LATVIAN NORMAL HEIGHT SYSTEM TESTING USING GNSS MEASUREMENTS

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Abstract
After height system replacement in Latvia, there is a transformation formula for point height difference theoretical value in any place of Latvia. Performing practical Global Navigation Satellite System (GNSS) measurements and obtained data mathematical processing, there is also a possibility to calculate point height difference, in this case – practical values. There were thirteen 1st class levelling network points selected in territory of Latvia and got the theoretical and practical values of them. As the result, it is possible to compare height differences between Baltic Normal Height System 1977 and Latvian Normal Height System 2000,5. The practical and theoretical values should coincide, but just 3 of selected geodetic points the height difference comparing practical and theoretical values is close to zero and point height difference of all measured points differs in 17 cm amplitudes indicating problems with transformation formula or need to improve geoid model.
Key words: Latvian Normal Height System, GNSS, elevation.

Introduction

Since 1st December 2014 in Latvia Cabinet of Ministers and state laws as a national height system finds the European Vertical Reference System realization in Latvia – Latvian Normal Height System 2000,5 (LHS-2000,5) (Celms, Bimane, & Reke, 2014). Prior to this, the Baltic Normal Height System 1977 (BHS1977) (Celms, Helfrica, & Kronbergs, 2007) was used as the national height system.

Nowadays the Global Navigation Satellite System (GNSS) offers more and more advantages. So to test LHS-2000,5 authors using GNSS measurements of 13 first class levelling points in the territory of Latvia obtained data compared with data calculated using the transformation formula for height difference calculation between two height systems (*Latvijas kvaziģeoīda modelis*, 2015). The global positioning for obtaining practical values was chosen because of their simplicity – using global positioning and calculating ellipsoidal coordinates it is possible to see the height difference control in height system datum point and regional main geodetic points (Lazdans *et al*., 2009). On these points where direct GNSS observations are not possible to do there is still need for precise levelling works (Celms *et al*., 2013).

The levelling network is a national height system forming element. Levelling network ensures the realization of various functions in the national economy (Celms, Kronbergs, & Cintina, 2013).

For precise GNSS measuring, it is necessary to have a precise quasigeoid model. Since 1st December 2014 Latvian specialists have developed a new quasigeoid model LV'14 with 4 cm accuracies (*Latvijas kvaziģeoīda modelis*, 2015).

The study aim is to figure theoretical and practical measurements obtained differences between BHS1977 and LHS-2000,5. To achieve the goal, the following tasks are set: 1) to do global positioning measurements in the national 1st class levelling network obtaining practical values of point height difference in two height systems; 2) to get point height difference theoretical values using height transformation formula; 3) to compare the obtained practical and theoretical values.

Materials and Methods

To do GNSS measurements to see practical values of point height difference in two height systems – BHS1977 and LHS-2000,5 – first of all, there was the national geodetic network point inspection done. There were some points selected and then visited on site to detect for each point the horizon above point and possibility to use GNSS methods for its height determination, the point location conformity to point abris. Also, global positioning real time measurements were done to detect the location of satellites above point. After inspection there were thirteen1st class levelling network points chosen as an appropriate geodetic point for GNSS measurements – ground marks 1415, 1001, 37, 1155, 1537, 1636, 1676, 1727, 8248 and fundamental marks 1484, 0608, 3389 and 1463 (Fig. 1).

There are 3 measurement sessions performed – 14th December 2012, 22th November 2013 and 27th November 2014 in the territory of Latvia at the same time using global positioning in post-processing mode. The measurement has taken 4 hours long in the morning about 10 to 14 o'clock in Latvia Positioning System Base Station (LatPOS) network. LatPos is GNSS continuously operating the network of Latvia (Celms, Ratkevics, & Rusins, 2014). On each point was installed GNSS receiver – Leica, Trimble, Topcon or GeoMax receiver – and 4 hours long collected GNSS data.

