IN-SITU TESTING OF GNSS RECEIVERS IN COMPLIENCE WITH ISO 17123-8 PROCEDURE

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Summary: *The paper presents the ISO 17123-8:2015 standard, for calibrating GNSS receivers in RTK mode. This standard calibrating method uses the principle of trilateration, determining a receiver location based on the known satellites coordinates and lengths from the satellite to the receiver in real-time. Measurement is done by the static and the RTK method in three measuring sessions. It is explained in details here, with illustration of the results obtained on the polygon designed according to the recommendations from the standard. The polygon is temporarily fixed in an appropriate place, allowing the modification of the standard method. Statistical results for the lengths are congruent, but for the height differences, the differences are noticed. One of the reasons is, certainly, presence of artificial and natural objects producing multipath reflection, which influence the quality of received signals and accuracy.*

Keywords: *GNSS, calibration, ISO 17123, RTK*

1. INTRODUCTION

Field testing and instrument calibration are counterparts of all metrology orientated geodetic engineers, which, in that way, confirm their competence and quality of obtained results. It is known that all measuring results are loaded with random and systematic errors. A task of each engineer is to find systematic impacts and to include it in the measurements or to eliminate them. New technologies and integration of measurement devices force, also, development of new calibration methods. The calibration methods go through a validation process and become eligible as methods specially developed in the

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laboratories accredited by the ISO 17025 standard. GNSS equipment is present on the market decades ago, while the ISO 17123-8 for RTK GNSS calibration is published in 2007, enabling the conditions for the accredited laboratories to incorporate this method into their activities.

2. BACKGROUND

2.1. STANDARDIZATION AND INTERNATIONAL STANDARDS

ISO (International Organization for Standardization) is the biggest volunteer developer of the international standards. The international standards give products specifications, services and practice, and help the industry to be more efficient and effective. They are developed through general agreement and help to remove the barriers of the world trade. The ISO standards represent strategic tools which lower the costs, by minimizing the errors and increase of productivity. They give the possibility to companies to access new markets, help the developing countries and allow global and fair trade. The organization is founded in 1947. Up to now, it published over 19 000 international standards which its member have bought.

According to the Serbian Standardization Law, Institute for Standardization of Serbia (ISS) is the only body for standardization of the Republic of Serbia (URL 1). Beside its other activities, ISS: publishes, develops, tests, changes, edits, and withdraws the Serbian standards and related documents; cooperates with European and international organizations for standardization and the national bodies; provides availability of Serbian standards to the public, and performs other tasks according to obligations from international contracts in the field of standardization, which obligates the Republic of Serbia.

ISO Technical Committee 172 „Optics and photonics“, Subcommittee 6 „Geodetic and Surveying Instruments“ (ISO/TC 172/ SC6) has presented Series of ISO Standards 17123 „Field procedures for testing geodetic and surveying instruments“ .Part 1: Theory; Part 2: Levels; Part 3: Theodolites; Part 4: EDM instruments; Part 5: Electronic Tacheometers; Part 6: Rotating Lasers; Part 7: Optical plumbing devices; Part 8: GNSS field measurement systems in real-time kinematic (GNNS RTK).

2.2. STANDARD ISO 17123 - Part 8

In 2007, ISO presented the overall standard method for testing the GNSS receivers, for the real-time measurements. The development of the methods, 8 countries from the sub-committee took part, the measurements are performed in 10 countries, by the representatives of the main manufacturers of the GNSS equipment. This standard prescribed the procedure of calibrating the GNSS receivers in the RTK mode, intended for use in surveying, civil engineering, and industrial measurements. Basically, the testing results show whether the GNSS equipment functions correctly, and whether is possible to achieve precision stated by the instrument manufacturer. The testing concept reduces to comparison of the distance D^M and a height difference h^M between two points, with previously determined nominal-standard values (D^T, h^T). The standard values D^T, h^T are determined by the surveying methods that provide better precision. The polygon assumes points fixed at the distance smaller than 20 m. Receivers testing according to ISO 17123-8 comprises [1] [2]:

- the simplified field test procedure, and
- the full field test procedure.

