MEASURING UNCERTAINTY OF THE HORIZONTAL AND VERTICAL CLINOMETERS ON DJERDAP I DAM
MERNA NESIGURNOST HORIZONTALNOG I VERTIKALNOG KLINOMETRA NA BRANI DJERDAP I

Stefan Istodorović*, Žarko Nestorović*, Srđan Kuzmanović**

*EPS AD Beograd, Ogranak Đerdap Kladovo, Stefan.Istodorovic@eps.rs
**Đerdap Usluge AD Kladovo

Keywords: level, measuring uncertainty, statistical test
Ključne reči: libela, merna nesigurnost, statistički test

ABSTRACT

The dam's monitoring is of crucial importance for their stability estimation. For that purpose, different measuring instruments of declared high accuracy are utilized including telecoordinometers, teleclinometers and pendulums. The automated equipment could only be checked in laboratories. Among the automated system for measurements exist with digital portable horizontal and vertical clinometers. These digital portable clinometers are used to determine the changes in their bases over time. The measurements of those bases are based on the highly accurate level position measurement and data registration of the level slope. The determination of those changes is related to the measured value of the level's position and on the standard deviation of the measurement. In this research, the measuring uncertainty was tested by the infield measurement obtained by digital portable horizontal or vertical clinometers. The results showed that horizontal clinometer has measuring uncertainty while measuring uncertainty for vertical clinometer was not detected.

APSTRAKT

Osmatranje velikih brana je kritično za ocenu njihove stabilnosti. Za tu svrhu koriste se različiti geodetski instrumenti sa visoko deklarisanom tačnošću merenja kao što su telekoordinometri, teleklinometri i viskovi. Automatizovani instrumenti se jedino mogu proveravati u ovlašćenim laboratorijama. Među automatizovanim instrumentima koriste se i digitalni prenosni horizontalni i vertikalni klinometri. Horizontalni i vertikalni klinometri koriste se za određivanje promene njihovih baza tokom vremena. Merenja na ovim bazama zasnivaju se na visokotačnm merenju položaja i registrovanju podataka o nagibu libele. Određivanje promena nagiba libele povezano je sa rezultatom merenja položaja libele i standardnom devijacijom merenja. U ovom istraživanju testirana je merna nesigurnost rezultata terenskih merenja izvršenih horizontalnim i vertikalnim klinometrima. Rezultati su pokazali da postoji merna nesigurnost kod horizontalnog klinometra dok kod vertikalnog klinometra merna nesigurnost nije otkrivena.

INTRODUCTION

The DJerdap 1 dam is an object of high importance and high potential risk and hazard [1]. Those kinds of dams are to be monitored regularly by different types of instruments and different physical and geometrical parameters should be registered as bases for making conclusions about the dam's stability and consequently for adequate decision making. Figure 1 shows the clinometers in the position for measurements.

