TOPO-GEODETIC TOOLS OPTIMISATION FOR EFFICIENTELY BEHAVIOUR MONITORING IN SERVICE STAGE OF CIVIL ENGINEERING STRUCTURES

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Abstract

Monitoring the behavior in service stage of civil engineering structures is absolutely necessary for ensuring stability and safety through their exploitation. Achievement of an efficient monitoring process of structures is done by using modern topo-geodetic methods and techniques which guarantees the correctness of the data with the highest accuracy of the obtained results. The progress of the equipment area for determining geometric elements, means of calculation and reporting data influences the upgrade of methods and procedures in topographic measurements. The purpose of this paper is to implement the theory of decision using qualitative and quantitative criteria in a cycle of observations in monitoring the behavior in time of a viaduct engineering structure using three different topographical devices. We proposed a comparative analysis using three topo-geodetic technologies for monitoring vertical spatial displacements. The accuracy with which the monitoring marks are determined on the viaduct is extremely important for obtaining an optimal monitoring system over time. The objective described in this paper is in the North- West part of Galati city, which is a structure over 50 years old with a length of 1.3 kilometers. The viaduct is an important access road DJ 252 (Galaţi-Matca-Tecuci) that links the city of Galati to the platform of Arcelor Mittal steel plant, requiring permanent monitoring due to the age and the continuous dynamic actions it was subjected to during the exploitation and which can transmit to the foundation ground important settlings that cause irrecoverable structural degradation.

Key words: optimization tools, spatial displacements, civil engineering structures, satellite technology, total station, classic level

Determining vertical spatial displacements is particularly important for a viaduct engineering structure to avoid the loss of human lives and material. In this part of the paper we will build a monitoring in time algorithm based on qualitative and quantitative criteria and the decision will be made according to the accuracy with which we will achieve results on the objective movements, the optimal tool that will provide us with low costs and a reduced time according to *figure 1* (Decision theory course) (Mândru L., Begu L.S., 2009).

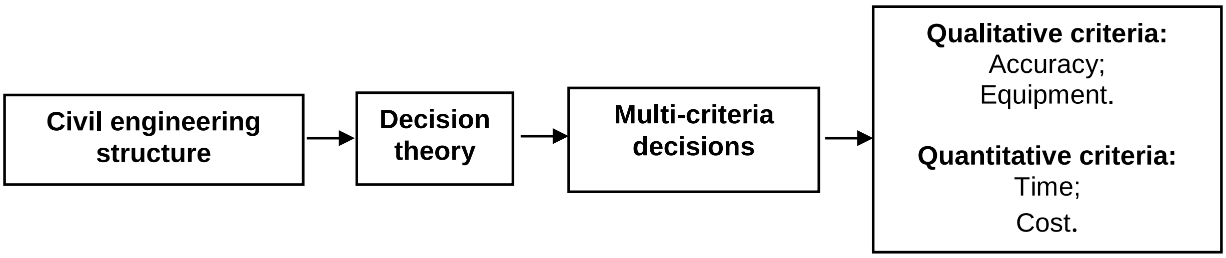

Figure 1 **The decision theory in monitoring civil engineering structure**

Monitoring the behavior in time of an engineering structure by topographical methods involves analyzing the initial data related to the objective and then making the decision regarding the quality of the monitoring task, automatically involving and determining the accuracy value with which we will perform the readings and topographic tools used. Also, quantitative criteria will be taken into account as time and cost because they are directly proportional to the qualitative criteria (Decision theory course) (Mândru L., Begu L.S., 2009).

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MATERIAL AND METHOD

The studied objective (*figure 2*) has been materialized over its entire length of 40 monitoring marks (R1, R2, ..., R40) for monitoring the compaction at distances of about 150 meters at the ends of the joints (Morariu *et al*, 2018). Also, a control point network consisting of 7 points (P1, P2, ..., P7) was made for a better control in the processing of the observations and the error compensation (Morariu *et al*, 2018, Lepadatu *et al*, 2017, Morariu *et al*, 2017).