For precise data processing and adjustment after measuring, there were collected data from 3 nearest LatPOS base stations from LatPOS home page

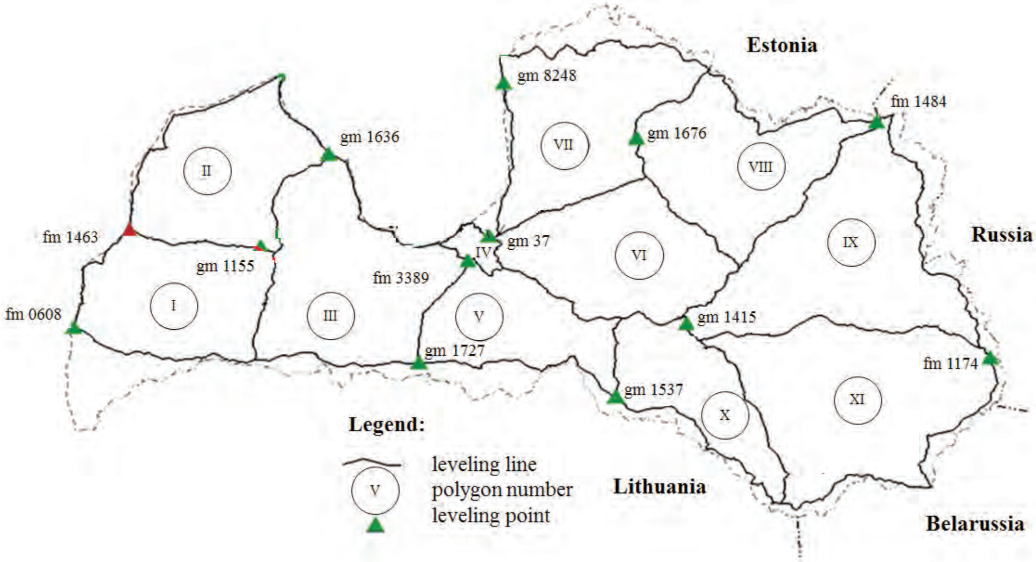

Figure 1. Performed GNSS measurements in 1st class levelling network.

choosing respective base stations. The data from GNSS receivers and LatPOS stations were used for data adjustment and point height determination (Reiniks, Lazdans, & Ratkus, 2010). Fig. 2. shows the location of measured points and LatPOS base stations.

Setting relevant parameters during data processing the point height can be adjusted in both height systems – BHS1977 and LHS2000,5. The difference between both height systems is the practical value – using GNSS method measured height difference (Celms, Eglaja, & Ratkevics, 2015). For getting more precise results, an average value of point height from all 3 measuring sessions was calculated.

Theoretical values of point height difference – the height difference between BHS1977 and LHS-2000,5 – has been determined by Cabinet Regulation No. 879 (adopted on 15 November 2011.) 'Regulations Regarding the Geodetic Reference System and the Topographic Map System'. The regulation defines the height transformation formula from BHS 1977 to LHS-2000,5:

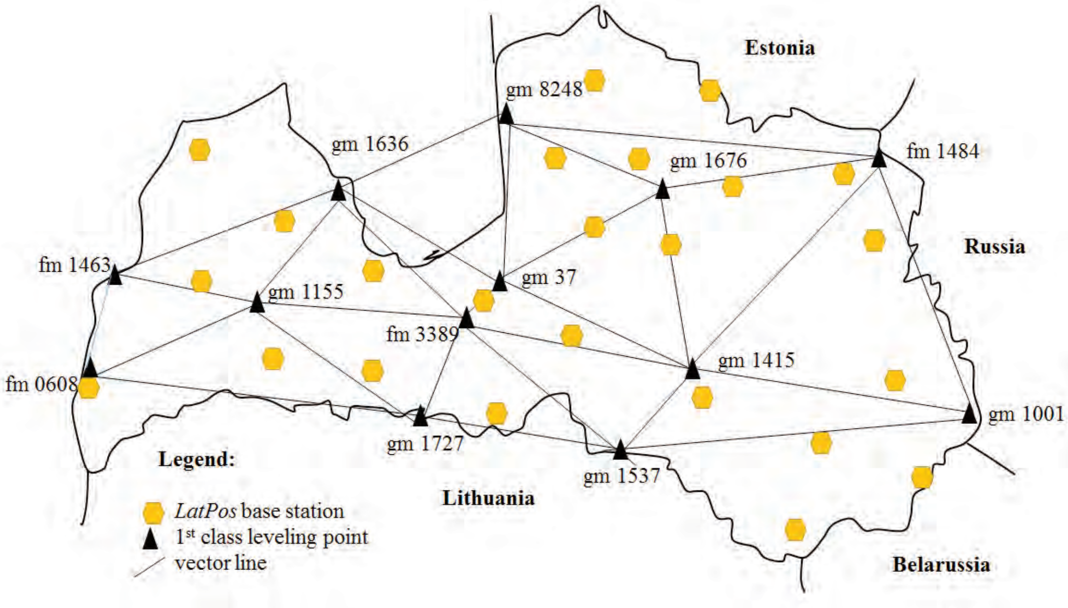

Figure 2. Vector lines between measured 1stclass levelling network points and location of LatPOS base stations.

