DISPLACEMENTS DETERMINATION USING SCANNING WITH TOTAL STATION AND REFLECTORLESS METHOD

Adrian Marius TRIFAN, Eng. PhD Student,Total Survey, adrian.trifan@totalsurvey.eu

***Abstract**: The proposed monitoring method completely eliminates the materialization of the object points, measurements are carried out in reflectorless mode with automatic pointing. Practical verification of the reflectorless method was performed through a case study where the studied subject was chosen so as to mimic the complex behavior of the dams displacement. Calculations were performed using "Detect" computing program. The program has implemented a new statistical approach for determining significant plane or vertical displacements and allows exporting the results in standardized formats.*

***Keywords:** displacement analysis, reflectorless method, elimination of object points, Detect calculation software, displacement analysis using scanning*

1. Introduction

Classical geodetic methods require installation of reflective targets or monitoring prisms on the body of studied object, their integration into a geodetic network and comparing determined coordinates at different time epochs. Measurements made at different time epochs are compared to determine if significant displacements occurred. The most used comparing statistical method is global congruence test which was developed by Pelzer in the '70s. - [1] .

Displacements occurred between two epoch measurements are expressed as $d = X_2 - X_1$, where X_1 and X_2 represent coordinates vector determined in each epoch of measurements. Assuming that the vectors X_1 and X_2 are uncorrelated and have Q_{xx1} and Q_{xx2} associated variance covariance matrices , then the variance covariance matrix of displacements becomes $Q_{dd} = Q_{xx1} + Q_{xx2}$. Weighted standard deviation of the vector displacement becomes :

$$\sigma_0 = \pm\sqrt{\frac{(V^T PV)_1 + (V^T PV)_2}{f}} \tag{1}$$

Where f represent the total number of freedom degrees for the two epochs of measures and is calculated as $f = f_1 + f_2$. The F value is calculated to be compared with the extracted Fisher distribution table threshold value . – [2]

$$F = \frac{dQ_{dd}^{-1}d^T}{\sigma_0 f} \tag{2}$$

If the F value is larger than the threshold value then the two networks are not congruent, so the displacements can be considerated significant. If the F value is smaller than the threshold value then the two networks are congruent so the displacements can be considered insignificant. If the networks are not congruent, other statistical tests are apply to locate displaced points. – [1]

Classical methods for determining displacements and deformations are rigorous, but has some disadvantages: the whole monitoring results are provided with delay, only after all measurements are done for all points included in monitoring geodetic network, algorithms for detecting and locating displacements became considerably complicated when the configuration of points included in geodetic network is changed, also there are situations when we can not actually installed a large number of object points because the visual appearance of the studied object would suffer. – [3]

Reflectorless method, proposed for monitoring building displacements in time, represent a quick method for providing informations because measurements can be performed automatic or semi-automatic, eliminating completely the need of aiming to object points. The method is suitable for a total automation of the whole process: measurements, data processing and informations can be provided completely automatic without the operator intervention. This method represents a precise method of monitoring, throughout the use of adequate equipments can be provided dimensions of displacements with errors of ± 3..4 mm. The necessary costs for implementing a monitoring system that works with reflectorless method is up to 50% less than in classic monitoring systems.

2. The method principle –[4]

In case of monitoring using reflectorless method, the object points are not embodied on the studied object. This aspect offers many advantages but there is one major disadvantage, because displacements can be determined just on a specific direction called reference direction. In “0” epoch, from the station point A, are measured the following elements: slope distance L_{A1}, azimuthal direction/orentation Θ_{A1} and zenith direction ζ_{A1} . Using all these elements the X_1, Y_1 Z_1 coordinates are calculated for the object point 1.