Figure 2 **Monitored objective - Viaduct - Galați City, Romania**

In the first phase, measurements were made using the traverse method supported at the both ends by known coordinate points with Leica TCR 407 modern digital station (ST) starting from point P2 and closing on P7, the X, Y and Z readings were determined of the settling`s marks.

The second observation cycle was conducted using satellite technology using GPS Stonex S8 (GPS) (*figure 3a*) using all real-time satellite constellations to measure each monitored mark on the viaduct across its entire length. The final step for obtaining the vertical spatial displacements of the engineering structure consisted in the use of the classical method with the high precision geometric level done with Ni002 (NC) classical level (*figure 3 b, c*).

The procedure was carried out as follows: stationing with the classic level started from the control point P2 reading the visible markings, the next level stations being in the middle of the joints to be able to determine all the monitoring marks. In total, there were 10 stations with forward and backward aimings in order to be able to get the closure of a traverse, it`s value should be 0.

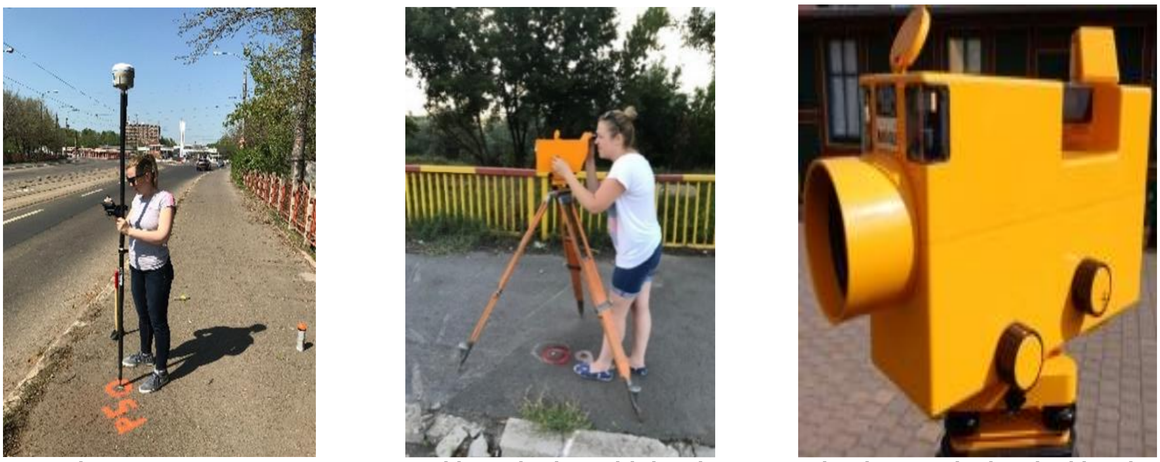

Figure 3 **a)GPS Stonex S8 measurements b) Stationing with level on control point P6 c) Classical level Carl Zeiss Ni 002**

The proceeding of high precision levelling was processed using a calculation program by manually adjusting the observations in Excel, where the formulas were introduced and the settlings values were obtained. The results acquired with the total station were downloaded using the Leica Geo Office Tools program, the compensation and processing of determinations being automatically made in the machine's memory. Also, real-time satellite technology readings were discharged and compared to the original data of the studied object.

RESULTS AND DISCUSSIONS

After discharging and processing the data on the three directions X, Y and Z of monitoring marks over the length of the viaduct were compared with the initial data. The results for the vertical spatial displacements on Z obtained will be presented according to each instrument used to determine the objective`s movements in *table 1*.

