ESTABLISHMENT OF A GRAVIMETRIC POLYGON OF CALIBRATION IN SINAIA, PRAHOVA COUNTY

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***Abstract**: National Centre of Cartography conducted between May 2016 - September 2017 the execution project "Establishment of a gravimetric polygon of calibration in Sinaia, Prahova County". The gravimetric polygon consists of 5 stations spread over a distance of 11 km and is located at a maximum altitude difference of 775 m covering a gravity interval of 160 mGal. The polygon will be used to check the accuracy of relative spring gravimeter before and after the measurements in the gravimetric network, and to determine the calibration factor/constant for recalibrating our gravimeters. In this article are presented the main activities to create the gravimetric polygon, the results obtained so far and the prospects for the coming years*.

Keywords: *gravimetric polygon, accuracy of relative gravimeters, gravimetric measurements.*

1. Introduction

For accomplishing the HB.13 measure, part of the Institutional Strategic Plan approved by Order no. 763/ 05.16.2014 of the Ministry of Regional Development and Public Administration, about the rehabilitation and modernization of the National Geodetic Network (RNG) of precision leveling by determining a quasi-geoid for Romania's area and in correspondence with the National Centre for Cartography's strategy, it is necessary to establish a gravimetric polygon of calibration near Sinaia city, which meets the following conditions:

- it's located at a relatively short distance from CNC headquarters;
- the difference of gravity between the extreme points is around 160mGal, satisfying the requests of the equipment producer – Scintrex;
- the polygon's points are easily reachable by auto transport, making possible to measure the entire calibration line in a closed loop during one day;
- the materialization of the points was possible with lasting marking systems and in geotechnical stable soils;
- in some points it's possible to measure with absolute gravimeters and with relative gravimeters fixed on tripods in order to determine gravity's vertical gradient.

Sinaia gravimetric base allows, after an initial period of almost 6 months, to establish the constant calibration correction because the relative gravimeter sensor changes its elastic

proprieties due to the stress relaxation effects, leading to a slight and progressive modification of the calibration constant and to the appearance of instrumental drift errors.
The gravimeter sensor's drift caused by an unavoidable creep of the quartz spring, can vary nonlinear during daily measurements, imposing the calculation of a drift function on a calibration line that contains several points of known gravity. The calibration constant modifies significantly after a few years when the users have to re-caliber the gravimeter on a calibration line/polygon according to producer's recommended methodology.

In the past, in our country, the Brasov-Poiana Brasov gravimetric base was used, made of 3 points, for which were determined the gravity differences used to calibrate relative gravimeters. During the years 1990-2000, within UNIGRACE project, Romanian specialists in collaboration with finish specialists determined by absolute measurements a new calibration line between the cities Cluj-Napoca and Beliș. Also, with the making of the new Ist order gravimetric network, there were made two calibration bases on the routes Iași-Bacău-Băneasa and Baia Mare-Cluj Napoca-Sibiu-Băneasa. All these calibration bases have disadvantages regarding the difficult access to the measurement stations (the Brasov-Poiana Brasov line) or the long distances (for the other calibration bases).

2. Project objectives

Within this project, the purpose was to materialize the calibration polygon's stations and to determine their position through different types of measurements:

-relative gravimetric measurements for transmitting gravity from the 1st and 2nd order national gravimetric network

-geometric levelling works for binding the stations to the Black Sea 1975 (1990 edition) normal heights system

-GNSS determinations with static method and RTK for determining the stations ellipsoidal coordinates in the ETRS89 European reference system

Within the polygon, as much as possible, it's expected for absolute gravity determinations, vertical gravity gradient determinations to be made, as well as relative gravimetric determination repeated in a longer period of time to ensure a high precision of the gravity differences between the polygon's stations.

