EUROPEAN VERTICAL REFERENCE SYSTEM TESTING USING GNSS MEASUREMENTS IN LATVIA

Armands Celms, Ilona Reķe, Jānis Rusiņš
Latvia University of Agriculture, Faculty of Environment and Civil Engineering,
Department of Land Manegement and Geodesy

Abstract
Since 1st December 2014, Latvia as a national height system is determined by implementing the European Vertical Reference System in Latvia – Latvian Normal Height System 2000,5 (LHS-2000,5). For height calculations, a transformation formula exists for acquiring the theoretical value of the height difference between LHS-2000,5 and Baltic Normal Height System 1977 (BHS-1977) in any place in Latvia. The performed practical GNSS measurements and the obtained mathematical processing data lead to the possibility of having ellipsoidal heights of a point. However, by using the geoid model concerning mathematical correlations it is possible to achieve the normal height of a point, in this case point height that corresponds with LHS-2000,5. As a result, it is possible to compare the differences between the theoretical and practical values in BHS-1977 and LHS-2000,5. The study provides an analysis of the differences between the theoretical and practical measurements concerning BHS-1977 and LHS-2000,5 and its possible causes.
This study aims at determining differences between BHS-1977 and LHS-2000,5, obtained by completing theoretical and practical measurements. To achieve the goal the following tasks are set: 1) to perform global positioning measurements in the national I class levelling network in order to obtain practical values of point height difference in two height systems; 2) to obtain point height difference theoretical values using the height transformation formula; 3) to compare the obtained practical and theoretical values.
Key words: Latvian Normal Height System, GNSS, elevation.

Introduction

Starting from 1st December 2014, the Cabinet of Ministers and state laws have established the European Vertical Reference System realization in Latvia as the national height system – Latvian Normal Height System 2000,5 (LHS-2000,5) (Celms, Bimane, Reķe, 2014). Prior to that, the Baltic Normal Height System 1977 (BHS-1977) was used as the national height system (Celms, Helfrica, Kronbergs, 2007).
Nowadays the Global Navigation Satellite System (GNSS) offers ever more advantages. So to test LHS-2000,5 authors used GNSS measurements of 12 first class levelling points in the entire territory of Latvia and compared the obtained data with the data calculated using transformation formula for the height difference calculation between two height systems (Latvian quasigeoid model, 2015). The global positioning for obtaining practical values was selected because of its simplicity – using global positioning and calculating ellipsoidal coordinates makes it possible to observe the height difference control concerning the height system datum point and regional main geodetic points (Lazdans *et al.*, 2009). On these points, where it is not possible to perform direct GNSS observations, it is still necessary to carry out precise levelling works (Celms *et al.*, 2013).
The levelling network is an element that forms the national height system. Levelling networks ensure the realization of various functions in the national economy (Celms, Kronbergs, Cintina, 2013).
Precise GNSS measuring requires having a precise quasigeoid model. As of 1st December 2014, Latvian specialists have developed a new quasigeoid model LV'14 with the accuracy of 4 cm.
The study aims at determining differences between BHS-1977 and LHS-2000,5, obtained by completing theoretical and practical measurements. To achieve the goal the following tasks are set: 1) to perform global positioning measurements in the national I class levelling network in order to obtain practical values of point height difference in two height systems; 2) to obtain point height difference theoretical values using the height transformation formula; 3) to compare the obtained practical and theoretical values.

Methodology of research and materials

First of all, in order to perform GNSS measurements to obtain practical values of point height difference in two height systems, BHS-1977 and LHS-2000,5, the national geodetic network point inspection was carried out. Certain points were selected and then visited onsite to detect the horizon above point and the possibility to use GNSS methods to determine the height of each point (the point location conformity to point abris). Also, real time global positioning measurements were completed to detect the location of satellites located above the point. After the inspection, twelve I class levelling network points were selected as appropriate geodetic points for GNSS measurements – ground marks 1415, 1001, 37, 1155, 1537, 1636, 1727, 8248 and fundamental marks 1484, 0608, 3389 and 1463 (Fig.1)