Table 1

Analysis of vertical spatial displacements values

No. mark	Initial data		ST	(GPS)	NC	ΔZ_ST	ΔZ_GPS	ΔZ_NC
R1	Z	45.00	44.98	44.91	45.02	-0,02	-0,09	0,02
R2	Z	45.25	45.33	45.19	44.72	0,08	-0,06	-0,53
R3	Z	45.28	45.32	45.22	45.22	0,04	-0,06	-0,06
R4	Z	45.92	45.89	45.28	45.23	-0,03	-0,64	-0,69
R5	Z	45.89	45.87	45.86	45.11	-0,02	-0,03	-0,78
R6	Z	47.07	47.00	46.96	45.10	-0,07	-0,11	-1,97
R7	Z	47.06	46.99	46.95	45.66	-0,07	-0,11	-1,4
R8	Z	48.27	48.17	48.13	45.66	-0,1	-0,14	-2,61
R9	Z	48.29	48.20	48.17	45.67	-0,09	-0,12	-2,62
R10	Z	49.48	49.41	49.37	45.68	-0,07	-0,11	-3,8
R11	Z	49.50	49.43	49.38	46.70	-0,07	-0,12	-2,8
R12	Z	50.56	50.53	50.49	46.71	-0,03	-0,07	-3,85
R13	Z	50.60	50.58	50.49	46.80	-0,02	-0,11	-3,8
R14	Z	51.79	51.76	51.69	46.79	-0,03	-0,1	-5
R15	Z	51.83	51.79	51.71	46.76	-0,04	-0,12	-5,07
R16	Z	53.00	52.96	52.86	46.81	-0,04	-0,14	-6,19
R17	Z	53.02	52.98	52.91	46.81	-0,04	-0,11	-6,21
R18	Z	54.35	54.31	54.22	46.86	-0,04	-0,13	-7,49
R19	Z	54.36	54.33	54.24	46.87	-0,03	-0,12	-7,49
R20	Z	54.19	54.16	54.09	48.01	-0,03	-0,1	-6,18
R21	Z	54.25	54.22	54.11	49.16	-0,03	-0,14	-5,09
R22	Z	54.36	54.33	54.27	49.14	-0,03	-0,09	-5,22
R23	Z	54.35	54.31	54.24	49.21	-0,04	-0,11	-5,14
R24	Z	52.96	52.95	52.84	49.21	-0,01	-0,12	-3,75
R25	Z	52.94	52.93	52.83	49.19	-0,01	-0,11	-3,75
R26	Z	51.71	51.68	51.58	50.25	-0,03	-0,13	-1,46
R27	Z	51.72	51.70	51.60	50.28	-0,02	-0,12	-1,44
R28	Z	50.54	50.48	50.42	50.32	-0,06	-0,12	-0,22
R29	Z	50.48	50.46	50.38	50.35	-0,02	-0,1	-0,13
R30	Z	49.38	49.35	49.27	50.32	-0,03	-0,11	0,94
R31	Z	49.44	49.38	49.30	51.47	-0,06	-0,14	2,03
R32	Z	48.22	48.18	48.07	51.46	-0,04	-0,15	3,24
R33	Z	48.21	48.16	48.09	51.53	-0,05	-0,12	3,32
R34	Z	46.99	46.92	46.89	51.57	-0,07	-0,1	4,58
R35	Z	46.96	46.90	46.87	51.52	-0,06	-0,09	4,56
R36	Z	45.92	45.88	45.83	52.71	-0,04	-0,09	6,79
R37	Z	45.90	45.86	45.84	52.72	-0,04	-0,06	6,82
R38	Z	45.46	45.44	45.39	52.74	-0,02	-0,07	7,28
R39	Z	45.44	45.42	45.40	52.90	-0,02	-0,04	7,46
R40	Z	45.01	45.00	44.93	52.92	-0,01	-0,08	7,91

After obtaining the results of the three types of topographic instruments (total station, GPS-satellite technique, classical level) along a measurement cycle, the following were found:

- the values of the vertical spatial displacements determined with the total station and the GPS are similar to the original data, but the results with the classical level are clearly different from the initial heights;
- the difference between the readings with modern digital equipment and those with the classic level are due to manual data recording by

the operator, also it may be due to the vibrations generated by the stretched traffic resulting in decalibration of the equipment causing systematic errors;

- vertical moves of the objective are observed between all the structure`s marks, dismissive of the instrument used; vertical spatial displacements range from 0.01 meters to 0.10 meters, especially for the marks: R2, R6, R8, R9, R11, R13, R15, R28, R31, R34;

- compactions on the civil engineering structure are normal due to its age and of the marshy soil producing the instability of the objective, but also the intense traffic on the viaduct due to the vibrations and the weight of the cars;

- the measurements and results obtained with the modern digital total station are optimal due to the time, cost and precision as against satellite technology where the time is low, the instruments requires only one operator, but the Z errors can be very high due to the dependence on the geometry of the satellites and the visibility towards them.