3. Works designing

The positions of the polygon's points were established after recognizing the area in which the polygon was designed and are presented in the layout map of the designed gravimetric points of the calibration polygon and levelling landmarks from Sinaia

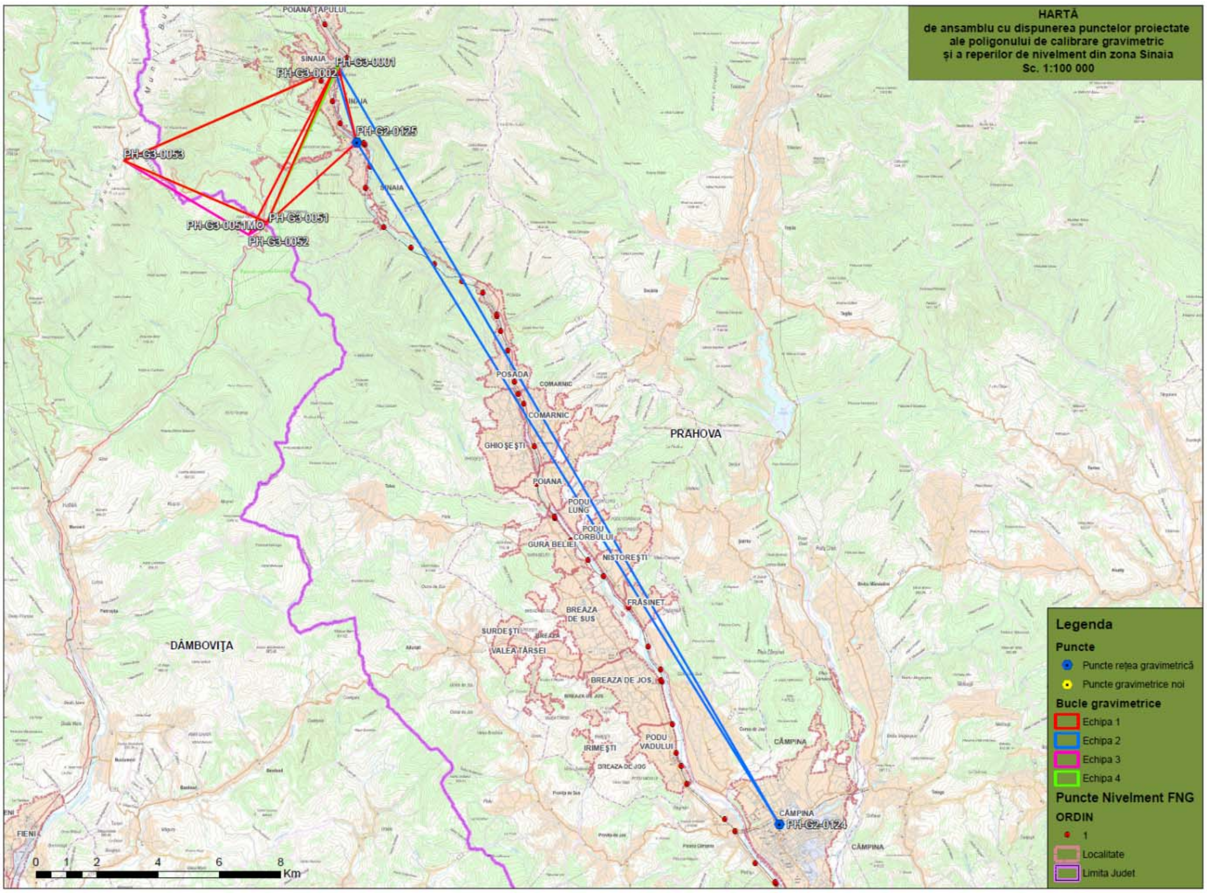

Fig. 1. Layout map of the designed gravimetric points of the calibration polygon and levelling landmarks from Sinaia

In order to avoid large instrumental drift variation during the measurements, it was imposed that the duration of a loop (session) was, as much as possible, a maximum of 3 hours.

