STUDY ON APPLICATION OF MICROTRILATERATION GEODETIC NETWORK FOR MONITORING OF HYDROTECHNICAL CONSTRUCTIONS

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Abstract: *Among geodetic methods for monitoring of hydrotechnical constructions, the application of horizontal geodetic networks in the form of triangulation, trilateration, or a combination thereof, to determine horizontal displacements of a certain dam, is performed assuming that the direction along which the most significant position changes are expected is known. Therefore, the design of a horizontal geodetic network for dam monitoring favourable geometry will be taken into account, to highlight with high precision horizontal displacements of the control points in the direction of interest. In the case study, the design and distance measurements on the model within a microtrilateration geodetic network are presented in order to determine the dam's horizontal displacement vectors, exemplifying the adjustment computation using least squares method and evaluating the precision of the results, of which practical conclusions and recommendations of this method will be deduced.*

Keywords: microtrilateration, monitoring, dam, precision, model.

1. Introduction

Spatial geodetic networks, determined by GNSS technology, have the dominant role in geodetic network creation nowadays. However, classical geodetic networks, obtained by triangulation / trilateration, remain important for applications on limited areas, as in the case of monitoring some large engineering objectives. In the case of the monitoring of some hydrotechnical constructions over time, these networks are designed so that their geometrical configuration would allow the determination of the coordinates of control points which are located on the construction, with high accuracy on a previously established reference direction. For example, at a dam, this direction along which the most significant horizontal displacements are expected is the water flow direction, transverse to the dam's body. That is why, the error ellipses, which characterize the positioning area of the new points in the network, will need to have a specific configuration, so that the ellipse's small semi-axis should be oriented along this reference direction. In addition, the ellipse's allure will be highly flattened, so that the semi-axis ratio would be very large, with the advantage of obtaining a high accuracy on the required direction, simultaneously with relatively large errors on the additional direction, which is not relevant. If the design of a triangulation network is considered, the directions of intersection to the new points have to form angles as obtuse as possible, while for the trilateration networks these angles should be as sharp as possible. If the angular measurements are combined with the distance ones, resulting a triangulation / trilateration network, the ellipses’ configuration is not rigorously anticipated, this fact depending of the involvement of weights in the distinct measurement of angular and distance elements.

Practical implementation of a microtrilateration geodetic network may have certain advantages, both regarding the work procedure and the simplicity of calculation. This way, the calculation of the horizontal displacement vector of a dam, through several cycles of measurements, may be a viable alternative versus the classical approach through geodetic microtriangulation networks.

2. Materials and methods

To simulate the situation of a dam monitoring, a system in the form a wainscot plate was built, on whose vertical surface 15 control points were marked, which were placed on 3 rows with a 50 cm horizontal spacing and a 35 cm vertical spacing between them (Figure 1).

