ABSOLUTE GRAVIMETRIC DETERMINATIONS OF LONG-STANDING NON-TIDAL GRAVITY CHANGES IN JÓZEFOSŁAW ASTRO – GEODETIC OBSERVATORY OF WARSAW UNIVERSITY OF TECHNOLOGY AND AT MAIN TECTONIC UNITS ON POLAND TERRITORY

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1. INTRODUCTION

Absolute gravimetric investigations of the long-standing, not tidal variations of the gravity using ballistic FG – 5 No. 230 gravity meter, bought by Warsaw University of Technology at 2005, were performed on Polish territory on four stations outside the Teisseyre – Tornquist Zone (T-T Zone) as well as at Józefoslaw Astro - Geodetic Observatory located near Warsaw, in the vicinity of that zone, near a northern edge of T – T zone on Precambrian Platform. Row results of observations were corrected by Earth's tide influences, loading effects of the Earth's crust and ocean, by polar motion influence to the gravity as well as from the reason of gravitational and deformation influences of the atmosphere. A precision of the gravity determination may be evaluated from a scatter of results obtained from 24 hours observations (12 sets, 1,000 falls) as 0.2 μGal. The total r.m.s.e. as equal to 2.1 μGal was evaluated.

Absolute gravity determinations in previous campaigns on Polish territory were performed using various ballistic gravity meters, many types and quality, as well as there were spread in time. In 2006 with our apparatus FG – 5 No. 230 there were obtained the gravity values minor on all investigated stations. It was about 17 μGal at Lamkówko station, near Olsztyn, in Satellite Observatory of Warmia – Mazury University and 12 μGal in Borowiec Astro-Geodynamical Observatory of the Space Research Centre (Polish Academy of Sciences) with comparison to the results from 8 – 10 years before obtained by Polish absolute gravity meter ZZG. From comparison of our results with obtained by the Italian IMGC absolute ballistic symmetrical meter we noticed the difference of 13 to 20 μGal on Lamkówko station and the variation since 1996 to 2006 on Giby (station of the gravity national fundamental net) only 5 μGal. Taking into account other determinations by foreign staffs on this place one can notice the differences reaching 10 μGal. On very stable station Ojców (Polish Academy of Sciences seismic fundamental station) a decrease of gravity equal to 9 μGal has been noticed after 9 years.

Mentioned above, pointed out differences might have the sources in gravity global or regional variations in the vicinity of stations as well as in incorrect earlier determinations of the vertical gradient of gravity above absolute stations.

2. ABSOLUTE GRAVITY DETERMINATIONS IN JÓZEFOSŁAW ASTRO – GEODETIC OBSERVATORY

Since June 2005 the Warsaw University of Technology has possessed the FG – 5 No. 230 absolute ballistic gravity meter, which gave an occasion for performing precise investigations related to scientific studies of the long – term gravity changes at our observatory, investigations of the gravity variations at main tectonic units on the territory of Poland, unification of gravimetric reference system for Polish GNSS stations and geodynamical test - fields as well as for modernization of the Polish "zero order" national gravity network and modernization of the gravimetric calibration base-lines in Poland.

Till 2001 gravimetric monitoring of absolute gravity value was performed by ZZG (originally constructed in Poland by Prof. Z. Ząbek) gravity meter (Ząbek, 1996), which was occasionally controlled by the foreign gravimetric groups from Germany and Finland with FG – 5 and JILAg apparatus (Ząbek et al., 2002). Since June 2005 the determinations using FG – 5 No. 230 have been carried out in new building of Observatory. The observations have been performed once a month. They could answer several questions concerning the long – term stability of the gravity at Józefosław.

Astro – Geodetic Observatory was established at 1957. In 1991 it was joined to the International GPS Service for Geodynamic (IGS) and now are performed there the GPS/ GLONASS observations in the frame of IGS/IGLOS/EUREF. In Józefosław at 1997 was established the reference station in Unification of the Gravimetric Nets in Central Europe Countries (UNIGRACE) campaign organized by Section "Geodesy" of the Central Europe Initiative.

The stand in gravimetric part of Astro – Geodetic Observatory at Józefosław was especially prepared to improve conditions and give a possibility for observations by four absolute gravimeters simultaneously. It was connected gravimetrically with a station of Polish Fundamental Gravity Network (POGK'99), was supplied with a height above Baltic sea level and geographical coordinates by GPS determinations (Barlik et al., 2009c). It ought to be add that in the same laboratory section there is placed since 2001 a tidal instrument ET- 26 dedicated to the stationary gravimetric registrations (Bogusz, 2009).

