4.3.10. ABSOLUTE GRAVITY MEASUREMENTS DURING THE CERGOP-2 PROJECT IN ROMANIA AND BULGARIA

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4.3.10.1. Introduction

Austria takes part at the project CERGOP-2 (Central Europe Regional Geodynamics Project – Phase 2) by the Austrian Academy of Sciences (OeAW). In this project a high number of permanent GPS stations record tectonic movements. For a correct interpretation of the observed moving vectors at the GPS-stations it is necessary to know about the dynamics of the potential field resp. the local gravity value. The BEV[1] operates an absolute gravity meter and cooperates with the OeAW during such international projects. The complete number of 10 absolute gravity stations (Romania 4, Bulgaria 6) were defined by the responsible persons of Romania and Bulgaria and measured during three weeks (6.-24. September 2004).

4.3.10.2. Programme of measurements in Bulgaria[1]

- ### Scheduling

A phase of 10 days were supplied by the BEV for the absolute measurements in Bulgaria. Therefore the number of the stations and the schedule of the observations was arranged together with Prof. Georgi Milev who is responsible for the project in Bulgaria. At least 6 stations (Fig. 4.3.10.2.) were measured in different duration:

Sofia and Rozhen: 2 nights + 1 day (27-32 hours).

Varna, Gorna Oryahovitsa, Sandanski, Belogradchik: 1 night (11-14 hours).

- ### Realization

Using a van for transportation of the equipment the journey went via Constanta in Romania towards Varna the first station in Bulgaria. In further succession the stations Sofia – Sandanski – Rozhen – Gorna Oryahovitsa – Belogradchik were observed. After reaching the concerned station first the vertical gravity differences were measured using a relative gravimeter for deriving the vertical gradient of gravity. Thereafter the absolute gravimeter was assembled and after about 2 hours of warming up the absolute gravity observations during the night could be started. Dependent to the station further measurements were taken during the following day and the second night. In the morning the absolute gravity instrument was disassembled and packed for traveling to the next station. All the relative and absolute gravity measurements were performed by Diethard Ruess and Christian Ullrich from the BEV. During the campaign the Austrian team was supported by the geodesist Nikolai Dimitrov from the Bulgarian Academy of Sciences.

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[1] **BEV – Bundesamt fuer Eich- und Vermessungswesen (Federal Office of Metrology and Surveying)**

A power drop of the used He-Ne laser occurred during the night of the first observation run in Varna which made it necessary to change the sequence of the program. At the second station in Sofia the laser could be serviced successfully. The measuring program could be finished in the order Sofia – Sandanski – Rozhen – Gorna Oryahovitsa – Belogradchik without any further technical problems however without the assistance of Mr. Ullrich who became ill and returned ahead of time.

4.3.10.3. Instrumentation

- **Absolutgravimeter**

The absolute gravity observations were executed using the absolute gravimeter JILAg-6 which was produced 1986 by *J. Faller*, University of Colorado, USA. Observing the free fall time and distance is measured using a Michelson interferometer combined with a Iodine stabilized He-Ne laser (Winters, 1996) and a Rubidium frequency standard (Fig. 4.3.10.1.). Upgrades in 1994 and 1997 by Micro-g (T. Niebauer, Colorado, USA) allow to run the instrument with software of the succeeded instrument FG5.