For making the gravimetric measurements, the following conditions have been taken into consideration:

- a work session (called composed loop) closes the point of departure over at about 3 hours
- for each point 7 series of successive determinations (cycles) were done, each of them lasting 60 seconds.

The gravimetric measurements were made with the loop method, the points being stationed successively, closing the measurements in the point of departure.

For determining the drift's short period variations, in the future it's expected for profile and step methods to be used in addition.

In order to perform measurements, during the projects Scintrex relative gravimeters - Autograv CG5 were used, with 1 microGal reading resolution and a residual instrumental drift smaller than 0.02 miliGal/day.

For GNSS-Static and GNSS-RTK measurements GNSS-RTK receivers were used, which measure on L1 frequency, as well as L2 frequency, ensuring the possibility (during data processing) of linear combination between phase measurements, leading to the diminishing or eliminating the ionosphere effect.

In transmitting heights to newly determined points, digital levels with bar code staff were used.

4. New points materialization and performing measurements

The new points were materialized with metallic bolts situated in concrete boards and in stable ground, to ensure preservation.

To setup the new points, a series of specific rules were followed, such as:

- the new points were materialized as much as possible in a flat terrain, without sudden change of elevation around them;
- areas exposed to strong wind are to be avoided, as well as areas around large trees;
- points weren't chosen near excavations, dams, drainage channels, groundwaters;
- it was avoided to choose points near main roads, railways, factories or heavy equipment, which can be exposed to strong vibrations.

An example of a gravimetric point fixed in the concrete pedestal of a cross is illustrated below.

Fig. 2. Intermediary gravimetric point in the calibration polygon

The 4 teams that measured with CG5 Scintrex Autograv relative gravimeters were:

- Team 1 and 2 from CNC, during 5 different days
- Team 3 from The Faculty of Geology and Geophisics from the Bucharest University, during one day
- Team 4 from SC Prospectiuni SA, during one day

The work loops (sessions) planning on days in the gravimetric polygon is presented in the next table.

Table 1. Work loops (sessions) planning

Ziua 1	Ziua 2	Ziua 3			Ziua 4_1	Ziua 4_2	Ziua 11	
Echipa 2	Echipa 1	Echipa 1	Echipa 3	Echipa 4	Echipa 1	Echipa 1	Echipa 1	Echipa 2
PH-G3-0002	PH-G3-0001	PH-G3-0001	PH-G3-0001	PH-G3-0001	PH-G3-0001	PH-G3-0001	PH-G2-0124	PH-G2-0124
PH-G3-0001	PH-G3-0002	PH-G3-0002	PH-G3-0002	PH-G3-0002	PH-G3-0051MO	PH-G3-0051MO	PH-G3-0001	PH-G3-0001
PH-G2-0125	PH-G3-0051	PH-G3-0052	PH-G3-0052	PH-G3-0052	PH-G3-0053	PH-G3-0053	PH-G3-0002	PH-G3-0002
PH-G2-0124	PH-G3-0052	PH-G3-0051MO	PH-G3-0051MO	PH-G3-0051MO	PH-G3-0001	PH-G3-0001	PH-G3-0053	PH-G3-0053
PH-G3-0001	PH-G2-0125	PH-G3-0053	PH-G3-0053	PH-G3-0053			PH-G2-0125	PH-G2-0125
PH-G3-0002	PH-G3-0001	PH-G3-0051MO	PH-G3-0051MO	PH-G3-0051MO			PH-G2-0124	PH-G2-0124
		PH-G3-0001	PH-G3-0002	PH-G3-0002				
			PH-G3-0001	PH-G3-0001				

PH-G3-0001 - punct inițial de plecare în buclă

For the polygon points/stations in the Sinaia area, GNSS determinations were made by static method, in order to obtain, after the measurements processing, an ellipsoidal height within 7-10 cm range.

Also, differences of level by precision levelling were transmitted in the points nearby levelling lines.