$$H_{(II)} = H_{(I)} + a_1 + a_2 \cdot M_0 \cdot (LAT - LAT_0) +$$
$$+ a_3 \cdot N_0 \cdot (LON - LON_0) \cdot \cos(LAT) \quad (1)$$

Where $H_{(I)}$: height in BHS1977 (m);
$H_{(II)}$: height in LHS-2000,5 (m);
M_o: radius of curvature in the meridian of GRS80 (m) in P_o,63840416.7 m;
N_o: radius of curvature perpendicular to the meridian of GRS80 (m) in P_o,6393195.1 m;
LAT: latitude in ETRS89 (radian);
LON: longitude in ETRS89 (radian);
$P_o(LAT_o,LON_o)$: Reference point of the transformation LAT_o = 56°58' = 0.994255897 radian; LON_o = 24°53'= 0.434296096 radian;
a_1: vertical translation 1.49392900367864 E-0001 m;
a_2: slope in the direction of the meridian 7.99066182789555 E-0008 m;
a_3: slope in the direction perpendicular to the meridian 9.48289473646151 E-0008 m.

For unknown reasons, the regulation defines two parameters – slope in the direction of the meridian a_2 and slope in the direction perpendicular to the meridian a_3 – in meters, but it must be a mistake because parameters a_2 and a_3 can be determined only in radians or seconds. For the height difference calculations the authors of research adopted these values of both parameters in radians (Celms, Reke, & Ratkevics, 2015).

Calculating results with the transformation formula a height difference between BHS1977 and LHS-2000,5 is not a constant value of a whole territory of Latvia but differs from 125 mm in the south-east part of the country to 173 mm in the north-west part of the country (Fig. 3.) and depends on point location in the territory (coordinates). The amplitude between south-east and the north-west part of the country is 48 mm.

Using the transformation formula, the authors of research calculated point height difference between both height systems of the same 1st class levelling network points measured with GNSS. As point height in BHS 1977 $H_{(I)}$ was used with GNSS measured point height in BHS1977 average value from all 3 sessions.

Results and Discussion

Adjusted results from performed GNSS measurements of all 3 sessions are listed in Table 1. The measured data can be adjusted both in BHS1977 using geoid model LV 98 and in LHS-2000,5 using new geoid model LV'14. Next column shows the difference between both values and for more precise data there are calculated an average value of point height difference between BHS1977 and LHS-2000,5 – practical values of point height difference in two height systems.

Unfortunately, sometimes, there were not possible to do GNSS measurements of the point in all 3 sessions. Some points have changed their locations because of road construction works and in some cases, there was a problem with data adjustment.

Point No. 1636 – 0.268 m has the biggest average height difference, but point No. 1415 has the smallest average height difference – 0.058 m. Based on further results, these values are not comparable to each other, but they will be compared with theoretical values of point height difference in two height systems.

The theoretical values of point height difference in two height systems authors of research calculated using the transformation formula and as point height in