Our station was examined taking into account distribution of gravity perturbations on the top of gravimetric pillar to determine reductions from other points of the pillar top to the place in which our apparatus No. 230 used to be situated during gravity measurements performed by the staff. It make possible to compare indications of gravimeters taking part in future calibration sessions. The same is presumed considering the vertical gradient of gravity to reduce the gravity resulted from ballistic instrument to the level of stand pillar. The vertical gravity gradient was examined using LaCoste & Romberg Model G No. 986 gravimeter till 1.5 m above the pillar. A program of the gravity differences determination contained two schemes of sequences in gravimeter readouts, namely the first one with h - 0 – 50 – 100 – 150 – 150 – 100 – 50 – 0 given in cm and the second one with height differences as follows: 0 – 50 – 0 – 100 – 0 – 150 – 0 – 150 – 0 – 100 – 0 – 50 – 0 (Korbacz, 2005). To realize a low of the gravity gradient distribution it was used a function:

$$g(h) = a + b \cdot h + c \cdot h^2, \tag{1}$$

where a, b and c were unknowns determined by adjustment. Such approach to the problem of gravity reduction with a height differences has been applied during

processing of gravity campaigns during international meetings in Sevrés. In Table 1 are given the values of mentioned unknowns.

Table 1. Coefficients in vertical gravity gradient formula up to 150 cm above Józefosław absolute gravity station

Coefficient	Value of a factor	Standard error
a **[mGal]**	**4821.541**	**0.0035**
b **[mGal/m]**	**- 0.2712**	**0.0008**
c **[mGal/m^2]**	**+ 0.01699**	**0.0004**

One can see that a formula for the gravity vertical gradient at Józefosław gravimetric observatory for an interval from 0 to 150 cm above the absolute station is as follows:

$$W_{zz}^{0-150} = -0.2712 + 0.0339 \cdot h_{metr} \quad [mGal/m] \qquad (2)$$

In an interval between 150 cm and 100 cm to reduce gravity to a level of 100 cm as it is accepted in gravimetric practice a proper formula is as follows:

$$W_{zz}^{100-150} = -0,2420 \pm 0.0003 \quad [mGal/m]. \qquad (3)$$

In Table 2 are placed values of coefficients proper for gravity reduction from a level of 100 cm onto the pillar top in Józefosław laboratory according to formula (1).

Table 2. Coefficients in reduction formula for interval 0 to 100 cm above gravimetric absolute pillar in Józefosław observatory

Coefficient	Value of a factor	Standard error
a **[mGal]**	**4821.540**	**0.0029**
b **[mGal/m]**	**- 0.2674**	**0.0008**
c **[mGal/m^2]**	**+ 0.0149**	**0.0004**

For the vertical gravity gradient along the same length interval (up to 1m above pillar in observatory) a proper formula is as follows:

$$W_{zz}^{100-0} = -0.2674 + 0.02984 \cdot h_{metr} [mGal/m]. \qquad (4)$$

One can see that the real vertical gravity gradient above our pillar significantly differs from its normal ellipsoidal value (-0.30855 mGal/m).

From given formulae comes out that to reduce of the observed gravity by our FG-5 No. 230 instrument from the level of 1 m (given by computer of this apparatus) to the pillar level in Józefosław laboratory it is needed to introduce a reduction with a value equal to *237.6* μGal. A value of such kind reduction from the level of 130 cm (proper for FG-5 instrument) to the level of the pillar's top is equal in Józefosław to *324* μGal.

For evaluation of the total error of determined gravity in Józefosław it ought to be taken into consideration following three types of components: measurement precision, errors of model (tides, air pressure, vertical gravity gradient) and instrument's type error. Such total uncertainty calculated using Gauss' formula:

$$\sigma_{grav} = \sqrt{\sigma^2_{observ} + \sigma^2_{\mathrm{mod}\,el} + \sigma^2_{instr}} \qquad (5)$$

obtained in Józefosław a value equal to *2.07* μGal (Barlik et al., 2009c). It is necessary to add that for calculation of barometric correction to normal pressure introduced to the observed in Józefosław gravity a following formula has been used:

$$\Delta g_{bar} = 0.345\left(p - p_{norm}\right) \ \left[\mu Gal / hPa\right] \qquad (6)$$

Presentation of gravity determination results obtained in Józefosław during a period from 2005 till 2010 gives Fig 1.

