RIGA TECHNICAL UNIVERSITY

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# *EUPOS®-RĪGA* geodetic reference network and multifunctional use of it

**Summary of Doctoral Thesis**

**Riga – 2012**

**RIGA TECHNICAL UNIVERSITY**

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**Summary of Doctoral Thesis**

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Prof. Dr.phys
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**Riga – 2012**

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# Contents

# GENERAL CHARACTERISTICS OF THESIS

## Topicality of Thesis

Geodetic reference network of Riga did not meet requirement of performance of surveying works already long time ago. Polygonometric network is severely destroyed by street reconstruction and construction. It has been formed during decades. However, accuracy of the remaining part is no longer satisfying. Polygonometric network was established for separate regions of city parallel with construction of new blocks. Polygonometric network was not as one coordinate reference system that is internally coherent and uniformly aligned. Also elevation network was large enigmatic system, accuracy of which could be only guessed. In Riga, urgent necessity either to restore geodetic coordinate system or to create new one has been matured.

It turned out that also a number of neighboring countries have similar concerns. An idea emerged to establish auxiliary ground based system GBAS (*Ground Based Augmentation System*) to Global Navigation Satellite System (*GNSS*).

In the result of necessity to form wide-scale GNSS network, which covers territories of several countries and is run under unified standards, system EUPOS® was established. In the establishment of the network, countries of Eastern Europe took part. Based on principles of EUPOS®, local GNSS network – ***EUPOS®-RĪGA*** – was established. GNSS network of Riga City is based on five base stations of permanent operation, four of them are surrounding Riga City and one is situated in the center – main building of Latvian University (Fig. 1). Spacing between base stations does not exceed twelve km. The small distance between the base stations provides more accurate height measurements. Hardware of company JAVAD provides reception of signals from both GPS and GLONASS satellites, because in urban environment, where celestial horizon is covered by surrounding buildings, greater number of satellites is important. Researches described in the Thesis have been carried out with aim to analyze possibilities, reliability, and applicability in other sectors of the economy of the system EUPOS ®-RĪGA more deeply**.**

By creating GNSS positioning system in Riga City, advanced electronic geodesic coordinate network with extensive capabilities to use it in land surveying, cartography, creating and use of Riga geographic information system, construction, navigation, traffic organization, and in many other applications has been obtained. Analogously, as mobile phones, GNSS technologies are currently widely introduced throughout the world, and Riga,

as developed European city is obtaining many benefits by quicker mastering of this advanced technology.

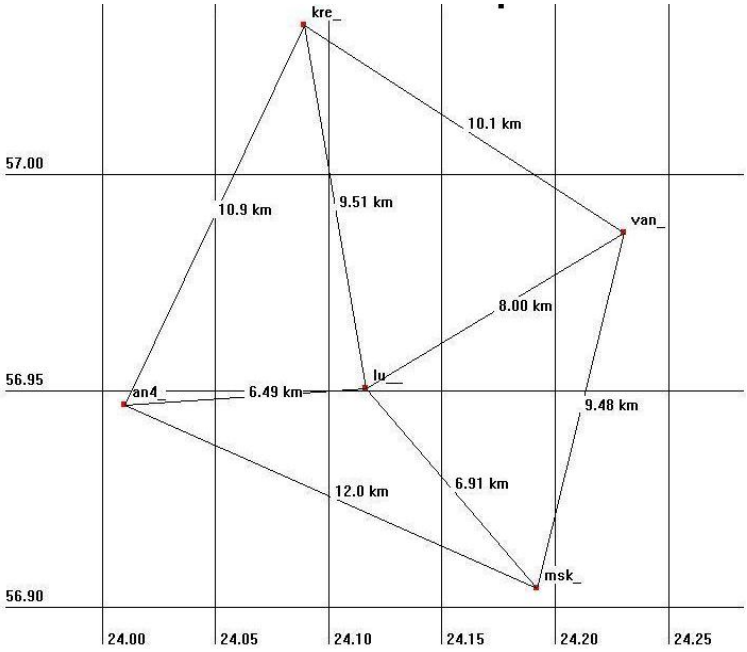


Fig 1. ***EUPOS-RIGA*** scheme of GNSS network

## Aims of Thesis

Create and underpin geodetic reference system for determination of coordinates in the territory of Riga City, which is:

- ACCURATE – cm accuracy at the global scale in system ETRF89 with its realisation in Latvia, which is named LKS92 system,
- ACTIVE – integrated set of reference stations with permanent operation RTCM correction data of DGNSS positioning obtained by them, which as continuously data flow can be received via mobile telephony GPRS system by GNSS information users,
- INTEGRATED – continuously operating, in the united coordinate space of the world is connected with national and international agencies and standards (i.e. European positioning system EUPOS and network LatPos of continuously operating stations of Latviam Geospatial Information Agency (LGIA), International GNSS service IGS and network EPN of continuously operating GNSS stations of Europe),

- MULTIFUNCTIONAL – securing of high accuracy reference system for geodesy, geophysics, land surveying and differentiated accuracy applications for navigation on the see, in air and on land, mapping, charting and diverse purposes of creating and use of geoinformation systems.

## Scientific novelty of Thesis

- New, advanced, high accuracy geodetic reference network is created for Riga City;
- Statistical methods are used for quality analysis of GNSS stations of ***EUPOS®-RĪGA***;
- It is shown with real GNSS measurements, that use of system ***EUPOS®-RĪGA*** in GNSS measurements ensures meeting of technical requirements for performing geodetic engineering and technical works in Riga in static and real time measurements;
- Existence of large deformations of the vertical reference network of Riga is proved by use of system ***EUPOS®-RĪGA***.

