ON THE HORIZONTAL AND VERTICAL COLLIMATION DEPENDENCY ON ZENITH ANGLE AND DISTANCE
ZAVISNOST HORIZONTALNE I VERTIKLNE KOLIMACIJE OD ZENITNIH ODSTOJANJA I DUŽINA

Žarko Nestorović*, Milan Trifković**, Miroslav Kuburić**,
* EPS AD Beograd, ogranak Đerdap, Kladovo, zarko.nestorovic@eps.rs
** Građevinski fakultet u Subotici

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ABSTRACT

The contemporary digital automated total stations provide possibilities of increased efficiency in the process of measurements. The increase of quality of total station construction reduces the certain errors related to its measuring characteristics. This characteristic should increase the accuracy because eliminate the influence caused by measurement duration and inner measuring uncertainty of total station. The only remain influence on reducing measuring uncertainty of obtained results could be caused by surveyor’s experience and influence of external influences such as atmosphere, light and type of target applied. Bearing in mind that every single geodetic instrument has got its own characteristics it is necessary to investigate them in the conditions where that instrument is utilized. In this research the horizontal and vertical collimation of high accurate total station was researched from their dependence on zenith angle and distance. After that the influence of light intensity was included in research. The analysis was provided by utilizing multidimensional linear regression model.

APSTRAKT

Savremene digitalne automatske totalne stanice obezbeđuju mogućnosti za povećanje efikasnosti procesa merenja. Povećanje kvaliteta konstrukcije totalnih stanica smanjuje određene greške povezane sa njihovim mernim karakteristikama. Ove karakteristike povećavaju tačnost zbog eliminacije uticaja izazvanih trajanjem merenja i unutrašnjom mernom nesigurnošću totalnih stanica. Jedine preostale greške koje se pojavljuju vezane su za iskustvo geodete koji vrši merenja i uticaja spoljnih uslova kao što su uticaji atmosfere, svetlosti i tipa signala. Imajući u vidu da svaki geodetski instrument ima svoje sopstvene karakteristikeneophodno je istražiti u uslovima gde taj instrument može biti korišćen. U ovom istraživanju sprovedeno je određivanje horizontalne i vertikalne kolimacije visokoprecizne totalne stanice sa aspekta njihove zavisnosti od zenitnih odstojanja i dužina. Zatim je izvršeno istraživanje i uticaja intenziteta svetlosti. Analiza je izvršena primenom višedimenzionalne regresije.

INTRODUCTION

Contemporary automated total stations provide the high efficiency and accuracy of measurement enabling their utilization in wide areas. Efficient measurement followed by high accuracy does not mean that all errors are excluded. On the contrary it only means that some errors mostly influenced by the construction of total station and duration of the measurement are minimized. The influences left, which affect the measurements, are related to the physiological characteristics of the surveyor, its experience, external conditions and remining imperfections of total station. The characteristics of target also could be the source of measuring uncertainty, but it will not be the issue of research in this experiment. The sources of errors are well researched and explained in the literature related to the topic of geodetic metrology [1-4].

For this purpose, the experiment was designed and conducted with aim to find out if the double horizontal and vertical collimation is dependent on the zenith angles and slope distances. It encompassed the three black and white targets approximately belonging to the same vertical plane. The measurements were provided in two sets of angles from the ten positions with the distances between 2 and 6 meters between total station and targets at the step of approximately 0.5 m. The experiment also encompassed registration of light intensity because it was provided in indoor condition. The condition for measurements is shown on figure 1.

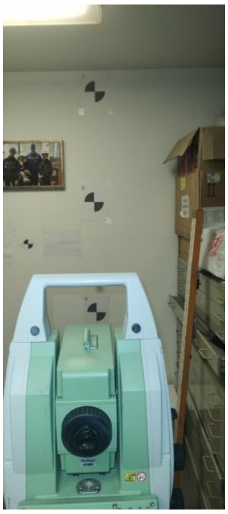

Fig. 1. The condition during measurements

Measurements were provided under the relatively poor light conditions and the conditions were not changed during the measurement. The distance between instrument and rods were approximately 2.1 and 6.0 meters. The short distance and indoor area were chosen to because this total station is often used in the similar conditions for solving real tasks. For statistical analysis was utilized the student’s statistics, F-statistics and multidimensional linear regression model [5, 6].

MATERIALS AND METHODS

The materials for this research were obtained by measuring the three fixed target from the ten positions of total stations. The measurements were provided by the digital total station with the following measurement characterises:

- $\sigma_p = 0.5''$ for measured directions,
- $\sigma_Z = 0.5''$ for measured zenith angles and
- $\sigma_d = 0.6\text{ mm} + 1\text{ppm}$ for measured directions.

The additional data was the measured light intensity at the telescope of total station. The difference of light intensity is caused by the position of the lamps related to the position of total station. The obtained data are given in table 1.