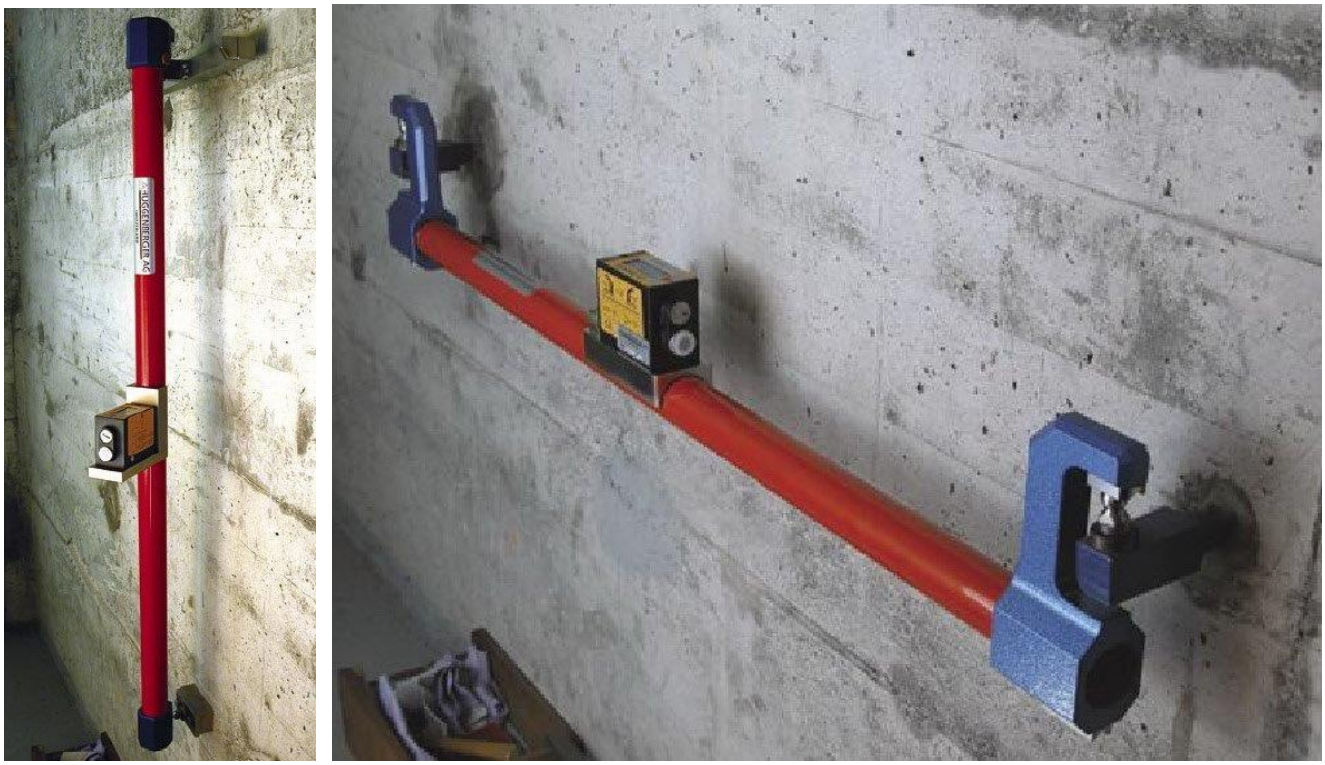

Fig. 1. Vertical and horizontal clinometer

The determination of horizontal and vertical changes of the clinometer's base slopes represents the stability of the dam between the two measurements. The clinometers measure relative movements of the fixed base-related horizontal and vertical planes because they are based on the level principles. Bearing in mind the characteristics of levels in this research measurements in different positions of clinometers were conducted. The measurements provided by the horizontal clinometer encompassed the different bases changing their position by ten-time rotation. The measurements provided by the vertical clinometer were realized in three positions by its rotation around the base at the pace of 90 degrees. The measurements were provided twice, and results were statistically analyzed including the differences obtained in two measurement epochs.

MATERIALS AND METHODS

The materials for this research were obtained by measuring the positions of horizontal and vertical clinometers on June 26th and July 16th in the year 2024. The measurements provided by the vertical clinometer encompassed data registration on the four bases in three positions. The position of the vertical clinometer means that the measurements were realized by the vertical clinometer's rotation around the vertical axis at the pace of 90° (0°, 90°,180°). The results of measurements by vertical clinometer shoved stability and results were identical except in the conditions of a high level of vibrations where the

deviations could be considered as neglectable. The measurements showed that a low level of measuring uncertainty implicates that the sensitivity of the vertical clinometer is too low for the analysis. For this reason, the results of the vertical clinometer were not further considered in this research.

The results of measurements provided by the horizontal clinometer encompassed eleven measurements in two positions on eight different bases. The results of those measurements are given in Table 1. The units in tables and further analysis are millimetres [mm].

Table 1. The results of measurements provided by horizontal clinometer in two epochs

