Accuracy Testing of RTK Service of the Permanent Station Network in the Republic of Serbia

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Key words: GPS, RTK, accuracy, permanent station, CORS, CORS network

EXECUTIVE SUMMARY

The permanent station network in the Republic of Serbia was established towards the end of 2005. when it started to be used for commercial purposes. The network was primarily developed as a support to users in surveying, but also as a support for solving problems in the field of engineering works, developing geodetic networks and navigation. Consequently and depending on the required accuracy, the network was conceived to have three customer services. For the current commercial purposes, the RTK service of the network has been most commonly used, mainly for surveying. Therefore, we have tested the accuracy of RTK service. Also we have established whether this service has been realised in compliance with the projected accuracy. For that purpose, experimental measuring has been conducted on the points with already known coordinates and a detailed analysis of the obtained results has been carried out. The conclusion of the conducted experiment is that the RTK service of the permanent station network provides accuracy of coordinates of newly established points within the margins of 2-3 cm, which has been foreseen by the general design of the network.

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1. INTRODUCTION

The creation of reference networks for the territory of the Republic of Serbia was initiated towards the end of XIX century, when chains of triangles were developed in the territories under the control of the Austro-Hungarian Monarchy, in classical geodetic datum defined by the point *Hermanskogel* in Austria and the parameters of the ellipsoid *Bessel*. Based on those chains, in the period 1900 to 1948, the Trigonometric Network of the 1st order was developed for the SFR of Yugoslavia on the ellipsoid *Bessel*. The measurement reduction was conducted without knowing vertical deflections and ellipsoid heights. The coordinates of this network are still in use.

The trigonometric network of the 1st order has been repeatedly assessed as the one that does not meet contemporary requirements of accuracy and reliability (Milovanović et al., 1995; Delčev, 2001). The development of new technologies has resulted in a new concept of developing reference networks, and thus in 1989 the Europeran Reference Frame (EUREF) project creation was initiated. For the purpose of integrating into EUREF, GPS observations were performed in the former FR of Yugoslavia in 1998, forming Yugoslav Reference Frame (YUREF), the basis for development of new reference network for the territory of Serbia.

The new Serbian Reference Network (SREF) has been developed for the purpose of replacement of the existing classic trigonometric networks and for the more efficient use of new measuring technologies, above all GPS. The network covers the entire territory of Serbia. The points are easily accessible, on average 10 km apart them. The network was previously used for developing geodetic networks, for real estate surveying and engineering works, but it is rarely used nowadays.

The next step in the development of reference networks of the Republic of Serbia was the replacement of the passive SREF network with a new, active one. Thus the Serbian Active Geodetic Reference Frame (AGROS), a permanent stations network, was designed and realised. The network is comprised of 32 points, 70 km apart on average, with GPS receivers, systems for communication and constant power supply. The receivers constantly receive satellite signals and transfer them via the communication system to the control centre that further communicates with final users. In this way, with only one GPS receiver the user can determine the position of the point with the required accuracy. Depending on accuracy, three different services of the permanent station network can be used.

2. YUREF

In the first half of 1998, the Department of Geodesy of the Faculty of Civil Engineering realised the "Project of Yugoslav Reference GPS Network" where points from trigonometric networks of the 1st order were selected for integrating Yugoslavia into the EUREF. The project foresaw the selection of eight points for the YUREF network, evenly distributed along the entire territory of SRY (Fig. 1), out of which seven were points of the trigonometric

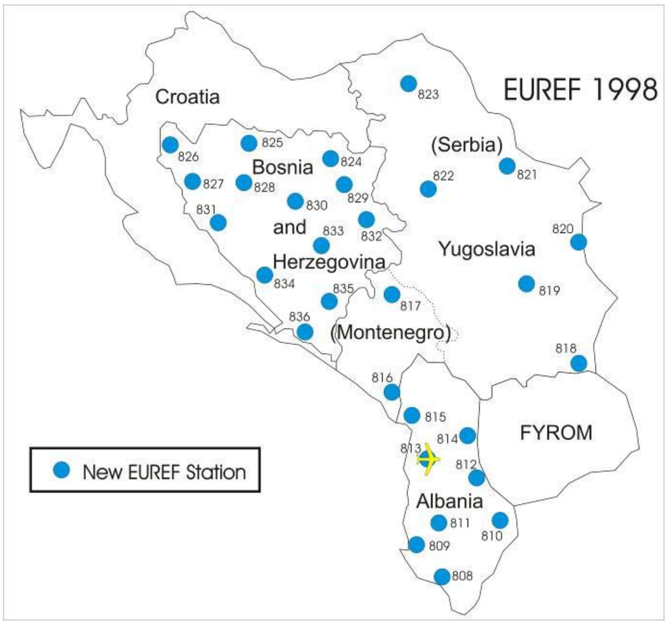

Fig. 1: EUREF - BALKAN98
(Altiner et al, 1999)

network of the 1st order and one from the monitoring network of the dam of "Ćelije" lake.