The former method consists of the measuring session in the static mode, resulting in the baseline $D_{1\text{-}2}$, between the points R_1 and R_2. Afterwards, the baseline is moved up to 10 m, proceeding to the latter method which consists of three base-rover measuring sessions (B-R_1, B-R_2), done in different time intervals. The full field test procedure is used for removing the gross errors, estimation of the measuring uncertainty, and statistical testing. After the standard, the series consists of five measurements at the points R_1 and R_2, which are performed in five minutes intervals. It takes about 25 min to complete one series of measurements, i.e., determining the coordinates of the points R_1 and R_2. The result of each measurement are the orthogonal coordinates of the points $R_2(x_{ij,2}, y_{ij,2})$ and $R_1(x_{ij,1},y_{ij,1})$, as well as the heights $h_{ij,2}$ and $h_{ij,1}$.

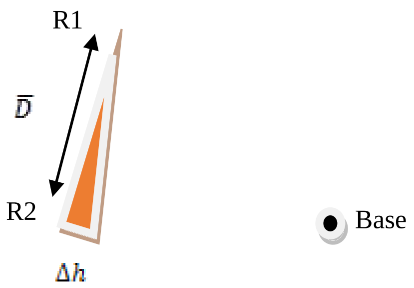

Figure 1: The baseline R_1-R_2

The next step, after completion of the measurements, is two-step estimation process. The first step is testing and extraction of the gross errors, which are excluded from the further analysis. In the second step, for each measurement set $j = 1, \dots 5$ within the three series $i = 1, \dots 3$, the distance and the height difference are determined using:

$$D_{i,j} = \sqrt{(x_{i,j,2} - x_{i,j,1})^2 + (y_{i,j,2} - y_{i,j,1})^2};\ \Delta h_{i,j} = h_{i,j,2} - h_{i,j,1} \tag{1}$$

with the differences:

$$\varepsilon_{D_{i,j}} = (D_{i,j})^{\mathrm{M}} - (D_{i,j})^{\mathrm{T}};\ \varepsilon_{h_{i,j}} = (h_{i,j})^{\mathrm{M}} - (h_{i,j})^{\mathrm{T}} \tag{2}$$

The gross error test is expressed as:

$$\left|\varepsilon_{D_{i,j}}\right| \leq 2.5 \cdot \sqrt{2} \cdot s_{xy};\ \left|\varepsilon_{h_{i,j}}\right| \leq 2.5 \cdot \sqrt{2} \cdot s_h \tag{3}$$

where s_{xy}, s_h are standard deviations. In the case the conditions (3) are not fulfilled, it means that there are the gross errors and the measurements should be repeated. After the gross error testing is over, one should estimate the unknown parameters by forming the mean values:

$$\bar{x}_k = \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} x_{i,j_k};\bar{y}_k = \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} y_{i,j_k};\ \bar{h}_k = \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} h_{i,j_k} \tag{4}$$

Deviations from the arithmetical mean are calculated as:

$$r_{xi,j,k} = \bar{x}_k - x_{i,j,k};\ r_{yi,j,k} = \bar{y}_k - y_{i,j,k};\ r_{hi,j,k} = \bar{h}_k - h_{i,j,k} \tag{5}$$

the residuals:

$$\sum r_x^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{xi,j,k}^2$$
$$\sum r_y^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{yi,j,k}^2 \qquad (6)$$
$$\sum r_h^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{hi,j,k}^2$$

and the empirical standard deviation of single values:

$$s_x = \sqrt{\frac{\sum r_x^2}{m}};\ s_y = \sqrt{\frac{\sum r_y^2}{m}};\ s_h = \sqrt{\frac{\sum r_h^2}{m}} \qquad (7)$$

Experimental standard deviation for a single position (*x*,*y*) and experimental standard deviation for a single height (*h*):

$$s_{\mathrm{ISO-GNSS\ RTK}\ xy} = \sqrt{s_x^2 + s_y^2};\ s_{\mathrm{ISO-GNSS\ RTK}\ h} = \sqrt{\frac{\sum r_h^2}{m}} \qquad (8)$$

where $m = (3 \cdot 5 - 1) \cdot 2 = 28$ is a degree of freedom (ISO 17123-8).

After that, a hypothesis tests are done, in order to answer the question: whether the calculated empirical standard deviation is lower or greater from the one claimed by the manufacturer.