5. Processing gravimetric measurements

Pre-processing of gravity data involved removing erroneous measurements, the calculation of the averages of the raw readings, and applying the corrections to reduce the readings.

The applied corrections were the following:

- terrestrial tide and ocean loading correction;
- free air correction;
- polar motion correction.

Reduced gravimetric data were placed in a functional model comprising independent readings and the form of the following equation

$$l(t)+v=g+N_0+\Delta F(z)+D(t) \qquad (1)$$

in which:

- t - time measurement;
- l: reading low value of the instrument;
- v: correction;
- g: gravity value of the station;
- N0: a constant bias;
- ΔF: (z) calibration function;
- z: reading gravimeter;
- D(t): function gravimeter drift

Calibration function $\Delta F(z)$ is estimated under a polynomial form

$$\Delta F(z)=\sum_{k=1}^{m} Y_k z^k \qquad (2)$$

where:

- k is the polynomial degree
- Y_k are the calibration coefficients.

The gravimeter drift function was modeled with a polynomial form

$$D(t)=\sum_{p=1}^{a} d_p (t-t_0)^p \qquad (3)$$

where:

- t_0 is the initial epoch;

- *a* is the polynomial degree.

Based on the functional model presented previously, the gravimetric measurements were adjusted with indirect measurement method.

The adjusted gravity differences between the gravimetric polygon's points and the correction applied to these differences are presented in the next table.

Table 2. The adjusted gravity differences between stations

From	To	Meter no.	Date	Time (t)	dt (hour)	dg (mGal)	dD (µGal)	dv (µGal)	Adjusted dg (mGal)
PH-G3-0001	PH-G3-0002	393	2016-07-13	7:32:05	0.269	-0.6266	-1.5	-2.0	-0.6301
PH-G3-0002	PH-G3-0051	393	2016-07-13	7:48:15	0.676	-45.7574	-3.8	1.9	-45.7593
PH-G3-0051	PH-G3-0052	393	2016-07-13	8:28:50	0.309	8.627	-1.8	2.5	8.6278
PH-G2-0125	PH-G3-0052	393	2016-07-13	8:47:21	1.145	-46.1454	6.5	1.2	-46.1377
PH-G2-0125	PH-G3-0001	393	2016-07-13	9:56:03	0.397	-8.3702	-2.3	-3.6	-8.3761
PH-G3-0001	PH-G3-0002	393	2017-03-07	8:53:34	0.364	-0.6293	0.2	-1.0	-0.6301
PH-G3-0002	PH-G3-0052	393	2017-03-07	9:15:24	1.026	-37.133	0.5	1.0	-37.1315
PH-G3-0052	PH-G3-0051MO	393	2017-03-07	10:16:57	0.488	-7.9868	0.2	3.9	-7.9826
PH-G3-0053	PH-G3-0051MO	393	2017-03-07	10:46:12	0.847	105.8186	-0.4	1.4	105.8197
PH-G3-0053	PH-G3-0051MO	393	2017-03-07	11:37:02	0.663	105.8184	0.3	1.0	105.8197
PH-G3-0001	PH-G3-0051MO	393	2017-03-07	12:16:48	0.605	-45.7514	-0.3	7.4	-45.7443
PH-G3-0001	PH-G3-0002	432	2017-03-07	8:33:06	0.298	-0.6218	1.3	-9.7	-0.6301
…	…	…	…	…	…	…	…	…	…

Two fixed points were included in the gravimetric micro-network formed by the polygon's points and the adjusted absolute gravities of them, resulted after the adjustment, are presented in the next table.