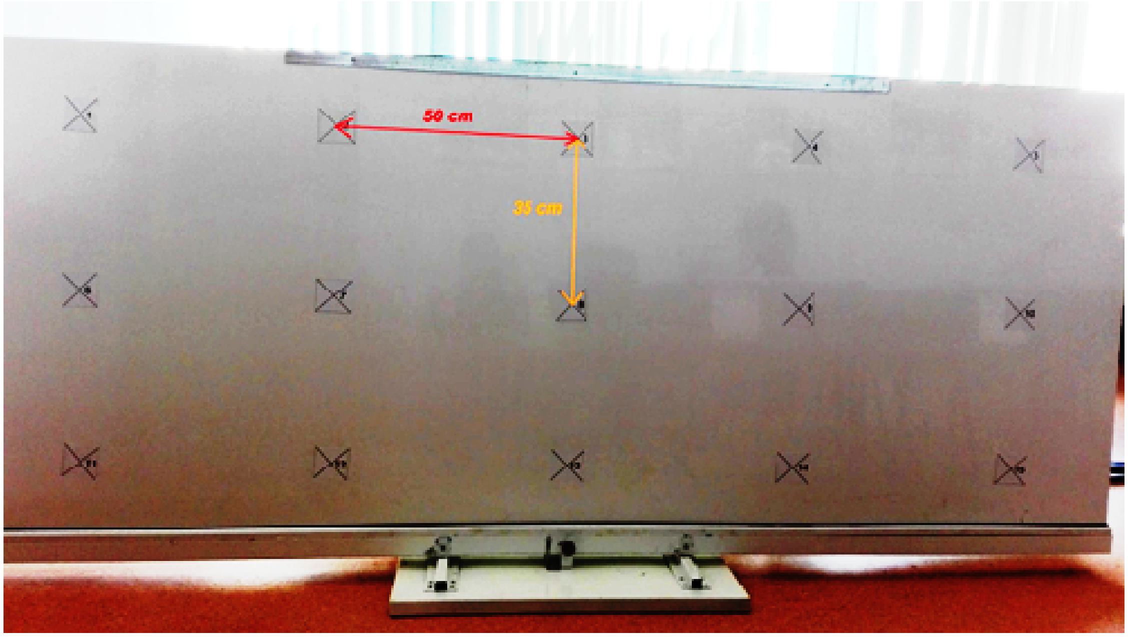


Figure 1- The spacing of the control points materialized on the wainscot plate

The microtrilateration geodetic network was projected with 4 station points (A, B, C and D), which were materialized on a wooden beam with a 70 cm horizontal spacing (Figure 2).

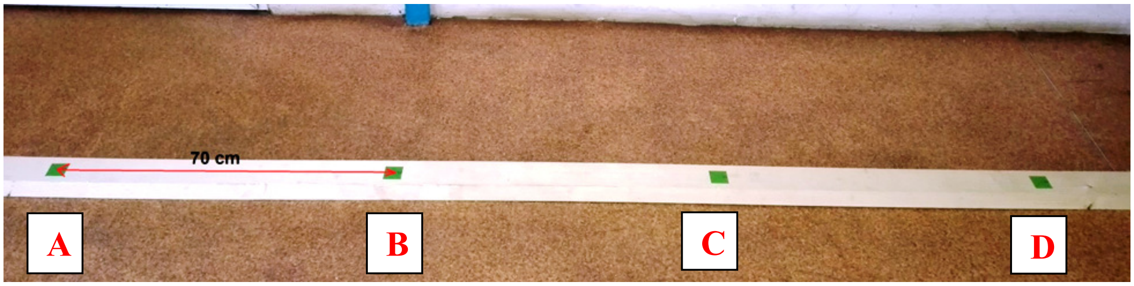


Figure 2- The spacing of the station points materialized on the wooden beam

Point A also represents the rectangular XOY system origin, from which have been performed supplementary horizontal direction measurements in every observation cycle towards the 15 control points, in order to obtain a preliminary coordinates set.

The OY axis connects station points (A, B, C, D), being pointed in the beginning of every cycle of measurements, on the AD direction. The OX axis is chosen to be perpendicular on the OY axis, being oriented on the perpendicular direction on the model plate surface (the direction of system displacement).

The layout of the microtrilateration network with control points, station points and the direction configuration is represented in Figure 3.