## Practical value of Thesis

- Securing with high quality 3-D global coordinate system for performance of engineering, technical and surveying works in good quality is created for Riga City.
- Study concerning quality of results of measurements of GNSS base stations and factors, which have an effect on it, is carried out.
- Applicability of GNSS RTK method in surveying, construction (especially determination of heights) works is proven.
- Methodology and principles are developed for aligning of data of ***EUPOS®-RĪGA*** **a**nd the local geodetic network, as well as for examination of accuracy of orthophotomap.

## Theses put forward for *viva voce*

1. Advanced, complying with international standards (EUPOS®), electronically provided, telematically achievable real time digital data flow auxiliary system is

created for use of information of Global Navigation Satellite Systems. This system is named ***EUPOS® - RĪGA;***

2. Determination of coordinates with high accuracy for base stations of ***EUPOS® - RĪGA*** in systems LKS92 and ETRF89 in the coordinate space of Latvia and world is provided;
3. Wide opportunities of application of ***EUPOS® - RĪGA*** are justified, particular importance is attached to studies of vertical motions of Earth.

## Composition and volume of Thesis

Doctoral thesis is independent scientific research, and it contains an introduction, 4 chapters, conclusions and references. Thesis volume includes 98 printed pages, 54 figures, 13 tables, and literature references, containing 82 publication titles.

## Approbation and publications of Thesis

Results of the present thesis have been reported and discussed in international conferences.

- Abele M., Balodis J., Rubans A., Silabriedis G. Project on the Automated Digital Camera for Vertical Deflection Determination. International Symposium EUREF – 2004. Bratislava, June 2-5, 2004. http://www.euref-iag.net/symposia/symposia_2004_Bratislava.html
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- http://www.euref-iag.net/symposia/Symposium2005-Vienna.html
- Ābele M., Balodis J., Mūkins E., Silabriedis G., Štrauhmanis J.. Cooperation in Geomatics. International Conference „Cooperation on Applied Earth Observation/GMES". Berlīne, 2005.g. 25-27.septembris. www.dlr.de/dlr-eo-conference.
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- Abele M., Balodis J., Balodis K., Caunite M., Janpaule I., Mitrofanovs I., Rubans A., Silabriedis G. and Zarinsjh A. Implementation of New Positioning System in Riga. International Symposium EUREF – 2008. Brussels, June 18-20, 2008.
- Silabriedis G., Balodis J., Baņuka D. Analyses of the Positioning System EUPOS-RIGA Multipath. Proceedings of the International Symposium on Global Navigation Satellite Systems, Space-based and Ground-based Augmentation Systems and Applications. Berlin, Germany, 11 - 14 November 2008. (Poster). p.125.
- Abele M., Balodis J., Caunite M., Janpaule I., Rubans A., Silabriedis G., Zarinsjh A. Engineering process of SLR for LEO orbiters. Proceedings. 16th International Laser Ranging Workshop. Poznan, Poland, 13-17 October 2008. pp 641-643. Published
- December 2009. Publisher: Space Research Centre, Polish Academy of Sciences
- Janpaule I., Caunite M., Balodis J., Silabriedis G. *EUPOS*® NETWORK SOLUTION. Proceedings of the International Symposium on Global Navigation Satellite Systems, Space-based and Ground-based Augmentation Systems and Applications. Berlin, ISBN 978-3-938373-93-4. Germany, 1-2 December 2009. pp.61-67.

- Balodis J., Silabriedis G., Caunite M., Janpaule I., Balodis K., Rubans A., Aleksejenko I., Otto R., Ratkus B., Reiniks M., Mitrofanovs I., Plotnikovs S., Zvirgzds J. *EUPOS®-RIGA* NETWORK ELEVATION ANALYSES. International Symposium on Global Navigation Satellite Systems, Space-Based and Ground-Based Augmentation Systems and Applications, Berlin, Germany, 30 November – 2nd December 2009; Conference Proceedings. Senate Department for Urban Development, Berlin, Germany 2010; Publication ISBN 978-3-938373-93-4; p. 68-72.
- Balodis J, Janpaule I., Normand M., Rubans, A., Silabriedis, Zarinshj A. Measuring of the Environmental Changes. EURO-ECO Hannover 2010. 2.-3. Dezember 2010. DAS INTERNATIONALE SYMPOSIUM "OKOLOGISCHE, TECHNOLOGISCHE UND RECHLISCHE ASPEKTE DER LEBENSVERSORGUNG". Programm Abstrakts. Pp. 14-15.
- Balodis J., Caunīte M., Janpaule I., Kenyeres A., Rubans A., Silabriedis G., Rosenthal G., Zariņš A., Zvirgzds J., Ābele M. EUPOS and SLR Contribution to GOCE Mission // ESA Living Planet Symposium 2010 Proceedings, Norvēģija, Bergena, 28.jūnijs-2. jūlijs, 2010. pp. 1.-7
- Abele M., Balodis J., Rubans A., Silabriedis G., Zarinsjh A. SLR for LEO Ranging. 17th Workshop on Laser Ranging. Bad Koetzting Germany. May 16 – 20, 2011. http://cddis.gsfc.nasa.gov/lw17/index.html
- Balodis J., Janpaule I., Normand M., Silabriedis G., Zariņš A., Zvirgzds J. GNSS TĪKLU ANALĪZES LAIKA RINDAS. Proceedings of the International Symposium on Global Navigation Satellite Systems, Space-based and Ground-based Augmentation Systems and Applications. ISBN 978-3-938373-94-1. Germany, 10-11 October 2011.
- Silabriedis G., Balodis J., *EUPOS® -RIGA* permanent station network improvement, United Nations/Latvia Workshop on the Applications of Global Navigation Satellite Systems, Riga, Latvia, 14 – 18 May 2012.

The main results of Thesis are disclosed in nine publications.