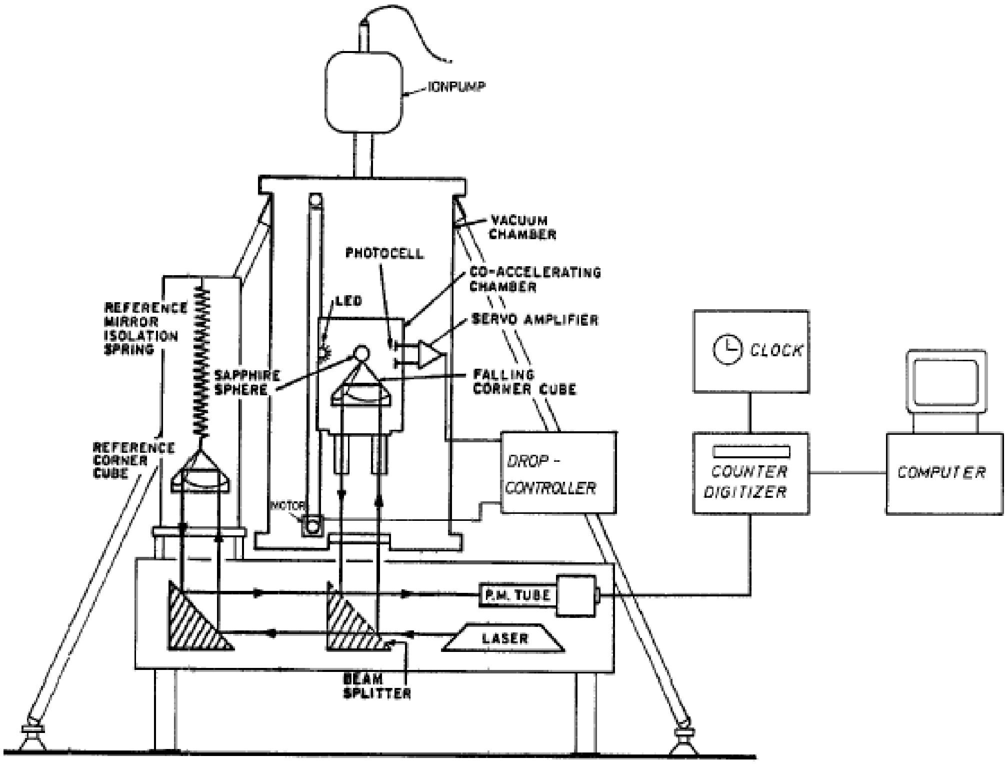

Fig. 4.3.10.1. Schematic of a JILAg absolute gravimeter

The free fall is observed at a optical prism within an evacuated tube. A Ion-pump keeps permanent a air pressure of about 1,3.10^{-3} *Pa* (~1.10^{-6} *Torr*). The free falling prism is escorted by a drag free chamber which works also as lift for bringing back the object to the starting point automatically. The reference corner cube is uncoupled from the seismicity using a "Superspring" during the falling time of ~0,2 seconds. The optical interferences are detected by an avalanche photo diode, then converted in right angle pulses by a Zero-Crossing-Detector, scaled and counted. Every 4000 scaled pulses of the interferometer are compared with the timing pulses of the Rubidium frequency standard.

For the determination of the g-value a run over 10 – 40 hours is used with about 170 drops per hour. Each drop contains 680 pairs of time – distance data. The calculation of g is made using the formula 1:

(1)
$$x_i = x_0 + v_0 t_i + \frac{g}{2} \cdot t_i^2 + \frac{1}{6} \gamma v_0 t_i^3 + \frac{1}{24} \gamma g_0 t_i^4$$

x_i = falling distance
t_i = falling time
v_0 = starting velocity
γ = vertical gradient of g
g = gravity
x_0 = starting point

As reference for g the height of 1 /3 falling distance is defined, which is 84 *cm* over the floor for the JILAg-6. For comparing the results with an other type of absolute gravimeter the gravity difference to the other reference height has to be measured by a relative instrument.