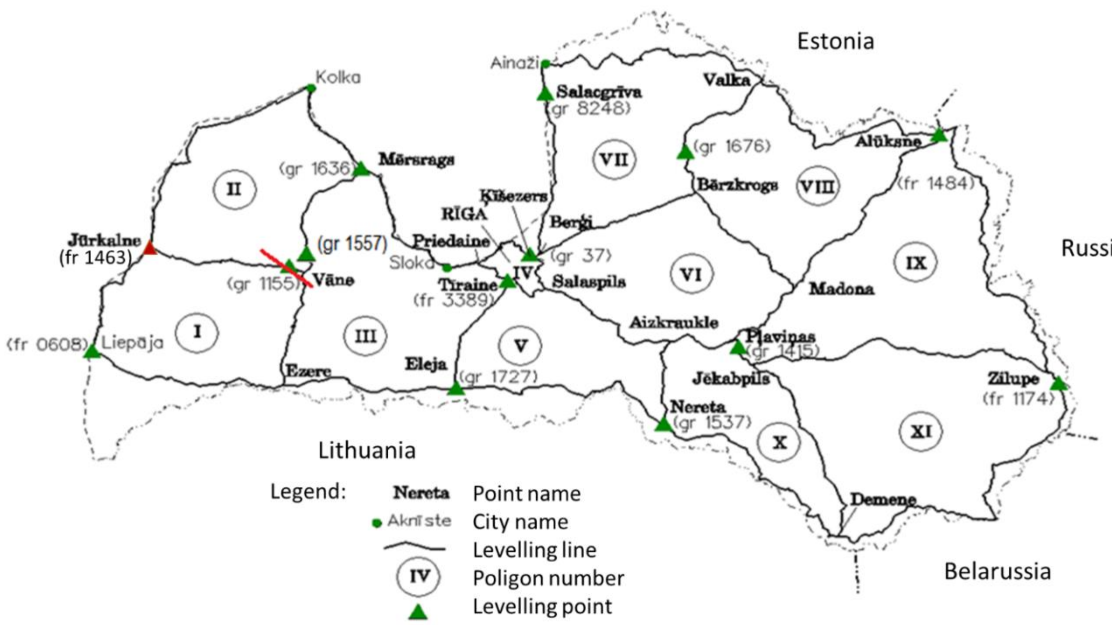

Fig.1. Performed GNSS measurements in I class levelling network

Three measurement sessions were completed, on 14th December 2012, 22th November 2013, and 27th November 2014 in the entire territory of Latvia, simultaneously using global positioning in the post-processing mode. The measurement took four hours, from about 10 AM to 14 PM in the Latvia Positioning System Base Station (LatPOS) network. LatPos is a continuously operating GNSS network of Latvia (Celms, Ratkevics, Rusins, 2014). At each point a GNSS receiver (Leica, Trimble, Topcon or GeoMax receiver) was installed that collected the GNSS data for four hours.

In order to ensure precise data processing and adjustment after measuring, data from three nearest LatPOS base stations from LatPOS home page choosing respective base stations was collected. The data from GNSS receivers and LatPOS stations was used for data adjustment and point height determination (Reiniks, Lazdans, Ratkus, 2010). Fig. 2. shows the location of the measured points and the LatPOS base stations.

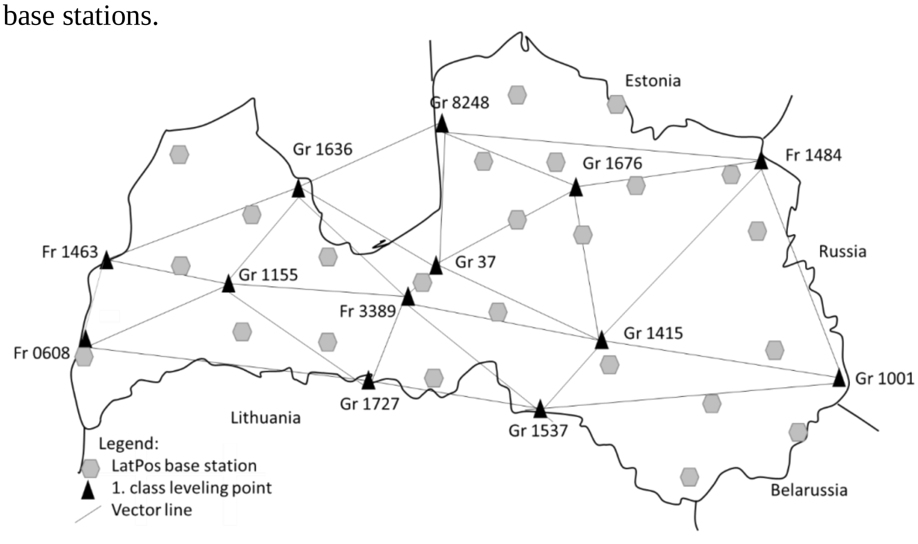

Fig. 2. Vector lines between the measured I class leveling network points and the locations of the LatPOS base stations

Setting relevant parameters during data processing the point height can be adjusted in both height systems, i.e. BHS-1977 and LHS-2000,5. The difference between both height systems is the practical value – the height difference, calculated using the GNSS method (Celms, Eglaja, & Ratkevics, 2015).