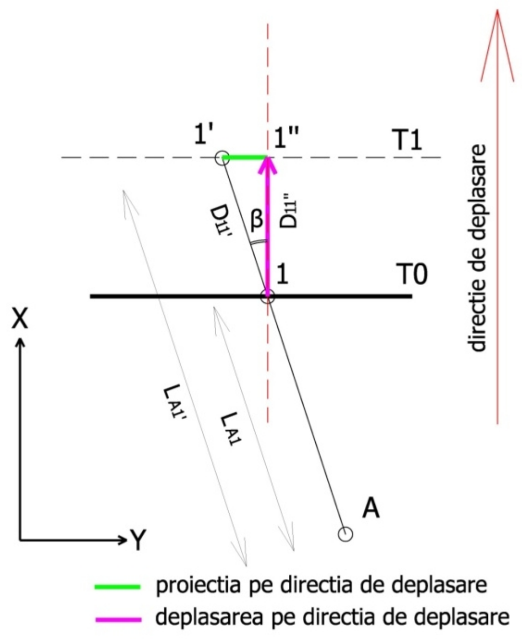


Fig.no.1 The principle of reflectorless method

In “1” epoch, measurements will be performed toward theoretical point 1 measured in epoch "0". Based on the known coordinates of the station point as well as the object point, the necessary angles elements required for angular positioning are automatically calculated by servo motorized total station. Using angular elements the motorized total station is "moving" toward point 1 measured in epoch "0". Calculations of horizontal and vertical orentation angle are performed automatically by the equipment. After positioning of the total station on the theoretical direction of point 1, it is performed measurement of $L_{A1'}$ distance. The slope distance is used to calculate $X_{1'}$, $Y_{1'}$, $Z_{1'}$ coordinates. Variation of plane distance $D_{11'}$ it is calculated based on planimetric coordinates of points 1 and 1’ or as the difference between the measured horizontal distances.

$$D_{11'} = \sqrt{(X_{1'} - X_1)^2 + (Y_{1'} - Y_1)^2} = D_{1'} - D_1 \qquad (3)$$

Distance variation $D_{11'}$ it is calculated along the sight axis defined by the station point and point 1, measured in epoch “0”. If the movement direction is knowned than it can be calculated $D_{11''}$ displacement, along the movement direction through the β angle calculated as the difference between orientation of the movement direction and orientation of measured object point.

$$\begin{aligned} \beta &= \theta_{direction} - \theta_{A1} \\ D_{11''} &= D_{11'} \cos\beta \end{aligned} \tag{4}$$

If the studied object has a displacement along the sight axis, on the X direction of the coordonate system axis (figure 1), than $D_{11''}$ displacement is determinable. If the movement occurs on a perpendicular direction to the direction of sight, in the Y direction of the coordinate system axis (figure 1), than the displacement is indeterminable. This aspect is the only disadvantage of reflectorless method.The method can be used only in situations when expected displacements fit on a movement direction aprioric known.

Reflectorless method can be used successfully also to monitor vertical displacements. In some cases vertical deformation calculation can be simplified by comparing point heights measured in different epochs.

$$d_{vertical} = Z_i^{T1} - Z_i^{T0} \tag{5}$$

If a rotation occurs between two successive measurement stages of the studied object, measurements made from different stations can induce errors in determining the movement. In case when reflectorless measurements are made from a single station, the error due to the studied object rotation can be eliminated, if two points measured successively are taken into account, basically if it is applied a discretization correction. Deformation calculations through out two successive measured points takes into account the degree of discretization of the measured object and can be applied only if between two successive measured object points do not occur deformations.

3. Statistical analysis of the monitored parameters

Depending on the chosen measurement method, using reflectorless method it is posible to determine one of the following values:

• changes of plane or spatial distance
• planimetric displacement on a particular reference direction or the vertical displacement
• planimetric and vertical displacements corrected with discretization correction

Although the calculations required to determine the monitored parameters and their statistical tests are much simpler than in the case of classical methods, they are still laborious and not suitable for manual calculation. For this reason, I developed in collaboration with a specialized software company a new computer program ("DETECT") that allows calculation of distance changes and plane or vertical displacements determined using reflectorless method.