GPS observations were performed in the period September 4 to 9, 1998 with the receivers *Trimble 4000SSE*, in 5 sessions, with the session duration of 24 hours and data rate of 15^s. At the same time, GPS observations were performed in Bosnia and Herzegovina and Albania - EUREF GPS campaign BALKAN98 (Fig. 1). For the purpose of connecting networks, the observations were simultaneously performed at permanent stations *Wettzell*, *Matera*, *Graz-Lustbuehel and Zimmerwald*, as well as on the EUREF points: *Penc*, *Sofia*, *Malija*, *Ilin Vrh* and *Ramno*, for the control of the obtained results.

The measuring results were processed with the *Bernese Software version 4.0* at *Bundesamt für Kartographie und Geodäsie, Frankfurt am Main*. The coordinates of 8 points were calculated within the coordinate reference base and epoch campaign (ITRF96 for 1998.7 epoch), but the definite values were obtained by transforming them into the European reference system ETRS89. The obtained accuracy of the coordinates is: $\pm 2\ \mathrm{mm}$ in latitude and longitude and $\pm 6.5\ \mathrm{mm}$ in altitude (Altiner et al, 1999).

3. SREF

The main motives for the initiation of this campaign were numerous and accumulated problems related to the use of the existing trigonometric network of the 1st order. The main goals of the campaign were gradual replacement of trigonometric networks of higher orders, possibility for efficient use of the new measurement technology and the creation of conditions for the adoption of the new state reference system. For that purpose, the following main project parameters were defined:

- Homogeneous coverage of the entire state territory,
- Average spatial resolution of 10 km,
- Appropriate deviation of relative spatial positions of 1 cm.

Considering the scope and complexity of the set goals, the realisation was carried out with the use of GPS satellite measurement technology and consistent system of quality management.

The selection of point location of the new state reference network was conducted in complete compliance with the defined inter-station distance and characteristics of GPS technology. Each location is easy to reach by a vehicle, and it is at least 300 m apart from the potential sources of interference and multiple reflexions. The points are stabilised with marks made of armoured concrete (Fig. 2). Out of 838 points, about 25% of them were within the existing

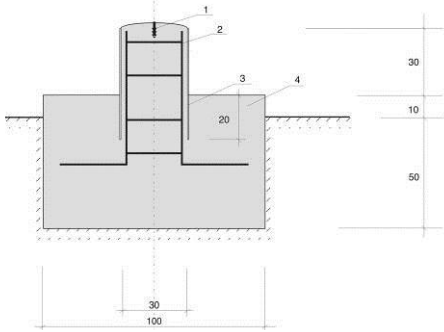

Fig. 2: Monumentation

trigonometric networks of the 3^{rd} and 4^{th} order. The GPS measuring in SREF was conducted by the Republic Geodetic Authority (RGA) of the Republic of Serbia, in cooperation with the Yugoslav Army. All the measurements were carried out with the two-frequency receivers *TRIMBLE (4000SSE, 4400, 4800),* in measuring sessions of 90 minutes, with contiguous vertical angle of 15° and data rate of 15^s. The dynamics of the measuring campaign was conditioned by various factors and consequently the entire realisation encompassed the period of 5 years, although more than 90% of works were carried out in 1998 and 2002.

After the measuring on 838 points and preliminary processing of 1662 GPS vectors had been completed, a definite geometric configuration of SREF was formed and its adjustment was carried out. In order to define the network datum, the coordinates of 7 points were fixed at the measuring campaign BALKAN98.

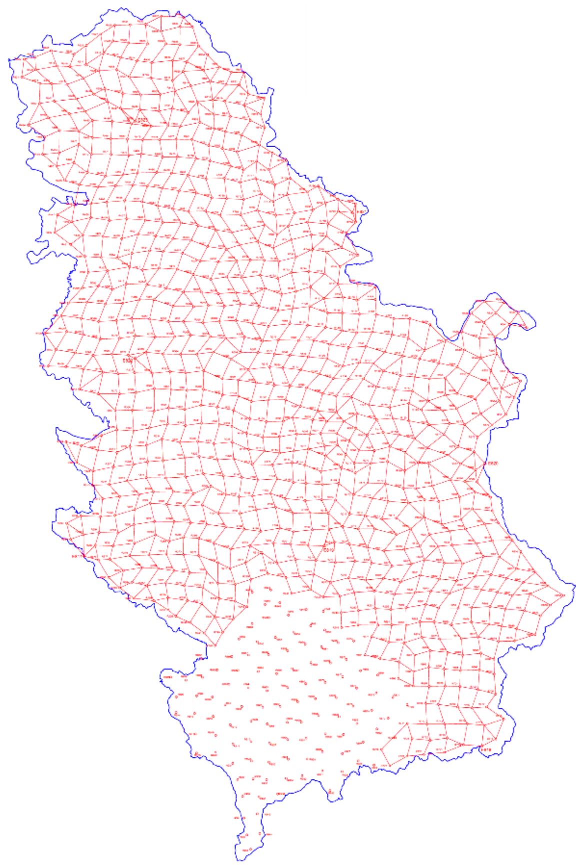

Fig. 3: SREF network (RGA, 1998.)