## STRUCTURE OF THESIS

### First chapter

In the introduction, very poor quality of Riga geodetic reference network and the need to drastically improve the situation is explained. An innovative solution in creation of national and international geodetic networks originated in the U.S. and Germany, and it quickly spread to Eastern Europe in the form of initiative project European positioning system ***EUPOS®***. ***EUPOS®-RĪGA*** and LatPos were one of the first systems, which were developed and introduced actively in the manufacture in surveying industry. Last stage of the whole Riga levelling network reconstruction was in the years 1975-1977. In fact, it was a very important work, and in the thesis author's view, it was a work of high quality. However, the information on this work was not available for a long time until the technical report was found in archives. Therefore, at the end of the first chapter, results of this levelling are discussed in greater detail. This network is still in use in the height system Baltic 1977.

### Second chapter

In the second chapter, researches of stability and quality of operation of system ***EUPOS®-RĪGA*** are described with comparison to station RIGA – 1884 of the International GNSS Service (*IGS*) and European Permanent Network (*EPN*). Quality of coordinates of base stations was controlled every hour during one month, in order to study the impact of interference and reflection of radio waves on accuracy of measurements of receiver aerials. In German town Garbsen, calibration of all five GNSS aerials was carried out by use of calibration robot of company Geo++. So system ***EUPOS®-RĪGA*** of high accuracy is obtained and is operating, which in 90% cases can provide 1-2 cm measurement accuracy, when measurement time is several seconds in RTK mode.

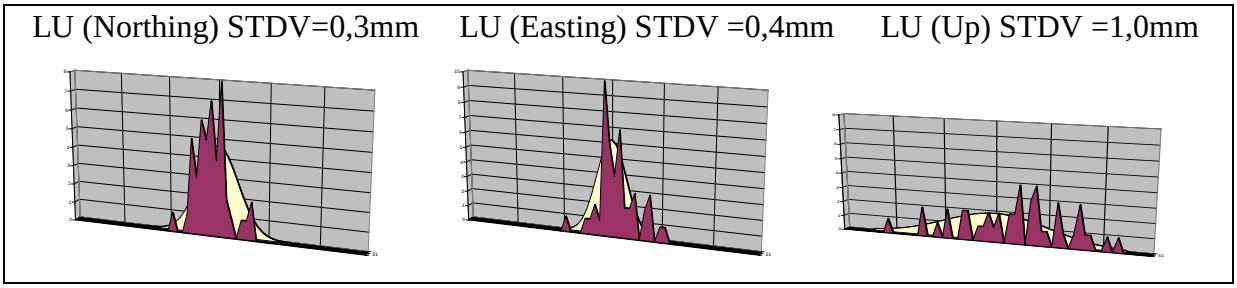


Fig. 2. Distribution of results of station Lu according to x, y and H (division of points 1mm)

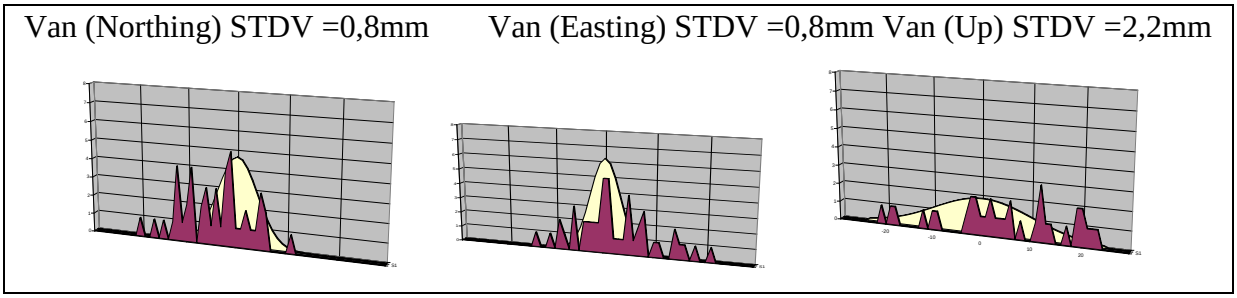


Fig. 3. Distribution of results of station Van according to x, y and H (division of points 1mm)

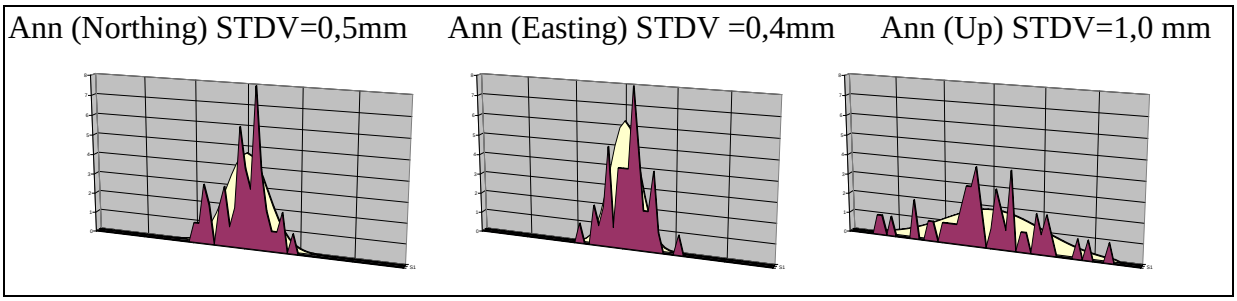


Fig. 4. Distribution of results of station Ann according to x, y and H (division of points 1mm)