DETECT calculation program has implemented a new statistical approach for analysis of monitored parameters. Testing are performed considering that the measurements are sizes directly measured by applying the Student test for comparison of averages of two populations, case with small samples and equal standard deviations . – [5]

Testing is based on the calculation of t_c value calculated based on variation of monitored parameter $\Delta_{parametru}$, weighted standard deviation σ of monitored parameters, and the number of measurements m^{t0} performed at reference epoch and m^{tn} number of measurements made at the current epoch.

$$t_c = \frac{|\Delta_{parametru}|}{\sigma\sqrt{\frac{1}{m^{t_0}} + \frac{1}{m^{t_n}}}} \tag{6}$$

From Student distribution tables the threshold value t_{prag} are extracted for desired risk coefficient. In practice we will work with a risk factor of 0.05 which corresponds to a probability of 95% or 0.01 which corresponds to a probability of 99%. Decision on statistical hypothesis requires a comparison of statistics t_c with t_{prag} threshold value extracted from Student distribution table for the probability of 95% or 99% and $f^{t0} + F^{tn}$ degrees of freedom: - [3]

Probability of 95%:

• If the t_c is smaller than or equal to the value extracted from Student distribution tables, than the H_0 hypothesis is true with a probability of 95%, so variation of monitored parameter $\Delta_{parametru}$ is insignificant.

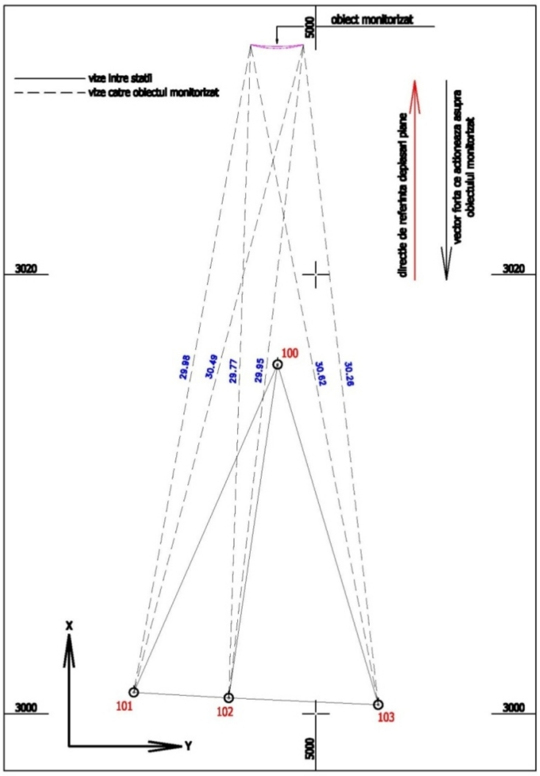
• If the t_c is higher than the the value extracted from Student distribution tables, the H_1 hypothesis is true with a probability of 95%, so variation of monitored parameter $\Delta_{parametru}$ is significant.

Probability of 99%:

• If the t_c is smaller than or equal to the value extracted from Student distribution tables, than the H_0 hypothesis is true with a probability of 99%, so variation of monitored parameter $\Delta_{parametru}$ is insignificant.

• If the t_c is higher than the the value extracted from Student distribution tables, the H_1 hypothesis is true with a probability of 99%, so variation of monitored parameter $\Delta_{parametru}$ is significant.

4. Case study



For practical verification of the determining method and to check Detect calculation software a case study was conducted where it was tested the following method: determination of plane displacements corrected with discretization correction, measured from a single station with preserving total station position and height between successive measurements epochs.

The micro-geodetic network used for making measurements consisted of four points station: 100, 101, 102, and 103 disposed as shown in figure 2.

Fig.1 Micro-geodetic monitoring network

Measurements were made from 102 and 103 stations 102 and 103, the point station number 100 was used to check orientations. From station 101 measurements were performed to verify the other work hypotheses.

Measurements were made using two total stations: motorized Trimble S8 DRPlus total station that ensures 2" angular accuracy and 2mm + 2ppm distance precision in reflectorless mode and Sokkia SET 2030R3 total station thar ensures 2" angular precision and 3mm + 2ppm distance precision in reflectorless mode.

With Trimble S8 total station measurements were performed from station 103 and with Sokkia SET2030R3 total station measurements were performed from station 102.

The coordinate system was chosen so that the direction of OX axis of the coordinate system coincides with the reference direction of displacements.