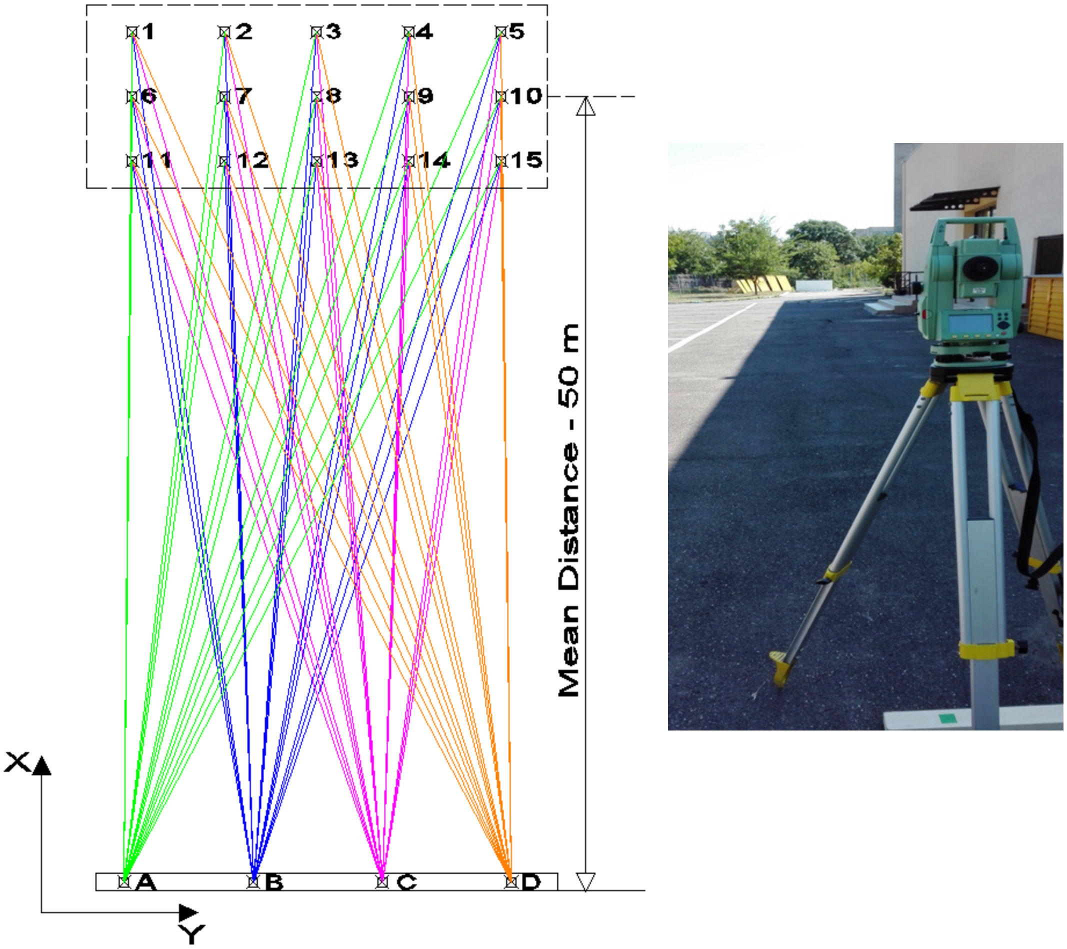


Figure 3- The layout of the microtrilateration geodetic network

The distance measurements were performed using the total station Leica TC(R) 405, in the reflectorless mode, for medium lengths of approximately 50 meters. According to the technical specifications, the distance measuring precision is 3mm + 2ppm.

Measurements were performed from the 4 station points, resulting 3 distances for every control point. By station processing, mean distance and mean square error, expressed in absolute and relative form have been obtained. The values interval for mean distance error was set between [0.1 – 0.6 mm], and in the relative expression, between [1:500 000 – 1:80 000].

The microtrilateration geodetic network was rigorously adjusted, applying the least squares principle, the indirect observation method, to every measurement cycle.

For preliminary elements computation, it was taken into account the assignment of arbitrary coordinates to station point A (1000, 1000), the other station points being translated on OY axis, by 70 cm each. The preliminary coordinates of the control points have been obtained by radial survey from station point A, knowing the values of the horizontal directions measured from that station point to station point D (located on the OY axis) and to all 15 new points (1, 2, ... , 15).

The functional model was weighted for every measured distance, according to the mean square errors determined in the station measurements processing stage.

3. **Results and discussions**

After calculation of the adjustment process of the microtrilateration geodetic network, the evaluation reports of result precision for all three measurement cycles could be elaborated, where the plate was moved on OX direction by 1 cm each time. For the initial cycle, the results obtained for the definitive coordinates of control points, the mean square errors on the axis coordinate direction and the elements of errors ellipses for the new points are further presented (Table 1).

Table 1 – Control points coordinates and elements of precision computation (cycle "0")

No. point	Adjusted coordinates		Mean square errors		Error ellipse elements		
	X (m)	Y (m)	s_x (m)	s_y (m)	A (m)	B (m)	Θ (g c cc)
1	1050.556	1000.342	0.0009	0.0423	0.0423	0.0007	99.1111
2	1050.487	1000.848	0.0007	0.0422	0.0422	0.0007	99.7444
3	1050.418	1001.281	0.0007	0.0422	0.0422	0.0007	100.2889
4	1050.348	1001.822	0.0011	0.0434	0.0434	0.0007	101.1000
5	1050.278	1002.356	0.0015	0.0604	0.0604	0.0009	101.3000
6	1050.527	1000.340	0.0010	0.0435	0.0435	0.0007	98.9778
7	1050.459	1000.890	0.0015	0.0810	0.0810	0.0009	99.0889
8	1050.390	1001.395	0.0009	0.0809	0.0809	0.0009	99.7333
9	1050.322	1001.805	0.0009	0.0808	0.0808	0.0009	100.2444
10	1050.252	1002.246	0.0014	0.0440	0.0440	0.0009	101.5111
11	1050.498	1000.178	0.0010	0.0960	0.0960	0.0009	99.6778
12	1050.429	1000.735	0.0009	0.0606	0.0606	0.0009	99.9556
13	1050.359	1001.309	0.0007	0.0421	0.0421	0.0007	100.3222
14	1050.292	1001.726	0.0026	0.0851	0.0851	0.0011	101.7444
15	1050.221	1002.292	0.0014	0.0440	0.0440	0.0009	101.5778