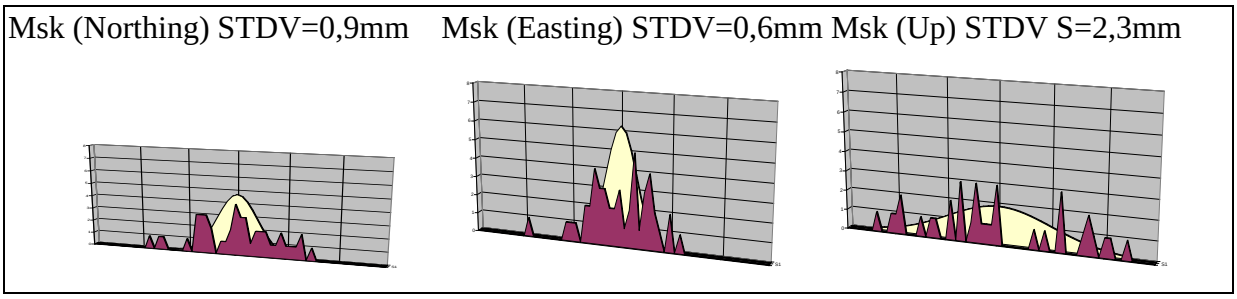


Fig. 5. Distribution of results of station Msk according to x, y and H (division of points 1mm)

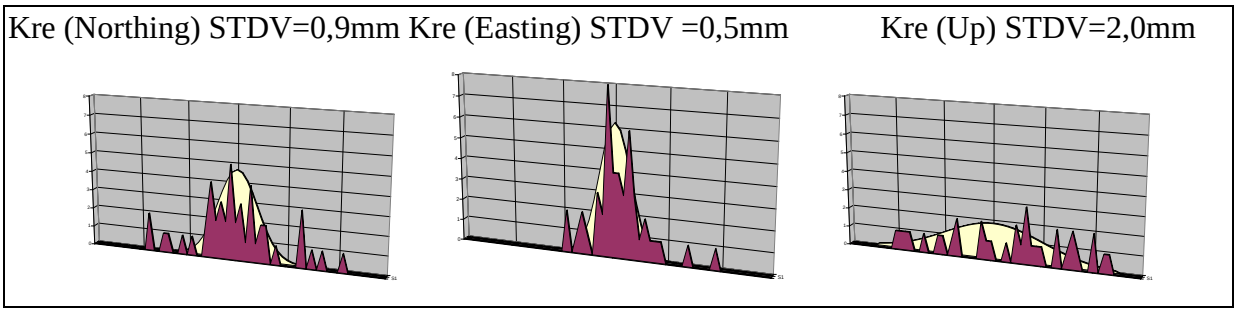


Fig. 6. Distribution of results of station Kre according to x, y and H (division of points 1mm)

When we look at figures (Fig. 2-6), we see that horizontal coordinates x, y according to calculations of production software PINACLE are closest to normal distribution.

It should be noted, that these calculations were approximated to real measurement process, which is in RTK mode – this time we did not take IGS improved orbits, satellite clock corrections and information on ionosphere. We used only real field measurement data. Distribution of horizontal coordinates furthest from the normal distribution is for Van and Msk stations.

When we look at chart of distribution of results of vertical coordinate, we can draw a conclusion that distribution of results only for Ann station is more or less close to the normal one. Median for Lu station is moved aside from centre. Results of determination of height of stations Van, Msk and Kre are far from the normal distribution. Search for possibilities of improvements of determination of height coordinates will be continued and conclusions will be ready in the near future.

## Third chapter

Originally it was planned that researches of the third chapter would be devoted to accuracy of height component, by use of ***EUPOS®-RĪGA***, and it was planned to use Riga City levelling network of mainly RTK measurements as standard for further researches of height changes. However, it was soon discovered that levelling network is badly deformed. By use of ***EUPOS®-RĪGA*** RTK measurements and classical geometric levelling methods, control measurements of levelling network points were carried out. Significant deformations of levelling network were established (Fig.7.).

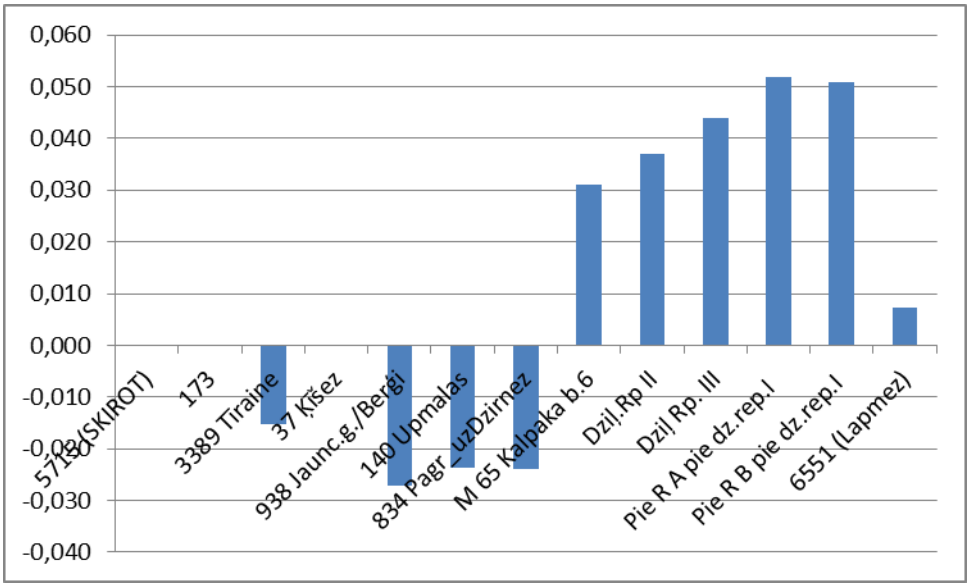


Fig.7. Height differences (m) of first order levelling data (RTK-LGIA)

In order to study possible vertical earth motions in Riga city more in details, information on DGNSS measurements of height network points done already earlier was collected and also new DGNSS static and RTK measurements were performed. Mainly RTK method was used for measurements, due to two reasons. Firstly, results can be obtained immediately in the course of measurements and it is no need to waste time for collecting of base station information, as well as for post-processing. Secondly, after loading of observation data in PC it was possible to look at amplitude of measurement errors caused by ionosphere fluctuations. This gave also opportunity to assess, how many measurements should be repeated in one site of measurements, in order to gain confidence on accuracy and plausibility of the end result. For example, Rp 8540 measurement set can be seen in figure 8. Rp 185 measurement set can be seen in diverse representations (Fig.9).