1.

$$H_0: s_{\mathrm{ISO-GNSS\ RTK}\ xy} \le \sigma_{xy};\ H_1: s_{\mathrm{ISO-GNSS\ RTK}\ xy} > \sigma_{xy}; \qquad (9)$$

$$s_{\mathrm{ISO-GNSS\ RTK}\ xy} \le \sigma_{xy} \cdot \sqrt{\frac{\chi_{1-\alpha:m}^2}{m}}$$

$$s_{\mathrm{ISO-GNSS\ RTK}\ xy} \le \sigma_{xy} \cdot \sqrt{\frac{\chi_{0,95:56}^2}{56}} \qquad (10)$$
$$s_{\mathrm{ISO-GNSS\ RTK}\ xy} \le \sigma_{xy} \cdot 1{,}15$$

2.

$$H_0: s_{\mathrm{ISO-GNSS\ RTK}\ h} \le \sigma_h;\ H_1: s_{\mathrm{ISO-GNSS\ RTK}\ h} > \sigma_h \qquad (11)$$
$$s_{\mathrm{ISO-GNSS\ RTK}\ h} \le \sigma_h \cdot \sqrt{\frac{\chi_{1-\alpha:m}^2}{m}}$$
$$s_{\mathrm{ISO-GNSS\ RTK}\ h} \le \sigma_h \cdot \sqrt{\frac{\chi_{0,95:28}^2}{28}} \qquad (12)$$

$$s_h \le \sigma_h \cdot 1{,}22$$

The theoretical values of the standard deviations of the position σ_{xy} and the height difference σ_h are declared by the manufacturer and, congruent to testing, the hypotheses can be accepted or rejected.

In the case of two series, Fisher test shows whether to experimental standard deviations of the position ($s_{\mathrm{ISO-GNSS\ RTK}\ xy}$, $\tilde{s}_{\mathrm{ISO-GNSS\ RTK}\ xy}$) and the height difference ($s_{\mathrm{ISO-GNSS\ RTK}\ h}$, $\tilde{s}_{\mathrm{ISO-GNSS\ RTK}\ h}$) belong to the same population. The following hypothesis is tested:

3.

$$H_0: s_{\mathrm{ISO-GNSS\ RTK}\ xy} = \tilde{s}_{\mathrm{ISO-GNSS\ RTK}\ xy}; H_1: s_{\mathrm{ISO-GNSS\ RTK}\ xy} \ne \tilde{s}_{\mathrm{ISO-GNSS\ RTK}\ xy} \qquad (13)$$
$$\frac{1}{F_{1-\frac{\alpha}{2};n;m}} \le \frac{s_{\mathrm{ISO-GNSS\ RTK}\ xy}}{\tilde{s}_{\mathrm{ISO-GNSS\ RTK}\ xy}} < F_{1-\frac{\alpha}{2};n;m} \Leftrightarrow 0{,}59 \le \frac{s_{\mathrm{ISO-GNSS\ RTK}\ xy}}{\tilde{s}_{\mathrm{ISO-GNSS\ RTK}\ xy}} < 1.7 \qquad (14)$$

$$H_0: s_{\mathrm{ISO-GNSS\ RTK\ h}} = \tilde{s}_{\mathrm{ISO-GNSS\ RTK\ h}};\ H_1: s_{\mathrm{ISO-GNSS\ RTK\ h}} \ne \tilde{s}_{\mathrm{ISO-GNSS\ RTK\ h}} \qquad (15)$$
$$\frac{1}{F_{1-\frac{\alpha}{2};n;m}} \le \frac{s_{\mathrm{ISO-GNSS\ RTK\ h}}}{\tilde{s}_{\mathrm{ISO-GNSS\ RTK\ h}}} < F_{1-\frac{\alpha}{2};n;m};\ 0{,}47 \le \frac{s_{\mathrm{ISO-GNSS\ RTK\ h}}}{\tilde{s}_{\mathrm{ISO-GNSS\ RTK\ h}}} < 2.13 \qquad (16)$$

3. RESULTS AND DISCUSSION

3.1. TEST POLYGON

Field testing was performed at the temporary fixed polygon (Fig. 2). The test equipment comprises the base receiver (Topcon Legacy E) and the rover (Topcon HiPer GGD) with L1 + L2 accuracy of 3 mm + 0.5 ppm, L1 accuracy of 5 mm + 0.5 ppm. RTK L1 + L2 accuracy is 10 mm + 1.5 ppm, while on L1 it is 15 mm + 2 ppm.

