HIGH-PRECISION GEODETIC MEASUREMENTS PERFORMED IN THE INITIAL OBSERVATION CYCLE FOR MONITORING THE HORIZONTAL DISPLACEMENTS OF THE ENCLOSURE AND COUNTERSCARP WALLS OF THE SUCEAVA SEAT FORTRESS

Horaţiu-Iulian HOGAŞ, Associate Professor, Ph.D. Eng.,"Gheorghe Asachi" Technical University of Iasi, Romania, e-mail: hhogas@yahoo.com
Cristian ONU, Lecturer Ph.D. Eng.,"Gheorghe Asachi" Technical University of Iasi, Romania, e-mail: cristi_onu@yahoo.com

Abstract: *For the purpose of determining the horizontal displacements of the enclosure and counterscarp walls of the Suceava Seat Fortress, high-precision geodetic measurements were required. Thus, a local geodetic monitoring network was designed, materialized, and determined to obtain the planimetric positions of the control points placed on the mentioned walls, which will serve as reference points for future observation cycles.*

Keywords: *deformation monitoring; in-situ behavior of structures; micro-trilateration; enclosure wall; counterscarp*

1. Introduction

The Seat Fortress of Suceava, also known as the Suceava Fortress, is a medieval fortress located on the eastern outskirts of Suceava Municipality (in northeastern Romania), situated on a terminal spur of a plateau at an altitude of 70 meters above the Suceava floodplain. From here, the entire Suceava Valley can be seen. The use of the term Seat Fortress of Suceava is preferred over Suceava Fortress because Suceava had two fortresses: the Seat Fortress and the Western Fortress (Șcheia Fortress), both built by Voivode Petru Mușat (c. 1375 – c. 1391). The Seat Fortress of Suceava was built at the end of the 14th century by Petru II (Petru Mușat), later fortified in the 15th century by Stephen the Great, and destroyed in the 17th century (1675) by Dumitrașcu Cantacuzino [6].

Currently, the Suceava Seat Fortress has been partially consolidated and completed as part of a large project. It has been opened as a museum space and was included on the list of historical monuments in Suceava County in 2015. In the second half of 2023, works began on the rehabilitation, restoration, and conservation of the Suceava Seat Fortress and its protection area. The specific objective of the project is to increase the attractiveness of the Suceava Seat Fortress and its protection area, in order to promote tourism development and stimulate the economic growth of Suceava municipality [7].

The extensive process of monitoring deformations through geometric methods involves the use of high-performance, highly precise measuring equipment, as well as the rigorous processing of observations made during each measurement cycle. Prior to this, it is necessary to verify the stability of the reference points within the local geodetic monitoring network, which are considered fixed. When designing a local geodetic monitoring network, it is essential to establish an optimal number of fixed reference points, with statistics demonstrating that 3-4 fixed reference points can ensure high accuracy and good efficiency, both in terms of execution time and cost efficiency [2]. Fixed reference points are intended to provide a plane of comparison against which the displacements of the control points are determined and are located outside the zone of influence of the observed construction.

Given the technical assessment of the construction and the implementation of rehabilitation/consolidation works (Figure 1), alongside the Special Monitoring of Behavior over Time Project No. UCT204/2022, which requires high-precision geodetic measurements to monitor the evolution of horizontal displacements, specialized geodetic measurements were conducted on 12.12.2024. The objective of these measurements was to establish the local geodetic monitoring network and, consequently, to develop the comparison plan for subsequent measurement cycles.

Fig. 1 Executution of rehabilitation/consolidation works at the Suceava Seat Fortress

2. Methods, instruments and equipment used

The local geodetic tracking network includes a number of 3 fixed landmarks, materialized by reinforced concrete bollards and 26 control points/sighting marks (Figure 2), located on the tracked objective, respectively 12 control points positioned on the enclosure wall and 14 embedded in the counterscarp wall.

The 3 fixed/reference landmarks were located as far as possible outside the area of influence of the observed construction, in accessible locations for observations and reciprocal sightings. The 26 control points/sighting marks were located in the field according to the Special Tracking Project.