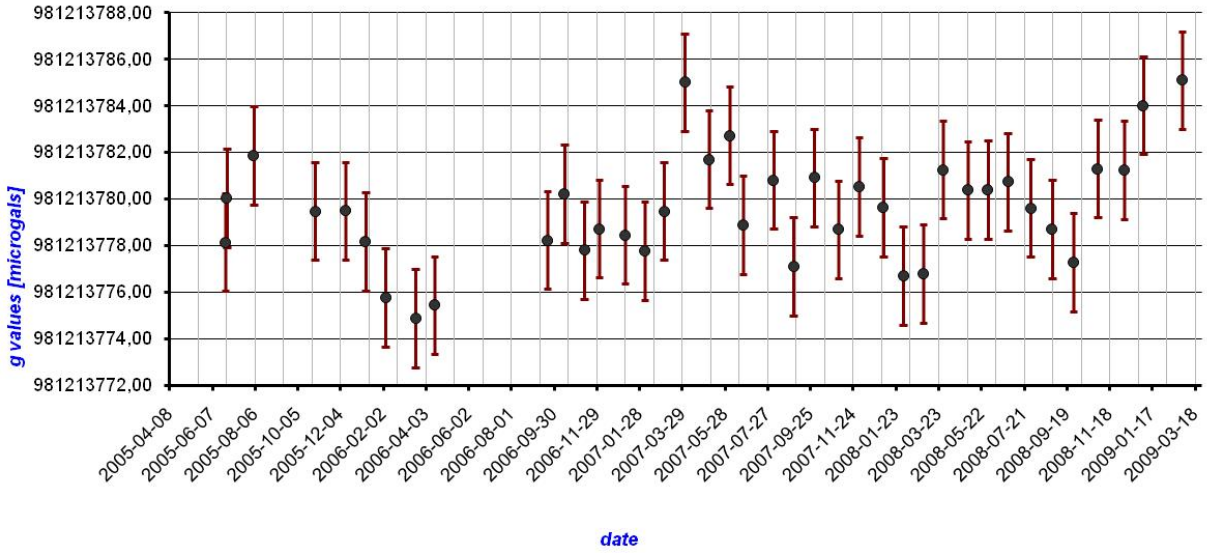

Figure 1: Results of absolute g determination in Jozefoslaw gravimetric laboratory obtained using FG-5 No. 230 absolute gravimeter.

Taking into account the Bouguer's reduction formula and a porosity of the Earth's crust in a vicinity of laboratory it was obtained (Barlik et al., 2006) following formula enabled to eliminate of an influence of water table changes Δh to gravity on the gravimetric absolute station:

$$\Delta g_{watertable}\left[mGal\right] = 0.01027 \cdot \Delta h\left[m\right], \qquad (7)$$

because a recognized effective density is equal $\rho = 0.245$ [g/cm^{-3}]. In Fig. 2 one may consider an unmistakable correlation between gravity and water condition changes on gravimetric station Józefosław.