The assessment procedure was attributed by the following important parameters and results:

- Total number of measurements: 4986,
- Total number of unknowns: 2514,
- Standard deviation of unit weight: 6.28,
- Redundancy: 50%,
- Average standard of absolute positions (3D / 2D / 1D): 12 mm / 6 mm / 10 mm,
- Average standard of relative positions (3D / 2D / 1D): 9 mm / 5 mm / 8 mm.

Due to the applied datum conditions, definite point coordinates of the new state reference network are related nominally to ETRS89 and the epoch 1998.7 and as such, they were put in commercial use at the beginning of 2003.

4. SERBIAN ACTIVE GEODETIC REFERENCE FRAME (AGROS)

AGROS (Fig. 4) is a permanent service of precise satellite positioning in the territory of the Republic of Serbia and it was being established in phases, from 2002 to 2005, and on December 16, 2005 its economic use began.

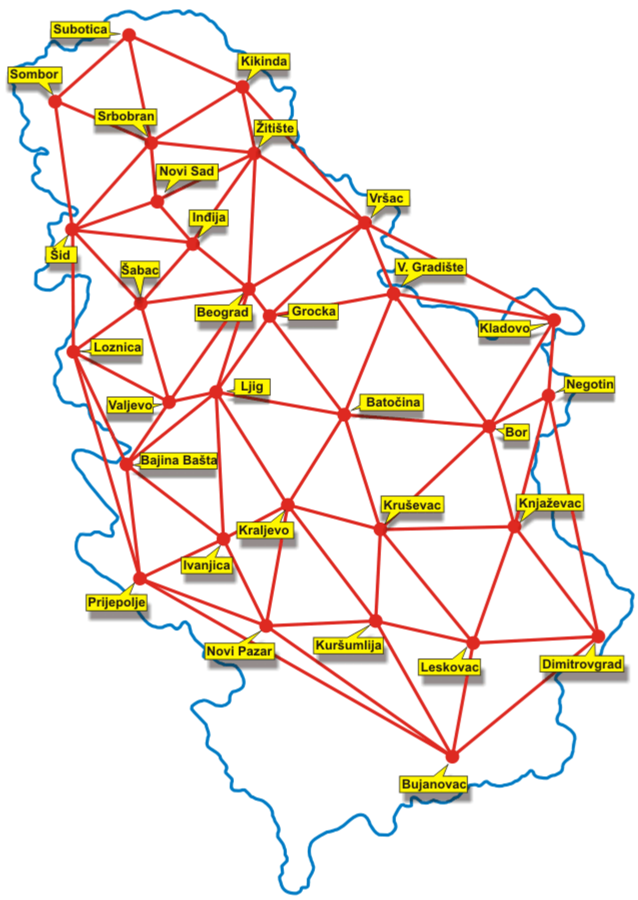

Fig. 4: Spatial distribution of permanent stations AGROS (RGA, 2005.)

The goal of the RGA project was to solve, in a highly efficient, simple and economically justifiable fashion, a series of problems, primarily in the field of surveying and cadastre, but also in many other activities that are an integral part of a wide range of economic activities and scientific research (vehicle navigation, works in agriculture and forestry, air transportation, aerophotogrametry, forming GIS systems, engineering-technical works, etc.).

The activities on establishing the network began in December 2001 with the preparation of the necessary technical documentation, and in February 2002 cooperation was established with the European Academy of Sciences of Urban Environment related to forming the network of permanent stations of 16 countries of Central and East Europe region, also known as EUPOS *(European Position Determination System)*. It was then decided that after the harmonisation of technical standards, the existing AGROS project would become a sub-project of the EUPOS system (Milev et all, 2004; Rosenthal, 2008). AGROS was established according to the EUPOS regulations like as a CORS (Continuously Operating Reference Station) network.

The existing services *(user segment*) that can be used are presented in Table 1.

Table 1: AGROS services

Number	Service	Accuracy [m]	Description
1.	AGROS RTK	0,02- 0,03	Positioning using the real time kinematics method
2.	AGROS DGPS	0,5 - 3,0	Positioning using the differential method
3.	AGROS PP	0,01	Positioning using the static method

4.1. The network concept

AGROS was designed as a central system comprised of three interlinked segments (Fig. 5):

1. segment comprised of permanent stations,
2. communication segment, and
3. user segment.

Segment of permanent stations

According to the AGROS project, this segment is comprised of permanent stations with clearly defined characteristics of the devices, stabilisation and spatial distribution.

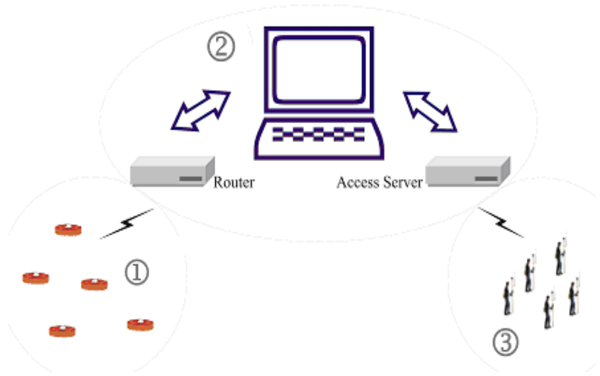

Fig. 5: AGROS chart

The equipment necessary for the work of a permanent station is as follows: geodetic two-frequency GPS receiver; GPS antenna; telecommunication line; rooter; modem; source of constant power supply.
All the data received by a GPS receiver from any GPS-satellite via communication equipment are sent to the control centre for further processing.