For more precise results, the average value of point height from all three measuring sessions was calculated.

Theoretical values of point height difference – the height difference between BHS-1977 and LHS-2000,5 – has been determined by the 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:

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

Where $H_{(I)}$ denotes height in BHS-1977 [m];

$H_{(II)}$ denotes height in LHS-2000,5 [m];

M_o denotes radius of curvature in the meridian of GRS80 [m] in P_o, 63840416.7 m;

N_o denotes radius of curvature perpendicular to the meridian of GRS80 [m] in P_o, 6393195.1 m;

LAT denotes latitude in ETRS89 [radian];

LON denotes longitude in ETRS89 [radian];

$P_o(LAT_o,LON_o)$ denotes reference point of the transformation, LAT_o = 56°58’ = 0.994255897 radian; LON_o = 24°53’= 0.434296096 radian;

a_1 denotes vertical translation 1.49392900367864 E-0001 m;

a_2 denotes slope in the direction of the meridian 7.99066182789555 E-0008 m;

a_3 denotes slope in the direction perpendicular to the meridian 9.48289473646151 E-0008 m.

For reasons unknown, 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 metres, which is probably a mistake, because parameters a_2 and a_3 can be determined only in radians or seconds. In order to complete the height difference calculations, the authors of the study adopted the values of both these parameters in radians (Celms, Reke, Ratkevics, 2015).

Having calculated the results using the transformation formula, a height difference between BHS-1977 and LHS-2000,5 in the entire territory of Latvia results as not a constant value, but differs from 125 mm at the south-east part of the country to 173 mm at the north-west part of the country (Fig.3.) and depends on the point location in the territory (coordinates). The amplitude between south-east and the north-west part of the country is 48 mm.

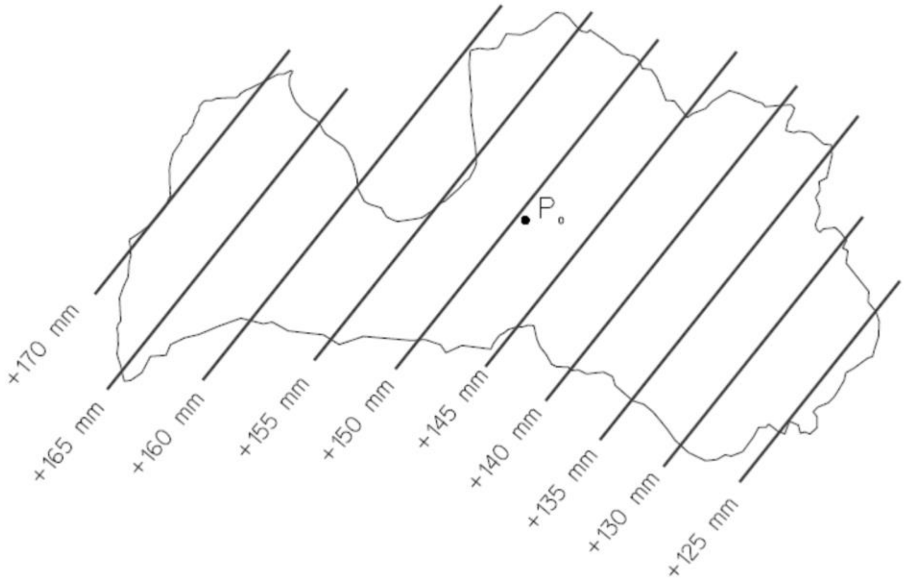

Fig. 3. The height difference between BHS 1977 and LHS-2000,5

Using the transformation formula the authors of this study calculated the point height difference between both height systems of the same I class levelling network points measured with GNSS. $H_{(I)}$ was used as point height in BHS 1977 with the GNSS measured point height in BHS-1977 average value for all three sessions.