4.1 Studied object

To test whether reflectorless method gives optimal results when complex strain occurred, the studied object was chosen to mimic the behavior of dams. This was installed a as in figure 3.

By using a mechanical jack negative displacement has induced so that in reference epoch, the studied object have a curve shape. Between successive measurements, the studied object movements were increased, and reflectorless measurement was performed after each induced shift.

Fig.3 The studied object - longitudinal view

Fig.4 The studied object - transversal view

There where marked a total of 36 points on wood board arranged in 4 rows with 30 cm horizontal spacing and 25cm vertical spacing. Each row was composed of nine points as can be seen in figure 4. The points were placed on the vertical and horizontal lines of the object with midline formed of 1004, 1013, 1022, and 1031 points.

4.2 Measurements

To compare displacements determined by clasical method with displacements determined by reflectorless method, the measurements made with Sokkia SET2030R3 total station was done in all epochs with manually pointing of object points 1000 to 1035 marked on the wooden board. Measurements were performed reflectorless with distance measured in one position and coordinates of object points were calculated with TerraModel 10.41 software. Trimble S8 total station allaw to record measurements by scanning. This feature completely automates the entire process of measuring points included in the defined measurement grid without operator intervention. The main advantage of this method is given by the speed of recording the measurement, time required for overall angular position of the total station, measurement point and recording is not more than 2,3 seconds. This method can significantly increase the number of points measured and analyzed, and implicitly we have more information on the displacements of the studied object.

In order to performe scanned measurements the scan area was defined : quadrilateral method specifying two points on one edge in this case points 1000 and 1008 and one point on the opposite edge, point number 1035. After defining the scan area, the horizontal and vertical spacing was specified, respectively 10cm. Trimble S8 total station automatically calculated the total number of points included in the scanning grid points (225 points) arranged by 9 rows with 25 points on each row. Since the scanned area was 2.4m wide by 0.75m high, the finally row was scanned with 5 cm vertically spaceing, so in total there were eight vertical rows spaced 10 cm and one row spaced at 5 cm. In each epoch the points were measured by scanning and they were recorded with 10000-10224 numbers. Figure 5 present the scanned grid points area. It is noted that the last row is spaced 5 cm because the defined scan area has a height of 75cm. The green line represent the direction of scanning (scanning on rows).

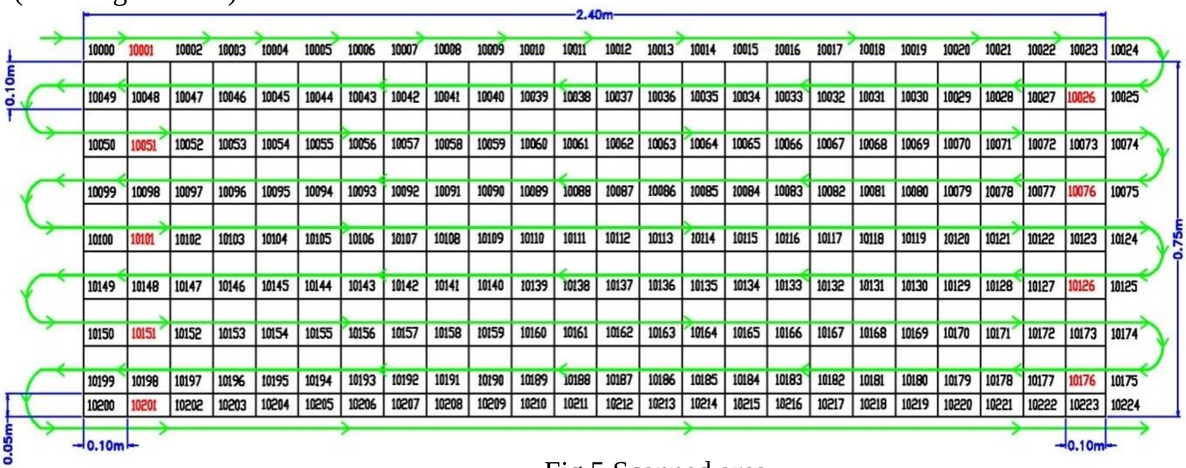


Fig.5 Scanned area

Analysis method of corrected plane displacements (with discretization correction) measured from one station assumes determination of displacements by analysis of successive pairs of measured points – [3] . Since scanned rows has an odd number of points the pairs were formed: 10000-10001, 10002-10003, 1022-1023, 1024-1025. It is observed from figure number 5 that points 1024 and 1025 were not located on the same row, therefore points marked red in the above figure have been removed, so were analyzed in total 216 object points.