Communication and user segment

The communication segment is basically comprised of: control centre, telecommunication components that ensure communication between the GPS segment and control centre and the telecommunication component necessary for the communication between the control centre and user segment.
The structure of the control centre has to ensure the reception of data from permanent stations, their processing and the communication with users. Based on the stated requests, the project defined the following (minimum) control centre configuration: PC and adequate application for supporting the work of the control centre, server for the reception of data from permanent stations and server for the communication with users.
The permanent stations are designed to continuously communicate with the control centre via classic analogue and digital telephone lines, while the communication with users goes via the Internet, GPRS or GSM technologies, through three user services:

- Service for the support to real time positioning, with the accuracy of 0,5-3 m,
- Service for the support to real time kinematics positioning, with the accuracy (horizontally) of ≤ 2 cm (Fig. 6),
- Service for the support to high precision geodetic measuring (post-processing).

It is also defined that the mentioned communication between the control centre and users is carried out in the following way:

- In case of the first service, through the use of standard data formatting RTCM SC 104 V. 2.0,
- In case of the second service RTCM SC 104 V.2.3. together with 20, 21 type of messaging and RTCM message type 59 for backing up the network operation in the FKP regime,
- Data takeover provided by the third service is based on the international standard data format RINEX. 2.0 (2.1 ...).

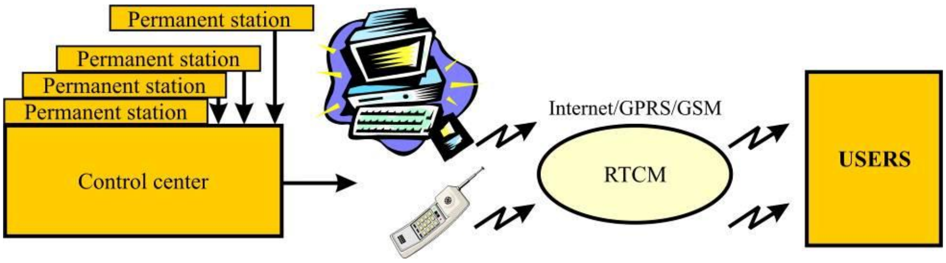

Fig. 6: Chart showing RTK service with the accuracy ≤ 2 cm

4.2. The network realisation

The main precondition for the selection of locations was an even coverage of the territory of Serbia and a maximum distance between the stations of 70 km. An additional, imposing precondition was appropriate communication infrastructure. The majority of locations for the stations are RGA buildings, which additionally facilitated the project realisation.

Fig. 7: Type 1 – Pedestal on the concrete base

Fig. 8: Type 2 – Pedestal on the metal console

Fig. 9: Type 3 – Pedestal on the column

The antenna stabilisation was carried out on the selected locations with specially designed pedestals. The stabilisation was carried out in three ways (Figures 7-9).
The equipment at permanent stations comprises of geodetic GPS two-frequency receivers *Trimble* (models *4400* and *5700*) with corresponding antennas (*Choke Ring* and *Zephyr Geodetic*). Besides the geodetic equipment, each station has adequate telecommunication equipment which sends the gathered data to the control centre via telecommunication line.

4.3. Determining coordinates

4.3.1. Measuring

Measuring within the network is divided into two groups:

- Measuring vectors between YUREF points and the closest AGROS points for connection with the national datum,
- Measuring vectors between permanent stations.

GPS measurements (Fig. 10) are performed by the method of relative static positioning. The procedure and results are related to appropriate base lines, i.e. vectors. The measuring for connecting with the national datum was carried out in the period from 15/11/2005 to 07/12/2005. Duration of the session is 3 hours with a data rate of 15 seconds.