For the adjusted distances which were calculated in the first measurement cycle, their values are further presented, followed by corrections and mean square errors after adjustment computation (Table 2).

Table 2 – Adjusted distances, corrections and mean square errors (cycle ”0”)

Symbol	Distance D (m)	Correction v (m)	Error S_D (m)	Symbol	Distance D (m)	Correction v (m)	Error S_D (m)
A-1	50.558	0.0006	0.0011	C-1	50.568	-0.0014	0.0007
A-2	50.494	0.0012	0.0011	C-2	50.490	-0.0020	0.0007
A-3	50.434	0.0012	0.0011	C-3	50.418	-0.0020	0.0007
A-4	50.381	0.0006	0.0011	C-4	50.349	-0.0025	0.0008
A-5	50.333	0.0017	0.0018	C-5	50.287	-0.0014	0.0009
A-6	50.529	0.0005	0.0012	C-6	50.538	-0.0015	0.0008
A-7	50.467	0.0031	0.0027	C-7	50.462	-0.0012	0.0009
A-8	50.409	0.0031	0.0027	C-8	50.390	-0.0012	0.0009
A-9	50.354	0.0034	0.0027	C-9	50.324	-0.0014	0.0009
A-10	50.302	0.0003	0.0013	C-10	50.259	-0.0028	0.0009
A-11	50.498	0.0003	0.0012	C-11	50.513	-0.0003	0.0020
A-12	50.434	0.0002	0.0013	C-12	50.433	-0.0007	0.0012
A-13	50.376	0.0013	0.0011	C-13	50.359	-0.0017	0.0007
A-14	50.321	0.0002	0.0013	C-14	50.293	-0.0024	0.0021
A-15	50.273	0.0002	0.0013	C-15	50.229	-0.0032	0.0009
B-1	50.558	-0.0002	0.0007	D-1	50.587	0.0010	0.0011
B-2	50.487	-0.0008	0.0007	D-2	50.503	0.0016	0.0011
B-3	50.421	-0.0008	0.0007	D-3	50.425	0.0016	0.0011
B-4	50.360	-0.0008	0.0008	D-4	50.348	0.0005	0.0012
B-5	50.305	-0.0002	0.0012	D-5	50.278	0.0002	0.0013
B-6	50.529	-0.0003	0.0008	D-6	50.558	0.0010	0.0011
B-7	50.460	0.0006	0.0017	D-7	50.474	0.0008	0.0012
B-8	50.395	0.0006	0.0017	D-8	50.395	0.0008	0.0012
B-9	50.334	0.0011	0.0017	D-9	50.323	0.0009	0.0012
B-10	50.276	-0.0021	0.0009	D-10	50.252	0.0003	0.0013
B-11	50.501	-0.0004	0.0010	D-11	50.535	0.0035	0.0033
B-12	50.429	-0.0001	0.0009	D-12	50.447	0.0044	0.0018
B-13	50.363	-0.0011	0.0007	D-13	50.365	0.0015	0.0011
B-14	50.302	-0.0010	0.0013	D-14	50.293	0.0019	0.0032
B-15	50.246	-0.0009	0.0009	D-15	50.221	0.0003	0.0013

In all three cycles of measurements, the statistic data did not identify blunders in the distance measurement process. Also, it was confirmed the correct, a priori, selection of the standard deviation (s_0=1) before the adjustment, at the weighting estimation, in the generation of the functional model of adjustment.

The errors ellipses which resulted after the 15 control points adjustments from the measurements cycles are presented in Figure 4.