I measurement - June 26th, 2024																
Meas. N°	**Base 1**		**Base 2**		**Base 3**		**Base 4**		**Base 5**		**Base 6**		**Base 7**		**Base 8**	
	I p	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**
1	-2.075	-1.897	-1.930	-2.032	-1.962	-2.030	-2.026	-2.210	-1.987	-2.025	-1.923	-2.072	-2.061	-2.443	-2.300	-2.488
2	-2.076	-1.895	-1.931	-2.031	-1.949	-2.048	-2.001	-2.111	-1.989	-2.025	-1.930	-2.012	-2.051	-2.493	-2.273	-2.482
3	-2.075	-1.895	-1.931	-2.030	-1.950	-2.045	-1.993	-2.101	-1.989	-2.025	-1.920	-2.018	-2.061	-2.508	-2.329	-2.497
4	-2.075	-1.895	-1.931	-2.030	-1.947	-2.034	-1.990	-2.109	-1.989	-2.042	-1.955	-2.118	-2.057	-2.494	-2.356	-2.361
5	-2.076	-1.894	-1.931	-2.030	-1.946	-2.036	-2.002	-2.096	-1.986	-2.027	-1.956	-2.094	-2.059	-2.520	-2.358	-2.326
6	-2.076	-1.895	-1.930	-2.030	-1.947	-2.036	-2.033	-2.103	-1.985	-2.057	-1.991	-2.104	-2.061	-2.518	-2.307	-2.256
7	-2.076	-1.896	-1.930	-2.030	-1.949	-2.038	-2.025	-2.118	-1.986	-2.068	-1.979	-2.102	-2.072	-2.534	-2.249	-2.269
8	-2.076	-1.896	-1.930	-2.030	-1.949	-2.037	-2.039	-2.127	-1.983	-2.061	-1.943	-2.108	-2.081	-2.492	-2.239	-2.261
9	-2.076	-1.896	-1.930	-2.031	-1.950	-2.037	-2.049	-2.121	-1.984	-2.082	-1.995	-2.115	-2.091	-2.471	-2.264	-2.343
10	-2.076	-1.896	-1.930	-2.030	-1.951	-2.038	-2.045	-2.118	-1.983	-2.075	-1.982	-2.137	-2.162	-2.474	-2.312	-2.285
11	-2.076	-1.896	-1.931	-2.031	-1.953	-2.037	-2.032	-2.117	-1.988	-2.084	-1.979	-2.156	-2.164	-2.464	-2.417	-2.407
$\bar{x}_{1j}$	-2.0757	-1.8955	-1.9305	-2.0305	-1.9503	-2.0378	-2.0214	-2.1210	-1.9863	-2.0519	-1.9594	-2.0942	-2.0836	-2.4919	-2.3095	-2.3614
$m_{\bar{x}_{1j}}$	0.0005	0.0008	0.0005	0.0007	0.0044	0.0049	0.0212	0.0310	0.0023	0.0239	0.0275	0.0448	0.0409	0.0273	0.0535	0.0939
II measurement - July 16th, 2024																
Meas. N°	**Base 1**		**Base 2**		**Base 3**		**Base 4**		**Base 5**		**Base 6**		**Base 7**		**Base 8**	
	I p	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**
1	-2.087	-1.916	-1.960	-2.046	-1.986	-2.045	-2.075	-2.192	-1.998	-2.050	-2.050	-2.086	-2.075	-2.190	-2.070	-2.112
2	-2.086	-1.916	-1.961	-2.047	-1.986	-2.044	-2.073	-2.204	-2.007	-2.052	-2.052	-2.089	-2.053	-2.185	-2.060	-2.110
3	-2.086	-1.917	-1.961	-2.047	-1.985	-2.044	-2.058	-2.232	-2.007	-2.054	-2.054	-2.089	-2.100	-2.182	-2.092	-2.121
4	-2.086	-1.918	-1.961	-2.046	-1.988	-2.058	-2.042	-2.252	-2.003	-2.052	-2.052	-2.087	-2.100	-2.177	-2.140	-2.136
5	-2.088	-1.918	-1.961	-2.046	-1.988	-2.060	-2.035	-2.252	-2.003	-2.046	-2.046	-2.094	-2.074	-2.191	-2.138	-2.145
6	-2.088	-1.918	-1.961	-2.046	-1.989	-2.060	-2.085	-2.284	-1.996	-2.038	-2.038	-2.096	-2.013	-2.189	-2.140	-2.145
7	-2.087	-1.918	-1.960	-2.044	-1.987	-2.062	-2.157	-2.326	-1.995	-2.037	-2.037	-2.094	-2.028	-2.178	-2.135	-2.167
8	-2.086	-1.917	-1.958	-2.043	-1.988	-2.063	-2.151	-2.293	-1.995	-2.038	-2.038	-2.091	-2.033	-2.184	-2.163	-2.145
9	-2.085	-1.917	-1.958	-2.043	-1.991	-2.067	-2.123	-2.260	-2.000	-2.037	-2.037	-2.095	-2.053	-2.188	-2.212	-2.178
10	-2.086	-1.917	-1.958	-2.045	-1.991	-2.062	-2.136	-2.298	-2.000	-2.036	-2.036	-2.093	-2.134	-2.174	-2.267	-2.155
11	-2.087	-1.918	-1.960	-2.046	-1.987	-2.064	-2.134	-2.275	-2.000	-2.039	-2.040	-2.090	-2.166	-2.187	-2.148	-2.182
$\bar{x}_{2j}$	-2.0865	-1.9173	-1.9599	-2.0454	-1.9878	-2.0572	-2.0972	-2.2607	-2.0004	-2.0435	-2.0436	-2.0913	-2.0754	-2.1841	-2.1423	-2.1451
$m_{\bar{x}_{2j}}$	0.0009	0.0008	0.0013	0.0014	0.0019	0.0086	0.0444	0.0404	0.0043	0.0072	0.0072	0.0033	0.0467	0.0057	0.0596	0.0245