Vertical spatial displacements between the initial data and the topographic devices used to determine each mark on the viaduct will be presented in *figures 4, 5, 6*.

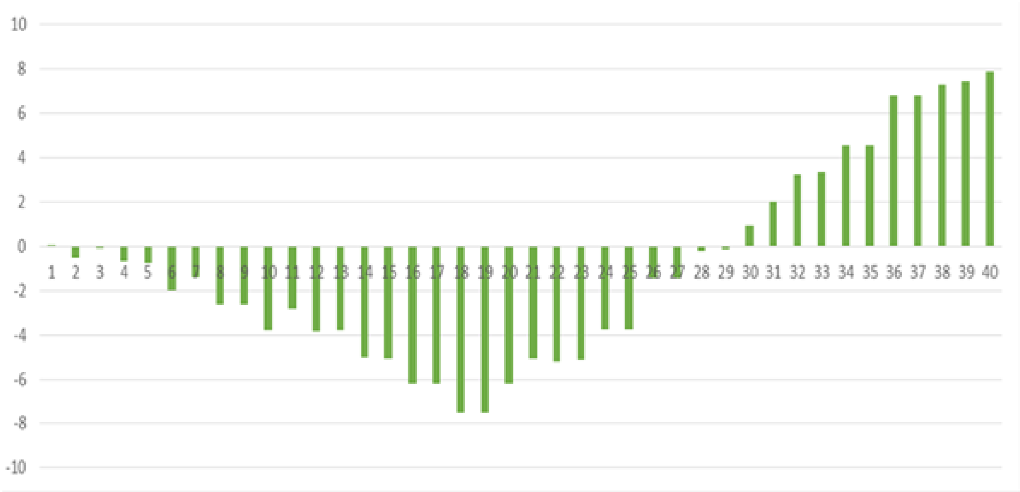

Figure 4 **Vertical spatial displacements – classic level**

It can be observed that the readings performed with the classic level (*figure 4*) have very large differences from the initial data. The values of the marks R1 – R29 are between 0.02 – 8 meters causing big differences towards first observations. This is due to the classic way of working: reading on the invar levelling staff and writing the values manually on the field notebook, vibrations that can move the device during measurements producing systemic errors and processing the settlings values made at the office by applying formulas in a calculation program is useless due to field readings. It is recommended to perform another observation cycle with a classical level to solve the problem of errors produced by the operator's data acquisition method.

Figure 5 **Vertical spatial displacements – GPS**

In the case of GPS or satellite technique (*figure 5*), the cumulative values are close to the original viaduct`s data, but the instrument may present errors on direction Z due to satellites. The value of mark R4 of – 0.64 meters can be due to a mistake during the measurements, also values of monitored points R15-R19, R25-R28, R31, R32 are normal due to structures`s age. Working time and costs are low, the precision is good for determining vertical spatial displacements. An alternative to avoiding errors by GPS is by installing a rover base on a control point and stationing at least one hour while making readings for each monitored mark using real-time readings by satellite technique through GPS devices.

In the case of total station (*figure 6*), displacements appear for all the structure`s marks R1-R40. Values of the vertical spatial displacements are between – 0.07 and 0.08 meters.