- **Relativgravimeter**

The secondary gravity observations were made wit the spring gravimeter La Coste & Romberg LCR-D51 for

- **checking the stability of the absolute station**
- **transfer of the g-value from the absolute reference point (84 cm) to the bench mark on the floor respective to another reference point (FG5)**
- **determination of the vertical gravity gradient**
- **transfer of the g-value to bench marks of the national gravity base network**

4.3.10.4. Results in Bulgaria:

- **Overview:**

The coordinates and the heights of the stations presented by the Bulgarian colleagues in WGS84 for calculating the earth-tide corrections are listed in the following Table 4.3.10.1.:

Table 4.3.10.1. Coordinates of the stations

station	latitude	longitude	height [m]
Varna	43.1961	27.9203	11
Sofia-Metrologia	42.6670	23.3670	573
Sandanski	41.5670	23.2833	251.9
Rozhen	41.6931	24.7439	1722
Gorna Oriahovitsa	43.1167	25.6833	155
Belogradcik	43.6167	22.6670	606.9

Fig. 4.3.10.2. Absolute gravity stations measured 2004

- **Used parameter:**

All measured absolute gravity values are related to the reference height 84 cm over the floor. On each station the relative gravity differences were measured at the positions 6 *cm*, 84 *cm*, 130 *cm*, the last one is the common reference height of FG5 absolute gravimeters. Adopting that the vertical gravity gradient is linear it can be derived by these relative measurements and used in formula 1 for the solution of the fall equation.

The normal air-pressure is calculated by using the geoid-height. The air-mass correction is calculated using an admittance-factor of 0.3 *µGal/hPa*.

The pole motion correction is calculated using the parameters of the INTERNATIONAL EARTH ROTATION SERVICE, EARTH ROTATION PARAMETERS EOP (IERS) C 04 IAU2000. (http://hpiers.obspm.fr/eop-pc/).

The runs of absolute gravity measurements contain a certain number of sets with 170 drops in a time interval of 20 seconds.

The earth tides are corrected using an earth tide model after Timmen-Wenzel.

4.3.10.5. Station descriptions

- **Station Varna**

Time interval: September 14th -15th, 2004

Fig. 4.3.10.3. Measurement of the gravity gradient and the absolute value in Varna

The station Varna is situated in the cellar of the astronomical observatory „N. Copernicus" about 100 m offshore in the centre of the city. There during the project UNIGRACE absolute gravity measurements were made in 1998 by D. Ruess with the JILAg-6 instrument. The underground of the station Varna is sand and in combination with the disturbance of the city and the near sea the seismic interference level is quite high. After the first run over night a power drop of the laser stopped a second registration. Therefore only 13 sets in one run can be used. The quality of the result corresponds to the unquiet situation of the station with a drop sigma of 212 microGals and a set sigma of 18,8 microGals. The g-value of the absolute station was transferred with the relative gravimeter LCR-D51 to an outside point at the staircase of the entrance of the observatory.

Fig. 4.3.10.4. Outside point in Varna; point A1 at the staircase of the observatory

- ## Station Sofia – Metrologia

Time interval: September 16th – 18th, 2004


Fig. 4.3.10.5. Absolute gravity station in Sofia (Metrologia Institute)

The new absolute station in Sofia is situated in the building of the metrological institute in Sofia in a special laboratory. Due to the assistance of a laser specialist in Sofia the troubles with the laser could be solved and the measurements could be continued. One set of testing the setup and two further runs gave a total number of 34 sets measured at this station. The basement of the building is very compact and stable. Therefore the results gave a good quality in spite of the place near the city with a drop sigma of 30 – 50 microgals and a set sigma of 3 – 7 microgals. The gradient and the transfer to the benchmark was measured with the relative gravimeter.

- ## Station Sandanski

Time interval: September 18th – 19th, 2004


Fig. 4.3.10.6. Absolute gravity station Sandanski

The new absolute gravity station was installed in an adjoining room of the free air theater in Sandanski. The basement is quit stable and the situation quiet, that gave a high quality of the result with a drop sigma of 13 microgals a set sigma of 2,4 microgals. The observation lasted one night.