4.3 Plane corrected displacements determination using scanning

Plane corrected displacements with discretization and statistical analysis calculations was performed using Detect software with statistical probability of 95%. Detect calculation program can be accessed on the website at www.tsdetect.ro adress . – [3]

In epoch number 2 were analyzed in total 216 points of which 91 points may be statistically considered displaced and 125 points stable, with the maximum recorded displacement of -0.010m at point 10162. Figure 6 presents a capture from Detect software with analysis report summary for T1-T2 epochs.

SUMAR RAPORT ANALIZA

Parametru Monitorizat	Deplasare cu corectie de discretizare 2D
Mod Masuratoare	Masuratori dintr-o singura statie, aceiasi pozitie si inaltime a aparatului

	Informatii	**Temperatura**	**Data**	**Stadiul fizic al lucrarii**	**Total puncte masurate**
Transa referinta	T1	12.0	23-11-2013	Constructie Finalizata	216
Echipament utilizat	Trimble S8		**Precizie distante**		2 mm + 2 pmm
Transa curenta	T2	11.8	23-11-2013	Constructie Finalizata	216
Echipament utilizat	Trimble S8		**Precizie distante**		2 mm + 2 pmm

	Nr. total de puncte analizate	**Din care stabile**	**Din care deplasate**	**Deplasare maxima**	**In punctul**
Analiza	216	125	91	-0,0100	10162
	Puncte deplasate	10009 10010 10011 10012 10013 10014 10015 10016 10034 10035 10036 10037 10038 10039 10040 10041 10059 10060 10061 10062 10063 10064 10065 10066 10067 10083 10084 10085 10086 10087 10088 10089 10090 10091 10092 10107 10108 10109 10110 10111 10112 10113 10114 10115 10116 10132 10133 10134 10135 10136 10137 10138 10139 10140 10141 10157 10158 10159 10160 10161 10162 10163 10164 10165 10166 10167 10168 10180 10182 10183 10184 10185 10186 10187 10188 10189 10190 10191 10192 10207 10208 10209 10210 10211 10212 10213 10214 10215 10216 10217 10218			

Fig.6 Detect software, analysis report summary for T1-T2 epochs

In epoch number 3 were analyzed in total 216 points of which 166 points may be statistically considered displaced and 50 points stable, with the maximum recorded displacement of -0.029m at point 10211. In epoch number 4 were analyzed in total 216 points of which 193points may be statistically considered displaced and 23 points stable, with the maximum recorded displacement of -0.069m at point 10213. In figure 7 is presented the chart of plane displacements corrected with discretization correction determined by Detect calculation software in epoch 4.

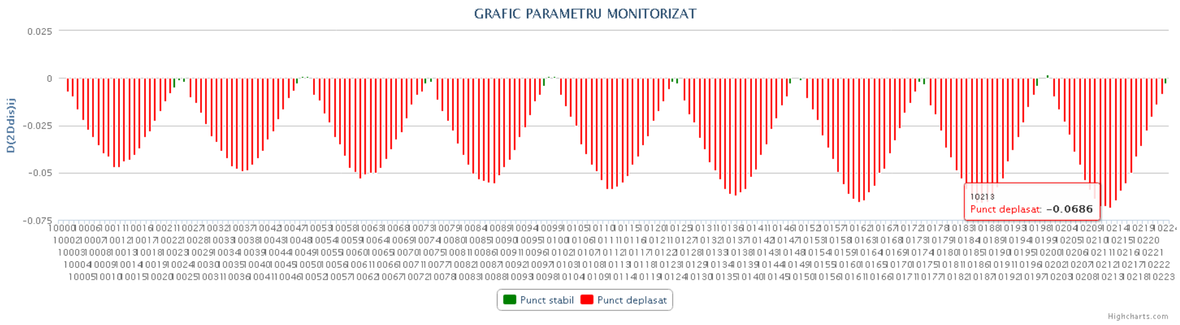


Fig. 7 Chart of plane displacements corrected with discretization correction determined by Detect calculation software in epoch 4