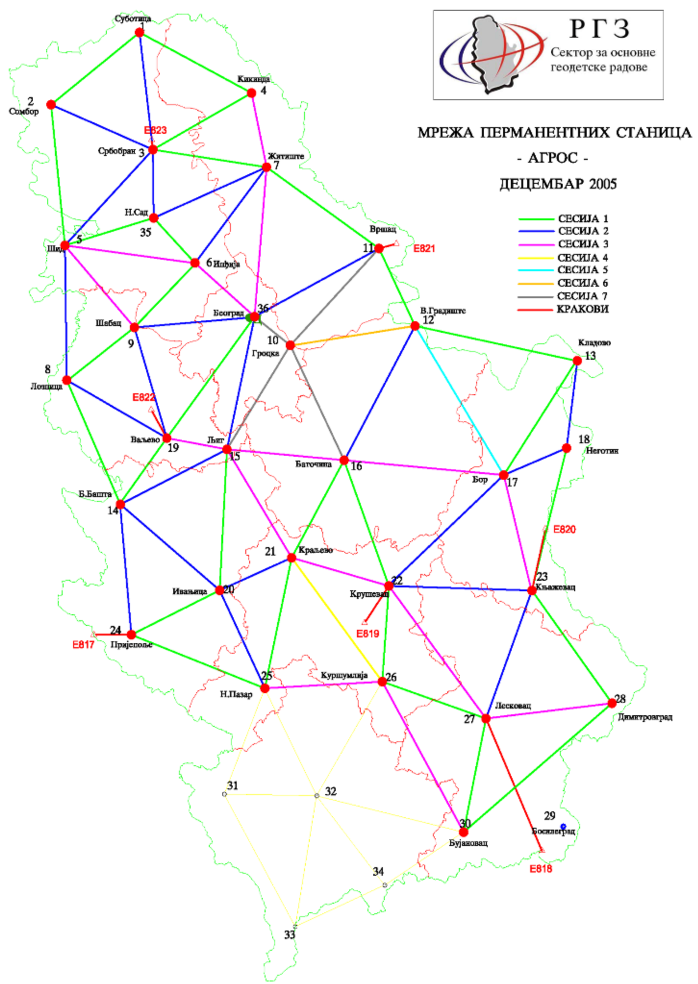

Fig. 10: Measurement plan

The measurements were carried out with the receivers *Trimble 5700*. The measuring of vectors in the permanent station network was performed in the period from 05/12/2005 to 09/12/2005 and from 21/12/2005 to 22/12/2005. The measuring data were downloaded from the AGROS control centre.

On permanent stations, the receivers were already set and configured for the reception of signals in the interval of 1^s. The data were downloaded by forming independent 24 hour sessions with the data rate of 15^s. The measuring was carried out by teams of the Sector for Basic Geodetic Works of RGA.

4.3.2. Data processing

Data processing was carried out for the purpose of obtaining definite coordinates of the permanent station network points, assessing accuracy of the performed measuring and the obtained results.

The preformed data processing encompassed the following steps:

- Processing of the performed GPS measurement - vector processing,
- Quality control - polygon closing,
- Calculating coordinates - free adjustment,
- Calculating coordinates in the system of State Reference Network.

- **Vector processing**

Vector processing was conducted after it had been assessed that the measurements were performed under favourable conditions, with the sufficient number of satellites and sufficient signal strength, without interruptions.

For absolute point coordinates based on the WGS84-ellipsoid (NIMA, 2000), necessary for proper processing, code solutions were used for absolute positioning, ensured by receivers themselves. Vector processing was conducted by days, and all the vectors that had not been dismissed due to poor statistical indicators (low SNR, large error ellipses and high PDOP) were used in the adjustment. The vector processing was conducted with precise ephemerides, with commercial software (Trimble Total Control).

- **Calculating coordinates in the system of State Reference Network**

The point coordinates in the ETRS89 system were determined by adjusting vectors with the defined measuring plan. The network was adjusted by using the data of definite processing of GPS vectors. *"The adjusted parameters were the coordinate differences dx, dy, dz in WGS84. The adjustment was carried out according to the least squares method using indirect adjustment with conditions of unknown parameters. The functional part of the mathematic model is defined without additional parameters, so that the basic unknown parameters were presented only by residuals of coordinates. The stochastic part of the mathematic model is defined by the covariance matrix comprised of covariance matrices of the vectors participating in the adjustment. The network datum is defined by coordinates of the seven main points of YUREF. By adjusting the network of reference points, the Cartesian coordinates X, Y, Z were obtained, as well as the coordinates B, L, h based in the WGS84-ellipsoid. The obtained average accuracy of the adjusted coordinates was: 3D/2D/1D 9 mm/ 4 mm / 8 mm. "* (RGA, 2003)

5. TESTING ACCURACY OF RTK SERVICE

In the exploitation of the AGROS network so far, RTK service has been the most used service (Gučević, J. Ogrizović, V., 2003; Vasilić, V. et al, 2006). Accordingly, testing the quality of the RTK service is necessary in order to determine whether the actual measurement accuracy is in accordance with the declared accuracy.
The testing requires points with known coordinates in the ETRS89 system, and in this paper they are points of SREF. The points of the SREF network have the necessary accuracy of coordinates (~1 cm), the coordinates have been determined regardless of AGROS and their maintenance is in responsibility of the RGA.
The testing of the RTK service quality of the AGROS network was carried out on the previously selected points of the SREF network (17 to 49 km apart from permanent stations). Measurement analysis and processing was carried out based on the requirements stipulated in (RGA, 1998; RGA, 2005).
The measurement was conducted with the receivers *Trimble 5700*. The measurement and processing were performed by the procedure of preparation and execution of measuring:

- locating the point,
- center adjustment,
- measuring the antenna height in three positions,
- establishing communication (initialisation) with the RTK services of the AGROS network, and
- measuring.