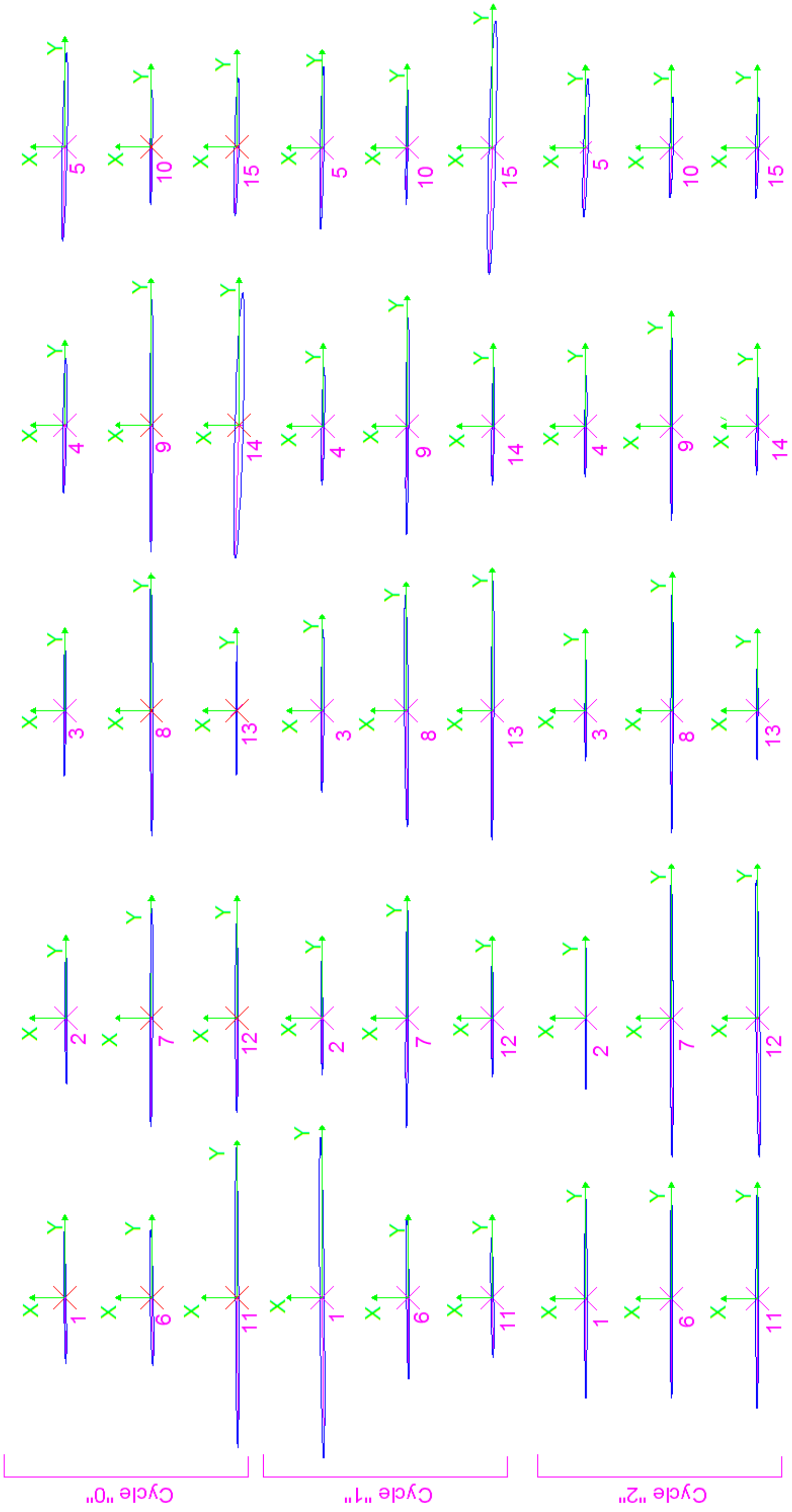


Figure 4 – Errors ellipses in the control points, for every measurement cycle

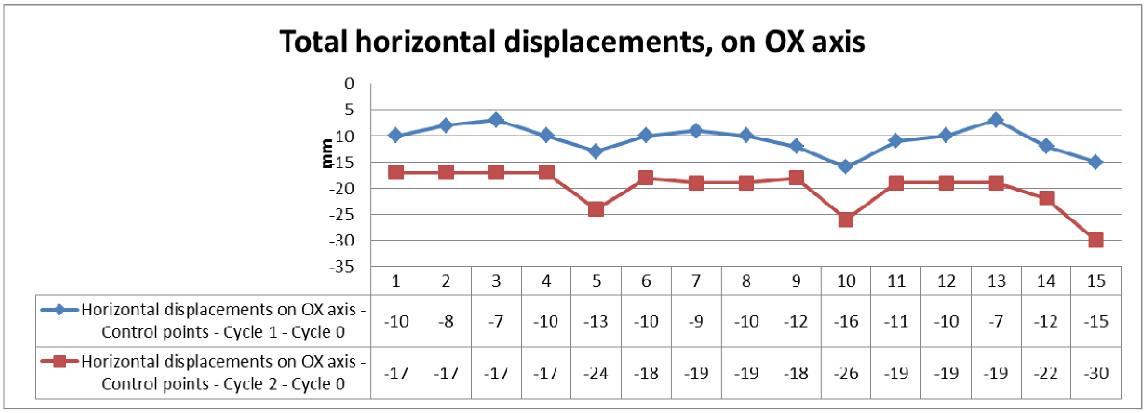
The horizontal displacements of the control points, on the OX direction, have been calculated as total differences between the coordinates corresponding to cycles 1, 2 and the initial cycle 0, and respectively, as partial differences, between the consecutive cycles 1 and 2.

This direction corresponds, in the real case of method application to dam monitoring, to the water flow direction and so, to the most probable displacements in the direction of the maximum pressure exerted on the surveyed construction (Table 3).

Table 3 – The horizontal displacement vectors of the control points, on the direction of axis OX

No. point	Total differences (m)		Partial differences (m)
	cycle 1 – cycle 0	cycle 2 – cycle 0	cycle 2 – cycle 1
1	-0.0100	-0.0170	-0.0070
2	-0.0080	-0.0170	-0.0090
3	-0.0070	-0.0170	-0.0100
4	-0.0100	-0.0170	-0.0070
5	-0.0130	-0.0240	-0.0110
6	-0.0100	-0.0180	-0.0080
7	-0.0090	-0.0190	-0.0100
8	-0.0100	-0.0190	-0.0090
9	-0.0120	-0.0180	-0.0060
10	-0.0160	-0.0260	-0.0100
11	-0.0110	-0.0190	-0.0080
12	-0.0100	-0.0190	-0.0090
13	-0.0070	-0.0190	-0.0120
14	-0.0120	-0.0220	-0.0100
15	-0.0150	-0.0300	-0.0150

Based on the data obtained in Table 3, the graphics of the horizontal displacement vectors, on the OX axis direction, for the total displacement hypothesis have been built (*Figure 5*).



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
◆ Horizontal displacements on OX axis - Control points - Cycle 1 - Cycle 0	-10	-8	-7	-10	-13	-10	-9	-10	-12	-16	-11	-10	-7	-12	-15