Discussions and results

The adjusted results of GNSS measurements from all three sessions are listed in Table 1. The measured data can be adjusted both for BHS-1977, using the geoid model LV 98, and for LHS-2000,5, using new geoid model LV'14. The next column shows the difference between both values. For more precise data, the average value of point height difference between BHS-1977 and LHS-2000,5 has been calculated, i.e. the practical values of point height difference in two height systems.

Table 1

Point heights and height difference between BHS-1977 and EVRF2007 of the measured points

Session year	Point	Measured height in BHS-1977, m	Measured height in EVRF2007, m	Height difference between BHS-1977 and EVRF2007, 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	

Unfortunately, in some cases it was impossible to perform GNSS measurements of the point in all three sessions. Some points had changed their locations due to road construction works and in some cases there were problems concerning data adjustment.

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

The authors of the study calculated the theoretical values of point height difference in two height systems using the transformation formula and using $H_{(I)}$ as the point height in BHS-1977 with GNSS measured point height in BHS-1977 average value for all three sessions. The results, i.e. the height difference in the entire territory of Latvia and the height difference of each measured point are shown in Fig. 4. As seen in the figure, none of the measured point height differences coincide with the height differences resulting from the transformation formula, except point No.37 which is quite close to the calculated height difference.

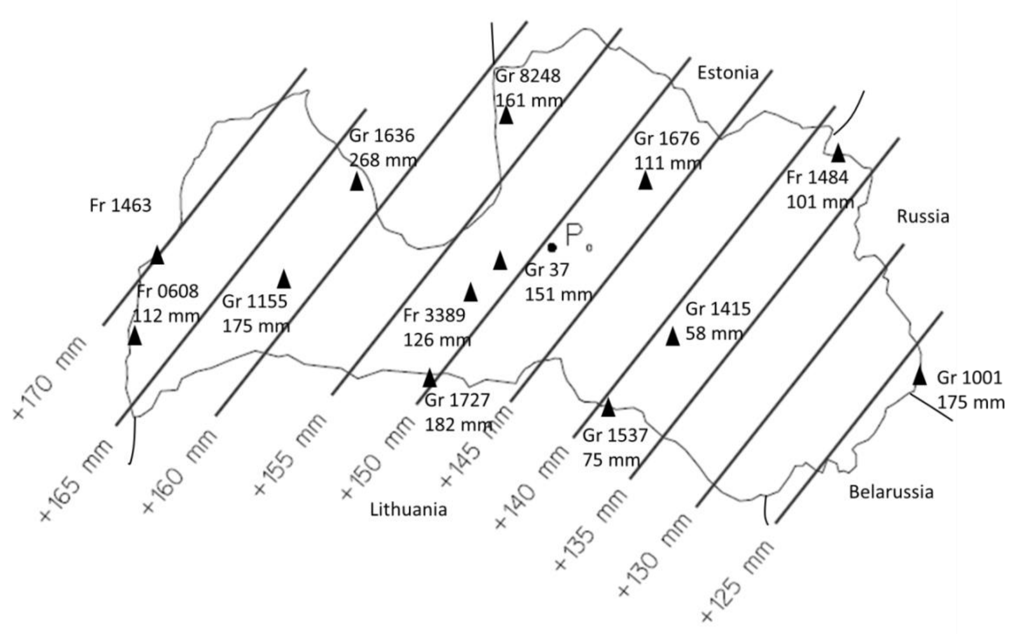

Fig. 4. Height difference between BHS-1977 and LHS-2000,5

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

Table 2

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

Point	**Calculated point height difference between BHS-1977 and LHS-2000,5 using GNSS measurements, m**	**Calculated point height difference between BHS-1977 and LHS-2000,5 using the 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	-0.040
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

The right column of Table 2 shows the difference between practical and theoretical values. The difference varies from -0.066 to 0.104 m, constituting a 17 cm amplitude. Point No.8248 has the smallest difference between practical and theoretical values: the height difference calculated by using GNSS measurements differs from the height difference calculated by using the transformation formula by just about 0.002 m. Point No.37 has the next closest difference, 0.007 m. Points No. 1415; 1484; 1537; 1676; 608 and 3389 have negative height differences. The negative aspect of this is that such a difference also displays negative values because the transformation formula shows the homogeneity of height difference. The most likely explanation is that the transformation formula does not work correctly or that the developed geoid model is not sufficiently precise. Consequently, this study requires further research.