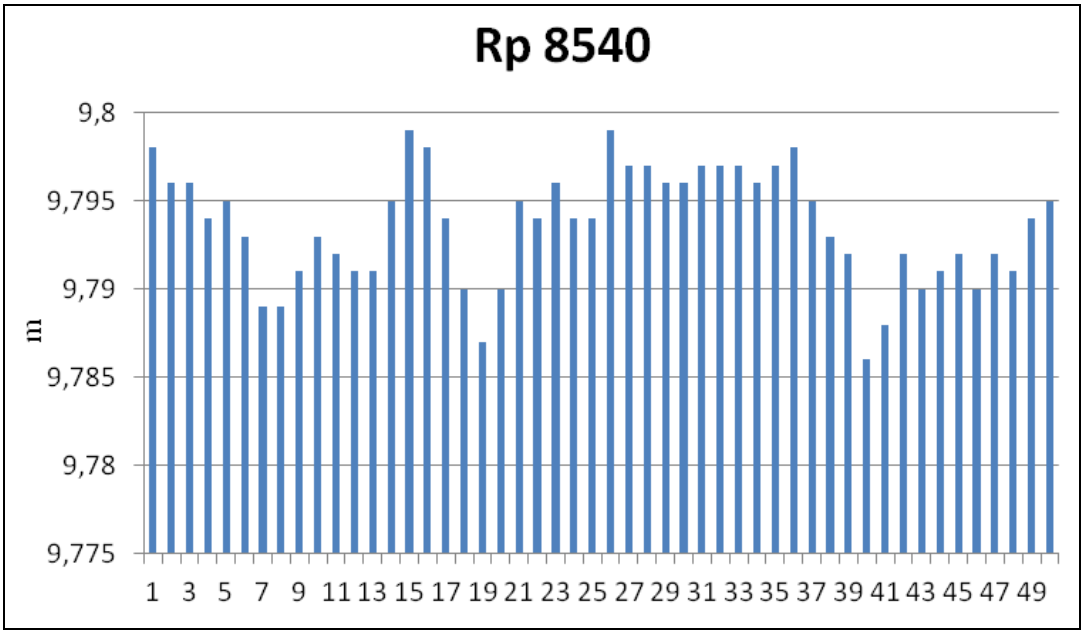


Fig.8. Height measurement result set consisting of 50 measurements every 10 seconds

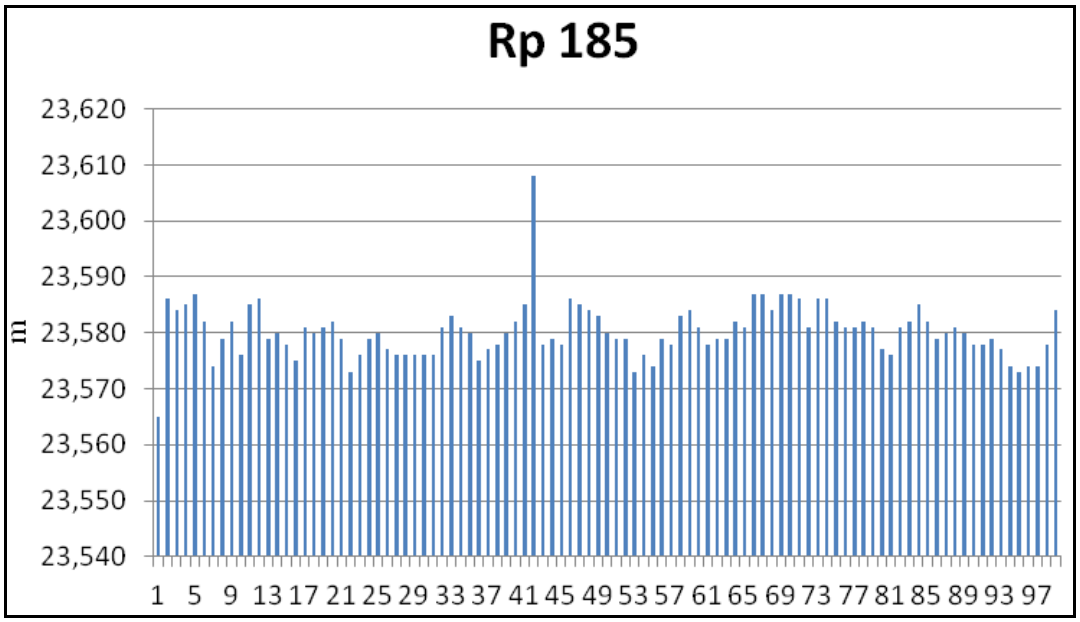


Fig.9. Height measurement result set consisting of 100 measurements every 10 seconds

Fluctuations of results of measurements are caused mainly by ionosphere. The nearer the base station is situated, the smaller is the amplitude of fluctuations. Base station is capable to approximate the model of changes of ionosphere more accurate and to determine RTCM correction parameters more accurate.