■ Horizontal displacements on OX axis - Control points - Cycle 2 - Cycle 0	-17	-17	-17	-17	-24	-18	-19	-19	-18	-26	-19	-19	-19	-22	-30

Figure 5- The graphic of the total horizontal displacement vectors, on OX axis, for the control points for all three cycles of observations

As can be noticed on the above graphic, the horizontal displacement vectors of control points 5, 10 and 15 have the highest values. This fact may be explained on the ground that these points are located in a marginal position, on the last grid column, area which moved less than the rest of the plate, indicating a light slewing motion, concomitant with a little deviated displacement from the measured direction (OX axis).

4. Conclusions

To highlight the controlled displacement by 1 cm at each measurement cycle, the arithmetic mean, standard deviation and mean square error for each series of values of the horizontal partial vectors have been computed.

From the statistical analysis of these data, a standard deviation with a value of 10.67 ± 0.67 mm, between cycle 1 and cycle 0, respectively, and of -9.4 ± 0.58 mm, between cycle 2 and cycle 1 has resulted, which demonstrates the fit of the accuracy of displacement determination to the simulated model at the millimetre level.

The simulated model application may be extended to larger distances as well, so as to highlight the errors obtained for different limits of the observed distances. Also, the increase in the quality of the used device, by its calibration under rigorous conditions, may improve the possibilities of analysis of the results obtained in geodetic network measurements.

5. References

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