Table 1. Results of collimation measurements [mm]

Meas Nº	Z	S [m]	Light [lx]	2C	2VV	Meas Nº	Z	S [m]	Light [lx]	2C	2VV
1	61.5617	2.3963	200	19.5	21.3	31	73.1496	3.9514	270	1.0	-1.8
2	81.2551	2.1285	170	1.9	1.9	32	81.2551	3.7928	120	2.2	2.2
3	105.1515	2.1788	93	-3.6	32.5	33	105.1515	3.8187	65	-0.5	12.3
4	61.5636	2.3958	200	8.9	3.6	34	73.1488	3.9518	270	1.1	0.9
5	81.2551	2.1289	170	7.0	7.0	35	81.2551	3.7930	120	-1.2	-1.2
6	105.1515	2.1784	93	-13.6	25.9	36	105.1515	3.8180	65	-3.9	3.0
7	65.0378	2.7041	175	23.4	9.0	37	75.5111	4.5706	220	5.1	-0.4
8	81.2551	2.4704	150	13.2	13.2	38	81.2551	4.4344	180	7.1	7.1
9	105.1515	2.5127	82	-0.3	20.4	39	105.1515	4.4567	140	0.5	8.6
10	65.0391	2.7038	175	1.9	-0.1	40	75.5112	4.5709	220	2.6	-2.0
11	81.2551	2.4698	150	-0.1	-0.1	41	81.2551	4.4348	180	-1.2	-1.2
12	105.1515	2.5128	82	-4.3	20.7	42	105.1515	4.4569	140	-1.8	2.1
13	68.7592	3.1512	140	2.9	14.3	43	76.6178	4.9396	170	5.2	-0.9
14	81.2551	2.9525	101	0.4	0.4	44	81.2551	4.8133	153	1.1	1.1
15	105.1515	2.9873	67	-4.2	13.2	45	105.1515	4.8335	112	0.6	1.3
16	68.7608	3.1513	140	6.5	-0.3	46	76.6172	4.9395	170	3.9	-0.4
17	81.2551	2.9514	101	0.5	0.5	47	81.2551	4.8132	153	2.1	2.1
18	105.1515	2.9871	67	-0.2	12.3	48	105.1515	4.8332	112	-1.0	1.1
19	68.7603	3.1506	121	4.6	-0.3	49	78.0768	5.5296	145	1.9	-2.2
20	81.2551	2.9519	103	1.3	1.3	50	81.2551	5.4174	106	1.3	1.3
21	105.1515	2.9873	78	0.6	11.3	51	105.1515	5.4358	85	1.1	-2.5
22	68.7603	3.1508	121	7.6	7.0	52	78.0762	5.5299	145	0.8	-1.3
23	81.2551	2.9516	103	-0.5	-0.5	53	81.2551	5.4176	106	2.6	2.6
24	105.1515	2.9874	78	-0.2	6.0	54	105.1515	5.4357	85	-4.2	2.6
25	71.2652	3.5639	130	2.6	12.0	55	79.0432	6.0176	220	1.2	-2.0
26	81.2551	3.3880	81	10.2	10.2	56	81.2551	5.9147	115	-0.3	-0.3
27	105.1515	3.4180	59	0.8	8.2	57	105.1515	5.9312	75	0.5	2.6
28	71.2677	3.5640	130	5.3	-1.9	58	79.0432	6.0177	220	2.6	4.5
29	81.2551	3.3869	81	0.7	0.7	59	81.2551	5.9147	115	3.4	3.4
30	105.1515	3.4172	59	-2.3	15.3	60	105.1515	5.9313	75	-1.6	0.1

The model for data analysis is based on the utilization of multiple dimensional linear regression which is described as follows:

$$Y_i = \theta_0 + \sum_{j=1}^{n} \theta_j x_j + \varepsilon_i \qquad (1)$$

where:

- Y_i – measured valued of dependent variable (horizontal or vertical collimation);
- i – the number of certain measured value (i=1~60)
- θ_j – coefficient;
- ε_i – free term;
- x_j – independent variables (zenith angles, distances and intensity of light) and

- n – number of independent variables

The method for data analysis is based on the student's and F-statistics. Test statistics are described as follows.

$$t = \frac{d}{m_d} = \frac{\bar{c} - \bar{v}}{\sqrt{\frac{m_{\bar{c}}^2}{m} + \frac{m_{\bar{v}}^2}{m}}} \sim t_{f,1-\alpha} \tag{2}$$

where:

- t – test statistics;
- $\bar{c}$ – average of horizontal collimation;
- $\bar{v}$ – average of of vertical collimation;
- $m_{\bar{c}}$ – root mean square error of horizontal collimation average value;
- $m_{\bar{v}}$ – root mean square error of vertical collimation average value;
- m – the number of measurements and
- $t_{f,1-\alpha}$ – quantiles of student's distribution for f – degrees of freedom and level of significance α.