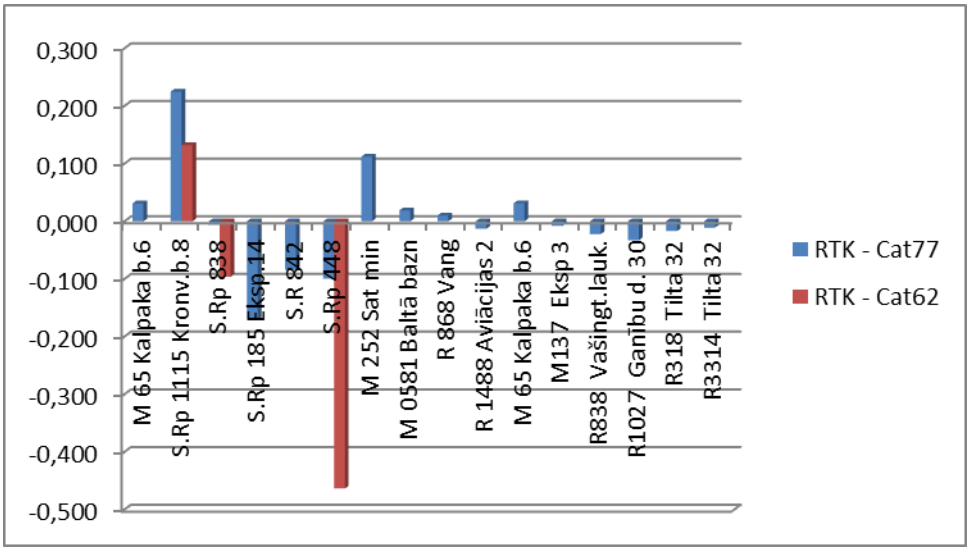


Fig.10. Chart on wall benchmark height differences (m)

The obtained differences of point heights present evidence about possible vertical motions of the ground. In the territory of Riga City, mainly subsidence processes can be observed (the most intense in area of Ganību Dambis and Sarkandaugava), although in some

places there is slight uplift of ground. The vast majority of designated points is situated in these places. Height changes in the centre of Riga are visualized (Fig. 10), however the amount of observations is not sufficient.

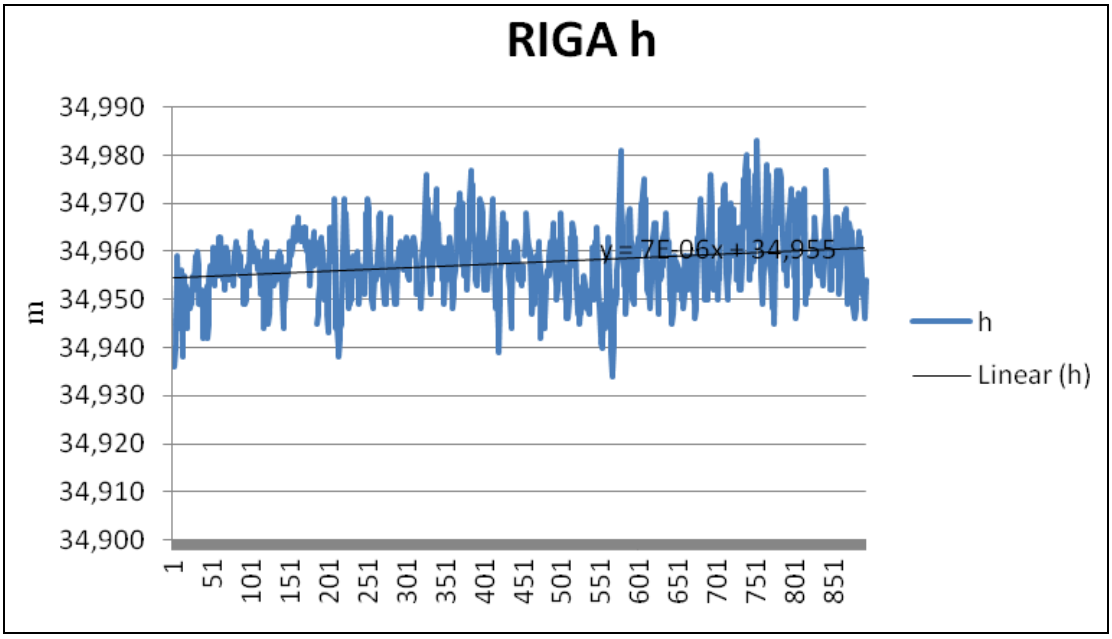


Fig. 11 Time series of observations of height of station RIGA of the international station network EPN/IGS

Conclusion can be drawn, that tectonic vertical motion of Riga on Eurasian Plate within the period from July 1, 2008 until December 31, 2010 has been directed upwards with velocity of movement 2-4 mm/year. Changes of station coordinates in international network unambiguously gives evidence on increase of height coordinate (Fig 11, 12, 13)

| Changes | RTK-LGIA | RTK - RG2 | RTK - Cat77 | RTK - Cat62 |
|---|---|---|---|---|
| **Higher ≥ 0** | 8 | 3 | 9 | 1 |
| **Lower ≤ 0** | 4 | 11 | 17 | 2 |
| **Total** | 12 | 14 | 26 | 3 |
| **Higher %** | 67% | 21% | 35% | 33% |
| **Lower %** | 33% | 79% | 65% | 67% |

Fig. 12 Summary of change of height benchmarks (mm)