Each point had 21 observations with the repetition interval of 15 minutes. Each observation consisted of three successive 30 seconds long data registrations. During the observation, the instrument was centred at the beginning of measuring and the stability during measuring was monitored and controlled optically. The measurement data (name of the point, antenna height, measuring time, initialisation time, number of satellites, PDOP) were filled in the field book

formed for each point per observation.
The analysis of the obtained results encompassed:

1) calculating a B, L and H coordinates from registered X, Y, Z coordinates,

2) forming differences according to coordinates and accuracy parameters:

$$\Delta B_i = B_i - B_0;\ \Delta L_i = L_i - L_0;\ \Delta H_i = H_i - H_0;\ \text{PDOP}$$

$i = 1, \ldots, n$ - number of observations ($n = 21$)
B_0, L_0, H_0 - point coordinates of the SREF network
B_i, L_i, H_i - measured coordinates

3) calculating mean values of deviation by coordinates for each point:

$$\left(\Delta\bar{B}\right) = \frac{1}{n}\sum_{i=1}^{n}\Delta B_i;\ \left(\Delta\bar{L}\right) = \frac{1}{n}\sum_{i=1}^{n}\Delta L_i;\ \left(\Delta\bar{H}\right) = \frac{1}{n}\sum_{i=1}^{n}\Delta H_i;\ \text{PDOP}_{avg}.$$

4) pointing extreme values for each point:

$$\left(\Delta B_i\right)_{min,max},\ \left(\Delta L_i\right)_{min,max},\ \left(\Delta H_i\right)_{min,max}.$$

Table 2 shows deviation values on characteristic points.

Table 2: Differences from conditionally accurate values

Point no.	$\left(\Delta\bar{B}\right)$ [mm]	$\left(\Delta\bar{L}\right)$ [mm]	$\left(\Delta\bar{H}\right)$ [mm]	$\left(\Delta B_i\right)_{min;max}$ [mm]	$\left(\Delta L_i\right)_{min;max}$ [mm]	$\left(\Delta H_i\right)_{min;max}$ [mm]	PDOP_{avg}
R365	-7.0	5.3	-7.6	-34.8; 20.3	-4.2; 21.4	-36.6; 42.3	2.12
R419	-4.4	1.6	-2.4	-37.1; 6.7	-6.4; 8.6	-25.4; 55.5	2.02
R754	6.2	-10.1	-2.4	-14.4; 22.4	-18.6; 7.0	-21.4; 45.5	2.90
R769	2.6	6.0	-3.5	-16.4; 21.6	-4.5; 16.4	-31.9; 21.4	2.36

Figures 10 to 13 show characteristic differences in direction of coordinates related to time.
The majority of coordinate differences on the all tested points are below 25 mm for position and 40 mm for height, except on certain points (such as the points R365, R419 and R754), where differences go even up to 37 mm, and 56 mm for height. With all big coordinate differences (>25 mm, and 40 mm for height) PDOP is also excessive (e.g. for R419, PDOP= 4,5; for R754, PDOP= 13,5), which could lead to the conclusion that big deviations along the coordinate axes occurred due to unfavourable geometry of satellites. In general, for all differences bigger than 25 mm and 40 mm for height, PDOP was bigger than 4.
Since the declared accuracy of coordinates for the RTK service is 20-30 mm, it means that the confidence interval for 95% probability is 40-60 mm, which points to the conclusion that all coordinate differences are within the accuracy range of the RTK service, even in the case of unfavourable distribution of satellites, where the maximum differences (on point R419) are 37.1 horizontally, and 55.5 mm vertically.
The paper examines to what extent the difference of coordinates correlates with the distance to the closest point of the permanent station network. For each measured point, the average of

coordinate differences was determined for all conducted series $(\Delta\bar{B})$, $(\Delta\bar{L})$ and $(\Delta\bar{H})$. All differences are below 11 mm for all coordinates. The measurement errors have the character of random errors with positive and negative values, which in the total sum are close to zero. Having that fact in mind, an analysis of absolute values of coordinate differences was carried out (Table 3).

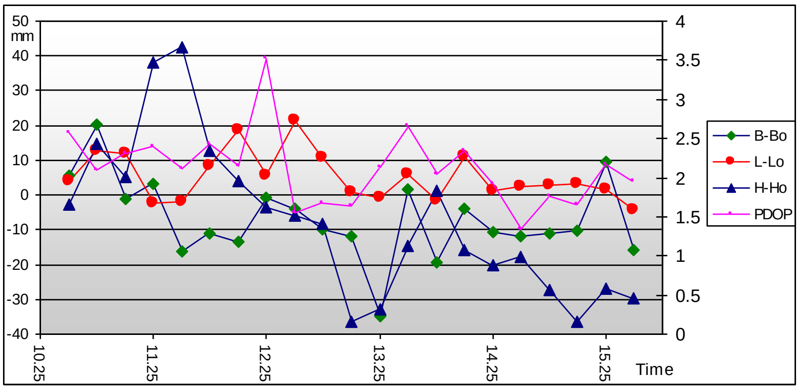

Fig. 10: Graph presenting differences for the point R365 (d= 31 km)