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

$$t = \frac{d_j}{m_{d_j}} = \frac{\bar{x}_{2j} - \bar{x}_{1j}}{\sqrt{\frac{m_{\bar{x}_{2j}}^2}{n_2} + \frac{m_{\bar{x}_{1j}}^2}{n_1}}} \sim t_{f,1-\alpha} \tag{1}$$

where:

- t – test statistics;
- $\bar{x}_{1j}$ – an average of first measurements on the base j;
- $\bar{x}_{2j}$ – an average of second measurements on the base j;
- $m_{\bar{x}_{1j}}^2$ – square error of first measurement set on the base j;

- $m^2_{\bar{x}_{2j}}$ – square error of second measurement set on the base j;
- n_{1j}, n_{2j} – the number of first and second measurements on the base j and
- $t_{f,1-\alpha}$ – quantiles of student's distribution for f – degrees of freedom and level of significance α.

Measurements obtained in the first (**I p**) and second (**II p**) positions of the horizontal clinometer mean the deviation from the horizontal position of the level rotated for 180°. Half of this difference is caused by the non-horizontality of the base and another half by the level's non-rectification. This model could be described as follows:

$$\Delta = l_{\mathbf{II\ p}} - l_{\mathbf{I\ p}} \tag{2}$$

From the aspect of horizontality changes between two epochs of measurements, these deviations are not relevant if the difference between two positions on one base remains equal in two epochs of measurements and if the differences in two positions between two epochs remain the same on the same base. This could be explicated by the following formula:

$$l^2_{\mathbf{II\ p},j} - l^1_{\mathbf{II\ p},j} = l^2_{\mathbf{I\ p},j} - l^1_{\mathbf{I\ p},j} \tag{3}$$

where index j denotes the base on which the measurements were provided. Of course, the equality is considered in a statistical sense determined by using an available set of data.

If the condition given by formula (3) is not fulfilled it is necessary to discuss the obtained differences to find out if those differences are important from the aspect of object stability nevertheless of their statistical significance.

RESULTS AND DISCUSSION

Statistical analysis is provided by introducing real values in formula (1) as follows:

$$t = \frac{d_j}{m_{d_j}} = \frac{\bar{x}_{2j} - \bar{x}_{1j}}{\sqrt{\frac{m^2_{\bar{x}_{2j}}}{11} + \frac{m^2_{\bar{x}_{1j}}}{11}}} \sim t_{10,0.95} = 2.7638 \tag{4}$$

It is obvious that in the case when statistics $t < 2.7638$ there is no reason to accept a hypothesis $H_a: d_j \neq 0$ while in the opposite case there is no reason for accepting a hypothesis $H_0: d_j = 0$. The obtained results of the statistical analysis provided by formula (1) are given in Table 2.

Table 2. Differences between two measurements, student's statistics t and accepted hypothesis

	Base 1		**Base 2**		**Base 3**		**Base 4**		**Base 5**		**Base 6**		**Base 7**		**Base 8**	
	I p	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**	**I p**	**II p**
d_j	-0.011	-0.022	-0.029	-0.015	-0.038	-0.019	-0.076	-0.140	-0.014	0.008	-0.084	0.003	0.008	0.308	0.167	0.216
m_{d_j}	0.0003	0.0003	0.0004	0.0005	0.0014	0.0030	0.0148	0.0154	0.0015	0.0075	0.0086	0.0135	0.0187	0.0084	0.0241	0.0293
t	34.3523	63.4240	69.7137	31.1044	26.0891	6.5031	5.1148	9.0989	9.5650	1.1094	9.8188	0.2149	0.4421	36.6492	6.9273	7.3902
H_0	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No

This result showed that in all except one case there were significant differences between measurements in two epochs. Also, according to the obtained results, it follows that differences between the two

positions of the horizontal clinometer differ significantly in two epochs of measurements. The results are given in Table 3.