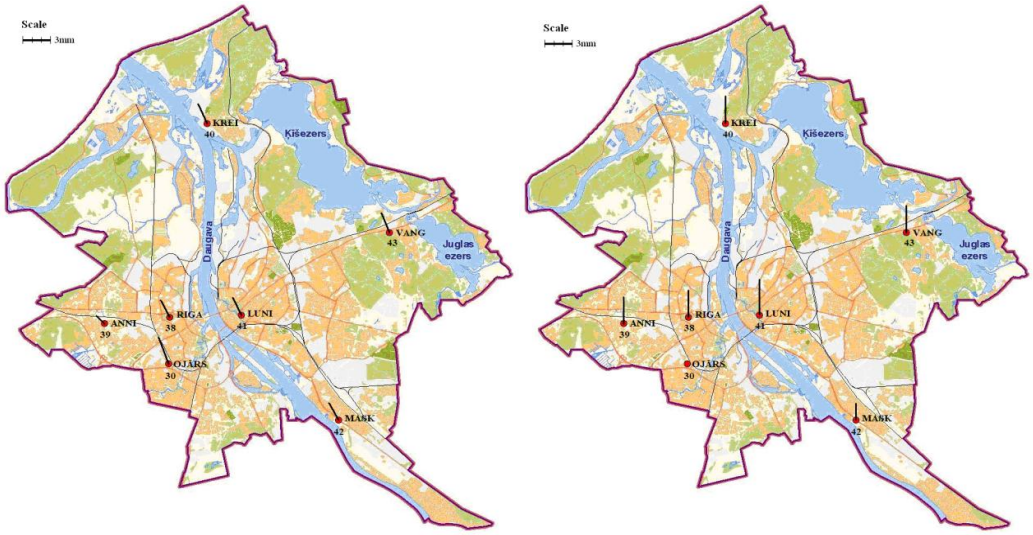


Fig. 13 Velocity vectors (x, y un H) of changes of coordinates of GNSS stations of Riga during a year

Value of height changes is inadmissible, when town planning works are performed. If we analyse measurement data stored by ***EUPOS®-RĪGA*** in general, time series of GNSS observations show uplift of the surface of earth 3-4 mm/year every year within the period of 2,5 years. More detailed studies show that in some territories also subsidence can be observed.

Conclusion should be drawn that height network of Riga City is significantly deformed. It shouldn't be used in civil construction. RTK measurement method should be used for obtaining of results of measurements of high accuracy. Accuracy of heights in RTK measurements depends on amount of repeated measurements, on distance to the nearest base station and on accuracy of geoid model.

## Forth chapter

In the forth chapter of the thesis, possibilities of multifunctional use of the system ***EUPOS®-RĪGA*** are described. Already in the third chapter, possibilities of determination of height are discussed, but in the forth chapter, also quality control of orthophotomap, obtaining and maintenance of data of underground utilities is described. Foreign experience is studied in the multifunctional use of GNSS network of land-based continuously operating base stations.

Under my leadership (2007-2008), procedure of the control of orthophotomap was carried out. It was very responsible work. In order to obtain map of high quality, the best methods were to be found both for the determination of coordinates of points of attachment of map and for establishment of errors and inaccuracies, when quality of accuracy of map is assessed. When control measurements are made by DGNSS method, we have to provide the highest accuracy, and measurement points shall be placed territorially sufficiently densely and surely identifiable on the orthophotomap.

We used Topcon HIPer+ with L1, L2 frequencies and R8 GNSS TRIMBLE with L1, L2, L2C, and L5 frequencies DGNSS receivers in the work. 7-10 minutes static measurements in 344 points were performed, and they were calculated in post-processing by Pinacle software. In the calculations, three (*out of five*) nearest DGNSS base stations were used, so that the distance to site of control measurements does not exceed 10 km.

Measurement coordinates were calculated by static method, where standard deviation in horizontal plane is RMS 0,8cm, in heights 1,02 cm. Orthophotomap error deviation vectors do not exceed approximately 15 cm and the mean error of depiction of site on orthophotomap is 8,1 cm (Fig. 14, 15)