The hypothesis about equality of vertical and horizontal collimations read as follows:
H_0: The vertical and horizontal collimation of total station are equal.
H_a: Otherwise.

The F statistics is provided as follows:

$$F = \begin{cases} \frac{m_{\bar{c}}^2}{m_{\bar{v}}^2}, & m_{\bar{c}} \geq m_{\bar{v}} \\ \frac{m_{\bar{v}}^2}{m_{\bar{c}}^2}, & m_{\bar{v}} < m_{\bar{c}} \end{cases} \sim F_{f,f,1-\alpha} \tag{3}$$

The hypothesis about equality of root means square errors read as follows:
H_0: The root means square errors of averages of horizontal and vertical collimation are equal;
H_a: Otherwise.
These two statistics should prove the significance of influence caused by level's bubble position on the determination of height differences in described conditions.

RESULTS AND DISCUSSION

The results will be given in following order: a) test hypothesis about equality of horizontal and vertical collimation, b) test hypothesis about equality of root mean square errors of horizontal and vertical collimations and c) the results obtained by multidimensional linear regression.
Statistical analysis is provided by introducing real values from table 1 in formula (3) as follows:

$$t = \frac{d}{m_d} = \frac{\bar{c} - \bar{v}}{\sqrt{\frac{m_{\bar{c}}^2}{60} + \frac{m_{\bar{v}}^2}{60}}} = \frac{5.1 - 2.0}{\sqrt{\frac{5.39^2}{60} + \frac{7.65^2}{60}}} = 2.5576 > t_{59,0.95} = 2.0010 \tag{4}$$

It is obvious, according to formula (3) and result obtained by formula (4) there is no reason for accepting hypothesis $H_0: d_j = 0$. This result means that the horizontal and vertical collimation of utilized total stations are not equal i.e. the vertical collimation, in actual complex of condition, is significantly higher than horizontal collimation.

According to obtained results it immediate follows that, in statistical sense, all differences are significant i.e. there is no reasons for accepting hypothesis about equality of height differences obtained when the level's bubble is in centre and on the edges of the working range.

The F-statistics with applied obtained values reads as follows:

$$F = \begin{cases} \frac{m_{\bar{c}}^2}{m_{\bar{v}}^2}, & m_{\bar{c}} \geq m_{\bar{v}} \\ \frac{m_{\bar{v}}^2}{m_{\bar{c}}^2}, & m_{\bar{v}} > m_{\bar{c}} \end{cases} = \frac{\frac{7.65^2}{60}}{\frac{5.39^2}{60}} = 2.0143 > F_{59,59,0.95} = 1.5405 \qquad (5)$$

It is obvious, according to result obtained by formula (5), that there is no reason for accepting hypothesis $H_0: m_{\bar{c}} = m_{\bar{v}}$ what means that horizontal and vertical collimation were not determined with the same accuracy and that the accuracy of vertical collimation is significantly smaller than the accuracy of the horizontal collimation.

The analysis of horizontal and vertical collimation is focused on find out how much the external conditions explain them which quantified with term R^2. The results obtained by multidimensional linear regression are given in table 3 (the "x" denotes the included independent variables).

Table 2. the results obtained by multidimensional linear regression

N°	Z	S	L	R^2 (2C)	R^2 (2VV)
1	x	-	-	0.40	0.12
2	-	x	-	0.02	0.28
3	-	-	x	0.16	0.10
4	x	x	-	0.41	0.43
5	x	-	x	0.40	0.13
6	-	x	x	0.20	0.35
7	x	x	x	0.41	0.43

From results obtained immediately follows that less than 50% of horizontal and vertical collimation is explained for the results obtained in existing complex of condition.

Maximum of explanation of horizontal collimation is obtained when the zenith angle, slope distance and light is included in the model. And it is obvious that similar explanation is obtained with the included zenith angles while the distances and light intensity do not improve significantly the term R^2.

Maximum explanation of vertical collimation is obtained when zenith angles and distances were included. It is also obvious that the same value of term R^2 is obtained without including the light intensity in the model.

The obtained model suggests that the model is not completed and it is neccessary to include some additional independent variables. This maight include the personal characteristics of surveyor in the external conditions. Consequently, further research shall include measurement with more surveyors in the same conditions in order to find out if the characteristics of surveyor influence the horizontal and vertical collimation.

CONCLUSION

The conducted experiment showed that horizontal and vertical collimations are not equal and that they are determined with different root mean square errors. The second conclusion could state those horizontal and vertical collimations are not only influenced by imperfection in construction of total station but also with the other factors which were not included into the model. This conclusion implicates that further research should encompass more surveyors in order to identify the missed independent influences i.e. independent variables.

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