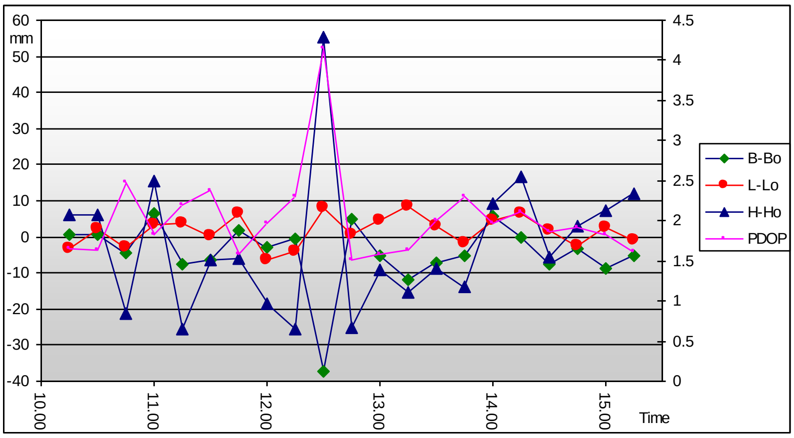

Fig. 11: Graph presenting differences for the point R419 (d= 23 km)

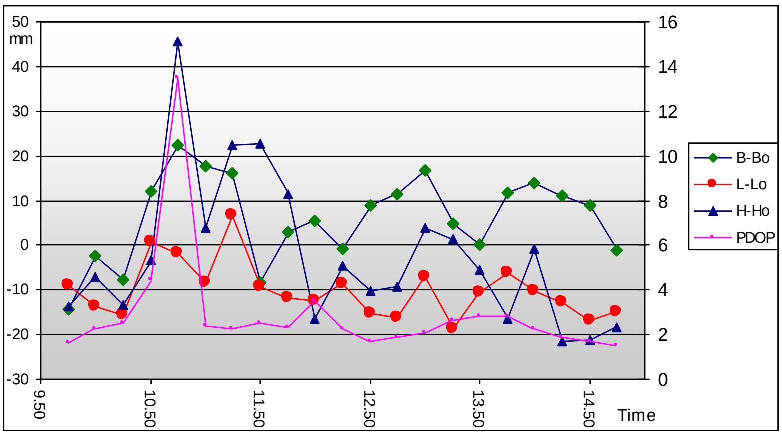

Fig. 12: Graph presenting differences for the point R754 (d= 29 km)

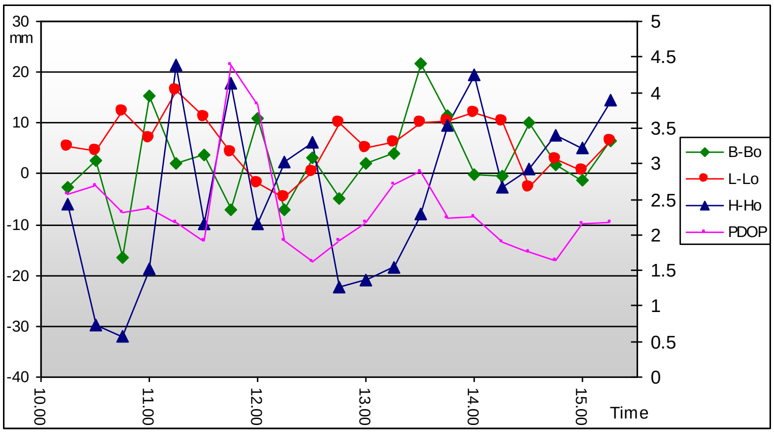

Fig. 13: Graph presenting differences for the point R769 (d= 39 km)

Table 3: Differences of absolute values

Point no.	$\left(\left\|\Delta\bar{B}\right\|\right)$ [mm]	$\left(\left\|\Delta\bar{L}\right\|\right)$ [mm]	$\left(\left\|\Delta\bar{H}\right\|\right)$ [mm]	$PDOP_{avg}$
R041	4.8	8.6	11.5	2.02
R058	8.5	4.9	9.4	2.06
R365	10.8	6.3	18.9	2.12
R754	9.5	10.8	13.0	2.90

Fig. 14 shows mean values of absolute coordinate differences for characteristic points, as well as mean values of PDOP.