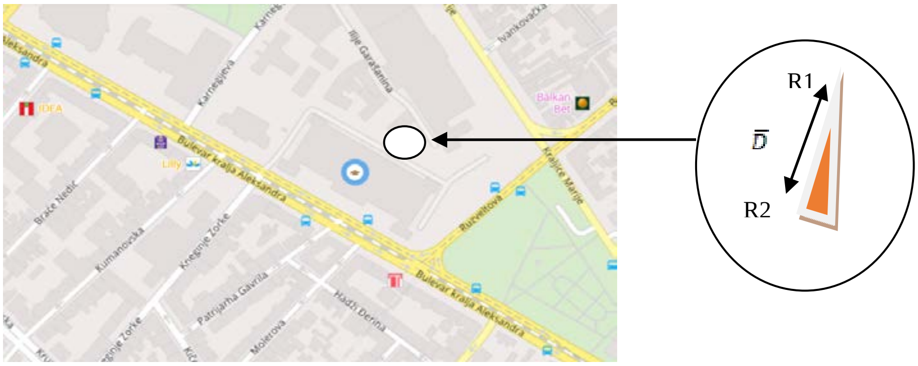

Figure 2. Disposition of the test polygon

First measurement phase comprises determining the baseline between the rover (R_1 point) and the base (R_2). The distance and the height difference are determined according to the coordinate differences obtained from the 30 min long session. In the second phase, the base is moved about 10 m from R1 and R2, when 10 measurements in 5 series between R_1 and R_2 are taken.

3.2. MEASUREMENT RESULTS PROCESSING

Gross error testing

Conditionally accurate values for the distance and the height difference are obtained from the static measurements as:

$$D_{1-2}=3{,}018 \text{ m};\ h_{1-2} = 0{,}123 \text{ m} \quad (17)$$

After that, the base is moved, while 10 baselines for both R_1 and R_2 points are determined by the rover. The distances and the height differences are calculated using (1). The results are given in Table 1 (distances) and Table 2 (height differences).

Table 1 Distances obtained by kinematic positioning

$D_{i,j}$	[m]	$D_{i,j}$	[m]	$D_{i,j}$	[m]	$D_{i,j}$	[m]	$D_{i,j}$	[m]
103-104	3,006	201-202	3,002	301-302	3,011	401-402	3,009	501-502	3,019
105-106	3,019	203-204	3,005	303-304	3,003	403-404	2,970	503-504	3,017
107-108	3,010	205-206	3,027	305-306	3,000	405-406	3,004	505-506	3,007
109-110	3,010	207-208	3,010	307-308	3,009	407-408	3,016	507-508	3,018
111-112	3,024	209-210	3,013	309-310	3,013	409-410	3,012	509-510	3,009
113-114	3,016	211-212	3,018	311-312	3,013	411-412	3,017	511-512	3,003
115-116	3,016	213-214	3,012	313-314	3,009	413-414	3,021	513-514	3,021
117-118	3,027	215-216	3,014	315-316	3,008	415-416	3,016	515-516	3,023
119-120	3,015	217-218	3,017	317-318	3,017	417-418	3,023	517-518	3,028
121-122	3,016	219-220	3,011	319-320	3,013	419-420	3,019	519-520	3,004

Table 2 Height differences obtained by kinematic positioning

$\Delta h_{i,j}$	[m]	$\Delta h_{i,j}$	[m]	$\Delta h_{i,j}$	[m]	$\Delta h_{i,j}$	[m]	$\Delta h_{i,j}$	[m]
103-104	0,109	201-202	0,114	301-302	0,078	401-402	0,139	501-502	0,108
105-106	0,113	203-204	0,107	303-304	0,121	403-404	0,107	503-504	0,110
107-108	0,122	205-206	0,087	305-306	0,162	405-406	0,122	505-506	0,107
109-110	0,105	207-208	0,124	307-308	0,122	407-408	0,110	507-508	0,110
111-112	0,095	209-210	0,122	309-310	0,102	409-410	0,118	509-510	0,115
113-114	0,152	211-212	0,096	311-312	0,110	411-412	0,097	511-512	0,115
115-116	0,126	213-214	0,103	313-314	0,115	413-414	0,097	513-514	0,097
117-118	0,079	215-216	0,097	315-316	0,110	415-416	0,107	515-516	0,098
119-120	0,096	217-218	0,098	317-318	0,117	417-418	0,120	517-518	0,093
121-122	0,086	219-220	0,113	319-320	0,095	419-420	0,100	519-520	0,117

The next step is calculation of the distances and height differences deviations, as the difference between the conditionally accurate values and the measured ones. The results of this phase are given in the Table 3 and Table 4.