The measurements were made using the Leica TCA 1100 total station, with an angular precision of 3" and a distance measurement accuracy of 2 mm + 2 ppm.

After carrying out all the necessary steps related to the design and materialization of the local geodetic tracking network, in the field, high-precision geodetic measurements were made, corresponding to the zero/initial observation cycle.

Fig. 2 Preparation of geodetic equipment for monitoring horizontal displacements

3. Results and discussions

Following the technical expertise assessment of the construction and the execution of rehabilitation/consolidation works, which are still in progress and scheduled for completion on 21.09.2026, the beneficiary has followed the legal framework and undertaken all necessary steps, including the development of the *Special Monitoring Project for Structural Behavior Over Time no. UCT204/2022*. Subsequently, the zero/initial cycle of high-precision geodetic measurements was carried out.

The arrangement of fixed landmarks and control points within the local geodetic tracking network, based on which the horizontal displacements of the studied object will be determined, is highlighted in Figure 3.

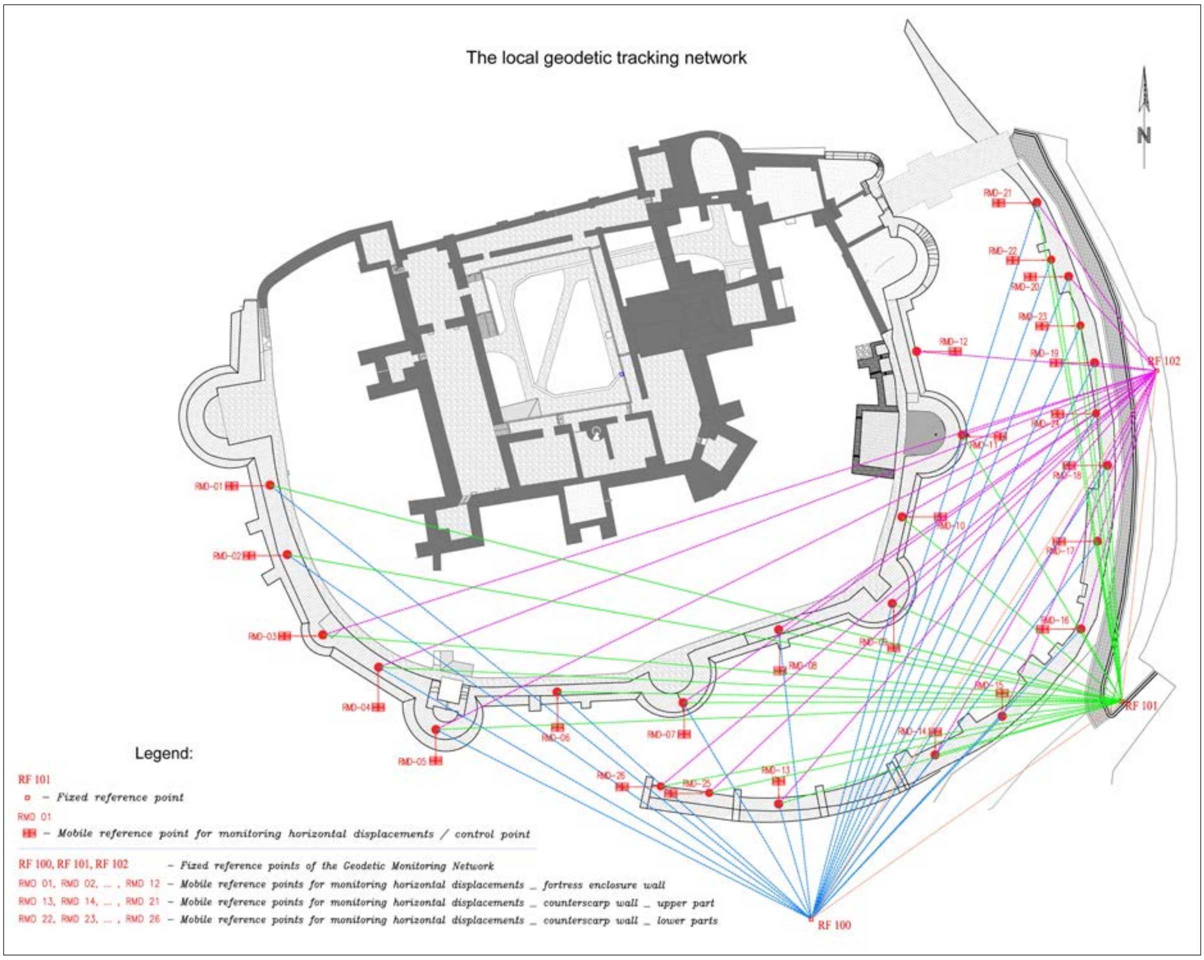

Fig. 3 Sketch of the local geodetic reference network and the placement of sighting marks