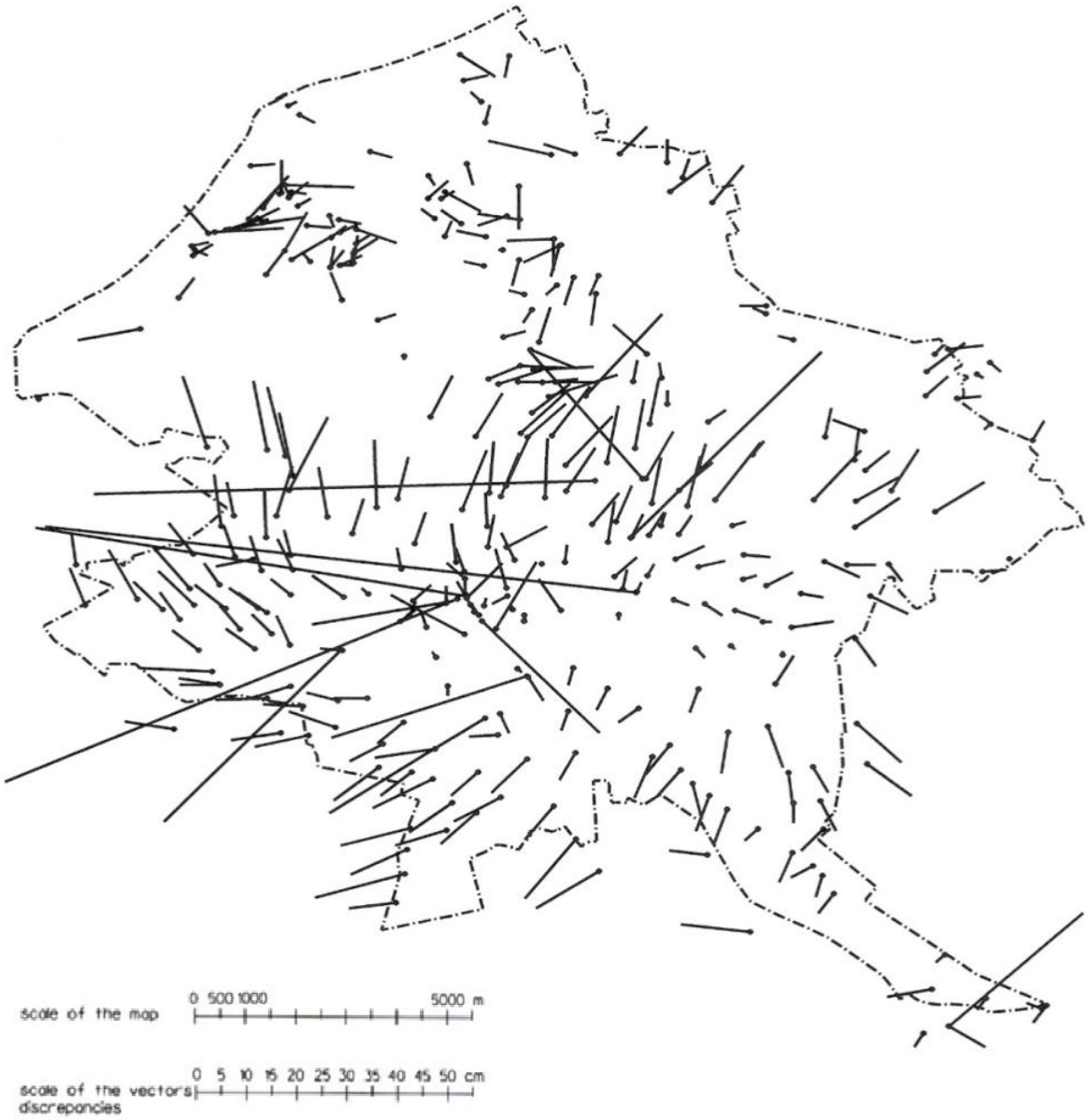


Fig. 14 Linear deviation of identified points of orthophotomap in the result of geodetic control


Fig. 15 Deviations of orthophotomap (*lower curves*) and deviations of accuracy of RTK measurements (*upper curves*). Division of horizontal axis -1cm, division of vertical axis – frequency of precision values in performed experiment

## CONCLUSIONS

Thesis „***EUPOS®-RĪGA*** Geodetic Reference Network and multifunctional use of it" is devoted to creation of land-based auxiliary system to Global Navigation Satellite System (*GNSS*) as subset of European global positioning system *EUPOS®*. Aim of the thesis was to create ***EUPOS®-RĪGA*** geodetic reference network of continuously operating GNSS base stations in Riga City and to investigate its adequacy to real time (RTK) measurements of high accuracy, continuously operating, active, with provision of RTCM correction for multifunctional use of them.

Research of stability and quality of operation of system ***EUPOS®-RĪGA*** is carried out and comparisons are made with base station RIGA - 1884 of International GNSS Service (*IGS*) and European Permanent Network (*EPN*). Quality of coordinates of base stations was controlled every hour during one month, in order to investigate the impact of radio wave interference and reflection on accuracy of measurements of aerials of receivers. In German town Garbsen, calibration of all five GNSS aerials was carried out by use calibration robot of company Geo++. As a result, system ***EUPOS®-RĪGA*** of high accuracy is obtained and operated, which in 90% cases is capable to provide 1-2 cm measurement accuracy, when measuring lasts several minutes in RTK mode.

By use of ***EUPOS®-RĪGA*** RTK measurements and classical geometric levelling methods, control measurements of points of levelling network were performed. Significant deformations of the levelling network were established. Value of them is inadmissible, when town planning works are performed. If we analyse measurement data stored by ***EUPOS®-RĪGA*** in general, time series of GNSS observations show uplift of the surface of earth 3-4 mm/year every year within the period of 2,5 years. More detailed studies show that in some territories also subsidence can be observed.

Conclusion should be drawn that height network of Riga City is significantly deformed.

Quality control of orthophotomap by multifunctional use of system ***EUPOS®-RĪGA*** was justified. As a result of performed works accuracy of the orthophotomap significantly increased. As use of system ***EUPOS®-RĪGA*** began, processes of obtaining and maintenance of data of underground utilities improved significantly.

## In the result of investigations made in the framework of Thesis:

1. New geodetic reference network ***EUPOS®-RĪGA*** of Riga City is created. It is based on space technologies.
2. Geodetic reference network ***EUPOS®-RĪGA*** is linked to coordinate system of Latvia LKS92 and of Europe ETRS89, as well as to global coordinate systems ITRF and WGS84.
3. Detailed examination of stability and accuracy of system ***EUPOS®-RĪGA*** and analysis of its operation in relation to geodetic reference points of LatPos, EPN (*European Permanent Network*) un IGS (*International GNSS Service*), which are situated in neighbouring countries of Latvia – Sweden, Finland, Russia, Lithuania, Estonia and Poland.
4. The accuracy of horizontal coordinates of stations of EUPOS-RĪGA is ± 1 mm. Accuracy of vertical coordinates ±3 mm.
5. Accuracy of determination of coordinates in field measurements, when geodetic measurements were made by use of geodetic equipment of Global Navigation Satellite System (*GNSS*) in the real time mode by use of GPS, GLONASS and ***EUPOS®-RĪGA*** information simultaneously, was investigated specially.
6. In 92% cases it is possible to determine coordinates in field measurements within a period that is less than one minute with 1-2 cm accuracy.
7. ***EUPOS®-RĪGA*** information can be used in geodetic measurements in cadastre, engineering geodesy, topographical surveying and mapping, as well as in other positioning measurements for utilities, in GIS applications a.o.
8. ***EUPOS®-RĪGA*** is auxiliary system of positioning, which significantly accelerates the performance of geodetic field works.
9. ***EUPOS®-RĪGA*** is basic tool for quality control of topographical survey and measurement of underground utilities.
10. Data base of measurements of utilities and topographical measurements, which ensures safety and quality of many engineering and technical works in Riga, is created in the institution "Rīgas ĢeoMetrs".

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I hereby confirm that I have elaborated the present Doctoral Thesis submitted for consideration at the Riga Technical University for obtaining of doctor's degree in engineering.

Doctoral Thesis has not been submitted for graduation at any other university.

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Date: .....

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