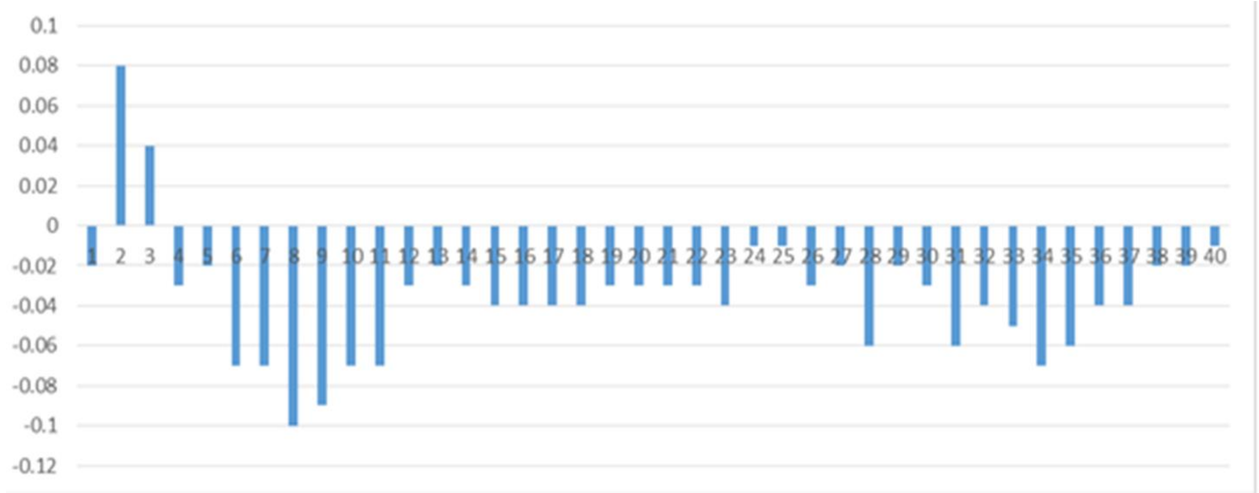

Figure 6 **Vertical spatial displacements – Total station**

Finally, we can state that the modern digital total station is the optimal device for monitoring the viaduct in service stage due to the values of the vertical spatial displacements, the determination with high accuracy, the accidental and systematic errors can be eliminated by compensating the errors. Errors are reduced due to the fact that the target distance can be up to 3500 meters and the readings are accurate. The time is reduced compared to the classic level and GPS, because it is no longer necessary to pass the values manually by the operator and stationing with the device at least two stations over the classical level and the measurements do not depend on the availability of the satellites to determine the monitored marks. So the device can be considered optimal in terms of accuracy, cost and time.

CONCLUSIONS

Stability and operational safety are important features provided by each civil engineering structure.

Monitoring in time the behaviour of civil engineering structures can provide a clear view of the movements of the objectives studied, thus avoiding possible material and human incidents.

Monitoring the behaviour in service stage of an objective by topographic methods involves creating an algorithm to optimize the monitoring activity in terms of quality and quantity through the decision theory.

Throughout the experiments it was found that modern digital techniques meet the requirements of an optimized system through the results obtained with the parameters: cost, time and accuracy.

The way we can achieve a more efficient monitoring of civil engineering structure over time is to realize a practical analysis of different types of topographic tools using different methods and compare the results in order to take the most optimal decision.

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REFERENCES

Decision Theory course, available online at: https://drl.ro/webtt/discipline/co/lectii/cursuri/CO210%20-%20Teoria%20deciziei.pdf.

Mândru L., Begu L.S., 2009 - *Optimizing decisions under risk and uncertainty*. Available at - https://ibn.idsi.md

Morariu D.I., Lepadatu D., 2018 - *Advanced method for station point control accuracy to monitor the behaviour in service stage of civil engineering structures using geodetic satellite technology*, Eighth International Conference On Advances in Civil Structural and Mechanical Engineering ACSM-2018, Paris-France.

Morariu D.I., Lepadatu D., Judele L., Cucos I., 2018 - *Station Points Stability Optimization For Efficiently Monitoring Behavior In Service Stage Of Civil Engineering Structures Using Topo Geodesic Methods*, 18th International Multidisciplinary Scientific GeoConference SGEM 2018, Albena – Bulgaria.

Lepadatu D., Covatariu D., Judele L., Săndulache G., Roșu A.R., Diac M., **2014** - *Spatial co-ordinates optimization of civil engineering and building services faculty's topographic network using gps technology*, Lucrări Științifice-Seria Agronomie 57 (2):113-116.

Diana-Ioana Morariu, **Daniel LEPADATU, 2017** - *Topo-geodetic modern methods and techniques for monitoring process*. Lucrări Științifice-Seria Agronomie 60(2): 139-144.

Trandafir R., 2004 - *Models and optimization algorithms*, AGIR Publishing , Bucharest.