Table 3: Deviations of measured distances from the conditionally accurate ones

$\varepsilon_{D_{ij}}$	[m]	$\varepsilon_{D_{ij}}$	[m]	$\varepsilon_{D_{ij}}$	[m]	$\varepsilon_{D_{ij}}$	[m]	$\varepsilon_{D_{ij}}$	[m]
103-104	0,012	201-202	0,015	301-302	0,007	401-402	0,009	501-502	-0,001
105-106	-0,001	203-204	0,012	303-304	0,015	403-404	0,048	503-504	0,001
107-108	0,008	205-206	-0,009	305-306	0,018	405-406	0,014	505-506	0,011
109-110	0,007	207-208	0,008	307-308	0,009	407-408	0,002	507-508	0,000
111-112	-0,006	209-210	0,005	309-310	0,005	409-410	0,006	509-510	0,009
113-114	0,002	211-212	0,000	311-312	0,005	411-412	0,001	511-512	0,014
115-116	0,002	213-214	0,005	313-314	0,009	413-414	-0,003	513-514	-0,003
117-118	-0,009	215-216	0,004	315-316	0,010	415-416	0,002	515-516	-0,005
119-120	0,003	217-218	0,001	317-318	0,001	417-418	-0,005	517-518	-0,010
121-122	0,001	219-220	0,007	319-320	0,005	419-420	-0,001	519-520	0,014

Table 3: Deviations of measured height differences from the conditionally accurate ones

hij	[m]	hij	[m]	hij	[m]	Hij	[m]	Hij	[m]
103-104	0,014	201-202	0,009	301-302	0,045	401-402	-0,016	501-502	0,015
105-106	0,010	203-204	0,016	303-304	0,002	403-404	0,016	503-504	0,013
107-108	0,001	205-206	0,036	305-306	-0,039	405-406	0,001	505-506	0,016
109-110	0,018	207-208	-0,001	307-308	0,001	407-408	0,013	507-508	0,013
111-112	0,028	209-210	0,001	309-310	0,021	409-410	0,005	509-510	0,008
113-114	-0,029	211-212	0,027	311-312	0,013	411-412	0,026	511-512	0,008
115-116	-0,003	213-214	0,020	313-314	0,008	413-414	0,026	513-514	0,026
117-118	0,044	215-216	0,026	315-316	0,013	415-416	0,016	515-516	0,025
119-120	0,027	217-218	0,025	317-318	0,006	417-418	0,003	517-518	0,030
121-122	0,037	219-220	0,010	319-320	0,028	419-420	0,023	519-520	0,006

The values of these deviations are compared to the boundary allowed values for the length and the height difference. The values are:

$$\rho_{D\frac{max}{gran}} = 2,5\sqrt{2}\sigma_D = 10\text{ mm};\ \rho_{h\frac{max}{gran}} = 2,5\sqrt{2}\sigma_h = 15\text{ mm} \qquad (18)$$

The measurements that do not fulfil the criteria (18) are marked grey in the Tables 3 and 4, based on the boundary allowed values of the length and height differences deviations.