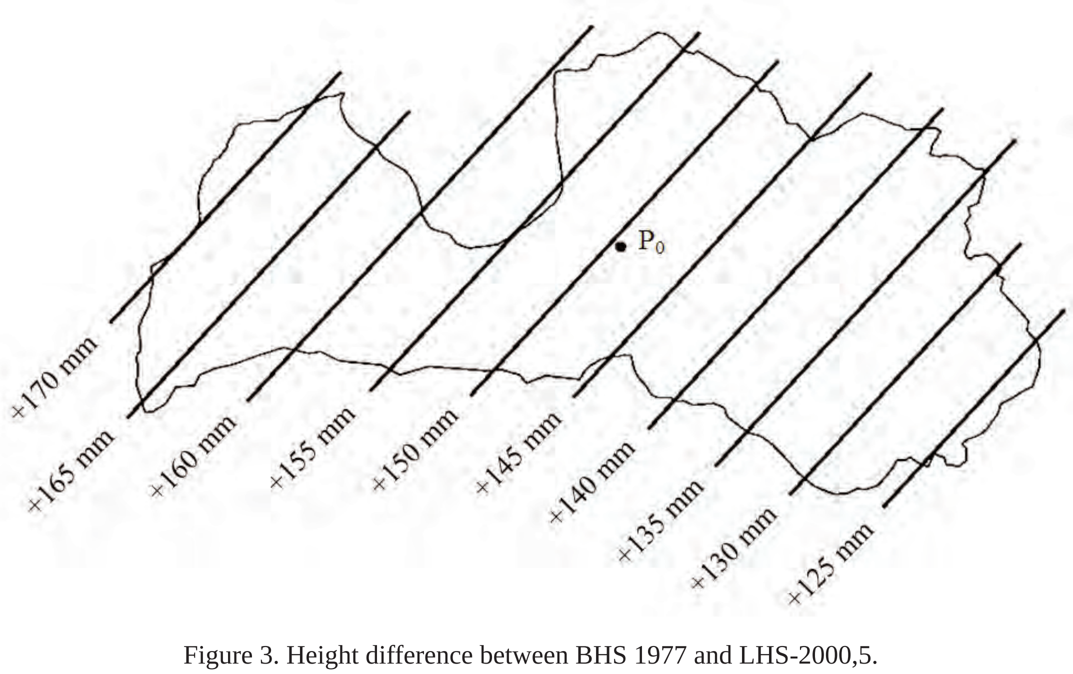

Figure 3. Height difference between BHS 1977 and LHS-2000,5.

Table 1

Point heights and height difference between BHS1977 and LHS-2000,5 of measured points

Session year	Point	Measured height in BHS1977, m	Measured height in LHS-2000,5, m	Height difference between BHS1977 and LHS-2000,5, m	Point average height difference, m
2012	1001	138.649	138.820	+ 0.171	+ 0.175
2013		138.662	138.846	+ 0.184	
2014		138.677	138.848	+ 0.171	
2012	1155	94.520	94.731	+ 0.211	+ 0.175
2013		82.026	82.188	+ 0.162	
2014		82.016	82.169	+ 0.153	
2012	1415	76.842	76.900	+ 0.058	+ 0.058
2013		76.853	76.911	+ 0.058	
2014		76.861	76.918	+ 0.057	
2012	1484	156.812	156.946	+ 0.134	+ 0.101
2013		156.739	156.755	+ 0.016	
2014		156.731	156.783	+ 0.152	
2012	1537	80.589	80.661	+ 0.072	+ 0.075
2013		80.458	80.538	+ 0.080	
2014		80.381	80.454	+ 0.073	
2012	1636	6.857	7.124	+ 0.267	+ 0.268
2013		6.852	7.120	+ 0.268	
2014		-	-	-	
2012	1676	58.536	58.650	+ 0.114	+ 0.111
2013		58.531	58.633	+ 0.102	
2014		58.509	58.625	+ 0.116	
2012	1727	32.393	32.575	+ 0.182	+ 0.182
2013		32.381	32.568	+ 0.187	
2014		32.387	32.565	+ 0.178	
2012	37	7.383	7.533	+ 0.150	+ 0.151
2013		7.357	7.509	+ 0.152	
2014		-	-	-	
2012	8248	4.723	4.829	+ 0.106	+ 0.161
2013		4.722	4.935	+ 0.213	
2014		4.694	4.858	+ 0.164	
2012	0608	-	-	-	+ 0.112
2013		5.727	5.838	+ 0.111	
2014		5.641	5.754	+ 0.113	
2012	3389	-	-	-	+ 0.126
2013		12.474	12.633	+ 0.159	
2014		12.394	12.488	+ 0.094	
2012	1463	-	-	-	+ 0.151
2013		-	-	-	
2014		13.476	13.627	+ 0.151	