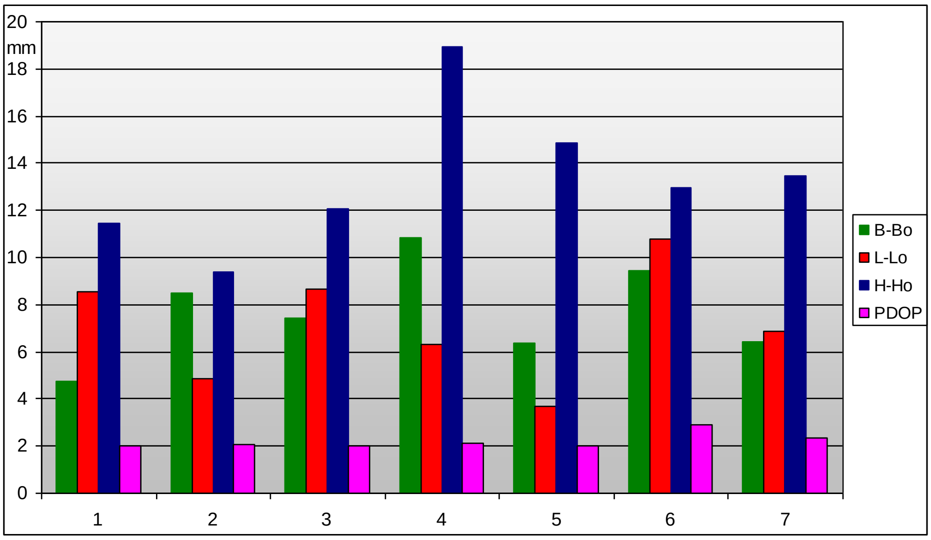

Fig. 14: Graph presenting absolute coordinate differences

The measured data indicate that the biggest differences are in height and that all the values of the coordinate differences are within the declared accuracy of the RTK service (30 mm).
Fig. 15 shows the correlation between the absolute coordinate differences and the distance to the closest permanent station. By modelling the coordinate differences with the linear model,

it has been concluded that there is no correlation between the absolute differences of coordinates and the distance to the permanent stations. The highest coefficient of linear regression that points to this correlation is 0,095 mm/km for the coordinate difference towards the L axis. That also shows that the declared accuracy of the RTK service of 2-3 cm is valid for the entire area of the permanent station network, the entire territory of the Republic of Serbia.

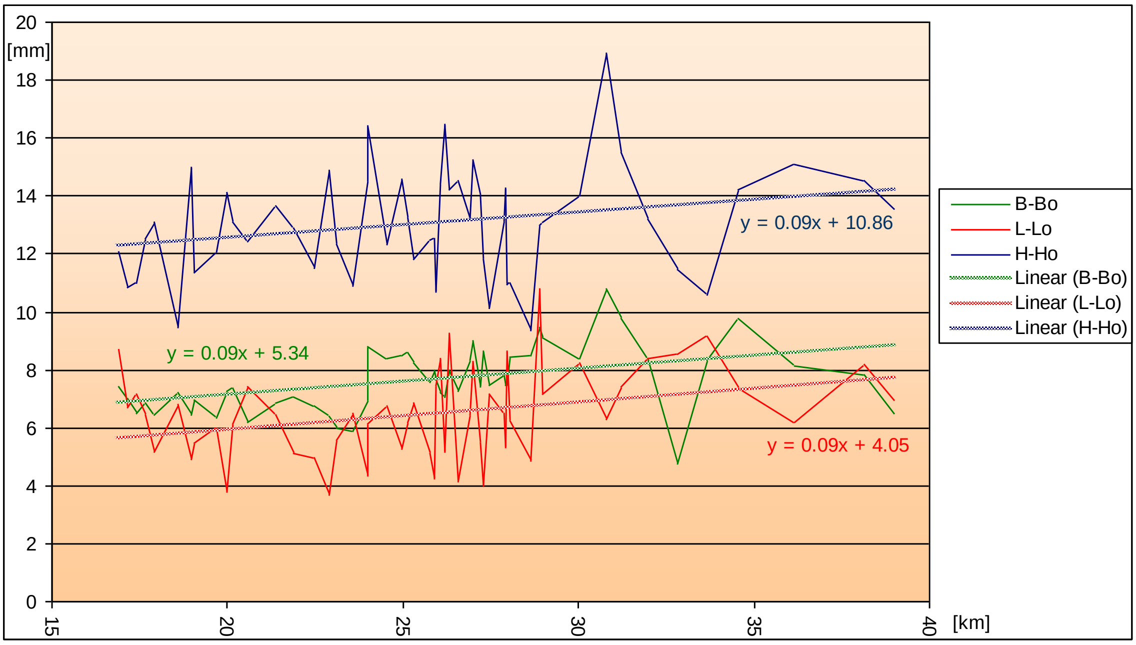

Fig. 15: Graph presenting differences in the function of baseline length

6. CONCLUSION

The permanent service of precise satellite positioning in the territory of the Republic of Serbia AGROS has been established to solve, in a highly efficient, simple and economically justifiable way, a series of problems, primarily in the field of surveying and cadastre, but also in many other activities that are an integral part of a wide range of economic activities and scientific research. These problems have been solved through three services of this network - RTK, DGPS and PP. The most commonly used service so far is the RTK service and for that reason the testing of the declared accuracy of that service has been conducted.

Based on the conducted measurement and analysis of the obtained results, the following conclusions can be drawn:

- the accuracy of the RTK service of the permanent station network is within the projected and declared accuracy, i.e. 2-3 cm;
- differences bigger than expected can occur only in cases of poor geometry of satellites, i.e. when PDOP is bigger than 4;
- there is no accuracy correlation (i.e. difference of measured coordinates) related to the point's distance from permanent stations;
- the accuracy of the RTK service is the same for all the points in the network, i.e. for the entire territory of the Republic of Serbia.

ACKNOWLEDGEMENTS

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BIOGRAPHICAL NOTES

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