 2000–2010 гг. Для вновь созданной сети нивелирования составлена система нормальных уравнений, в которую включены все поправки по ходам нивелирования. По результатам решения системы нормальных уровнений получены коэффициенты поправок (корелляты). Пользуясь правилами уравнения поправок, получены превышения отдельных ходов нивелировки. С целью общей оценки точности нивелировки вычислена средняя квадратическая ошибка на километр хода S = 0,785 мм/км. Оценены факторы, влияющие на величины полученных точностей и определены задачи для развития дальнейших исследований. В целом проведенная нивелировка даёт возможность использовать полученные значения превышений для улучшения характеристик существующей системы высот и успешного включения её в Европейскую высотную систему (European Vertical Reference System).

Accuracy Estimation of the Latvia First Order Leveling Network

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This study provides an assessment of the accuracy of performed first order leveling at the period from year 2000 to year 2010. For the newly created leveling network the normal equation system was made, which includes all leveling line corrections. In result of solving the normal equation system the correlates are obtained. Using the correction provision equations the elevation corrections for leveling lines are calculated. For assessment of the leveling accuracy the leveling kilometric standard deviation is calculated S = 0.785 mm/km. Discussed obtained accuracy value influencing factors and provided the recommendations for further research. In general, performed leveling provides the opportunity to use the estimated height values for existing height system actualization and successful inclusion in the European Vertical Reference System.