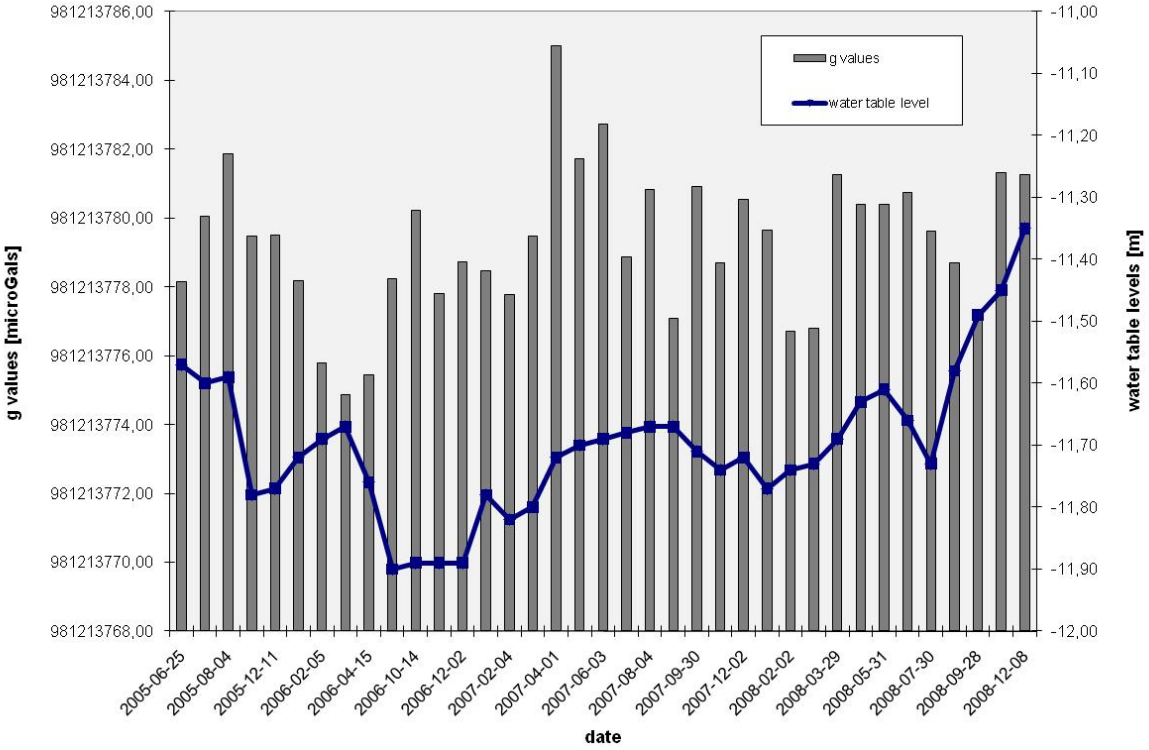

Figure 2: Combination measured absolute g values with water table levels in vicinity of Józefosław observatory.

Analysis observed and corrected gravity values (Bouguer correction only local hydrological effect) gives interesting remarks. Two gravity time series were compared – raw measured g values and corrected on local hydrological effect. Two models fitting functions were applied for both series:

- **first degree of Fourier series (harmonic function),**
- **regression line.**

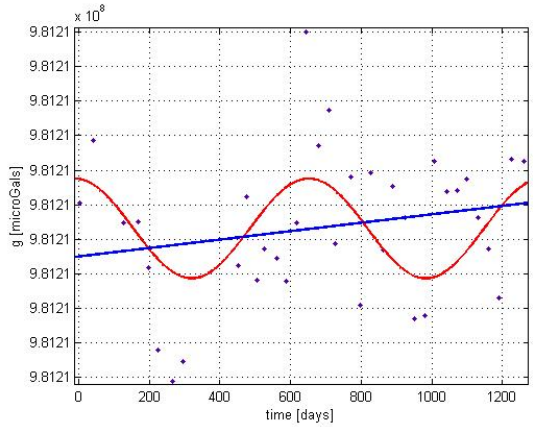

Figure 3: Linear and first degree Fourier series approximation for measured g values

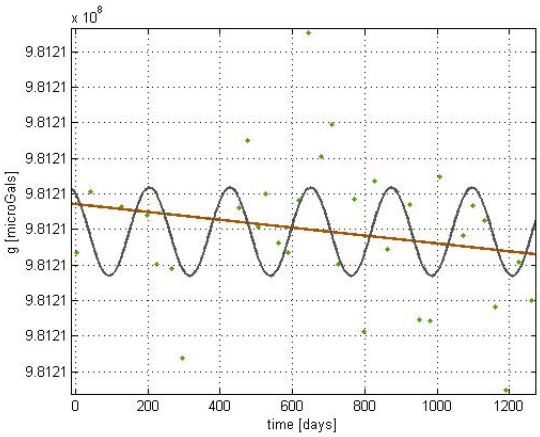

Figure 4: Linear and first degree Fourier series approximation for corrected g values

Measured values show increase linear tendency 0,43 Gals per year and long wave (ca. 750 days) with 1,43 Gals amplitude. Values after remove local hydrological effect shows decreasing tendency with linear trend - 0,38 Gals per year and shorter harmonic wave with period ca. 300 days and 1,06 Gals amplitude. Figures 3 and 4 presents results of fitting.

The average value of raw gravity was equal

$$g^{average}_{Józefosław} = 981\ \ 213\ \ 779.48\ \ [\mu Gal]$$

with r.m.s.e. = 0.41 [μGal].

Monitoring of the gravity changes on Józefosław station, during over three years, once a month, pointed out the quasi-periodic, non-tidal variations equal approximately with microGal amplitude and similar to different station tendency of decreasing of gravity. Their sources could be recognized as an influence of residual changes of the ground water level in a vicinity of Observatory building and gravitational effect of global geophysical fluids.

3. COMPARISION OF RESULTS GIVEN BY FG-5 No. 230 WITH OTHER ABSOLUTE BALLISTIC GRAVIMETERS

Polish absolute gravimeter FG5 No. 230 has been launched at mid 2005. Time of installation in Józefosław was so late for participating in International Comparison of Absolute Gravimeters (ICAG) at 2005 meeting. But that was involved at local comparison meetings in Pecny (Czech Republic) and Bad Homburg (Germany) at 2006. It was compared with similar apparatus possessed by German Bundesamt für Kartographie und Geodäsie and Czech Geophysical Observatory (Pecny) teams. During simultaneously measurements with FG5 No. 301 and FG5 No. 215 there was obtained very good agreement with previous ICAG gravity level (defined by both gravimeters). Difference equal only 0,7 μGals with an error of 0,5 μGals was obtained.