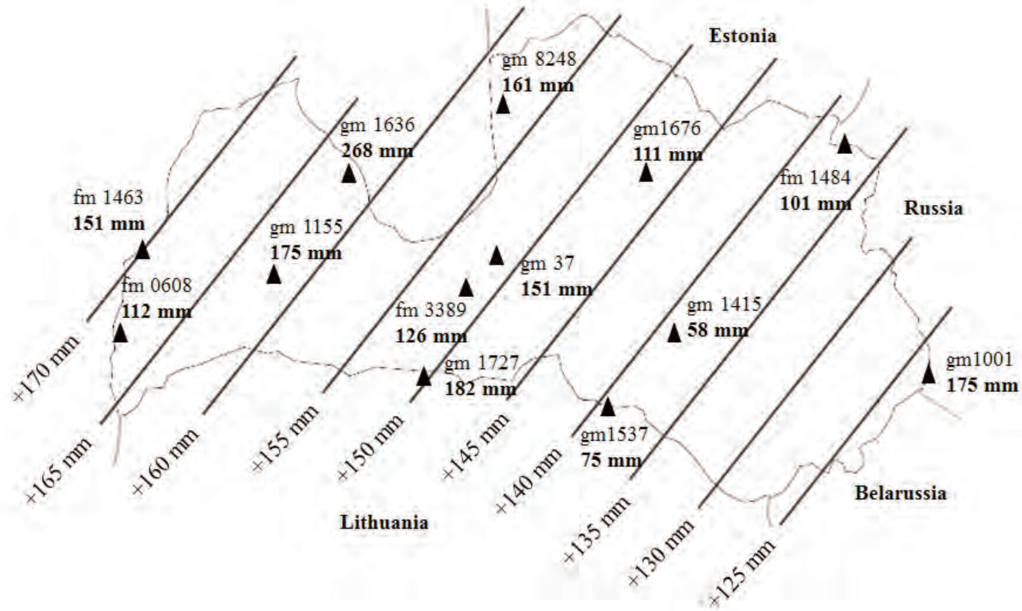

Figure 4. Height difference between BHS1977 and LHS-2000,5 comparing practical and theoretical data.

BHS1977 $H_{(I)}$ using with GNSS measured point height in BHS1977 average value from all 3 sessions. The results are showed in Fig. 4. – the height difference in the territory of Latvia and the height difference of each measured point. No one of the measured point height differences coincides with the height differences from transformation formula except point No. 37 which is quite close to calculated height difference (Fig. 4.).

The exact values of point height difference between BHS-1977 and LHS-2000,5 using GNSS measurements (practical values) and transformation formula (theoretical values) are shown in Table 2.

The last column of Table 2 shows the difference between practical and theoretical values. The difference varies from -0.066 to 0.104 m compiling 17 cm amplitude. Point No. 8248 has the smallest difference between practical and theoretical values – the height difference using GNSS measurements differs from height difference using transformation formula just about 0.002 m. Point No. 37 has next closest difference – 0.007 m. Points No. 1415; 1484; 1537; 1676; 608 and 3389 have negative height difference. The negative aspect is that difference between practical and theoretical values has also

Table 2

Calculated point height difference between BHS-1977 and LHS-2000,5

Point	Calculated point height difference between BHS1977 and LHS-2000,5 from GNSS measurements, m	Calculated point height difference between BHS1977 and LHS-2000,5 from transformation formula, m	Difference
1001	0.175	0.125	0.050
1155	0.175	0.163	0.012
1415	0.058	0.141	-0.083
1484	0.101	0.140	-0.039
1537	0.075	0.141	-0.066
1636	0.268	0.164	0.104
1676	0.111	0.150	-0.039
1727	0.182	0.151	0.031
37	0.151	0.144	0.007
8248	0.161	0.159	0.002
608	0.112	0.168	-0.056
3389	0.126	0.153	-0.027

negative values, because the transformation formula shows homogeneity of height difference. The possible reason could be that the transformation formula does not work correctly or geoid model is not developed sufficiently precise. Consequently, this study requires a further research.

Conclusions

GNSS measured data can be adjusted both in BHS1977 and in LHS-2000,5 using different geoid models – LV 98 and LV'14 – so giving an opportunity to calculate point height difference between BHS1977 and in LHS-2000,5. The calculated height difference of thirteen 1st class levelling points in the territory of Latvia comparing with using transformation formula calculated point height difference differs from each other in 17 cm amplitudes indicating problems with transformation formula or need to improve geoid model.

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