- **Station Rozhen**

Time interval: September 19^{th} – 21^{th}, 2004

Fig. 4.3.10.7. Absolute gravity station Rozhen

The absolute gravity station was installed in the cellar of the administration building of the astronomical observatory Rozhen. The gravity observation lasted 2 nights and the enclosed day. The floor of the cellar is relatively weak and it took quite a lot time to find the relative best place there using the relative gravimeter. Therefore quite high floor response occurred and reduced the quality of the results. Different orientations of the absolute gravimeter were used to find the position with the lowest noise level. In spite of the very quiet place on top of a mountain far away from any village or traffic road the drop sigma was only 8 *μGal* and the set sigma 6,3 *μGal*. Its recommended to reconstruct and advance the base for future gravity measurements.

- **Station Gorna Oryahovitsa**

Time interval: September 21^{st} – 22^{nd}, 2004

Fig. 4.3.10.8. Absolute gravity station Gorna Oryahovitsa

The station is situated in the underground parking of the municipal administration building of Gorna Oryahovitsa on a small concrete pillar in one edge of the garage. Both the central position in the city and the not optimal stable pillar affected the quality of the measurements. The drops sigma was 18 µGal and the set sigma was only 7,4 *μGal*.

- **Station Belogradchik**

Time interval: September 22nd – 23rd, 2004

Fig. 4.3.10.9. Absolute gravity station Belogradchik

The station was fixed in the garage of the new building belonging to the astronomical observatory in Belogradchik. The fundament was perfect and the location extremely quiet. That gave a drop sigma of 7 µGal and a set sigma of 1,6 µGal, a very good quality of the results.

4.3.10.6. Results

- **Absolute gravity measurements**

In Table 4.3.10.2 there are the results of the absolute gravity observations. The measured absolute gravity is referenced to 84cm over the floor. The transfer to the floor (benchmark) has to be made using the relative measurement results. Only in Varna it's possible to compare the new measurements with earlier ones. In 1998 Varna was measured during the UNIGRACE campaign with the JILAg-6 gravimeter. The value 1998 is about 10 µGal higher then 2004. Due to the quite difficult circumstances in 2004 the results are satisfying.

Table 4.3.10.2. Results of absolute gravity measurements and gradients

station	drops	g in 84 cm height [m/s²]	σ(drop) [µgal]	σ(set) [µgal]	M_0 [µgal]	gradient [µgal/m]	g on floor - benchmark [m/s²]
Varna	2210	9.80 470 405	212	18,8	5,2	291	9.80470749
Sofia-Metrologia	5100	9.80 234 425	44	5,6	1,0	310	9.80234686
Sandanski	2210	9.80 196 053	13	1,6	0,4	191	9.80196214
Rozhen	4556	9.79 908 327	8	6,3	1,2	352	9.79908623
Gorna Oriahovitsa	2040	9.80 421 887	18	7,4	2,1	289	9.80422130
Belogradcik	1870	9.80 358 472	7	1,6	0,5	334	9.80358752

Legend	σ(drop) = standard deviation of drop results σ(Set) = standard deviation of sets $\pm M_0$ = error of mean set result (set)/√n (set)

- **Relative measurements**

At 4 absolute gravity stations there were measured relative connections to eccentric outside points with the relative gravimeter LCR-D51. In Table 4.3.10.3 the results of these measurements are shown.

Table 4.3.10.3. Results of the relative connections

station	location	g on floor - benchmark [m/s²]
VARNA-A1	at the staircase in front of the observatory in Varna	9.80470401
SOFIA-A1	direktly beside the absolute point in Sofia	9.80234673
SAND-A1	point beside of the absolute station	9.80196366
ROZH-A1	point beside of the absolute station	9.79908619

4.3.10.7. Conclusion

The intended absolute gravity measurements for the project CERGOP-2 in Bulgaria are successfully executed. The station Varna was already measured in an earlier campaign and the gravity value was verified during this project. Five stations Sofia, Sandanski, Rozhen, Gorna Oryahovitsa and Belogradchik are new and fixed during this project.