Our instrument took a part in last European Comparison of Absolute Gravimeters (ECAG'2007) meeting in Walferdange (Luxembourg) and International Comparison Absolute Gravimeter (ICAG'2009) meeting in Sévres (France). Final and official results of this last campaign have not been yet published. Difference between indications given by our instrument and the mean gravity level obtained during ECAG'2007 meeting was defined as + 0.95 μGals with r.m.s.e. 0.23 μGals.

Operating frequency of our gravity meter's rubidium clock and laser head WEO100 have been calibrating periodically by Central Office of Measures in Warsaw.

Given above precision characteristics allow to formulate a conclusion that apparatus FG – 5 No. 230 may be qualify to a team of ballistic instruments of the highest precision.

4. MONITORING OF THE LONG-STANDING ABSOLUTE GRAVITY CHANGES AT MAIN TECTONIC UNITS ON POLAND TERRITORY

In Table 3 are presented results obtained before an interval of our gravity determinations on four stations located at main tectonic units on Poland territory. On stations Borowiec, Giby, Lamkówko and Ojców in the period between 1995 and 2001 absolute

gravity value was obtained using various apparatus. One can notice that Italian symmetrical (Cerutti, et al., 1997), German (Falk, 1996) and American (Stizza, 1996) took a part in measurements in Poland. In that table there are given also values obtained from elaboration of the Polish national gravimetric net (POGK).

Table 3. Absolute gravity value obtained on stations under examination located at main tectonic units on Poland territory before 2006.

(μGal, reduced to pillar level)

Station	ZZG (1997 - 2001)	IMGC (Italy) (1996)	POGK (1997)	FG-5 (1995)
BOROWIEC	981 246 150	981 246 139	981 246 150	981 246 147
GIBY	981 391 438		981 391 443	
LAMKÓWKO	981 377 619	981 377 614	981 377 622	
OJCÓW			981 014 406	981 014 405

For comparison in Table 4 there we put results of our determinations during three epochs of observations on the same four stations.

Table 4. Specification of the gravity determinations from three epochs obtained using FG – 5 No. 230 instrument

(μGal, reduced to pillar level)

Station	VG μGal/cm	2006 r.	2007 r.	2008 r.
BOROWIEC	-2,78	981 246 141	981 246 140	981 246 136
GIBY	-2,93	981 391 435	981 391 438	981 139 435
LAMKÓWKO	-3,28	981 377 600	981 377 607	981 377 600
OJCÓW	-2,23	981 014 392	981 014 396	981 014 397

At first, one can recognized that gravity determined by FG – No. 230 during three years on station BOROWIEC has have a tendency to decrease. The same a tendency pointed out from 1996 given in Table 3 and Table 4 was preserved. That decreasing about 14 μGal was lasted about 12 years. It may be a result of a water level depression in Kórnickie lake in a vicinity of this observatory as well as an effect of a soil wiping.

Acceleration of gravity observed on GIBY station maintains very stable from 1996. There are very stable water conditions. This point is situated in lake and forest surroundings Only the gravity value reported in POGK net differs of 6 – 7 μGal from mean value obtained by absolute determinations.

Taking into consideration the gravity monitoring on LAMKÓWKO station it may be pointed out that a decrease of this characteristics is very clear. During 10 years it was

equal to about 15 μGals. A source of such behavior may be recognized as a soil wiping as well as a raising up of elevation of this station, what was mentioned by (Kowalczyk, 2006).

From observations executed by FG - 5 No. 230 on OJCÓW station (Świętokrzyskie Mts., Malopolska Massif) results as a small increasing of gravity equal about 5 μGal in a period of 3 years of monitoring. It is the same tendency as in determination during 10 years before. It is in a good accordance with a depression – 2 mm/y of that region recognized by leveling works.

5. FINAL REMARKS

Recovered variations of gravity on Poland territory might have different sources in gravitational global or regional variations, especially in the hydrological influences in the vicinity of stations as well as in incorrect earlier determinations of gravimetric corrections, mainly in vertical gradient of gravity above pillars in observatories. From a content of the paper it is very clearly show that the gravity is more variable in comparison to a precision of its determination on Polish territory. It ought to be postulated that to update gravity value even in laboratories and especially on stations of national gravity fundamental network it is necessary to repeat in Poland the gravity determinations every 7 – 8 years. It is very evident that information connected with soil moisture should be included to father analysis.

Taking such solution into account the conservation of gravity for geodynamical purposes as well as for industrial needs will be provided with a sufficient precision and actuality.

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