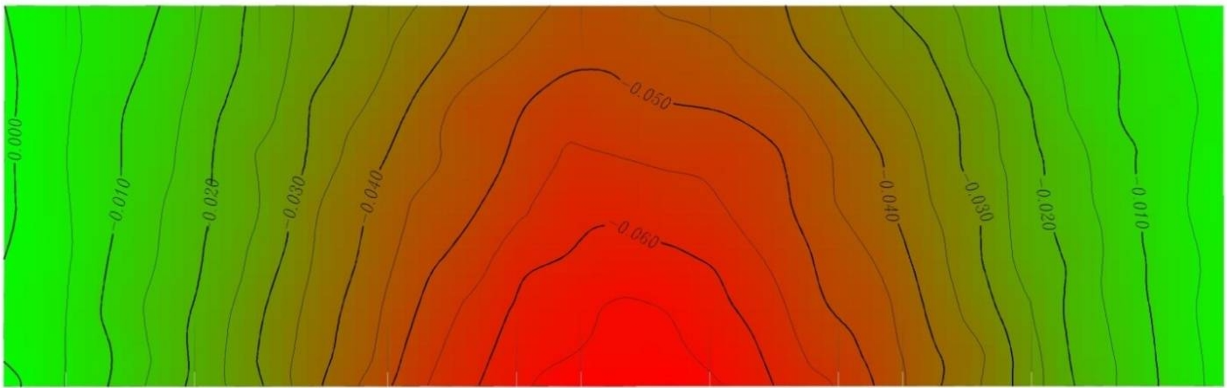


Fig.8 Isolines and displacement areas determined by scanning in epoch number 4

4.4 Verification of plane displacemnts determined values

In this case verification of results compared to classic method is difficult because the measured points were different (number and position) in the two measurement methods. A simple check could be carried out by comparison of the maximum displacement determined by two methods: classical and reflectorless scanning. In table 1 are summarized plane maximum displacement values detected by the two methods and the differences between results. –[3]

Table 1.Comparation between maximum displacement values

	MAXIMUM DISPLACEMENT VALUES (m)			**TOTAL STATION**
	T1-T2	**T1-T3**	**T1-T4**	
Classic	-0.008	-0.026	-0.065	Sokkia SET2030R3
Scanning - Reflectorless method	-0.010	-0.029	-0.069	Trimble S8
Differences	**0.002**	**0.003**	**0.004**	

The values of the differences fit accuracy values of distances specific to both equipments, respectively ±2..3 mm. Another test was performed by comparing plane displacements measured with the two methods in epoch 4 in common points. Three of the rows scanned has common points measured with both methods. Analyzing the differences in the 27 common points: points 1000-1008, 1018-1026 and 1027-1035 measured in epoch 4, resulted in a mean difference Δ_{dif} of 3mm which also falls within the accuracy of distances specific to both total stations.

$$\Delta dif = \frac{D_i^{clasic} - D_i^{reflectorless-scanare}}{27} = 3mm \tag{7}$$

5. Conclusion

The case study was conducted to test the calculation algorithms implemented in Detect software to determine displacements calculated with reflectorless method . This new method provided comparable results in comparation with classical method . Differences between determined values fall in accuracy of distances of total stations used to performe te test . Algorithms for locating displacements provided the expected results, statistical testing method implemented in DETECT software provide accurate and fast results. Object of the case study suffered during the four epochs of measurements complex movements but through determination and localization algorithms, plane displacements were provided, which recommend future practical use of this method on real models. The only disadvantage of this method for monitoring with automatic pointing is the fact that plane displacements are determined only on apriori known direction . Reflectorless method can also be used in conjunction with the classic method .

6. References

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