The high-precision geodetic measurements, related to the zero cycle, were carried out on 12.12.2024, between 09.30-16.30, a day characterized from a meteorological point of view by temperatures of approx. 0-2^{0}C, moderate wind and cloudy sky (Figure 4).

Fig. 4 Aspects during the execution of measurements in the intial/zero observation cycle

To obtain high precision geodetic measurements related to the zero observation cycle, a miniprism and a tripod were used as topographic accessories (Figure 5).

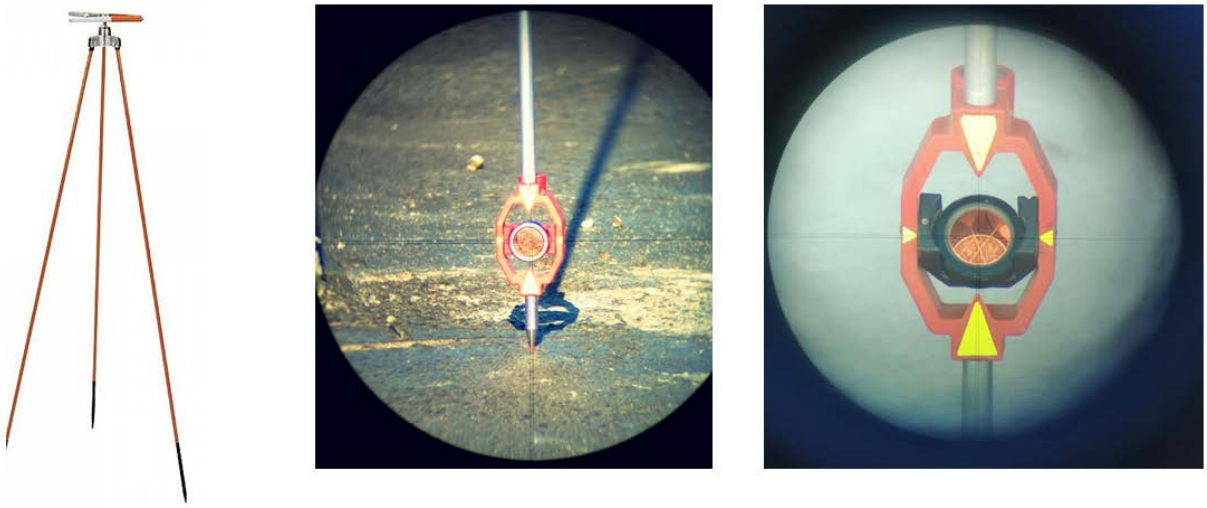

Fig. 5 Topographic accessories used

The processing of the measurements was carried out automatically, using the TopoSYS 7.0 computer program, in which calculations were carried out in stages, first to determine the provisional planimetric coordinates of the fixed landmarks and control points, by the closed traverse method, respectively the forward intersection method, and then, in the final stage, to determine the compensated coordinates and the average determination errors of the mentioned points, following the rigorous compensation of the entire network. The results obtained from the calculations were within the tolerances imposed by such works, the planimetric coordinates of the control points being determined with very high precision. A summary of the automated compensation process is presented in Figure 6.