Calculation of the standard deviation

The standard deviation of the length is obtained following the Error propagation law:

$$s_{xy} = \sqrt{\left(\left(\frac{\partial D}{\partial y}\right)^2 \sigma_y^2\right)_1 + \left(\left(\frac{\partial D}{\partial y}\right)^2 \sigma_y^2\right)_2 + \left(\left(\frac{\partial D}{\partial x}\right)^2 \sigma_x^2\right)_1 + \left(\left(\frac{\partial D}{\partial x}\right)^2 \sigma_x^2\right)_2}, \quad (19)$$

with $\left(\frac{\partial D}{\partial y}, \frac{\partial D}{\partial x}\right)_1, \left(\frac{\partial D}{\partial y}, \frac{\partial D}{\partial x}\right)_2$ – partial derivatives of the length D_{1-2}, giving:

$$s_{xy}=7{,}8 \text{ mm} \quad (20)$$

The standard deviation of the height difference is calculated as:

$$s_h = \sqrt{(\sigma_h^2)_1 + (\sigma_h^2)_2} = 22{,}8 \text{ mm}. \quad (21)$$

Hypotheses testing

To test the distance accuracy, we tested the hypothesis:

$$H_0: s_{xy} = \sigma_{xy}\,; H_1: s_{xy} \neq \sigma_{xy} \quad (22)$$

with the test statistics: $\chi^2 = 24.082$, which is compared to $\chi^2_{f,\alpha}$, for the confidence level $\alpha = 0{,}05$ and $f = m \cdot (n-1) \cdot p = 5 \cdot (10-1) \cdot 1 = 45$ degrees of freedom, giving $\chi^2_{45,0.05}$=61,656. Since $\chi^2 < \chi^2_{f,\alpha}$, there are no reason to reject the null hypothesis, which leads to the conclusion that the achieved accuracy is congruent to the requested one.
To test the accuracy of the height difference, we test the hypothesis:

$$H_0: s_h = \sigma_h; H_1: s_h \neq \sigma_h;$$

with the test statistics: $\chi^2 = 103.616$. It is compared to the probability $\chi^2_{f,\alpha}$, using the confidence level $\alpha = 0{,}05$ and $f = m \cdot (n-1) \cdot p = 5 \cdot (10-1) \cdot 1 = 45$ degrees of freedom. The obtained value is $\chi^2_{45,0.05} = 61{,}656$.
Herem $\chi^2 > \chi^2_{f,\alpha}$, which means that we are accepting the alternative hypothesis, concluding that the accuracy of the height differences is not congruent with the one declared by the manufacturer.
After the completed measurements and data processing, we conclude that the desired positional accuracy s_{xy} is achieved by the accuracy of the height differences s_h is out of the boundary conditions. These deviations are caused by the bad satellite constellation during the measurements and high multipath reflection from a number of high artificial objects in the vicinity of the receivers. That fact leads to a conclusion that an extreme caution should be paid on the location of the polygon and the characterization and location of the surrounding objects.

4. CONCLUSIONS AND REMARKS

In ISO 17123-8, it is not prescribed whether the base receiver belongs to the owner of the rover, or the laboratory receiver is used. That is why a CORS network's receiver can be used, as well as any other RTK capable receiver. There is a possible problem with the permanent network reflected in absence of communication with the control centre, which could cause the interruptions during the measurements. Instead of real-time measurements, post-processing kinematic method can be applied, with no loss in accuracy. Other influences that could degrade the accuracy of the calibration results are the errors of: clock, ephemeris, receiver phase centre, multipath reflection, troposphere and ionosphere and satellite geometry. Also, using the GNSS processing software [3] can include some errors related to the applied mathematical model.

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TERENSKO ISPITIVANJE GNSS PRIJEMNIKA U SKLADU SA PROCEDUROM ISO 17123-8

Rezime: *U radu je predstavljen pregled međunarodnog standarda ISO 17123-8: 2015 za etaloniranje sistema GNSS RTK. Ova standardna metoda etaloniranja koristi princip trileteracije tako što se na osnovu poznatih koordinata satelita i dužine od satelita do prijemnika u realnom vremenu može odrediti položaj prijemnika. Merenje se vrši statičkom metodom i RTK metodom u tri merne sesije i detaljno je opisano u ovom radu sa ilustracijom dobijenih rezultata na poligonu dizajniranom u skladu sa preporukama u standardu. Poligon je privremeno stabilizivon na odgovarajućem mestu, omogućivši modifikaciju standardne metode. U statističkim testiranjima za dužinu su dobijeni adekvatni rezultati ali je za visinsku razliku uočeno odstupanje. Jedan od razloga je svakako i prisustvo veštačkih i prirodnih objekata koji proizvode višestruke refleksije i utiču na kvalitet primljenog signala i tačnost.*

Ključne reči: *GNSS, етaлонирање, ISO 17123, RTK*