Table 3. Fixed points include in the compensation

No.	Station name	Fixed_gravity	σ	Weight
1	PH-G2-0124	980446.600	0.015	1
2	PH-G2-0125	980417.150	0.015	1

The adjusted absolute gravities and standard deviations resulted after the gravimetric adjustment are shown in the next table

Table 3. Adjusted absolute gravities and standard deviations of the new points

No.	Station name	Gravity	St. Dev.
1	PH-G3-0001	980408.8034	0.0099
2	PH-G3-0002	980408.1733	0.0099
3	PH-G3-0051	980362.4140	0.0095
4	PH-G3-0052	980371.0417	0.0092
5	PH-G3-0053	980257.2395	0.0092
6	PH-G3-0051MO	980363.0591	0.0100

The calibrations coefficients for CNC gravimeters resulted from adjustments are the following:

Table 3. The calibrations coefficients resulted from the adjustment

No.	Meter no.	Y_1	St. Dev.
1	393	1.0000692890	0.0001090981
2	394	0.9999994847	0.0001099258

6. Verification of measurements precisions and calibration of relative gravimeters

Estimating relative gravimeter's measurements precisions by users is extremely necessary in order to obtain trustworthy results after the processing of gravimetric measurements.

These measurement precisions are verified at the beginning and during the measurement process, based on gravimetric determinations on a line or calibration polygon that contains points with known absolute gravity.

For Scintrex Autograv relative gravimeters, after a certain period of time, the users must recalibrate the gravimeters similar as the Scintrex company initially did.

The reading shown by the relative gravimeter is calculated by the next formula:

$$SU = f_{cal}(SC,SF) = GCAL1\left(\frac{SF}{SC}\right) + GCAL2\left(\frac{SF}{SC}\right)^2 \quad (4)$$

where:

SU – uncorrected gravity reading;
f_{cal} – calibration function;
SC – corresponding output when the stable calibration voltage (V_{cal}) is applied;
SF – corresponding output when the gravity transducer output (V_{fb}) is applied;
GCAL1 - the main calibration constant that is determined on the Orangeville Calibration Line, 70 km north of Toronto;
GCAL2 – the calibration factor which accounts for a small quadratic nonlinearity, evaluated in the Scintrex gravity laboratory Since 1991, it has been reduced to zero by an electronic adjustment.

The gravimetric determinations are executed at every station in the measurements loops, in cycles of 60 seconds.Terrestrial tide and ocean loading corrections, free air corrections, polar motion and atmospheric pression corrections are applied. Then, the instrumental drift residual corrections based on repeated reading on station 1 are applied. The measurement error for a gravity difference is calculated with the following formula

$$E_{ij} = k * S_{ij} - g_{ij} \quad (5)$$

where:

E_{ij} – measurement error for a gravity difference between ***i*** and ***j*** stations
k – the scale correction factor
S_{ij} – The difference between drift corrected readings at station ***i*** and station ***j***
g_{ij} – the reference gravity differences between ***i*** and ***j*** stations.

The k scale correction factor is calculated using least-squares adjustment based on correction equations like the previous one. After the calibration test, the new calibration factor GCAL1' is calculated based on the former calibration factor GCAL1 using the formula:

$$GCAL1' = k * GCAL1 \quad (6)$$

The calibration factor GCAL1' determination precision must be around 0.01% (a measurement error of 0.01 mGal in a gravity test range of about 100mGal).

7. Conclusions

The calibration polygon near Sinaia is already used by CNC specialists to control gravimetric reading precisions, which can show the possible accidental measurement errors caused by a sensor that is not in normal operation parameters.

Also, the polygon will be used in the future for recalibrating gravimeters after a certain period of time when the calibration factor GCAL1 will no longer fit in the tolerance.

CNC will continue to make repeated gravimetric measurements, including in the polygon's micro-network at least 1-2 1st and 2nd order points from the gravimetric network, in order to accurately determine the absolute gravities and gravity differences between the polygon's points.

Also, as much as possible, absolute gravimetric measurements will also be made in at least the extreme points of the polygon.

We consider that the gravimetric polygon will accomplish in the future some high precision standards and will be useful to all the specialists in our country that make gravimetric determinations and can contribute to the verification of gravity differences between points.

8. References

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