Processing of the measurements taken and their rigorous compensation

Closed traverse

First station :101 known point, oriented
Intermediate stations:102,100
Last station :101 known point, oriented
Path :101 > 102 > 100 > 101
Calculated points :2
New points :102,100
Total length[m] :212.571
Direction closure error [gr]: -0.0020
Direction correction [gr]: -0.0005
Coordinate closure error X[m]: 0.004
Coordinate closure error. Y[m]: 0.004

Forward intersection

P1	P2	X	Y	dX[m]	dY[m]
101	102	....	....	0.000	0.001
100	102	....	....	-0.001	-0.001
100	101	....	....	0.001	-0.000

A total of 3 combinations, of which 0 are eliminated
Average coordinate, calculated from 3 combinations
Point 10
X = 683610.443 Y = 595607.791 Z = 337.119
Average error = 0.1[cm]

Name: MOBILE REFERENCE POINTS
Compensation method: Constrained to fixed points

Weight :Depending on distance
Total points : 21
Fixed points : 3
Number of unknowns : 36
Number of measurements : 122
Number of additional measurements : 86
Test significance level Tau: 5%
Confidence level : 1.96 sigma
Tau : 3.431
Tau-Tol : 2.881
Direction measuring stations : 4
Azimuth measurements : 0
Direction measurements : 61
Distance measurements : 61
A priori mean error of directions[sec] : 200.000
A priori mean error of distances [cm] : 2.000
Mean squared error of the weighting unit
From the normal equations : 13.76
From the correction equations : 13.76
Mean error of directions[sec] : 21.707
Mean error of distances [cm] : 0.237

Initial coordinates and coordinate corrections

Nrp	X0	Y0	dX[cm]	dY[cm]
102	683636.274	595650.973	0.000	0.000
100	683550.729	595596.696	0.000	0.000
101	683584.443	595645.266	0.000	0.000
...	...	...	...	...
10	*683610.443*	*595607.791*	*0.156*	*0.028*
11	683624.873	595617.843	0.135	0.532
...	...	...	...	...
16	683593.411	595640.732	-0.125	-0.077
17	683607.464	595643.699	0.178	0.006
...	...	...	...	...

Compensated coordinates and the mean errors of the coordinates

Nrp	X	Y	mX[cm]	mY[cm]
10	*683610.444*	*595607.791*	*0.150*	*0.141*
11	683624.874	595617.849	0.154	0.125
...	...	...	...	...
16	683593.409	595640.731	0.078	0.137
17	683607.466	595643.699	0.081	0.157

Fig. 6 Processing observations and their rigurous compensation

4. Conclusions and recommendations

The accuracy of the measurements performed was within the tolerances imposed for such works. The planimetric coordinates of the control points were determined with very high precision, the minimum error of their determination was 0.78 mm, and the maximum was 2.67 mm.

The control points were determined by the forward intersection method, based on measurements performed in the local geodetic tracking network, rigorously compensated, most of them resulting from three combinations, the differences between the three determinations being between 1 and 3 mm.

The planimetric coordinates, rigorously compensated, of the control points/sighting marks, obtained after processing the measurements performed in the initial/zero cycle of observations, will become reference values for subsequent measurement cycles/series.

It is noted that in the magnitudes of deformations and horizontal displacements of the control points, which will be obtained later, in addition to the influence of the phenomenon itself, there is also the influence of random errors, which accompanies any measurement process. For this reason, only after a longer period of time will it be possible to draw more complete conclusions regarding the behavior of the studied objectives.

The chosen technical solution has proven to be viable, the results obtained, remarkable indeed, being in accordance with expectations and technical regulations in force.

The beneficiary is obliged to ensure the integrity of the fixed landmarks and control points/sighting marks. In their absence, it will no longer be possible to establish a connection with the initial state or to accurately assess the condition of the structure's load-bearing system.

5. References

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