Table 3. The differences between measurements in two positions

I measurement - June 26th, 2024							
Base 1	**Base 2**	**Base 3**	**Base 4**	**Base 5**	**Base 6**	**Base 7**	**Base 8**
0.178	-0.102	-0.068	-0.184	-0.038	-0.149	-0.382	-0.188
0.181	-0.100	-0.099	-0.110	-0.036	-0.082	-0.442	-0.209
0.180	-0.099	-0.095	-0.108	-0.036	-0.098	-0.447	-0.168
0.180	-0.099	-0.087	-0.119	-0.053	-0.163	-0.437	-0.005
0.182	-0.099	-0.090	-0.094	-0.041	-0.138	-0.461	0.032
0.181	-0.100	-0.089	-0.070	-0.072	-0.113	-0.457	0.051
0.180	-0.100	-0.089	-0.093	-0.082	-0.123	-0.462	-0.020
0.180	-0.100	-0.088	-0.088	-0.078	-0.165	-0.411	-0.022
0.180	-0.101	-0.087	-0.072	-0.098	-0.120	-0.380	-0.079
0.180	-0.100	-0.087	-0.073	-0.092	-0.155	-0.312	0.027
0.180	-0.100	-0.084	-0.085	-0.096	-0.177	-0.300	0.010
0.180	-0.100	-0.088	-0.100	-0.066	-0.135	-0.408	-0.052
0.001	0.001	0.008	0.032	0.025	0.030	0.058	0.094
II measurement - July 16th, 2024							
Base 1	**Base 2**	**Base 3**	**Base 4**	**Base 5**	**Base 6**	**Base 7**	**Base 8**
0.171	-0.086	-0.059	-0.117	-0.052	-0.036	-0.115	-0.042
0.170	-0.086	-0.058	-0.131	-0.045	-0.037	-0.132	-0.050
0.169	-0.086	-0.059	-0.174	-0.047	-0.035	-0.082	-0.029
0.168	-0.085	-0.070	-0.210	-0.049	-0.035	-0.077	0.004
0.170	-0.085	-0.072	-0.217	-0.043	-0.048	-0.117	-0.007
0.170	-0.085	-0.071	-0.199	-0.042	-0.058	-0.176	-0.005
0.169	-0.084	-0.075	-0.169	-0.042	-0.057	-0.150	-0.032
0.169	-0.085	-0.075	-0.142	-0.043	-0.053	-0.151	0.018
0.168	-0.085	-0.076	-0.137	-0.037	-0.058	-0.135	0.034
0.169	-0.087	-0.071	-0.162	-0.036	-0.057	-0.040	0.112
0.169	-0.086	-0.077	-0.141	-0.039	-0.050	-0.021	-0.034
0.169	-0.085	-0.069	-0.164	-0.043	-0.048	-0.109	-0.003
0.001	0.001	0.007	0.034	0.005	0.010	0.048	0.046

The statistical analysis provided by formulas (2) and (1) led to the results given in Table 4.

Table 4. Differences analysis between two positions in two epochs

	Base 1	**Base 2**	**Base 3**	**Base 4**	**Base 5**	**Base 6**	**Base 7**	**Base 8**
Δ_i	-0.011	0.015	0.018	-0.064	0.022	0.087	0.300	0.049
m_{Δ_i}	0.0004	0.0004	0.003	0.014	0.008	0.010	0.023	0.032
t	27.105	39.752	5.710	4.544	2.887	9.109	13.103	1.549
H_0	No	No	No	No	No	No	No	Yes

According to the results given in Table 4, it is obvious that in all cases except one (for base 8) there is no reason for accepting hypothesis H_0.

CONCLUSION

The provided measurement for determining the measurement uncertainty for the horizontal clinometer showed that it is a very sensitive instrument and that its data could be treated as highly accurate. Furthermore, even though there is a significant difference between results obtained in the two positions of the horizontal clinometer those differences do not significantly affect the conclusions about the stability of bases regardless of their statistically significant significance. Obtained results by horizontal clinometer showed that changes in the horizontality of the bases could be determined by the accuracy of hundredths parts of millimetres. The results obtained by the vertical clinometer are identical in three positions and it suggests that its sensitivity was not on the level to register the small deviations from non-verticality.

ACKNOWLEDGEMENT

The authors express their gratitude to EPS JSC Belgrade, Branch DJerdap Kladovo because this research was provided under the regular activities.

LITERATURE

[1] Savić, LJ.,Savić, D.: Pregled metoda za ocenu sigurnosti brana, Jugoslovensko Društvo za Visoke Brane, Zbornik Radova, Kladovo, 2003.
[2] Maksimović, D., Savić Tomić, T., Pavić, M.: Uticaj inoviranog oskultacionog sistema na pouzdanost osmatranja, upravljanja I održavanja Glavnog objekta HE "Đerdap 1", Srpsko Društvo za Velike Brane –pp. 3-10, Prvi Kongres, Zbornik radova, Bajina Bašta, 2008.
[3] Perović, G.: Račun Izravnanja, Knjiga 1, Teorija Grešaka Merenja, Naučna knjiga, Građevinski fakultet, Beograd, 1989.
[4] Perović, G.: Metod Najmanjih Kvadrata, Naučna knjiga, Građevinski fakultet, Beograd, 2005.