Conclusions and proposals

GNSS measured data can be adjusted for both BHS-1977 and LHS-2000,5 by using different geoid models – LV 98 and LV'14 – thus allowing for calculating the difference in point heights between BHS-1977 and in LHS-2000,5. The comparison of the calculated height difference of 12 I class levelling points in the entire territory of Latvia to the point height difference calculated using the transformation formula shows a difference of 17 cm in amplitude which indicates that there are issues with the transformation formula or the need to improve the geoid model.

Regarding the significance of the geoid model to the precision of the geodetic result data, it is preferred to perform GNSS measurements of I class levelling networks in Latvia, Lithuania and Estonia. This way, the geoid model can be tested and verified on larger areas, thus contributing to certainity concerning the precision of the geoid model. I class geodetic network between Lithuania, Latvia and Estonia is physically levelled.

References

1. Celms A., Bimane I., Reke I. (2014). *European Vertical Reference System in Baltic Countries.* In Baltic Surveying. - Vol.1, pp. 49–55.
2. Celms A., Eglaja E., Ratkevics A. (2015). Latvia Positioning System Base Station Installation in Valka. Сучасні досягнення геодезичної науки та виробництва: збірник наукових праць Західного геодезичного товариства УТГК / Західне геодезичне товариство Українського товариства геодезії і картографії. Національний університет "Львівська політехніка" - Львів, 2015. - Вип.1(29), с. 39-43
3. Celms A., Helfrica B., Kronbergs M. (2007). Результаты нивелирования I класса в западной части Латвии (I Class Leveling Works in West Part of Latvia). In BALTIC SURVEYING `07 Internationalscientific-methodicalconference pp.14-18. Kaunas. (In Russian)
4. Celms A., Kronbergs M., Cintina V. (2012). Accuracy Estimation of the Latvia First Order levelling Network. In International scientific and technical conference GEOFORUM 2012 pp.44 – 47. Lvivska Politehnika.
5. Celms A., Kronbergs M., Cintina V., Baumane V. (2013). Precision of Latvia Levelling Network Nodal Point Height. In CIVIL ENGINEERING`13 4th International Scientific Conference, Volume 4 pp. 310-317. Jelgava.
6. Celms A., Ratkevics A., Rusins J. (2014). *Research of National Geodetic Network Elevations at Eastern Part of Latvia.* In Baltic Surveying. - Vol.1, pp. 84–91.
7. Celms A, Reke I., Ratkevics A. (2015). European Vertical Reference System Influence in Latvia. In 2nd International Conference Innovative Materials, Structures and Technologies, 30 September – 2 October 2015 p. 30. Riga: Riga Technical University
8. *Latvijas kvaziģeoīda modelis* (Latvian quasigeoid model). (2015). Retrieved 11 March, 2015, from http://map.lgia.gov.lv/index.php?lang=0&cPath=2&txt_id=130 (In Latvian)
9. Lazdans J., Aleksejenko I., Kaminskis J., Celms A., Kalinka M., Klive J., Reiniks M. (2009). Aktualitāte Latvijas sasaistē ar Eiropas augstumu sistēmu (Current Events Latvia Connecting with European Height System). LatviaUniversity scientific conference No.67.
10. Reiniks M., Lazdans J., Ratkus B. (2010). Valsts augstuma izejas līmeņa noteikšana (Determination of state height datum level). *Riga Technical University scientific articles.* Nr.7, 7-13. lpp. (In Latvian)

Information about authors

Armands Celms, Dr.sc.ing., assistant professor, Department of Land Management and Geodesy, Faculty of Rural Engineering, Latvia University of Agriculture. Address: Akademijas Street 19, Jelgava, LV–3001. E-mail: armands.celms@llu.lv

Jānis Rusiņš, Mg.sc.ing., lector, Department of Land Management and Geodesy, Faculty of Rural Engineering, Latvia University of Agriculture. Address: Akademijas Street 19, Jelgava, LV–3001. E-mail: jrusins@inbox.lv

Ilona Reķe, Mg.sc.ing. Department of Land Management and Geodesy, Faculty of Rural Engineering, Latvia University of Agriculture. Address: Akademijas Street 19, Jelgava, LV–3001. E-mail: ilona.reke@gmail.com